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Secondary Metabolites of Some Ethno-medicinal Plants of Arunachal Pradesh, India

Pallabi Kalita Hui,[1,*] *Debmalya Das Gupta*[1] and *Hui Tag*[2]

Introduction

The North Eastern (NE) region of India represented by seven Indian states, viz. Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura is a 'Global Biodiversity Hotspot' and represents one of the highest biodiversity of the Indian subcontinent. The region is often referred to as the *Seven Sisters* and Sikkim has also now been included in North eastern states. It is ecologically represented by the Eastern Himalayan biome and is rich in a number of endemic flora and fauna endowed with a rich biodiversity. Arunachal Pradesh popularly called as "*Land of Rising Sun*", falls under a geographical coordinates of 26°28' to 29°30' North Latitude and 90°30' to 97°30' East Latitude spreading over a geographical area of 83,743 sq. km. It shares borders with Assam and Nagaland in the South, Tibet (China) in the North and North East, Bhutan in the West and Myanmar in the East. The state being primarily a hilly tract is nestled in the foothills of Himalayas situated on the Great Eastern Himalayan Mountain Range and is recognized as the 12th Global Biodiversity Hotspots. It covers a vast diversity of flora and fauna making it one of the richest biotic province of the Republic of India. Parallel with this, nature has exceedingly endowed the state with rich bio-resources along with the second largest area under forest cover, i.e., the total area of 68,045 sq.km in the whole of India after Madhya Pradesh (Anonymous 2008).

Arunachal Pradesh is a tribal state comprises of 19 districts inhabited by 26 major tribes and 110 sub-tribes of diverse culture and lifestyle, with a traditionally rich Indigenous Knowledge System (IKS), across different geographical regions since time-immemorial (Fig. 12.1) (Tag et al. 2005). The majority of the local tribal communities originally belonged to Mongoloid racial stock but their long history of migration coupled with geographical isolation has altogether contributed to varied distinctive characteristics which are reflected in their language, dress and customs and customary laws amongst different tribes and sub-tribes. The richness of life form, i.e., the flora and fauna that occur in the pristine forest presents a panorama of

[1] Department of Biotechnology, National Institute of Technology Arunachal Pradesh (NIT AP), Yupia-791112, Papum Pare, Arunachal Pradesh, India.
[2] Department of Botany, Rajiv Gandhi University, Rono Hills, Doimukh-791112, Papum Pare, Arunachal Pradesh, India.
* Corresponding author: pallabi2008rgu@gmail.com

The Internet of Things (IoT) Augmentation in Healthcare: An Application Analytics

Tathagata Adhikary[1], Amrita Deb Jana[1], Arindam Chakrabarty[2], and Saikat Kumar Jana[1(✉)]

[1] National Institute of Technology, Arunachal Pradesh, Yupia, India
saikatmicro4@gmail.com
[2] Rajiv Gandhi University, Itanagar, Arunachal Pradesh, India

Abstract. Healthcare technologies using IoT possess the ability to integrate different systems and generate inter-operable services. Applications of IoT in healthcare include tracking/monitoring, identification/authentication, sensing and data collection/sharing. Advancements in Artificial Intelligence (AI) couple intelligent decision making and reasoning algorithms with data from different sources enabling rapid processing and complex analysis of data. The market for IoT based healthcare systems is at infancy, but is growing at a rapid rate. Developments in continuous health monitoring devices and distributed health management including telemedicine are few outcomes of the approach of IoT. e-health technologies are directed to remote monitoring of patients providing out-patient care with ease by real-time data transfer and updation from connected devices. This review provides an insight to the pros and cons of IoT in healthcare technologies along its recent attempts, future scopes and challenges on its way .

Keywords: Ambient Assisted Living · Healthcare · Internet of Things · Remote patient monitoring · Sensors

1 Introduction

Internet of things (IoT), as the name suggests, is a network formed by interconnecting heterogeneous things or objects aimed to solve an addressed problem that generally requires interdisciplinary approaches. These objects can be different technologies, devices or solutions that exploit the knowledge of several domains (like electronics, biotechnology, communication, social science etc.) and the concept of IoT provides them a platform for their synergistic effort of problem solving. In short, IoT is the integration of many devices, their operating software and databases. Among the six civil disruptive technologies (i.e. a technology which has the potential to enhance or degrade elements of national power and create a noticeable change) that are being listed by the report of National Intelligence Council's Global Trends 2025, IoT has found its place indicating its future prospects [1]. It focuses on automation of a system and adaptation to real time changes, thus imparting smartness using intelligent interface. IoT broadens interoperability and facilitates connection of virtual with physical objects for better communication within the designed system.

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In the era of digitization, data generated from the healthcare sector (like patient records, trials of new medicines/treatments etc.) is increasing day by day. A proper management and analysis of these data by IoT devices can not only be helpful for practitioners to provide authentic diagnosis of patients but also to healthcare industries for setting up plants and meet the local or global demand (for e.g. selection of location for a hospital and its equipment requirements). Advancements in Artificial Intelligence (AI) couple intelligent decision making and reasoning algorithms with data from different sources enabling rapid processing and complex analysis of data. This has led to the inflammation of demand and market of modernized devices. Wearable devices based on IoT for monitoring health such as fitness trackers, insulin and blood pressure monitor etc. are increasingly used for self-health management throughout the world. According to the report of Global Industry Analyst, the market for these devices is estimated to touch US$ 4.5 billion by 2020 while the total IoT based healthcare market is forecasted to reach US$ 158 with 50 billion interlinked devices [2, 3]. IoT in healthcare sector proved to have great potential to uplift the economic and social environment of people and government by offering advanced services and personalization that was never imagined before [4].

2 Architecture of IoT in Healthcare Related Technologies

The implementation of IoT requires a structured framework for smooth operation of devices interconnected within that framework. The architecture underlying IoT technologies can be visualized as a 3 tier model. The 1st layer is the data acquisition layer which is followed by the subsequent layers of data transfer and data processing, all of them connected to a security layer [5, 6].

From the perspective of healthcare, data acquisition layer is responsible for generating data like patient details, measured health parameters etc. Developments in radio frequency identification tags (RFID), personal digital assistants (PDAs), biosensors and imaging devices stand as one of the major cause of increasing the popularity of medical prototypes due to the ease of data acquisition process. Most of the wearables relies on different types of biosensors available in the market for logical data acquisition. Pulse sensors (include pressure, photoplethysmographic (PPG), ultrasonic and radio frequency (RF) sensors) for monitoring pulse is found to be useful in detecting cardiac arrest or vasovagal syncope [7–9]. While designing a pulse biosensor it should be noted that pulse reading from earlobe and fingertip will provide more accurate data than chest or wrist. Sensors developed to record the respiration rate of an individual can identify cases of asthma attacks, apnea episodes, lung cancer, etc. [10]. The 1st nasal sensor developed used a thermistor which can sense the change in temperature during inhalation and exhalation to measure the respiration rate [11]. Other techniques to count one's breath utilizes microphone, electrocardiogram (ECG) signals, pressure sensor, stretch sensor or fiber optic sensor [12]. Thermistors measuring body temperature are used to reflect health conditions like hypothermia, heat stroke, fever etc. Several other sensors like pulse oximeter sensor and EEG sensor generating data of oxygen level in blood and brain signals are also becoming popular in the market [13, 14]. As the widespread implementation of IoT is increasing the number of connected devices, the

data generated in a year by any IoT device is likely be around 847 Zettabytes (ZB) [15]. The Australian Government started My Health Record scheme using cloud based databases to keep patients' information [16]. Health-Care Record databases (HCR) that includes Federated Health-Care Record (FHCR) and Electronic Health-Care Record (EHCR) is an organized compendium of health related data of individual patient or population in electronic format [4]. These huge databases comprising all the possible details like medical history records, statistics, laboratory test results, protocols etc. is impossible for manual interpretation and can only be addressed by Machine Learning (ML) and computational offloading. ML uses AI algorithms to record, learn and analyze data and execute operations based on previously learned patterns [2]. On the other hand, computational offloading enables com-plex computation of heterogeneous data in a high-power environment and returns the result to the low-resource environment (i.e. devices that generate data and locally store them). Data mining of big data combined with ML proves to be a promising technique to identify unknown trends in a disease progression and establishing new symptoms and treatments. The motive of improving transparency and availability of data questions the security related to data. Sensitive health data should be accessed by authorized persons only. Cloud based systems mainly employ access control policies and data encryption for securing data. Access control policy identifies authorized users and restricts any unauthorized access of data. Authentication mechanisms can be a password, facial, voice or fingerprint recognition. Data encryption ensures security of data in the storage system. Even if illegal access to database is achieved, strong data encryption will not allow direct reading of information. Advanced Encryption Standard (AES) is a popular algorithm for encryption because of faster and stronger encryption than other encryption algorithms like Blue-Fish, DES and 3DES [17, 18].

A schematic diagram showing the architecture of IoT in healthcare is give given below (Fig 1):

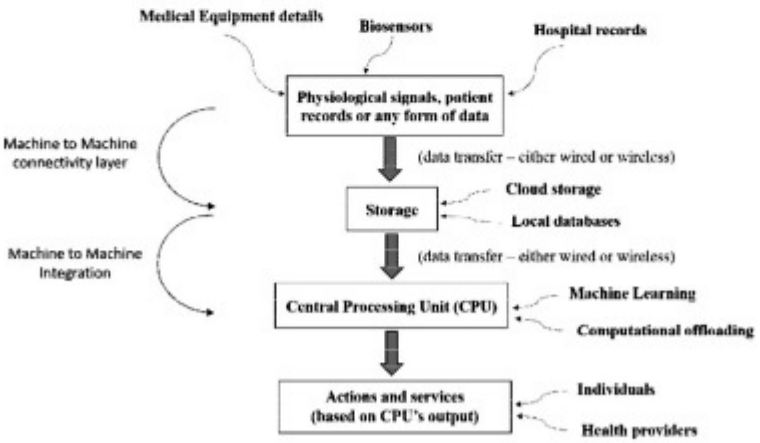

Fig. 1. Basic principle of IoT in healthcare

3 Applications of IoT Based Healthcare Technologies and Its Recent Advancements

With the rise in the demand for comfortable and assisted lifestyle, IoT is recently exploited in every possible way. These changes are the consequence of the following factors: 8.5% of the global population is aged 65 years or older and the value is expected to rise to 17% by 2050, life expectancy will increase from 68.6 years in 2015 to 76.2 years in 2050, more cases of chronic diseases, limited resources and lastly high expectations of society from technology [1, 2].

Different applications of IoT in healthcare (a.k.a. Internet of Medical Things (IoMT)) include tracking/monitoring, identification/authentication, data collection/sharing and sensing [2]. For e.g. tracking expensive and reusable items will lower the cost of investment. As declared by Dr. Peter Carter, the general secretary of the Royal College of Nursing, loss of reusable items poses as a responsible factor for the financial crisis of National Health Service (NHS). Considering Birmingham only, NHS has suffered a loss of £20,000 due to 2300 unreturned crutches on a year, hence tracking of similar medical inventories can cut down the unnecessary expenditure to a great extent and efficiently use scarce resources [4]. Researches in mobility aids made automation of wheel chair possible to a great extent by incorporating IoT. For safety issues, a remote support system can review status of the user and have access to the wheelchair controls.

IoT plays a vital role in distributed health management (like remote operation of an equipment, statistical analysis of a medical case study, off-site advice for minor ailments etc.) which enables central access to data for contextualized decisions, efficient and person-centric healthcare services [3]. Remote patient monitoring (RPM) utilizes smart technologies like phones or sensors to execute routine check-ups and transfer real-time data via cloud based services to professionals for their immediate and best opinion. Real-time Health Systems (RTHS) is becoming the most discussed area in healthcare as it assesses both static and dynamic data to provide comprehensive healthcare solutions. RPM is mostly implemented for elderly patients or patients with chronic diseases for rapid diagnosis and onset of treatment during a certain emergency, but is also popular among the health-conscious population. National Broadband Plan set up by the Federal Communications Commission (FCC) has predicted that the use of electronic health records (EHR) based RPM technology can save US$ 700 billion in healthcare industry over the period of 15 to 20 years [1, 3]. Kaa is a popular IoT platform that has the ability to cross-device connect and impart smart features in medical devices. Original Equipment Manufacturers (OEMs) that incorporate Kaa's functionality in their products seemed to achieve IoT related goals faster with minimal extra investments. Security being an issue in IoT, Kaa uses modern security and device authentication protocols like TLS for exchanging data between devices.

IoMT devices encourage more patient-physician interaction thus improving patient satisfaction and engagement. Sometimes a course of medication can exhibit side effects commonly known as Adverse Drug Reaction (ADR). The iMedPackis designed to address this challenge by combining pharmaceutical information and patient's health record to check drug compatibility. A variety of biosensor based virtual home assistants and wearable/implantable devices such as fitness tracker, heart rate and ECG monitor,

disease detector, devices measuring continuous glucose, insulin, alcohol in blood etc. are available in the market and consolidation of their data in a unified model can be exploited to detect health patterns and predict future trends using IoT and big data analysis. Tracking, sharing and analyzing these biometric measurements is a key job of IoT in wellness management. Combination of sensors for ECG, breath-ing rate, sleep position etc. and real time monitoring of their reports can certainly reduce cases of Sudden Infant Death Syndrome (SIDS). iDiab is a wireless device consisting of a body sensor system (hCheck) that measures blood sugar level along with heart rate and breathing rate and alerts via zPhone (an IoT communicator) when critical value is reached(for immediate on-demand health services) [19, 20]. Devices for diagnosis/ monitoring sleep cycles, chronic obstructive pulmonary disease, major depression disorder (MDD), cystic fibrosis, allergic rhinitis, blood oxygen saturation, melanoma and wound analysis for highly diabetic patients are few other examples of IoT based portable devices that exist today [5, 7, 8]. Diagnosis of melanoma and wound analysis makes use of phone's camera and compares the image with different databases. Apart from the mentioned sensors, accelerometers, gyroscopes and magnetometers are exploited in IoMT devices for fall detection, human motion etc., thus finding its place in elderly care and infant monitoring systems. Systems that have the ability to address health condition critically ill patients and provide independent life-style to the aged population is termed as Ambient Assisted Living (AAL). AAL utilizes the concept of keep-in-touch (KIT) smart objects and closed-loop healthcare services based on IoT [1, 4]. Some leading pharmaceutical companies have developed smart pills which when taken by an individual transmit signal to an outside sensor to monitor health and aid to take prompt actions whenever needed [20]. Recent innovations in neuro technology make use of sensors that depict neural functioning and possess the ability to control it. Moodables are mood enhancing IoMT devices that have been purposed to improve and repair brain processes. Thync and Halo Neurosciences are two leading companies in making wearables designed to elevate mood by sending low intensity current. Apart from all these few discussed applications of IoMT, the future is yet to witness more integrated and advanced systems through constant innovations in IoT technologies.

4 IoMTs in the Market – A Survey Study

See Table 1.

Table 1. The table given below enlists some of the established examples of IoT technologies in healthcare.

SI. No.	Name of the IoT gadgets/services	Purpose of use
1	Augmedix	Technology-enabled documentation service
2	Awarepoint	Cloud-based, Real-time Location System (RTLS) that delivers rapid-time-to-impact implementations, automating and streamlining asset management, ED and OR care, capacity management, patient flow, caregiver co-ordination, quality and regulatory compliance

(*continued*)

Table 1. (*continued*)

SI. No.	Name of the IoT gadgets/services	Purpose of use
3	Fitbit Flex	Fitness tracker that keeps a track of number of steps taken and calories burned for personal supervision
4	PulseOxiter	Report heart rate and blood oxygen saturation (SpO_2)
5	Skydio	Combines drone technology and computer vision technology to mimic visual perception and aid visually impaired people by detecting obstacles in the surrounding environment
6	GlowCaps	Keeps track of ones scheduled medications
7	Asus Vivo Watch	Measures heart beat accurately using pulse technology & built in optical sensors
8	Google Smart Contact Lenses	Takes tears from eyes and measures the presence of glucose level
9	Myo	Uses a motion controller to measure the angle of movement – helpful for patients who need to exercise after a fracture
10	Kinsa	An IoT thermometer that allows personalized guidance
11	OpenAPS	Automatic delivery of required amount of insulin
12	Pharma	Implantable long-term continuous glucose monitoring (CGM) system
13	Apple's Research Kit software	Mainly collects and tracks common symptoms of rheumatoid arthritis
14	Project Blue Sky	Monitors the progression and treatment of Parkinson's
15	Qardio	Remote monitoring of cardiovascular, lung and diabetes diseases
16	Ybrain	Wearable devices for Alzheimer's and mild cognitive impairment patients
17	Sproutling	Monitors and predicts a baby's sleep habits and optimal sleep conditions

5 Security Risks and Challenges Related to IoT-Healthcare

Although digitization may seem to be a blessing, it comes with the cost of security risks of data loss, leakage and manipulation. Healthcare services gather personal information and connection of data to global networks of information can be threaten-ing. Hence understanding security requirements, its challenges and privacy concerns are necessary. Any manipulation of data can cause serious damage to the outcome of systems. Protection is achieved by using dynamic algorithms that are capable of detecting an attack based on anomalous encounters during its learning phase [21]. Many attempts have been taken in this process, like the European Union General Data Protection Regulation (GDPR) announced hefty penalties for misusing and purging data, yet the threats cannot be overlooked [1, 4]. "Safe-Project" is introduced to encrypt and store patients' record in cloud based storage systems. Patients can give ac-cess to the persons of his/her choice. This sophisticated platform also blocks all actions for copying data like Ctrl+C or PtrScr [22].

As the number of manufactures and their products are rising, standard rules and regulations should be made to ensure interoperability and standardization of interfaces and protocols which is lacking currently. The non-homogeneity among medical devices is a major hurdle in the process of multiple device integration. Also there is a challenge to maximize security and simultaneously minimize resource consumption due to power, computation and memory constraints [3, 4]. Efficiency of IoT is high when there is easy real-time updation and uninterrupted long-term monitoring, thus power loss is certainly not entertained. This requires good computer programming and proper data packing and encryption [23].

6 Conclusions

IoT allows heterogeneous devices and technologies to smoothly interact with each other in a common intelligent framework with connected networks and centralized data. Key benefits obtained by using IoT in healthcare are increase in patient engagement, early diagnosis, better patient outcomes, reduced manual errors, efficient handling of resources and ease of providing services. India planned to develop a US$ 15 billion worth IoT industry understanding the massive impact it can cause on economy. Despite having challenges, the potential of IoT is making it a lucrative choice for improving economy and lifestyle of societies.

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Firewall Rule Anomaly Detection: A Survey

[1]Zahid Ahmed, [2]S Md S Askari

Department of Computer Science and Engineering

Rajiv Gandhi University

Arunachal Pradesh, India

[1]zahidprince786@gmail.com, [2]askari.sikdar@gmail.com

Abstract

Firewalls are the fundamental component in the security mechanism of a network. Firewall is a series of ordered filtering rules set by the administrator of a network. To set a large number of rules is a complex task. Sometimes in setting the rules in firewall system, there may be some error. Which may lead to conflicts between two or more rules which will results in rule anomalies. A major contribution of this work is to know the mechanism of firewall system, details about the anomalies, and various types of anomalies and the different techniques to sort out the anomalies.
KEYWORDS: Firewall Rule relation, Rule anomaly, Co-relation.

1 Introduction

In the last few years security has become the most burning issue in all over the world. Day by day the threat of network attacks are increasing hence the challenges are also increasing to protect the networks (small home network to large enterprise networks) .Everyone is aware of protecting the networks from unwanted attacks as well as the unauthorized access. Firewall is one of the key element which protects the network from unwanted attacks and unauthorized traffic. Firewall performs the task by filtering the network traffic which are coming inside or going out from the network. Filtering process takes place on the basis of some predefined set of ordered rules. As the number of rules increases the difficulty of adding a new rule or modifying some existing rules also increases and the possibilities of conflicting between two or more rules also increases. Conflict between two or more rules is known as ANOMALY. [3, 5, 4, 1, 2, 6] When anomaly occurs the firewall does not work properly. Sometimes it may happen that firewall allows those packets which should have been blocked and blocks those packets which should have been allowed [2, 10, 15, 17, 20]. There are several types of anomalies in firewall system. Many researches have been done to find permanent solutions for these anomalies and many algorithms have been proposed for detection and correction of these firewall rule anomalies in a firewall system.

This paper comprehensively attempts to analyze various types of rule set anomalies in firewall system and to present different solutions by the scientists in the recent time.

2 Firewall Rules and Rule Relation

A firewall is a network preservation system designed to avoid illegal entry to or from a private network. It acts as a security gourd in the gateway. Whenever a packet comes inside of a network or goes outside from the network, the packet passes through the firewall. A firewall examines a packet and decides whether it should be allowed to pass or should be blocked. A firewall can be implemented both as a hardware or software and sometimes by combining both the hardware and software. Network firewalls are often used to avoid illegal Internet users from entering a private network which is connected to the Internet [3].

Firewall rule format:

Firewall rule format depends on the network administrator. But the standard format consist the following fields: protocol, source IP, source port, destination IP, destination port and action.[3, 5, 4, 1, 2, 6].

<order><protocol><s-IP><s-port><d-IP><d-port><action>

An example of filtering rule format.

The rule format consist two parts.

• Predicate or Header

In the previous study of Khummanee et al [19] have defined a part of rule format as predicate part on the other hand in another study by Benelbahri and Bouhoula [8] have defined the same part as header part which consists of 5 fields. These are sequentially 1 bit Protocol, 32bits source IP address, 16 bits source port number, 32 bits destination IP address and 16bits destination port number. Predicate holds the address where from the packet is coming and to where the packet is going to. Simply it is an address part.

• Decesion

The decision part consist only 1 bit action field which holds the decision information. According to this action field the firewall, allows or blocks a packet.

2.1 Firewall rule relations

Filtering rules control the whole firewall system and based on these rules firewall performs the task. Firewall policy is a collection of a huge number of filtering rules, set by the network administrator. Among these rules one rule may be related with other rules. And to build an efficient firewall system, an administrator needs to determine all the possible relations between them. As described by Al-Shaer et al [3] the rule relation can be categorized as:

• Completely disjoint (CD)

Rules $\Re_a$ and $\Re_b$ are said to be completely disjoint if the following equation is satisfied-

$$\forall p,\ \Re_a[p] \cap \Re_b[p] = \varphi \qquad (1)$$

Where *a* and *b* are the orders of the rules and *p* is the individual fields of the rules.

i.e. *p ∈{protocol,s-IP,s-port,d-IP,d-port}*

• Exactly matching (EM)

Rules $\Re_a$ and $\Re_b$ are said to be exactly matching if the following equation is satisfied-

$$\forall p,\ [(\Re_a[p] \cap \Re_b[p] = \Re_a[p]) \wedge (\Re_a[p] \cap \Re_b[p] = \Re_b[p])] \qquad (2)$$

Where *a* and *b* are the orders of the rules and *p* is the individual fields of the rules.

i.e. *p ∈{protocol,s-IP,s-port,d-IP,d-port}*

• Inclusively matching (IM)

Rules $\Re_a$ and $\Re_b$ are said to be inclusively matching if the following equation is satisfied-

$$\forall p,\ [(\Re_a[p] \cap \Re_b[p] = \Re_a[p]) \wedge (\Re_a[p] \cap \Re_b[p] \neq \Re_b[p])] \qquad (3)$$

Where *a* and *b* are the orders of the rules and *p* is the individual fields of the rules.

i.e. *p ∈{protocol,s-IP,s-port,d-IP,d-port}*

• Partially disjoint (PD)

Rules $\Re_a$ and $\Re_b$ are said to be partially disjoint if the following equation is satisfied-

$$\exists p,\ [(\Re_a[p] \cap \Re_b[p] = \Re_a[p]) \vee (\Re_a[p] \cap \Re_b[p] = \Re_b[p])] \wedge \exists q\ [(\Re_a[q] \cap \Re_b[q] = \varphi)] \qquad (4)$$

Where a and b are the orders of the rules and p,q are the individual fields of the rules.
i.e. $p,q \in \{protocol,s\text{-}IP,s\text{-}port,d\text{-}IP,d\text{-}port\}$ and $p \neq q$.

• Correlated (C)
Rules $\Re_a$ and $\Re_b$ are said to be correlated if the following equation is satisfied:

$$\exists p, [(\Re_a[p] \cap \Re_b[p] = \Re_a[p])] \wedge \exists q[(\Re_a[q] \cap \Re_b[q] = \Re_b[q])] \quad (5)$$

Where a and b are the orders of the rules and p,q are the individual fields of the rules.
i.e. $p,q \in \{protocol,s\text{-}IP,s\text{-}port,d\text{-}IP,d\text{-}port\}$ and $p \neq q$.

3 Problems of firewall rule management

It is highly problematic to manage the filtering rules inside a firewall system. The main problem of firewall rule management is anomaly detection and removal [19]. If the filtering rules are not set properly, it may create some conflict inside the firewall system. Conflict occurs when two or more firewall rules are overlapped and all are having different action [3, 19]. Conflict within firewall rules can make a system in a halting state or it may lead a system to perform improperly [11].

For example, suppose there are two rules $\Re_1$&$\Re_2$.
$\Re_1$: TCP,150.120.*.*,any,190.160.70.*,any,accept
$\Re_2$: TCP,150.120.70.43,80,190.160.70.10,any,deny

Here both the rules are partially overlapped and they are inclusively matching with each other. i.e.$\Re_1 RIM \Re_2$. But both of these two rules are having different actions. So these two rules are conflicting with each other, and this scenario is considered as an anomaly.
iff $\forall i : \Re_x[i] \cap \Re_y[i] \neq \varphi \wedge \Re_x[action] \neq \Re_y[action]$
Where $i \in \{protocol,s-IP,s-port,d-IP,d-port\}$

4 Type of Anomalies

Because of the conflict between two rules, anomalies occur inside a firewall system. Several researches have been done on firewall rule anomalies. In different studies the types of anomalies are categorized and described differently [3, 16, 11, 8, 22, 9]. Based on those the following are the different types of rule anomalies in firewall system:

• Shadowing anomaly
As name implies shadowing anomaly takes place when one rule becomes the shadow of another previous rule. It means when the predicate part of one rule matches the predicate part of another previous rule but both are having different actions then the rule is known as shadowed rule of that previous rule.

Rule $\Re_a$ is said to be a shadowed by rule $\Re_b$ if the following equation is satisfied-

$$(\forall p, (\Re_a[p] == \Re_b[p]) \wedge (\Re_a[Decision] \neq \Re_b[Decision])) \quad (6)$$

$$(\forall p, (\Re_a[p] \supset \Re_b[p]) \wedge (\Re_a[Decision] \neq \Re_b[Decision])) \quad (7)$$

Where $\Re$ is a rule and a and b are orders of the rules such that $a < b$ and p is an individual predicate field of a rule.
i.e. $p \in \{protocol,s-IP,s-port,d-IP,d-port\}$

• Correlation anomaly

When two rules have different action fields and some predicate fields of the first rule are equal or subset of the corresponding predicate fields of the second rule and rest predicate fields of the second rule are superset of the corresponding predicate fields of the first rule then the rules are known as correlated rules.

Rule $\Re_a$ is said to be a correlated with rule $\Re_b$ if the following equation is satisfied-

$$((\exists p, \Re_a[p] \cap \Re_b[p] == \Re_a[p]) \wedge (\exists q\ \Re_a[p] \cap \Re_a[q] == \Re_b[q]) \wedge (\Re_a[Decision] \neq \Re_b[Decision])) \quad (8)$$

Where $\Re$ is rule and a and b are orders of the rules such that $a < b$ and p,q are the individual predicate field of a rule .
i.e. $p,q \in \{protocol,s\text{-}IP,s\text{-}port,d\text{-}IP,d\text{-}port\}$ and $p \neq q$.

• Generalization anomaly

When two rules have different action fields but all predicate fields of the second rule matches with all predicate fields of the first rule then the second rule is known as the generalization of the first rule.

Rule $\Re_a$ is said to be a generalization of rule $\Re_b$ if the following equation is satisfied-

$$((\forall p, (\Re_a[p] \cap \Re_b[p]) = \Re_a[p])) \wedge (\Re_a[Decision] \neq \Re_b[Decision]) \quad (9)$$

Where $\Re$ is a rule and a and b are orders of the rules such that $a < b$ and p is an individual predicate field of a rule.
i.e. $p \in \{protocol,s-IP,s-port,d-IP,d-port\}$

• Redundancy anomaly

A filtering rule is said to be redundant if it is present or absent in firewall system does not create any changes in the system. It means if this type of rule is removed from the system security policy will remain unchanged. This type of anomaly occurs when a rule is set twice in a firewall at different position or some times one rule may be a subset of some other rule. Usually this type of anomaly does not create any accuracy problem, but the only thing is that, this type of anomaly make the rule set extra large which may reduce speed and reduces the performance of a system.
Rule $\Re_a$ is said to be a redundant of rule $\Re_b$ if the following equation is satisfied-

$$\forall p, (\Re_a[p] = \Re_b[p]) \wedge (\Re_a[Decision] = \Re_b[Decision]) \quad (10)$$

Where $\Re$ is a rule and a and b are orders of the rules such that $a < b$ and p is an individual predicate field of a rule.
i.e. $p \in \{protocol,s-IP,s-port,d-IP,d-port\}$

• Irrelevance anomaly

A filtering rule is said to be irrelevant if it cannot examine any traffic that passes through the firewall system. As name implies this type of rule is irrelevant for a firewall system. Just like the redundant anomaly this type of anomaly also does not create any accuracy problem, but the only thing is that, this type of anomaly makes the rule set extra-large which may reduce speed and the performance of a system.

5 Anomalies Detection Approaches

The anomalies inside of a firewall system can create many problems. One of them is time complexity. Anomalies can decrease the performance of a system, creates improper functionalities and accuracy problems. Because of the anomalies the system cannot take accurate decisions. There are many different methods have been proposed till now to identify these rule anomalies of a firewall system. The different scientist has used different techniques to solve the problem. Followings are the approaches:

5.1 Policy Tree Representation

Al-Shaer et al[3] have proposed the Policy tree representation technique to discover the anomalies inside a firewall system. They have represented the firewall policy with the help of single rooted policy tree. They have claimed that this model maintain an elementary depiction of the filtering rules present in a ruleset and it has the ability to discover the rule relations and anomalies between two or more rules. Each node in a policy tree depict a network field and every path starting at the root node and ending at the leaf node represents an individual rule. Rules with the same field value at a distinct node will share the same branch of the tree. Leaf node consists the decision part of a rule.
They have also proposed an algorithm which is able to detect the anomalies in the firewall system. This algorithm works based on the Policy Tree representation. For two rules $\Re_x$ and $\Re_y$ the algorithm starts with an initial state assuming no relation between them. Then each field of $\Re_x$ is compared to the corresponding field of $\Re_y$. The comparison starts with the protocol

field then source IP address then source port then destination IP address and then stop at destination port. Based on this comparisons, the relation between the rules are determined and also the anomalies are determined. According to their study in the worst case the algorithm takes 10-240 ms of processing time to examine a security policy of 10-90 rules in a single firewall system. In a large network it takes 20-180 second

5.2 Tree-Rule Firewall

Xiangjian et al [14] have proposed the Tree rule. This is almost similar with the Policy Tree Representation technique proposed by E Al-Shaer et al [3].The only difference is, it is not a firewall anomalies detection technique. This is a technique to set the rules inside a firewall system which will provide the network administrator an anomaly free environment. They have claimed that this technique protects the system from conflict between rules. This technique reads the information, which is present in the header of a packet and then, it examines the first attribute of packet with the data, which is present in the root node of a rule tree. Then, the firewall examines the other attributes of the packet in a sequential manner with the help of search operation on relevant nodes at the corresponding levels. Attributes of the root node can be either Source IP, Destination IP or any attributes suitable for that particular work. For each column user can choose any attribute, before generating the Tree rules [14].In the basic design the root node has the number of lines equal to the number of users' computer, so each line is linked to some sub tree with duplicate data. To avoid this problem, they have also improved the design where they replaced the Single IP Address with a range of IP Addresses.
The time complexity of the basic design in worst case is *O(log2N)* and the time complexity of improved design in the worst case is *O(1 + log2N)*
In their study they have considered only three fields Destination IP, Destination port and Source IP.As rest of the fields are not considered, conflict may occur in those fields and which can create anomalies.

5.3 Tuple Based Approach

Benelbahri and Bohoula have proposed Tuple Based Approach for detection tof anomalies inside a firewall system [8]. In this technique for two rules $\Re_a$ and $\Re_b$ they have represented the fields relation as a 4-tuple: (Filed#, $\Re_a$#, $\Re_b$#,code)
Where "Field" is the order in the filtering rule," $\Re_a$ and $\Re_b$" are the first and second rule and the " Code "is the relationship code.

For *m* number of fields in the filtering rule and n number of filtering rules in filter F. The anomalies are determined by the product of all field codes corresponding to the same indexes a and b of the rules $\Re_a$ and $\Re_b$, and is denoted by:

$$P_{ab} = \Pi^{-1}{}_{n=1} C_{ab}(n) \quad (11)$$

This model calculates each 4-tuple and checks if it is equal to zero or not. If it is zero then rules are disjoint and then it stores them in the corresponding stack and then jumps to the next code. When an anomaly is detected, the system classifies based on these rules:

- if $P_{ab} > 1$ then redundancy anomaly.
- if $P_{ab} = -1$ then Irrelevant anomaly.
- if P_{ab} mod (g•s) = 0 then correlation anomaly.
- if P_{ab} mod g = 0 then generalization anomaly.
- if P_{ab} mod s = 0 then shadowing anomaly.

5.4 Inter-Difference Matrices (IDM) Approach

Another work done by Bouhoula et al[9] in their study they have introduced the Inter-Difference matrix approach for detecting anomalies inside a firewall system. In this technique they have used matrix to store the differences between two rules. IDM approach can be defined as a matrix whose element represents the difference of elements belonging to the corresponding vector in the matrix F. For each field an IDM matrix is generated. The number of IDM matrices are equal to the number of fields m and each element e_{ab}, represents the difference between the values of the same field f_{ax} and f_{bx} of the filtering rules $\Re_a$ and $\Re_b$. Some extra codes are used to denote the relationship between two or more rules; those are:

- 0 is the code for the difference relationship between two fields and -1 is the code for the difference between two action fields.
- 1 is the code for Equality relationship two fields including the action field.
- 2 is the code for Generalization relationship between two fields.
- 3 is the code for Shadowing relationship between two fields.

The Inter Difference Matrix E

$$E(v_k) = (e_{ab})_{1\le a,b\le n} = (f_{ax} - f_{bx})_{1\le a,b\le n} \quad (12)$$

To prove the existence of anomalies they calculate the product of the element of the vector and use the equation:

$$P_{ab} = \Pi^{-1}{}_{n=1} C_{ab}(n) \quad (11)$$

The above equation is similar with the equation which is used in tuple based approach done by Benelbahri and Bohoula [8].

5.5 Association Rule Mining (ARM)

Golnabi et all [13] have introduced another approach of detecting rule anomalies which is known as Association Rule Mining (ARM) technique. It is a comprehensive method to find out accurate, effective and desirable rules in the rule set of firewall system. Thousands of rules are present in a rule set among them some rules may not have any importance on firewall such as duplicate rules or rules which does not have any action on the decision field. These unwanted rules may create anomalies in the system. With the help of this method, these rules are filtered for further inquiry and to conclude a unique and distinct rule to more general rules.
This method executes in the following steps:[13]

• Analysis of firewall policy rules
Firewall consists of number of filtering rules, set by the network administrator. In this state the rules are, examine and generate a basic set of firewall rules to prepare firewall log raw data to select the rules for data mining.

• Association rule mining
Here it collects and extracts the rules from log raw data prepared in the previous step for performing the Apriori analysis. Here by calculating probability of the observed frequency based on the use of individual rule, the threshold for confidence and threshold for minimal support are evaluated. By applying the Apriori analysis, the rules having the confidence and support more than the respective thresholds are retrieved.

• Mining firewall log using frequency
This is a similar method with Association Rule which reads each line of firewall log raw file, extracts the rules for individual log record and counts its occurrence and generate the count for the individual unique combination of these rules [13].

• Filtering rule generalization
It is an algorithm to produce a minimum number of firewall rules for detecting anomalies and efficient use. Here a decision tree is generated where each level shows the rules from the log raw file.

• Rule ordering
Here the rules are ordered in a significant way based on the outcomes and performance. Here the ordering is not based on its generalization, rather it is relied on the belief that a particular rule should be applied first and the assumption is taken from the previous step.

• Anomalies detection
This is the final step where the anomalies are detected and removed from the rule set.

5.6 XML based open tool for anomalies detection

There is another technique which was proposed by Benelbahri et al[7] based on XML and the technique is known as XML based open tool to detect and resolve filtering rule anomalies. They have proposed this scheme to remove

the conflicts between two rules, and it is based on the concept of putting some resolve filters. With this technique they have tried to characterize all the possible conditions which can create conflict among the rules and gave a solution how to resolve them.
According to them the main reason of conflict between the rules is the organization of rules. Since the rules reflect the security policy, the network administrators are always tried to apply a comprehensive method of organizing filtering rule set in a proper manner. That is if the rules are organized in the proper way then the conflict can be avoided and the anomalies will never be formed. This method executes in two parts. Those are:

• Translator
As name implies the translator translates all representations to a unified and standard representation using XML tool. One of the advantages of XML documents is the hierarchical representation which forms a tree, and they have used this tool to form a tree structure of the rule set. It represents and stores both the filtering rule formats and sequence number in variable form which provides the clarity. They have used the LEX and YACC to carry out the translator module. This module presents each firewall product as a DLL file.

• Analyzer
The analyzer finds in its input an XML file. It extracts the filtering rule fields presented as node in the XML file and it understands the file. Then it applies the technique chosen by the user to detect and resolve the anomalies by invoking the appropriate DLL which holds the algorithm. This module consists of a set of DLLs implementing analyzing algorithm. This tool is presented as successive interfaces. Which allows the user to choose the analysis context [7].

5.7 Graph Based Approach

Fulp [12] has proposed a technique which mainly optimizes the performance of a firewall system. This approach does not directly deal with the anomalies present inside a firewall system rather it improves the performance of firewall system. The listed firewall has some limitations [14]. One of them is the swapping positions between two rules, which changes the firewall policy and creates security problems as well as it reduces the performance. There are a few techniques which can be used to arrange the rules in a systematic manner so that the rules can be listed properly. The technique is based on the ordered sets and directed acyclic graph to arrange the rules in a linear way so that the performance can be improved.
This approach completes the task in three steps:

• Firewall Rules and Policy Models
A rule r is modeled as an ordered set of tuples $r = r[1],r[2],....,r[k]$. Where every tuple belongs to predicate part of individual rule. Here the decision part is not considered. Ordering is necessary among the tuples because it increases the speed of comparing each packet with the corresponding tuples present in the system. Here the tuples are represented in ordered manner and every new rule is compared with other rules to find out the relations among them.

• Modeling Precedence Relationship
The precedence relationship between existing rules are modeled as a directed acyclic graph. The directed acyclic graph represents the proper integrity of individual rule. The integrity refers to the probability of the matching two rules with one another. Let $G = (V,E)$ be a policy directed acyclic graph for some rule set $\Re$, where vertices V represents the rules and edges E represents the precedence of relationship. These graphs are used to represent the integrity of the individual task. This structure is the best way to model the precedence of firewall rules.

• Rule list optimization
In this step using the policy directed acyclic graph the optimal order of firewall rule set is determined based on the precedence of the integrity of individual rule. As a result it is possible to construct a properly ordered and anomaly free rule set. [12].

5.8 Firewall anomaly detection by using model checker and visibility logic

For detecting the anomalies inside a firewall different approaches have been introduced by researchers. This technique is also one among them, and it was introduced by Khorachani and Halle [18]. This technique is based on model checker and visibility logic. They have described the anomalies by using Boolean algebra method and they have solved the problem by their own algorithm which was developed in JAVA platform. They have defined a set of binary relations suitable for distinguishing the visibility concepts such as occlusion ◊, obstruction ○ and covering □ .

The Boolean connectives is a simple process. For a set of rules:
$\Re, r \models *\Re\varphi$, *where* $* \in \{\Diamond, \circ, \Box\}$ and $\Re \in \{\cap, \subseteq, \supseteq\}$ and executes in the following way. First this algorithm computes the current rule r, the rule set $\{r_1, r_2, ..., r_n\}$ such that $R(r,r')$ holds. Now for different operators the process is as follows:

• If * is the operator ◊, the expression is true exactly when $\Re, r_{a,b} \models *\Re\varphi$ for some $r_{a,b}$.
• If * is the operator ○, the expression is true exactly when $\Re, r_{a,b} \models *\Re\varphi$.
• If * is the operator □, the expression is true exactly when $\Re, r_{a,b} \models *\Re\varphi$ for all $r_{a,b}$.

This visibility logic takes input according to the visibility logic formula φ, a rule base $\Re$ and a starting rule r and then compares the rule relation by considering their own logic $\Re, r \models \varphi$. Depending upon this logic, it returns an output as "true" or "false". They have tested the approach using four different rule sets ranges from 100 to 4000 rules. The complexity of their algorithm is $O(\Re^k)$. Where $\Re$ is the size of the rule set and k is the number of nested operators in the formula to verify.

5.9 Algorithm Resolve-Anomalies

This is another algorithm proposed by Abedin et al[1] that can simultaneously detect and resolve the anomalies, which are present in the ruleset. By using reorder and split operation this approach generates a new ruleset which is purely anomaly free. The algorithm consists of two modules.

• **Module 1**:- It investigates all the rules present in a ruleset and brings out a set of dissimilar rules, that is anomaly free.

• **Module 2**:- It investigates the rules and tries to join all the rules so that the size of a ruleset can be reduced, thus it can able to bring out a ruleset without introducing any new anomaly.

In this algorithm, they had resolved the anomalies as follows:

In case of shadowing anomaly, if two rules are exactly matched, it preserves the rule having deny in action field. In case of inclusively matched, the rules are shifted in a manner such that the superset rule comes after the subset rule. In case of correlation anomaly, the rules are broken down into several dissimilar parts for inserting them into a list. And finally in the case of redundant anomaly, the rule is removed from the ruleset.
This algorithm performs the operation by maintaining two comprehensive lists of rules.

• Old list
• New list

An old list holds the original firewall configuration with having the original ruleset, and the new list holds ruleset without any anomaly, that is the outputs of this algorithm. This approach is an incremental process, where each rule is taken from the old list and insert it into new rules list in such a manner so that the new rules list remains anomaly free.
An algorithm is there to control the whole process which is known as *Resolve-Anomalies*. First the global rule list is initialized, then it accepts rules from the old list one by one and calls algorithm insert. After that, it scans for the new list to resolve redundant anomalies that might survive on

the list. After that *Insert* Algorithm is used to add a rule into the new list in such a manner so that the list remains anomaly free. In case of an empty list, the rule is added to the list without any condition. Otherwise, the resolve algorithm is used in a for loop. The insert examines each and every new rule with all the rules present in a new list and if any conflicts occur, resolve handles it with a return value true and breaks the loop. Therefore, when resolve handles the rule, it sets the flag as true. Otherwise, the rule is dissimilar or superset with all the rules in a new list and it is added into last of the list. After that, the algorithm *resolve* is used to identify and resolve the anomalies between two rules which are similar. If the first rule sent to algorithm *Resolve*, $\Re$ is the rule being added, and *S* is a rule already present in the new list. In comparing them, following are the possibilities:

• $\Re$ and *S* are equal. If both are equal and having same decision, then any one can be removed, else the one with the reject action is retained.
• $\Re$ is a subset of *S*. $\Re$ inserted before S without considering the decision field.
• $\Re$ is a superset of *S*. $\Re$ may match with proceeding rules present the list, so it is permitted to be examined further. In this situation, no operation is performed.
• $\Re$ and *S* are correlated. The correlated rules are decomposed into dissimilar rules. First, the set of attributes where two rules are different from each other is determined, and then split is called for each of the different attributes in the for loop. After execution of the split, < and S contain the common part of the rules ready to insert.

There is another algorithm which is used to decompose two similar rules and it is known as Algorithm *split*. First it obtains the portions that are dissimilar between two rules and, then it performs the *insert* algorithm on that. After that, it evaluates the common portions of the two rules. If, $\Re$ and *S* are the two rules and *A* be an attribute for which *split* is called. Although these two portions are dissimilar with $\Re$ and *S*, their relation with the other rules in the new list is unknown, the rule is added into the new list by applying *insert* algorithm. Now the common portions of the two rules is evaluated. The dissimilar portions are evaluated before the common part is evaluated and added to the list. After the execution of this whole process, the new rules list contains those rules which are anomaly free.

5.10 Relational Algebra and Raining 2D-Box Model

This is another approach proposed by Mukkapati and Bhargavi [21] to detect the anomalies inside a firewall. In the meantime while all the other approaches are focused to find out the anomalies exist between any two rules in a ruleset, this approach also focused to find out those anomalies, which exist between more than two rules together at the same time. Therefore this approach can able to find out all the hidden anomalies in the ruleset. This method can help the administrator to examine and modify a complex firewall policy too. This approach defined and classified the various kind of anomalies by using a technique which is known as Raining 2D-Box Model. If *Rule-u* is defined as a rule number *u* from the ruleset and $u < v$, then *Rule-v* is the proceeding rule of *Rule-u* then, $\Re_u$ is a rule relation that has been mapped from a *Rule-u* by using some PROJECT operation to exclude the action attribute from the rule format. This approach has also present many definitions to discover the anomalies. Here the anomalies are analyzed and removed by using 6 theorems. And those are as follows:

• **Theorem 1**: A firewall does not change a policy even if *Rule-u* is removed from the ruleset, when *Rule-u* is shadowed.
• **Theorem 2**: A firewall does not change a policy even if *Rule-u* and *Rule-v* are swaped with each other, when Rule-u and Rule-v are sequentiall non-correlated.
• **Theorem 3**: A firewall does not change a policy even if *Rule-u* and *Rule-v* are swaped with each other, where $u < v$, and *Rule-m* is sequentially non-correlated and downward to *Rule-v*, and *Rule-v* is sequentially noncorrelated and upward to *Rule-u*.
• **Theorem 4**: A firewall does not change a policy even if *Rule-u* and *Rule-v* are swaped with each other, where *Rule-u* and *Rule-v* are correlated and *Rule-v* is shadowed, and *Rule-u* is sequentially non-correlated to *Rule−(u−1)* and also downward, and *Rule-v* is sequentially non-correlated upward to *Rule−(u + 1)*
• **Theorem 5**: A firewall does not change a policy even if *Rule-u* is removed from the Ruleset when *Rule-u* is sequentially redundant by Rule-v.
• **Theorem 6**: A firewall does not change a policy even if *Rule-u* is removed from the Ruleset when *Rule-u* is consecutively non-correlated to *Rule−(v −1)* and also downward, and *Rule-u* is redundant by *Rule-v*.

Here those rules are removed which are shadowed, and those rules too which are redundant with each other. When generalization anomaly or correlation anomaly are discovered an alert message is given to the administrator. Removing the shadowing and redundancy anomalies, and rules combination method can able to reduce the size of rule-set and able to make firewall policy easier to understand. Reordering the rules in the ruleset may also help an administrator to understand the ruleset easily. It can also increase the performance of firewall because the rules that are similar by many packets are set on top of the ruleset. Here many rules are combined together by using the UNION operation to the Relations. This method also present another theorem to describe the combination of rules. And the theorem is:

• Theorem 7: *Rule-u* and *Rule-v* can be combined to *Rule-w*, without changing the policy, if $\Re_w = \Re_u \cup \Re_v$, and decision fields are same, and $v = u + 1$.

For proving purpose they have used the 2D-Box Model technique to check the accuracy of anomaly formation so that after removing certain rule the security policy does not change.

6 Conclusion

With the exponential increase of threats on networks, the challenges of protecting networks is also increasing gradually. As the main gateway of a network, the firewall has a complete responsibility to protect the network from unauthorized access. The firewall can only be able to work properly when it has the list of rules without any anomalies. It is a big issue, and everyone is trying to resolve it, many researches have been done worldwide to sort out the anomaly problems. There are various approaches has been introduced by researchers to detect the anomalies, to resolve them and to improve the performance. Everyone is trying their best to find out the finest possible way to fix these problems. The efficient method is highly acceptable. We hope that our effort will help the other researchers around the globe to deploy the various anomaly concepts of firewall system, various issues related with anomalies and it can also give a brief summary of the existing approaches to proceed further in finding new optimal solutions.

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Post Harvest Technologies and Value Addition

Y. Disco Singh
S. Helen
Punabati Heisnam
B.N.Hazarika

Department of Post Harvest Management
College of Horticulture & Forestry
Central Agricultural University
Pasighat- 791102, Arunachal Pradesh

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Chapter 14

Traditional Storage: A Possible Post Harvest Management at Village Level

Ayam Victor Singh* and Helen Soibam

**Department of Botany, Rajiv Gandhi University Rono Hills, Doimukh, Itanagar, A.P., India.*

All India Coordinated Research Project on Medicinal and Aromatic plants and Betel vine, College of Horticulture and Forestry, CAU, Pasighat, Arunachal Pradesh-791102, India

Abstract

Smallholder farmers usually cannot afford high cost for fully equipped storage facilities but by using low cost traditional storage methods they can preserve and extend the shelf-life of their crops. Therefore, traditional storage will help farmers preserve their crops despite their financial limitations as major population of Indian farmers are poor and stays in the remote locations to overcome gluts, limiting price falls and shortage of commodity when prices are high.

Keywords: Storage, temperature, humidity, structures, etc.

Storage is the process of preserving the crops for future use. In other words, it directly affects the final yield quantity and quality. Therefore, once the crops are harvested, farmers have to use their knowledge and available resources to storage the crops properly and minimize post-harvest losses. Storage structure for fruits and vegetables hold huge importance as the amount of postharvest losses taking place in a developing country like India. It has been estimated that postharvest losses associated with fruits and vegetables alone in India stands in the range of 6-18% (Nanda et al. 2012). In this aspect information regarding low cost storage structures for fruits, vegetables and other horticultural produce is very important. Therefore, traditional storage will help farmers preserve their crops despite their financial limitations as major population of Indian farmers are poor, stay in the remote locations and can only afford construction of low cost storage structures to overcome gluts, limiting price falls and shortage of commodity when prices are high.

Storage conditions:

Temperatures, relative humidity and ethylene are considered to be the main storage conditions to keep into consideration while storing the commodities.

1. Relative Humidity: Transpiration rates (water loss from produce) are determined by the moisture content of the air, which is usually expressed as relative humidity. At high relative humidity, maintains weight, appearance, nutritional quality and flavor, while wilting, softening and juiciness are reduced with lower relative humidity as low relative humidity increase transpiration rates. A hygrometer or a sling psychrometer, not the appearance of the produce, should be used to monitor humidity. During storage relative humidity can be maintained by providing humidifier, regulating air movement and ventilation and wetting the storage room floor.

2. Temperature: Respiration and metabolic rates are directly related to temperatures within a given range. The higher the rate of respiration, the faster the produce deteriorates. Lower

temperatures slow respiration rates, ripening, senescence processes and also slow the growth of pathogenic fungi which cause spoilage of fruits and vegetables in storage thereby prolonging the storage life of fruits and vegetables.

3. Ethylene: Ethylene, also known as the 'death or ripening hormone' plays a regulatory role in many processes of plant growth, development and eventually death. Its action can be controlled using Potassium permanganate ($KMnO_4$) which is known to oxidize ethylene. Carbon dioxide and temperature over 30^{o} C also inhibits ethylene action.

Low-Cost Storage Structures:

Smallholder farmers usually cannot afford fully equipped storage facilities such as cold or refrigerate storage, controlled atmospheric storage, modified atmospheric storage, hypobaric storage etc. as these are costly. However, they can preserve the quality of their crops temporarily by using one of the traditional storage methods. Clamps, cellars, ventilated structures & evaporative cool chambers are some of the cost effective traditional storage structures. Some of the low-cost storage structures are discussed below:

1. Clamp storage: Clamp storage is used for preserving root and tuber crops that is based on insulation of crops with a layer of straw and a dry layer of soil or sand. If created properly, the clamp can be an effective storage method. However, it's important to choose a site where the rainfall or snowmelt doesn't accumulate and protects from wild animals, such as rodents.

2. Underground storage/Cellar: Smallholder farmers who grow root or tuber crops often use underground storage to preserve their crops. Underground storage is a farm practice of leaving the crops in the ground until needed. This method is used mainly for storing potatoes and carrots. The practice is efficient in preserving crop quality for some time in well-drained soils. However, its main disadvantage is that it occupies a large area of land, and it's not recommended on wet soils. Besides that, in some areas, the crops are vulnerable to cold damage.

3. Simple field warehouse: Simple field warehouses are mainly used for storing hay, grains, root, and tuber crops. The exact structure of a field warehouse will vary, depending on climatic conditions (humid or dry areas), crop requirements (grains require drying), as well as farmer's financial ability. For instance, some farmers can afford ventilation or some other quality long-term storage structure, while others can barely afford to store their crops in jute bags or bulks and build some kind of shed to protect their crops from the rain.

4. Pit storage: In order to preserve their crops, farmers often dig pits. The pits are usually used for storing grains, tuber and root crops. The shape, the size, as well as the construction material of the pit will vary from region to region. The costs of storing crops in the pits are usually lower than in above-ground structures. Properly created pit storage will provide relatively low and constant temperature and preserve the crops from rodents and insects. However, there is always a risk of water penetration and after long storage, the grain can acquire a certain fermented smell.

5. Pot-in-Pot: It is a simple design of evaporative cooler for use at home. The basic design consists of a storage pot placed inside a bigger pot that holds water. The inner pot stores food that is kept cool. One adaptation on the basic pot design is the Janata cooler, developed by the food and nutrition board of India (Roy and Khurdiya, 1985). A storage pot is placed in an earthenware bowl containing water. The pot is then covered with a damp cloth that is dipped into the reservoir of water. Water drawn up the cloth evaporates keeping the storage pot cool. The bowl is also placed on wet sand to isolate the pot from the ground.

6. Charcoal cooler: The charcoal cooler is made from an open timber frame of approximately 50mm × 25mm in section. The door is made by simply hanging one side of the frame. The wooden frame is covered in mesh, inside and out, leaving a 25 mm cavity which is filled with pieces of charcoal. The charcoal is sprayed with water and when wet provides an evaporative cooling. The frame work is mounted outside the house on a pole with a metal cone to deter rats and a good coating of grease to prevent ants from getting to the food (Odesola and Onyebuchi, 2009). The top is usually solid and thatched, with an overhang to deter flying insects.

7. Buried Containers: A 20-gallon trash can, buried in the ground, makes a convenient and economical storage for many kinds of vegetables. The container must be free of substances that might give off-flavor to the produce. Never use drums or containers that might have held pesticides or other chemicals.

8. Basement: A well-ventilated basement with central heating is generally dry and has a temperature range of 50˚F to 60˚F. It may be used for ripening tomatoes and for short-term storage of pumpkins, winter squash, potatoes, sweet potatoes, and onions.

9. ZECC (Zero Energy Cool Chamber): an on-farm rural oriented low-cost storage structure which operates on the principle of evaporative cooling was developed at IARI, New Delhi, using locally available raw materials such as bricks, sand, bamboo, dry grass, jute cloth etc. The chamber is an above-ground double-walled structure made up of bricks. The cavity of the double wall is filled with riverbed sand. The lid was made by using dry grass/ straw on a bamboo frame. A thatch/ tin shed made over chamber to protect from direct sun or rain or snow. ZECC had a maximum efficiency during the summer season wherein the vegetables could by stored afresh for longer period than the conventional storage and handling methods that was practiced as handling in bulk, room storage and packing in the gunny sacks. The rise in relative humidity (90% or more) and fall in temperature (15– 18°C) from the ambient condition could be achieved by watering the chamber twice a day. Performance evaluation of cool chambers at different locations was found to be satisfactory for short term maintenance of vegetables.

Storage area management:

Sanitation*:* At least once a year, remove all containers from the storage area and clean and dried them in the sun. The room itself should also be thoroughly aired, cleaned and washed down with a disinfectant, such as diluted chlorine bleach (1 cup bleach mixed with 9 cups water), to kill off any molds or bacteria that could lie dormant and ruin future crops.

Handling Vegetables and Fruits: Vegetables and fruits that are to be stored should be handled carefully to prevent damage.

Containers: Protruding wire staples in baskets and hampers are particularly damaging so should not be used during harvesting. Lightweight tub buckets and plastic-coated stave baskets (egg baskets) are good containers for harvesting. If the soil is sandy, rinse the containers frequently to reduce skin breaks. Standard apple boxes and lug boxes used for shipping tomatoes, grapes, and nectarines are good storage containers.

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Chapter 15

Post Harvest Management and Value Addition of Ginger for Higher Income

Ps. Mariam Anal*

Deptt. of Vegetable Science, College of Horticulture & Forestry, Central Agricultural University, Pasighat, Arunachal Pradesh

*Corresponding author: psmariamlui@gmail.com. Contact no. 8787409683

Spices are very important horticultural crops and a variety of spices are used in everyday cooking in the form of dried and fresh to add flavour, aroma, colour, etc. to food. E.g. ginger, turmeric, black pepper, cumin, cardamom, coriander, etc. Spices also enhance keeping quality of food and have medicinal values.

Ginger originated from India from where it was introduced to Africa and Caribbean, however no definite information on the primary centre of domestication of ginger is available (Prabhakaran, 2013). Ginger is one of the five most important major spices of India. India is the **largest** producer of dry zinger in the world, accounting for more than 60 per cent of world production. One third of the production of ginger in the country is exported. Among the leading state under ginger, north east occupied high place in terms of production. Assam occupied highest production of ginger in India (Anonymous).

State-wise area, production & productivity of ginger in north east India

State-wise	Area ('000 ha)	Production ('000 MT)	Productivity (t/ha)
Assam	**18.70 (1st)**	**166.50 (1st)**	8.90 (2nd)
Meghalaya	9.90 (3rd)	66.40 (2nd)	6.71
Mizoram	8.20 (4th)	60.00 (3rd)	7.32 (4th)
Arunachal Pradesh	7.70 (5th)	56.60 (4th)	7.35 (3rd)
Sikkim	12.30 (2nd)	55.90 (5th)	4.54
Nagaland	3.70 (6th)	50.20 (6th)	**13.57 (1st)**
Tripura	1.80 (8th)	7.60 (7th)	4.22
Manipur	**2.40** (7th)	**3.80** (8th)	**1.58** (8th)
Total	**64.70**	**467.00**	**7.22**

(Source: Anonymous)

Ginger is used both in fresh and dried form which adds flavour to food by creating spicy pungent taste. Ginger is a medicinal plant that has been widely used all over the world from ancient times, for remedy of various ailments like arthritis, cramps, rheumatism, sprains, sore throats, muscular aches, pains, constipation, vomiting, hypertension, indigestion, dementia, fever and infectious diseases (Ali *et al*. 2008). Ginger has direct anti-microbial activity and thus can be used in treatment of bacterial infections (Tan & Vanitha, 2004). Ginger rhizome can be used in the form of fresh paste, ginger tea (flavoring), dried powder and preserved slices (El-Ghorab *et al*., 2010). Ginger can be used in different commercial products like candy, cookies, teas, tinctures, sodas, jam, beer, capsule and syrup. Ginger

bread, confectionery, ginger ale, curry powders, certain curried meats, table sauces, in pickling and in the manufacture of certain soft drinks like cordials, ginger cocktail, carbonated drinks, etc. are some of the value added products of ginger. It is also used for the extraction of ginger oil, oleoresin, essences, tinctures, etc. (Pruthi, 1998). The chemical components of the ginger rhizome vary considerably depending on the location of cultivation and postharvest treatments.

Harvesting and Postharvest management

Harvesting of ginger depends upon the varieties and purpose. The crop comes to harvest in 6-8 months after planting. For green ginger or vegetable purpose and for the preparation of of ginger preserve, candy, soft drinks, pickles and alcoholic beverages, harvest the crop by about 6 month where the foliage is still green and vigorous whereas for dry ginger and preparation of ginger oil, oleoresin, dehydrated and bleached ginger, harvest the crop by 7-8 month after planting when the leaves turn yellow and plant started drying up.

Delaying harvest until all of the leaves have died and dried up is not recommended as it will reduce rhizome quality, increase fiber content, decrease storage life and increase the incidence of sprouting. The drawback of harvesting less mature ginger is that bulbs are susceptible to greater weight loss.

Light irrigation may be given before harvesting of ginger for easy digging. Dig the rhizome carefully with spade or khurpi in order to avoid damaging the rhizomes. The rhizomes are then gently pulled out of the soil, clean, pre-graded in the field for any unmarketable, damaged or diseased rhizome. Harvesting should not be done during very wet or very dry conditions as this will increase the amount of skinning and make removal of the rhizomes from the soil much more difficult. After cleaning by removal of rootlets, dirt, dried leaves and sorting out the rhizome, sundry for a day or two for marketing as green ginger or for other value added products. The harvested ginger may be preserved as planting material for next season as well as for marketing.

Preservation of seed rhizomes for planting

Ginger is harvested during December-January and planted during April-May. Hence need to preserve seed rhizomes for a period of about 3-4 months. The selected healthy rhizomes are treated with a solution of 0.1% Quinolphos and 0.3% Dithane M 45 for 30 min. The rhizomes are stored in pits dug in a cool and protected place. Layer of sand is spread at the bottom of the pit. Layer of rhizomes are alternated with dry sand or saw dust layers. Some gap is left at the top for aeration. Pits are covered with wooden planks giving 1 or 2 holes for aeration. Entire pit is plastered with mud leaving a hole.

Preparation for market

Before marketing the ginger, pre-cooling by forced-air or room cooling to 12 to 14 °C (54 to 57 °F) should be done. Relatively clean rhizomes for domestic market may not require any further cleaning. However, for export purpose it must be thoroughly cleaned before packing. The ginger for long term storage should also be washed immediately after harvest and then cured. Ginger should be scrubbed by hand or with a soft-bristled brush in clean water sanitized with 150 ppm HCL. Care is required during cleaning to prevent rhizomes breakage, which increases decay and shrinkage. A fungicide treatment benomyl (500 ppm) or thiabendazole (1000 ppm) can also be applied in the wash tank or as a separate overhead spray application after cleaning. Remove all damaged and injured rhizomes. The remaining marketable rhizomes should be sorted according to size and overall appearance. The ginger surface should be cleaned, bright yellow-brown and appear fresh. It should not be wilted or have any evidence of sprouting. Export quality ginger should be smooth and firm, with uniform shape and size be free from insect damage and decay and have a uniform peel colour typical of the variety. The internal flesh should be firm and uniformly cream or pale-yellow coloured, without any indication of darkening (Kaushal *et al.*, 2017).

Curing of fresh rhizome of ginger (Dried ginger)

Curing is the method of preserving ginger from fresh rhizome for future use by various steps such as soaking, peeling, washing, drying, etc. *Curing* help in reduce postharvest weight loss and decay. Preparation of commercial dry zinger involves series steps of curing. Fully developed rhizomes are harvested after 8 months of planting for preparation of dry ginger.

1. **Soaking in water:** The rhizomes are soaked overnight in cement tubs for easy removal of skin.
2. **Trampling:** Rhizomes are trampled under feet in the tub. Avoid damage to epidermal cells containing flavouring oil.
3. **Peeling:** The skin is peeled off, with sharp bamboo knives. Do not rupture epidermal cells. This step hastens drying process.
4. **Washing and Drying: Generally p**eeled rhizomes are washed and sundried for 8-10 days on cement floors to a safe moisture level but where unfavourable seasonal conditions prevail, improved drying methods using mechanical or solar dryers are also used.
5. **Polishing:** After drying the rhizomes are polished by rubbing with a coarse cloth to remove all bits of skin or dirt. These are called unbleached ginger. To get bleached Ginger, peeled rhizomes are soaked in 2% lime water for 6 hours, fumigated with sulphur for 12 hours and dried. After curing, the ginger should be kept in well ventilated containers for long-term storage. Yield of dry ginger is about 16 to 25% of the fresh Ginger which is depending upon the variety.

Peeling under the Lab in hygienic way

Solar tunnel drier

Cured ginger

Packaging: Ginger of roughly similar size should be packed in each market container. The container should be strong, well ventilated, and capable of being stacked without damaging the rhizomes. For the domestic market, wooden crates provide better protection to the ginger than mesh or synthetic sacks. For the export market ginger rhizomes should be placed in a clean, strong, well-ventilated fibreboard carton. The surface of the rhizomes should be thoroughly dry prior to packing.

Optimum storage conditions: Mature ginger rhizomes can be stored at 12 to 14°C (54 to 57°F) with 85 to 90% RH for 60 to 90 days. Storage at 13°C (55°F) with 65% RH leads to extensive dehydration and a wilted appearance (Paull and Chen 2015). Holding ginger at ambient temperatures will result in high moisture loss, surface shrivelling and sprouting of the rhizome.

Major Post-harvest Problems

Postharvest Diseases: Postharvest disease in ginger is usually due to injury to skin and flesh of rhizome during harvesting. Holding ginger at a less than optimal temperature and relative humidity (RH) will accelerate postharvest decay. Decay can be kept to a minimum by following careful harvesting and handling practices, sanitation of the wash water, curing of the rhizomes after washing to promote wound healing, application of a postharvest fungicide, and holding the rhizomes at 12.5°C (55°F) and 70 to 75% RH. Postharvest losses from diseases are caused by various microorganisms.

i) Soft Rot (*Pythium* sp.): It is a soil borne fungus which appear small brownish spots on the skin and gradually enlarge into sizeable lesions. As the decay progresses, the tissue breaks down into a soft and watery mass. It can be controlled by dipping in mancozeb and copper oxychloride (30 minutes dip) treatments for rhizomes. Ridomil MZ @ 1.25 g/L increased survival of rhizomes by about 30%

ii) *Bacterial Soft Rot (Erwinia rotovora)*: The symptom is soft wet rot of the tissue, which gives strong foul odour, the severity of disease is rapid under warm humid. It can be overcome by harvesting the rhizomes at full maturity stage, proper handling and curing. Ginger should keep in cool, dry and well ventilated conditions. It should not be stored in used bags of onion and potato.

iii) Watery Rot (*Rhizopus*): The symptom shows soft, watery rot progresses rapidly and rot an entire rhizome in a week. Under humid atmosphere the infected area is soon covered with white mould which eventually turns black. The post-harvest fungicide 2,6 dichloro-4 nitroaniline (Botran) is applied just prior to packing may reduce watery rot during transport to export market destinations.

Value addition of ginger for higher income

From ginger various value added products can be made for consumption as well as for higher income. Value addition is the highest recognition of the value of the product through processing, packaging and marketing. It is the process of changing or transforming a product from its original state to a more valuable state. Many value-added spices are used & impart a special taste to food preparations.

Value addition has several plus points, viz.

- The value added products are simple to carry,
- Having long-lasting flavours,
- With low bacterial contamination,
- Having higher income from food industry,
- Used as preservatives and also in pharmaceutical industry.

Fresh ginger results in losses weight, shrinkage, sprouting and rotting during storage after a month of harvesting. Thus, it can be overcome by processing to some value added products. The value added products of ginger are ginger pickle, ginger oil, ginger oleoresin, ginger shreds & flakes, ginger candy, ginger chutney, ginger soft drinks, ginger powder, salted ginger, ginger paste, crystallized ginger, etc. Different products of ginger are briefly describe below:

i) Salted ginger:

Fresh ginger with relatively low fibre harvested at about 6 months after planting can be used. Tender rhizomes with portion of the pseudo stem is washed and soaked in 30% salt solution containing 1% citric acid. (30% = 100ml water + 30g salt). After 14 days it is ready for use.

ii) Ginger powder

Cured ginger (dried ginger) is powdered to a fine mesh size of 50-60 (250 microns) to be used in various end products. Ginger powder forms an important component in curry powder. It also finds direct application in a variety of food products (Balakrishnan 2005).

Fig. Flow chart for salted ginger

iii) Ginger flakes

The procedure for preparing ginger flakes is illustrated below:

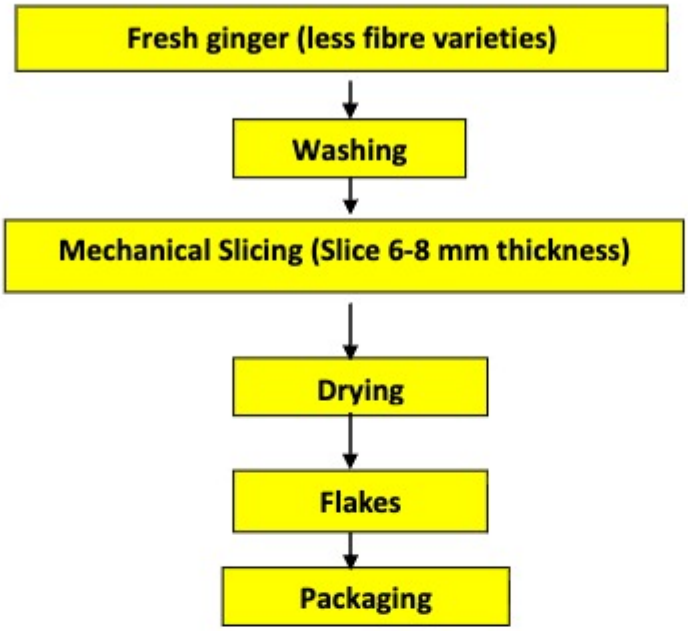


Fig. Flow chart for preparing ginger flakes

iv) Ginger candy

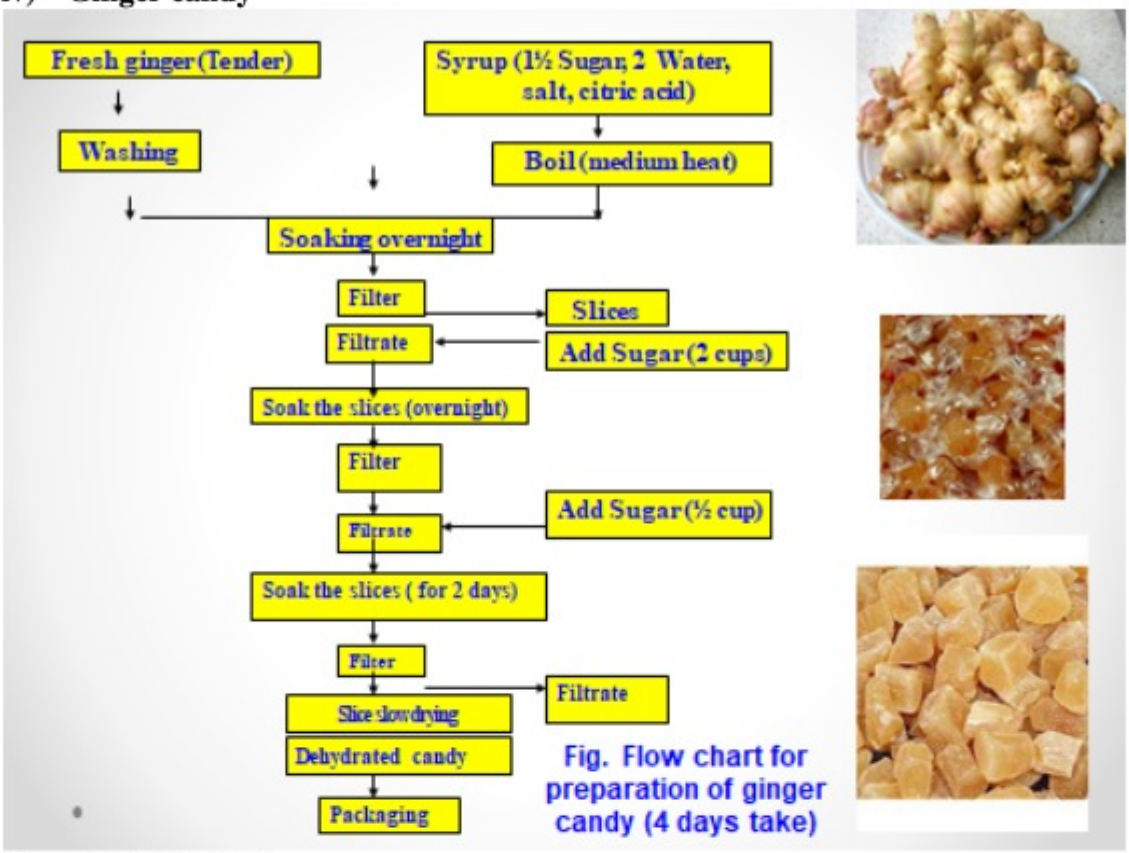
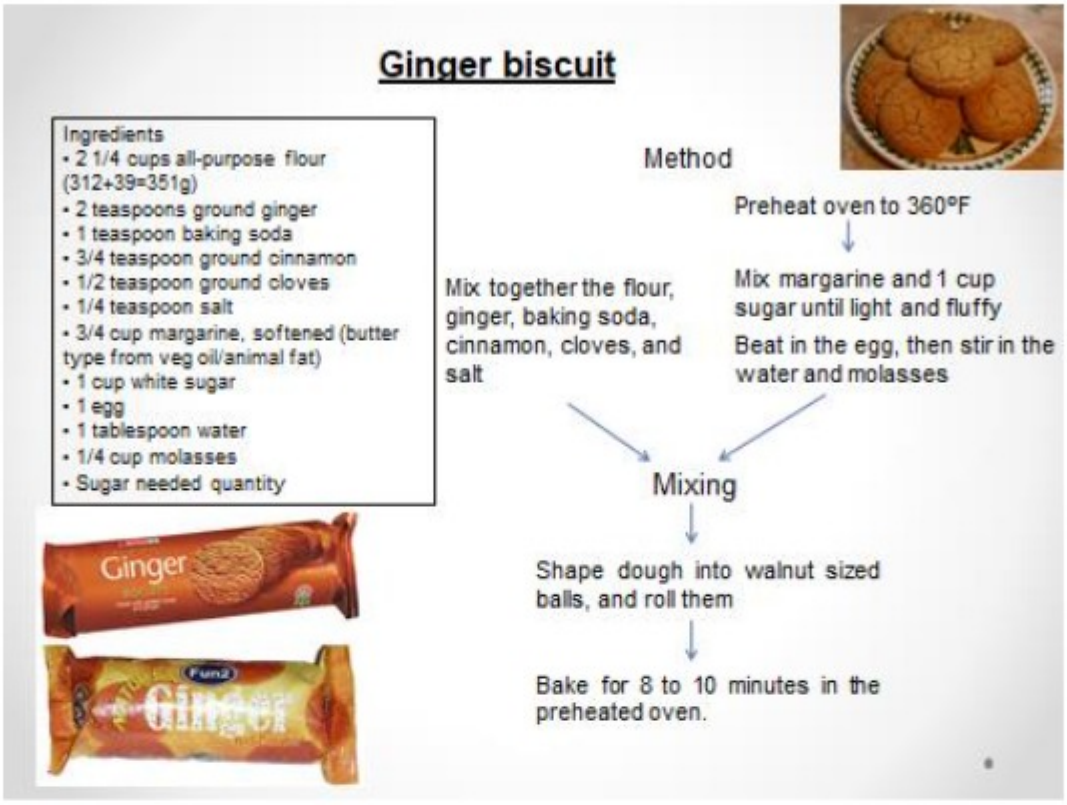


Fig. Flow chart for preparation of ginger candy (4 days take)

v) Crystallized ginger

vi) Ginger biscuit



vii) Ginger paste

viii)

ix)

x)

viii) Ginger oil

Ginger oil is obtained from the ground dried ginger rhizomes by distillation. Generally yield of oil ranges from 1.5-2.5%. But higher yield of about 4% has also been observed. Ginger oil contains sesquiterpene, high carbon compound like gingiberine and some oxygenated carbons also. Ginger is valued for its pungency, heat and flavour. The major pungent principle is due to the presence of organic compound called gingerol.

xi) Ginger oleoresin

It is the concentrated product containing oil and resin which is obtained by extraction of the dry ginger. Dry ginger powder on treating with organic solvents like acetone, alcohol, ethyl acetate, etc. yield a viscous mass that attribute the total taste and smell of ginger. It contains volatile as well as non-volatile constituent of the spice. The major non-volatile principal in oleoresin is gingerol. The oleoresin content in ginger varies from 4 -10 %. The residual solvent in the oleoresin should be below 30 ppm. It cannot be used directly because it is too concentrated and is difficult to dispense. 1 part = 20-40 parts of ground spices. But oleoresin can be used directly in fatty products like processed meat, fish, cheese, baked food and vegetables. Oleoresin has greater heat stability than essential oils.

Conclusion

Ginger is commercially and medicinally importance spice crop for having various economic uses. This crop is suitable to grow with climatic condition of the region. It is one of the most important spices of the region. Growing of ginger in large scale and proper post-harvest management are very important. Fresh ginger are perishable in nature and are spoiled due to improper handling, attack by microorganisms resulted to rhizome rot, wilting, etc. during storage. Keeping in mind the low shelf-life of fresh ginger and inadequate facility for their modern storage, value addition could be a viable alternative which will fetch higher price to the growers. Thus, value added products has a great scope and opportunity for higher income due to change in life style, health conscious, awareness of medicinal value of spices particularly ginger.

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A Noble Dead-end free Three-Dimensional Routing and Scheduling Techniques for Multi-Hop Wireless Networks

[1]Afruza Begum, [2]Md Anwar Hussain
Department of Electronics and Communication Engineering
North Eastern Regional Institute of Science and Technology
Nirijuli, Arunachal Pradesh, India
[1]afruza.moon@gmail.com, [2]bubuli_99@yahoo.com,

[3]S Md S Askari
Department of Computer Science and Engineering
Rajiv Gandhi University
Arunachal Pradesh, India
[3]askari.sikdar@gmail.com

***Abstract*—Multi-hop wireless networks are essential for communication infrastructure. Efficient routing techniques are very important for enhancing multi-hop wireless communication system. Most of the recent routing protocols are designed for two dimensional space, in real life scenario some nodes may be in 3D space. Dead-end is a critical issue in wireless networks when routing packets in a large geographical area. In this paper we have proposed dead end free 3D distributed routing protocol for multi-hop wireless networks based on minimum angle. Here we have presented the dead end router management technique for the 3D minimum angle routing protocol (3DMA). Through extensive simulation we have shown how dead end management is done and calculated the end to end throughput, delay and energy consumption for each user.**

***Keywords*—Multi-Hop, Dead End, Routing, Throughput, Three-dimension, Protocol**

I. Introduction

Multi-hop wireless network is very essential in modern communication infrastructure. It has been experiencing modernization which guarantees momentous impact on humanity. In practice multi-hop wireless networks modeled by Wireless Sensor Networks[16], Mobile Ad-hoc Networks, Wireless Mesh Networks and Vehicular Ad-hoc Networks[5] without any infrastructure [1]. Communication happens through radio range, two nodes U and V can communicate with each other if they are within transmission range of each other [4]. The longer distance communication, outside of transmission range, is done through one or more intermediate nodes used as a relay/forwarder towards the destination, this concept is called multi-hop wireless networks. Wireless networks consists of large number of nodes spread over geographic area, it is very important to design routing and scheduling techniques which is efficient dead end free and provide best path to reach destination with, maximum throughput and less delay.

Most of the recently proposed routing protocols are designed for 2D spaces. These protocols are not applicable in real life 3D scenario like air or space, underwater etc [2]. 3D embedding gives more accurate network behavior in real world applications [8] like forest fire monitoring [15][3], under water or ocean monitoring [17][11][7], atmosphere oe air [18] etc. From our study so far, we have found very less number of efficient three dimensional routing protocols have been proposed, may be because of designing of a 3D routing protocols are surprisingly more difficult than designing 2D routing protocols. Thats why we are motivated to develop efficient routing and scheduling techniques for challenging three dimensional environments.

In this paper we have presented a dead end free 3D routing protocol for multi-hop wireless networks based on minimum angle. Afruza et al.[4] proposed a 3D routing and scheduling techniques for multi-hop wireless networks based on minimum angle (3DMA), there is a problem of dead end in routing path. Here we have mainly focused on dead end router management techniques for 3DMA routing protocol. 3DMA is a distributed routing protocol, in which the sender node selects next hop forwarder for sending data packets to the destination, from the set of neighbors, within its transmission range which makes minimum angle with the reference line drawn from sender to destination and it repeats the same procedure until it gets the destination, if there is a path and if there is no path to forward packets to the destination i.e. a dead end problem is encountered at the first minimum angled neighbor then it will remove this minimum angled node from the selected path list and will select the second minimum angled neighbor as intermediate node in the path list, and will proceed with the minimum angled selection procedure of 3DMA to forward the packet to the destination, if there is path. And if it encounters the dead end again then it will remove the second minimum angled node from the path list selecting the third minimum angled neighbor if any and will try to proceed as before, and if again it faces the dead end situation then it will remove this third angled node too from the path list, looking for a minimum distance node from the rest of the neighbors if any. If there is no neighbor left or again dead end is encountered, then it will backtrack to the previously selected intermediate node removing this minimum distance node from the path list. From this intermediate node same procedure will be followed up until it gets the final path from the sender to destination.

This paper is organized as follows. Section II is the related works, section III is the methodology, section IV is the analysis of results and finally section V is the conclusion and future works.

II. Related Works

Now a days research in three dimensional routing in multi-hop wireless networks is gaining popularity because many applications such as underwater monitoring, forest fire detection,

air space or atmosphere monitoring, etc. need three dimensional routing for gathering information. In [14] Wang et.al proposed an efficient sub minimal ellipsoid geographical greedy face routing protocol (EGE3D). In this protocol when a neighbor node of the sender is set to one point in the ellipse, a vertical ellipse region is uniquely shaped. Ellipse zone is constructed from one neighbor node by this sender node and determines that this neighbor on the ellipse will keep the second least angle (sub minimal) to the line from source to destination, the packets are forwarded greedily until a local minimal is obtained inside the sub minimal ellipse. Here to avoid void node problem (VNP) they have used face algorithm. How to construct a 3D wireless sensor networks, how to achieve low connectivity and full coverages by using less number of sensors using wireless sensor networks, this problem is studied by Zhang et al.[19]. The authors designed a set of patterns that achieve the full coverage and K connectivities where $k <= 4$. They have proved the optimality of 1-, 2-, 3- and 4-connectivity and full-coverage, among regular lattice deployment patterns and proved their optimality under any value of the ratio of communication range (rc) over sensing range (rs). They have compared with 14-connectivity and observed when $rc/rs = 1$ the number needed to achieve 14-connectivity is around 2.5 times that the number needed to achieve 3- or 4- connectivity and 3.5 times that the number needed to to achieve 1- or 2- connectivity. The number difference increases as the ratio rc/rs decreases. They also have investigated the evolutions among all the proposed low-connectivity patterns In [8] the authors presented the design philosophy and basic principle like neighbor selection rules, routing hole bypass approaches and classifications of 3D geographic routing (3DGR) protocols and categorized current research work based on different criteria. They compared 3DGR from a variety of perspective and applications like, guaranteed delivery, path quality, reactive, distributed, complexity and communication overhead. They also have discussed various issues of 3DGR routing protocols like, limitations of networks model, lack of multidimensional geographic routing, lack of security in geographic routing protocols. Rubeaai et al. [2] have proposed a three-dimensional real-time routing protocol (3DRTGP) for wireless sensor networks. This protocol achieves real-time routing operations using adaptive packet forwarding region (PFR) and selecting fast forwarding nodes in the PFR. The PFR technique limits the number of nodes forwarding towards destination. They have given a heuristic solutions for void node problem in 3D wireless sensor networks. The 3DRTGP gives tuning techniques to make the protocol meet the delay and miss ratio requirements of applications. Shah and Kim[13] studied and discussed the various issues related to 3D wireless ad-hoc and sensor networks, mainly they have studied 3D underwater sensor networks (UWWSN) 3D airborne ad-hoc networks (AANET's). Design requirements and challenges in 3D, AANET's and UWWSN are discussed throughly. They also have highlighted the various research issues in 3D wireless ad-hoc and sensor networks. Fariborz Entezami and Christos Politis[6] have proposed a novel, real-time, position based and energy efficient routing protocol 3DPBARP, for WSNs based on spanning tree method. They have used greedy forwarding approach when looking for a path to the destination. The protocol uses unique restricted parent forwarding regions (PFR), that reduces the range of radio frequency to cover minimum number of nodes, only the parent nodes. It reduces the number of forwarding nodes as a result it improve in traffic and packet collision. They have used rainbow mechanism to avoid dead end routes. In [12] the authors proposed joint routing, scheduling and power control in multi-hop wireless network using linear relation between link capacity and interference noise ratio.

In [10] and [9] Hussain et al. have presented a simple two dimensional routing and scheduling technique for multi-hop wireless networks based on minimum angle and minimum angle intermediate node for 2D spaces. In [4] Afruza et al. have implemented 3DMA distributed routing protocol for 3D spaces, here when nodes are distributed randomly in the network, the 3DMA protocol [4] suffers from dead end router problem. From the literature survey so far, it is observed that the dead end router problem is a major issue in wireless networks and it is hardly addressed by the existing works. So we are motivated to find a solution to this dead end router problem. In this work we have implemented the 3DMA[4] with dead end router management technique for 3D spaces, in which it tries to find a path in all possible ways.

III. 3DMA PROTOCOL DESIGN

Consider a set of n wireless nodes is distributed in a 3D plane {X,Y,Z}. Each node knows the location of its own, location of neighbors, location of destination and all other nodes in the networks through GPS or some other centralize location management techniques. All the nodes in the networks have the transmission range R. Two wireless nodes $U(u_x, u_y, u_z)$ and $V(v_x, v_y, v_z)$ can communicate with each other if Euclidean distance between U and V satisfies the following equation-1

$$\|UV\| <= R \tag{1}$$

Where R is the radio transmission range, and $\|UV\|$ is the Euclidean distance between U and V and it is defined by the following equation-2

$$\|UV\| = \sqrt{(u_x - v_x)^2 + (u_y - v_y)^2 + (u_z - v_z)^2} \tag{2}$$

When the nodes of wireless networks are spread uniformly over large geographic area, dead end is a serious issue. Dead end means, when a sender is sending packets to destination, in the middle of the path there the situation may arise that no further nodes are there to forward packets to the destination. Therefore a good routing techniques is very much important so that the packets can be sent managing this dead end routing situation from source to destination through intermediate nodes. Afruza et al.[4] proposed a noble 3D routing and scheduling techniques 3DMA for multi-hop wireless networks. There it is considered that in the network the nodes are uniformly distributed in a 3D plane. But in real life scenarios nodes may not be distributed uniformly so dead end scenario may arise. Here we have added the dead end router management techniques to the 3DMA protocol[4].

In 3DMA routing protocol first a reference line is drawn from sender to destination. For Sender $S(s_x, s_y, s_z)$ and Destination $D(d_x, d_y, d_z)$, equation of line drawing from S to D is

given by the following equation-3

$$\overrightarrow{PQ} \leftarrow (s_x - d_x, s_y - d_y, s_z - d_z) \tag{3}$$

Where $\overrightarrow{PQ}$ is the straight line in a 3D space, s_x, s_y, s_z and d_x, d_y, d_z are the positional coordinates of sender S and destination D respectively.

Then the sender selects the intermediate/relay node from the set of neighbors of the sender which makes minimum angle with reference line drawn from sender to destination. Repeats this process until it gets the destination if there is no dead end in the path. Angle θ made by a node N from list of neighbor nodes, with the reference line drawn from sender S to destination D is calculated by the equation-4 given bellow

$$\theta = \cos^{-1}\left[\frac{\overrightarrow{SN} \cdot \overrightarrow{SD}}{\|\overrightarrow{SN}\|\|\overrightarrow{SD}\|}\right] \tag{4}$$

Where $(\overrightarrow{SN} \cdot \overrightarrow{SD})$ is the dot product of $\overrightarrow{SN}$ and $\overrightarrow{SD}$, $\|\overrightarrow{SN}\|$ and $\|\overrightarrow{SD}\|$ is the euclidean vector norms.

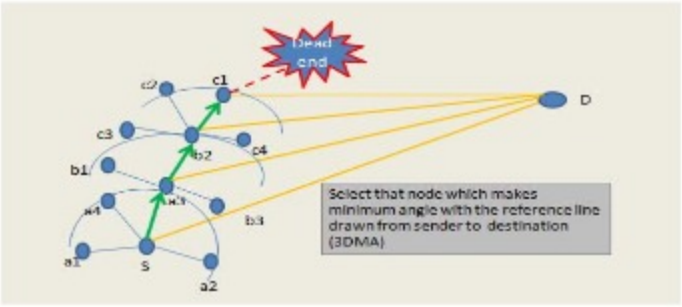

Fig. 1. Dead end Problem

Repeat the same procedure till its reaches to the destination. If any dead end is encountered in the path, as shown in figure-1 in 3DMA routing protocol [4]. Here sender node is denoted by S and destination is denoted by D. A reference line is drawn from S to D. a_1,a_2, a_3 and a_4 is the neighbor of S. Assume that a_3 makes minimum angle with reference line $\overrightarrow{SD}$, so a_3 is selected as a intermediate node towards destination D and a reference line is drawn from this selected IM a_3 to D. b_1, b_2 and b_3 are the neighbors of a_3, it is assumed that from the neighbor list of a_3, b_2 makes minimum angle with the reference line $\overrightarrow{a_3D}$, b_2 added as a IM in the selected path list and a reference line is drawn from b_2 to D. In the same way c_1 is selected as a IM and added to the path list from the neighbor list of b_2.

A. Dead End Management Technique of 3DMA

Now suppose the situation arises as shown in figure-1 that there is no node within the transmission range of c_1 to forward packets to the destination D, i.e encounters a dead end, then to avoid dead end and to find some others alternate route following steps are followed:

1. It will remove the last selected node from the path list and will select the second minimum angle node if any in the neighbor set of sender (b_2) as an intermediate/relay node to forward packets to the next step towards destination. Suppose c_2 forms second minimum angle from the neighbor list of immediate sender b_2, so c_2 will be selected as IM and will be added to the path list for forwarding towards destination D as shown in figure 2 and will follow the 3DMA IM selection procedure to forward packets towards destination if there is path.

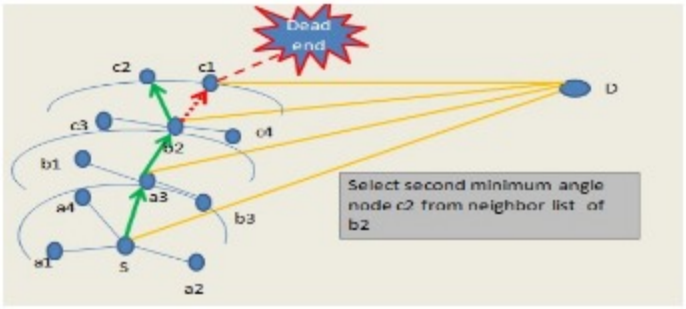

Fig. 2. Selection of second minimum angle node from neighbor list

If it encounters a dead end again from second minimum angle node (c_2) then it will go to step-2

2. It will remove the last selected node from the path list, and will select the third minimum angle node and will add it to the path list, from neighbor list of sender (b_2) if any and go ahead towards destination following 3DMA IM selection procedure if there is path, if there is no path i.e. dead end, then removing this last node from the path list, it will select the minimum distance node, if any and will add to the path list as shown in figure-4, and will proceed towards destination with 3DMA IM selection procedure. Assume c_3 is the 3rd minimum angle and c_4 is the minimum distance node of b_2 as shown in figure-3 and 4.

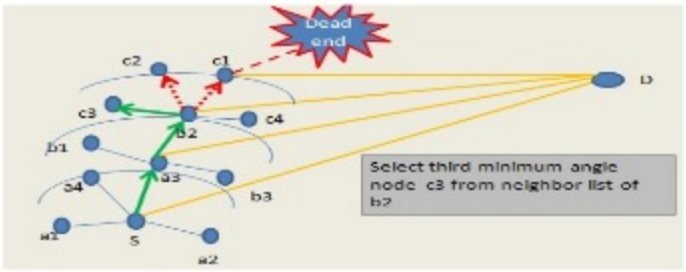

Fig. 3. Selection of third minimum angle node from neighbor list

If there is no path from c_3 or from c_4 to forward towards destination then it will go to step-3.

3. Removing this c_3 or c_4 from the path list it will backtrack to the previous selected IM in the selected path list, and will apply the step-1 (selection of 2nd minimum angle) and 2 (selection 3dr minimum angle and minimum distance node) as shown in figure-5, to go ahead towards destination. If no path is found this backtracking process will repeat as shown in figure-6 until it reaches the original source node (S) and will select the minimum distance node from the original source node S as a intermediate node and repeat the 3DMA route selection

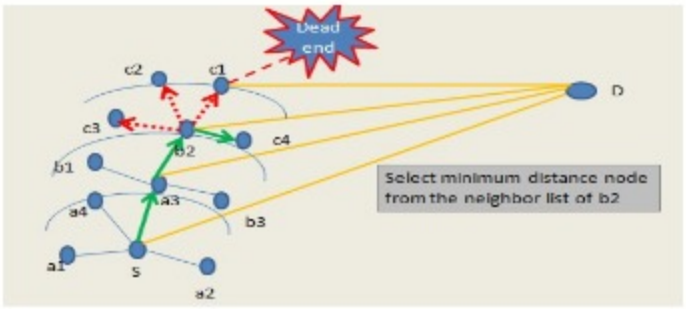

Fig. 4. Selection of minimum distance node among all neighbors

procedure and the dead end router management technique till it reaches to the destination.

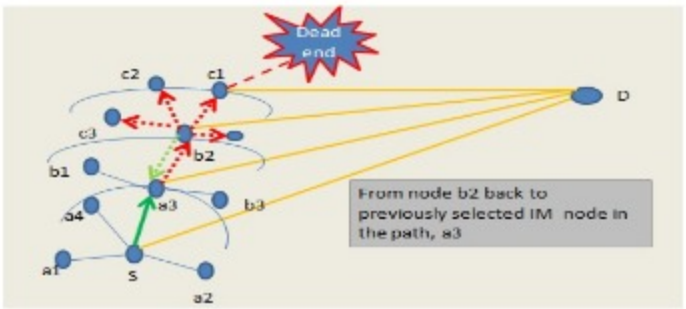

Fig. 5. Back to previous IM in the selected routing path.

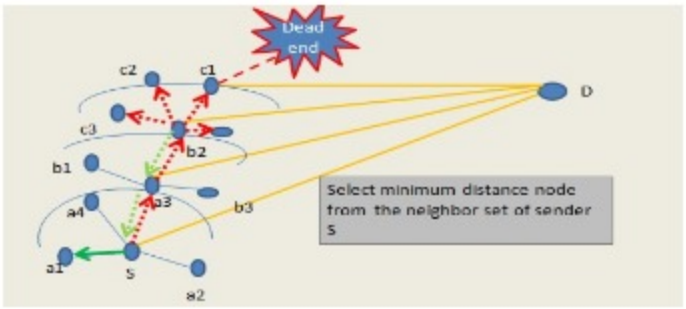

Fig. 6. Back to the original sender noder node.

The dead end management technique described above in point 1 (selection of 2nd minimum angle) and 2 (selection 3dr minimum angle and minimum distance node) will not execute if there is single neighbor of the sender (b_2), in this case only the step-3 will be executed to backtrack to previous IM in the selected path list. In figure-7 we have shown the simulation output of 3DMA routing protocol using dead end management technique for one user. From sender it goes through node a_1 and a_2 as an IM to forward packets towards destination (base station), but at a_2 it encounters dead end so it will backtrack (shown by black cursor), and it finds a new path to the destination.

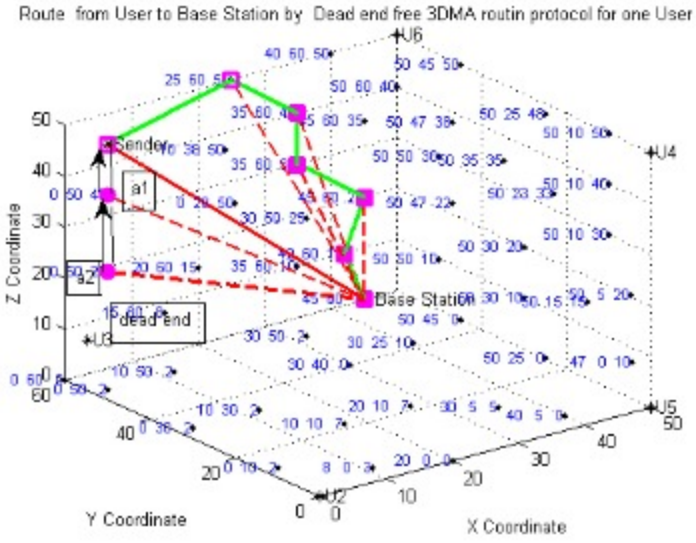

Fig. 7. Route for one user in a 3D plane by 3DMA routing protocol using the dean end management technique

IV. Performance Evaluation

Performance of the proposed routing techniques is evaluated by calculating End to End Throughput and Energy Consumption of each route from source to destination through simulation in Matlab Platform. For simulation purpose we have considered networks of 70 to 200 node distributed randomly in a 3D plane $\{X, Y, Z\}$. Each node has a transmission rang of 18 m. All the nodes scatter in the network can be source or destination, we have considered some of them as sender (User) node and one of them as a destination (Base Station). We have considered each node in the network knows the location of itself and others nodes in the network through GPS or some other location management techniques. Simulation perimeter which are considered common for all nodes are tabulated in table in table-I.

TABLE I: Network simulation parameters

Network parameter	Value
Data packet size	1 MB
Network Area	$50m \times 60m \times 50m$
Number of nodes	80 to 150
Range of node	18 m
E_{elec}	50nJ/bit
E_{amp}	$100pJ/bit/m^2$
Number of Sender	6

We have assumed that each node have burst profiles with modulation and coding rates to obtain different data rates with different transmission distances.

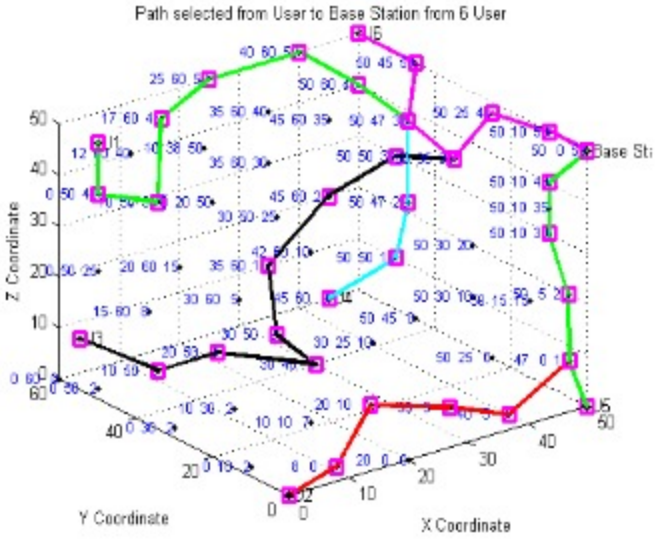

Fig. 8. Route constructed by dead end free 3DMA routing protocol for First Network

TABLE II: Performance Analysis of first Network shown in figure-7

Sender	ETH (Mbps)	No. of IM	Time(Sec)	Energy (Joule)
Sender1	0.7500	10	1.3333	1.53×10^{28}
Sender2	0.9167	8	1.0909	1.06×10^{28}
Sender3	0.7500	10	1.3333	1.63×10^{28}
Sender4	1.1786	6	0.8485	1.11×10^{28}
Sender5	1.6500	4	0.6061	0.53×10^{28}
Sender6	1.3750	5	0.7273	0.90×10^{28}

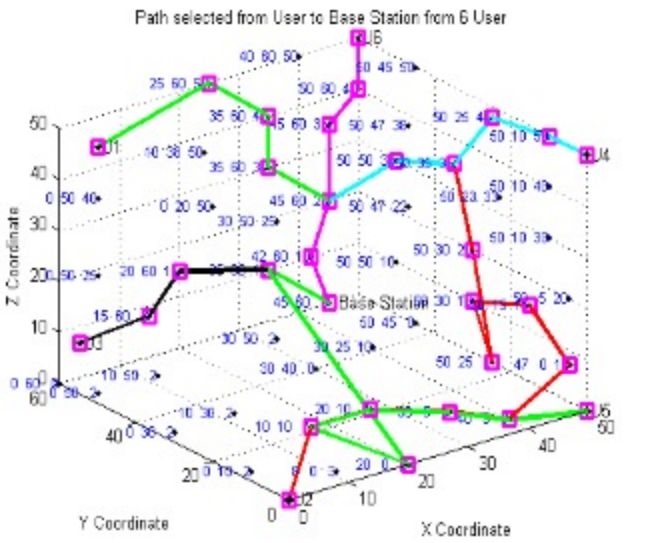

Fig. 9. Route constructed by dead end free 3DMA routing protocol for First Network

TABLE III: Performance Analysis of first Network shown in figure-8

Sender	ETH (Mbps)	No. of IM	Time(Sec)	Energy (Joule)
Sender1	1.0313	5	0.9697	1.54×10^{28}
Sender2	0.5156	13	1.9394	2.22×10^{28}
Sender3	2.0625	3	0.4848	0.56×10^{28}
Sender4	1.1786	6	0.8485	1.03×10^{28}
Sender5	0.5789	6	1.7273	3.89×10^{28}
Sender6	1.6500	4	0.6061	0.47×10^{28}

Figure 7 and figure 8 shows the selected routing path from sender (user) to destination (Base Station) considering each network has 6 sender (user) and one destination (base station). In the network-1 as shown in figure-8, we have considered the destination (base station) at the upper right edge and 6 sender is situated in all the other edge and the center of the network, in network-2, we have considered Base station (destination) is in the center and users are situated in all the edges of the network. The performances of dead end free 3DMA protocol are tabulated in Table-II and table-III, i.e. end to end throughput, number of intermediate nodes (IM), times needed to travel and energy consumption in routing path for each sender to reach the destination. The table-II and table-III show that throughput increases with the decreases of travel time and number of intermediate hops in the routing path. When throughput increases it decreases the energy consumption for sending data packets. From figure-7 and 8, the simulation output results we can see that, implementing the dead end router management technique to the 3DMA [4], it finds a path from sender to destination in almost all possible ways in a network where the nodes of the network are distributed randomly. It may took long path, more intermediate nodes but it will find path somehow with the dead end management techniques.

V. Conclusion and Future Work

In this paper we have presented a dead end router management techniques for our earlier implemented three dimensional routing protocol 3DMA[4]. Through simulation, the performance evaluation is done by calculating end to end throughput and energy consumption. This protocol resolves the dead end router problem of multi-hop wireless networks for 3D space. This dead end free 3DMA may chose long route when it encounters a dead end but finds a path to reach the destination by trying all possible ways in case of nonuniform 3D networks. In the current version of this protocol, one user can send at a time to the destination. we are working on developing efficient scheduling techniques so that more than one user can send at a time without interference, considering nodes mobility of wireless network and will compare the performance of our routing and scheduling techniques with others existing 3D routing and scheduling techniques.

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Demonetisation and Approaches Towards Digital India

Editors
Subit Dutta
Ratan Borman

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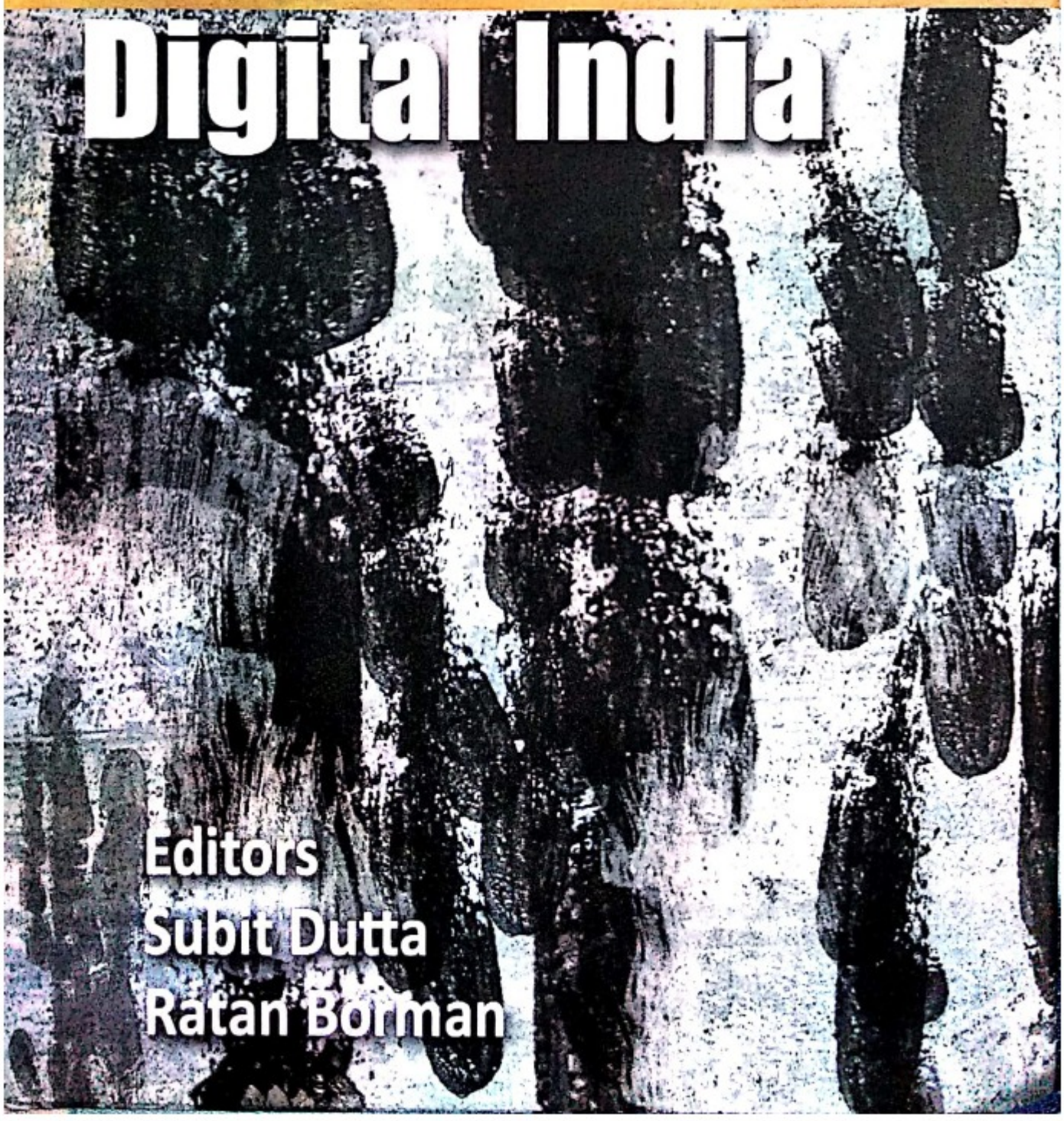
Universalization of Financial Literacy in India: A Stepping Stone for Achieving Digital Economy

Arindam Chakrabarty
Tenzing Norbu

Introduction

India is one of the emerging economies of the world with fourth fastest growth rate and the fifth largest economy of the world. As on 2016, the GDP of India was 2,263.52 billion USD and represents 3.65% of world economy. On the other hand, according to recent UN forecast, India is expected to cross China by 2024 in terms of population and projected to reach 1.5 billion in 2030. Another interesting facet is India has been enjoying its demographic dividend over all other developed nations. So, the vital responsibility remains how best the country would prepare its human resource in terms of knowledge, skill development, innovative entrepreneurial attempts, greater participation in economic activities etc in order to strengthen the economy and quality of life. The literacy in India is appreciating with 75% as of now. But the development story does not confine on literacy only rather it encompasses its purview towards achieving financial literacy. According to OECD financial literacy is defined as "the process by which financial consumers/investors improve their understanding about the financial products, concepts, risk and through information, instructions and/or objective advice, develop the skills and confidence to become more aware of financial risks and opportunities to make informed choices, to know where to go for the help, and to take other effective actions to improve their financial well-being". As on 2015, the financial literacy rate in

Demonetisation and Approaches Towards Digital India



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Does Demonetization Arrest the Demons of Indian Economy or Become a Devil by Itself?

Arindam Chakrabarty
Mudang Tagiya

Introduction

India is emerging as economic super power in the world. It has traversed a long path from the Nehruvian socialist ideology to a member of WTO reinforcing the open economy structure i.e. LPG (Liberalization, Privatization & Globalization) in the post colonial era. There is no doubt that India still preaches mixed economy model where state has reserved the overall control on countries economic affairs of the country without diluting the very presence and freedom of Indian corporate. However, the role of Government has remarkably changed over a long period of time i.e. from sole provider of public goods & services to a facilitator for economic activities to be performed by others. Here the role of transparency and good governance can be the change agent for holistic growth in the country. At the same time, there are series of constraints and limiting economic factors such as fiscal deficit, over tune of loans, meeting social responsibilities and security measures for the explosionary populations etc. which retard the growth trajectory. Another menace of third world country may be the mounting high corruption. The increasing pattern of informal/parallel economy, black money, fake currencies have been diminishing the India's future. On the other hand there was increasing dependency on paper currency and the volume exceeds 15,000 billion dollar where our total GDP is around 2253 billion dollar. The expenditure of preparation and maintenance of such

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A MITTAL PUBLICATION

DIGITAL IMPACT ON HUMAN RESOURCES PRACTICES

ABHIGYAN BHATTACHARJEE

Foreword by
Prof. Sri Krishna Srivastava

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15

PHYSICAL VIS-A-VIS VIRTUAL RESOURCES FOR EXCELLING CAREER MANAGEMENT FROM A NORTH EASTERN STATE OF INDIA

ARINDAM CHAKRABARTY, MUDANG TAGIYA

Introduction

India is a vast country with unity in diversity among caste, creed, religion, culture, food habits inspite of such deviations. India stands like a banyan tree with its glorious legacy and deep rooted, existance and poising for global leadership. This is the second largest population in the world and moving towards the most populated nation in near feature. Last two decade India's economic growth was quite encouraging and GDP was above 7 per cent altogether. Inspite of all these good indicators, there is coexistence of 'Rural Bharat' which is deprived of various resources like infrastructure, communication in comparison to the vibrant India. The irony remains with the shining story of India that it would not be sustainable if the village economy is equally strengthened simply because India is still an agrarian society where more than 50 per cent human resourcea are engaged directly or indirectly. Out of them, a major portion does not have basic literacy. If rural bharat is not a part of India's growth story, the resurgent India would not be able to survive because of huge unemployment, food crisis and other social-economic impediments. The success of India is critically linked to the degree of awakening of rural population, particularly when India

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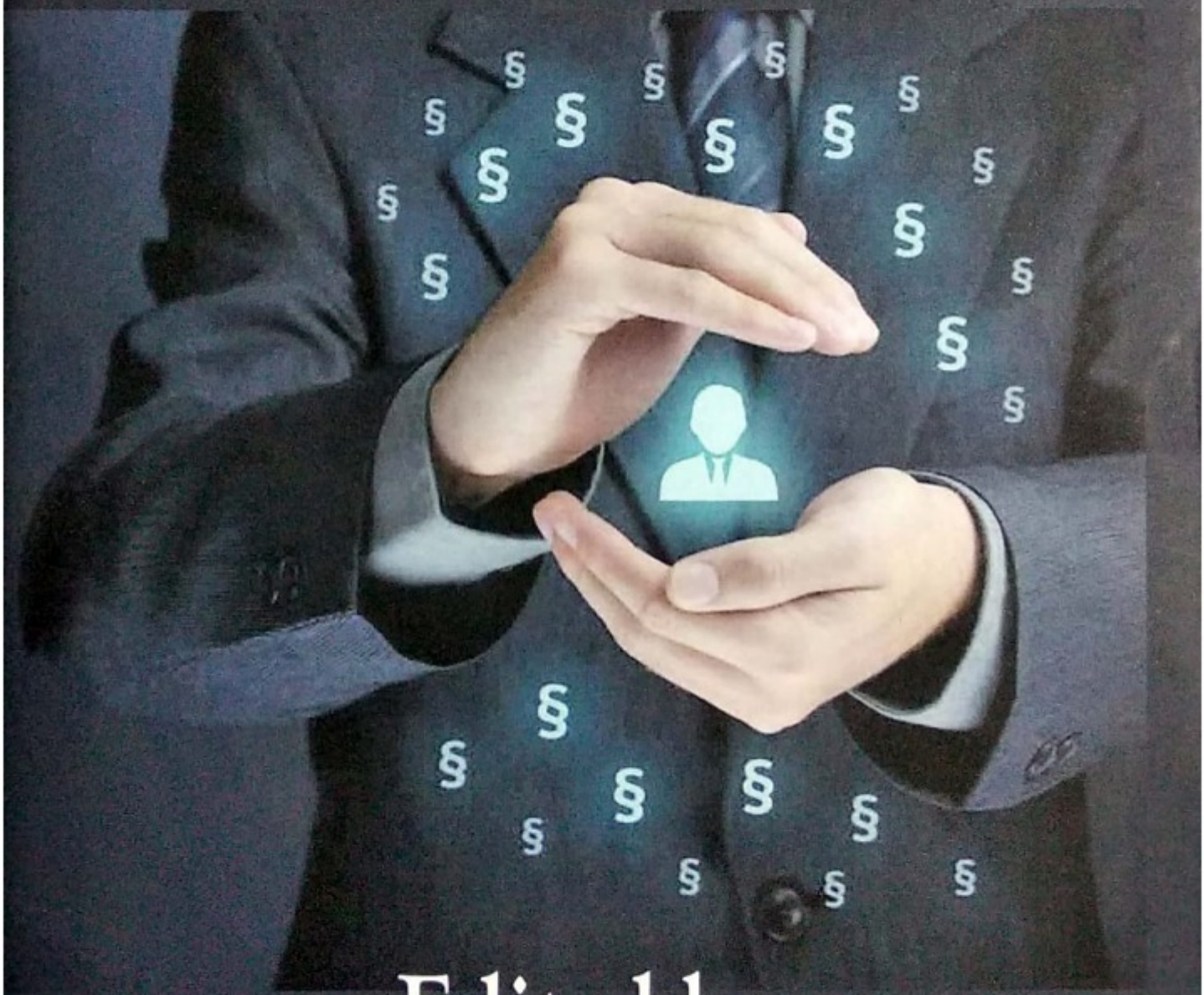

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Teething Problems of Arunachal Tourism : Strategy for Adequate & Quality Manpower Supply

Arindam Chakrabarty
Mudang Tagiya
Shyamalee Sinha

Abstract

Tourism is one of the fastest growing service sectors in the world. The fascinating part of this sector is that it can work with capital intensive mode as well as labour oriented mechanism; large scale entity as well as small scale or sole proprietary endeavour. The capital intensive notion is associated with creation of star hotels, restaurants; theme parks whereas the labour oriented enterprises include small ticketing agency, roadside dhaba, tourist service providers like rickshaw puller, auto driver, guiding activities etc. Tourism is mostly suffered by unorganised sectors. There lies the responsibility of the state and non-state actors to conduct capacity building programme particularly with respect to behavioural implementations. Ministry of Tourism, Govt. of India is committed to offer a dedicated scheme called CBSP (Capacity Building for Service Provider) which essentially aims to enhance behavioural skills of the tourist service providers who fall at the bottom of service pyramid. However, the organised sector can excel with the contribution of skilled and qualified professionals. The 'Act East Policy' of Govt. of India has given emphasis on infrastructural development in the region. The tourist inflow has been increasing in the region with an encouraging trend which creates the higher demands

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M-Commerce

Experiencing the Phygital Retail

By Punita Duhan, Anurag Singh

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Book Description

This volume presents a pragmatic approach to understanding and capitalizing on contemporary m-commerce trend. It comprehensively encapsulates the evolution, emergent trends, hindrances and challenges, and customer perceptions about various facets of how physical and online retail channels are merging, blurring, and influencing each other in new ways.

The rapid rise of m-commerce (or mobile commerce) has led to the emergence of new paradigms in the marketplace. The difference between physical and digital retail is diminishing, and a new "phygital retail" phenomenon is on the rise. Marketers need to understand this emerging paradigm and consider the new opportunities and challenges involved. This volume, *M-Commerce: Experiencing the Phygital Retail*, provides a comprehensive discussion of the contemporary m-commerce concepts along with the emerging paradigms in a pragmatic way. It presents empirical analyses and reviews on the myriad aspects of m-commerce, including both contemporary academic and business research.

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Vigor of M-Word of Mouth in Consumer Epoch

Yog Mishra, Anurag Singh, and Punita Duhan

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Editor(s)

Biography

Punita Duhan, MBA, is a faculty member in Business Administration at the Meera Bai Institute of Technology, operating under the Department of Training and Technical Education, Government of NCT of Delhi for the last 18 years. nurag Singh, PhD, is an Associate Professor at the Institute of Management Studies, Banaras Hindu University, India.

Reviews

"A sincere academic endeavor to cover various facets of m-commerce in a comprehensive manner. . . . This book enables the reader to comprehend contemporary m-commerce concepts along with the emerging paradigms in a comprehensive manner. The volume systematically puts together the efforts of researchers across the world in the shape of empirical analyses and reviews of the myriad aspects of m-commerce. . . . An excellent reference resource and a handbook for detailed and up-to date knowledge about m-commerce."
—From the Foreword by M. Jagadesh Kumar, Professor and Vice-Chancellor, Jawaharlal Nehru University, New Delhi, India

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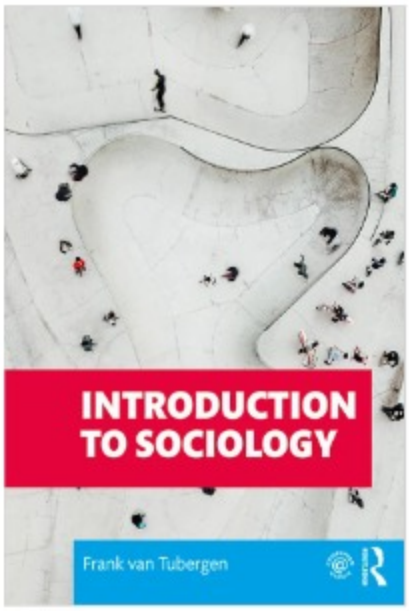

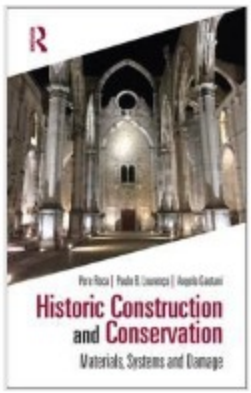

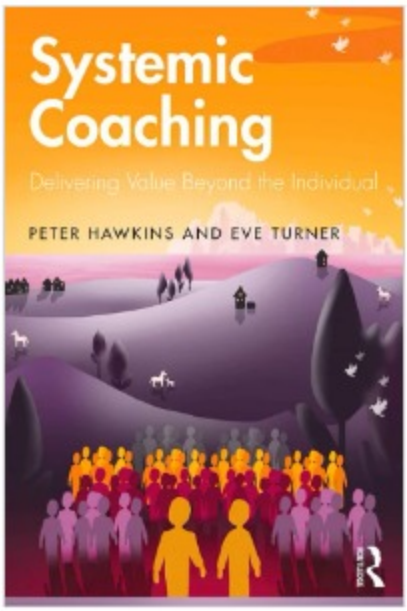

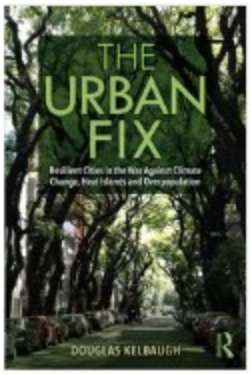

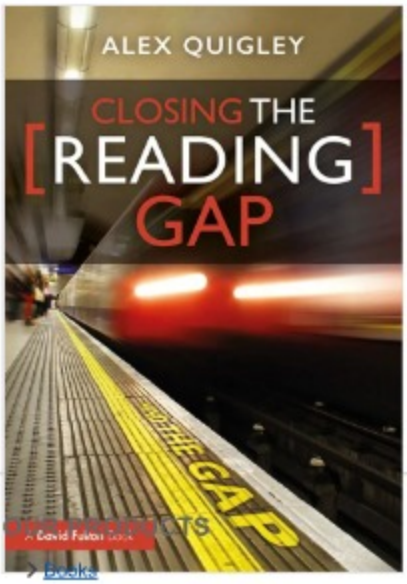

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Reforms in Managing Non-Government Organizations Through IoT

Arindam Chakrabarty(✉)

Department of Management, Rajiv Gandhi University (Central University), Itanagar, Arunachal Pradesh, India
arindam.management@gmail.com

Abstract. Despite gigantic efforts by the government at various levels, it has been observed that there have been far reaching goals to achieve social development and improvement of the quality of life particularly for the deprived, marginalized and under-privileged sections of the society. The models of 'development from above' or 'development from below' have been failing to accomplish desired results. The concept of 'Welfare State' has been severely compromised due to its increasing fiscal pressures. The for-profit firms have to confine on growth and profitability indicators undermining the task of societal upliftment. Both the socialist and the market-led models are inadequate for achieving holistic development. There lies the inevitable role of the third sector i.e. Non-Government Organizations (NGOs) and voluntary sector throughout the world. The sector is facing challenges manifolds globally. The issues like receiving foreign funds or hindrances of operating the International NGOs are gaining momentum in the context of growing antinational activities worldwide. The sector requires massive reforms as some western countries have introduced regulations for its performances. This paper has attempted to develop a framework for real time mentoring and regulating NGOs using the ecosystem of 'Internet of Things (IoT)'.

Keywords: Non-Government Organizations (NGOs) · Development · Welfare state · Reforms · Internet of Things (IoT)

1 Introduction

1.1 The Role of NGOs in Socio-Economic Transformations

Non-profit institutions (NPIs) are legal or social entities created for the purpose of producing goods and services whose status does not permit them to be a source of income, profit, or other financial gain for the units that establish, control or finance them. In practice their productive activities are bound to generate either surpluses or deficits but any surpluses they happen to make cannot be appropriated by other institutional units. The role of nonprofits particularly the Non-State Nonprofit Sector i.e. the Non-Government Organizations (NGOs) is increasingly important for inclusive economic development of a country. NGOs operate as the third sector along with the Government and the private for profit enterprises. The role of NGOs are more vivid for the elephantine and developing economy like India where there are challenges for the

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State to provide all the welfare measures to all of its citizen. In fact, the NGOs are the pillars of Nation building.

1.2 Emerging Challenges of NGOs

The commitments & achievements of these social service organizations need to be studied so that incumbent and the budding NGOs can get the roadmap to success. There are inherent challenges and contradictions within the ambit of its operations which need to be explored so that the outcome of the study could be a learning exercise for all the stakeholders. However, the former runs on the revenue that is generated from its users while the latter depends on its donors who would not avail the benefits of the services. It is difficult for the NGOs to hire and retain quality professionals as compared to the private firms. Regular fundraising is the real challenge for the sector to survive. Effective marketing strategy needs to be adopted for its sustainability. The sector essentially requires a dedicated framework for real time mentoring by the competent and Expert agency to look after and guide so that it could accelerate the pace of Socio-economic Transformations.

1.3 Issues of Transparency and Reforms in the Third Sectors of Economy

From recent past, there are undesirable signs of trust deficits, lack of transparency and massive financial irregularities among a section of the NGOs. The growing, inconsistencies with the operations of International NGOs, unaccounted foreign funding, illicit transactions, anti-state agenda among a small section of the third sector have created dubious perception and the environment of suspicions (Bloodgood and Tremblay-Boire 2011). The constructive criticisms from the experts are required to be recorded with their suggestions and inputs so that the very sector can be strengthened by augmenting dynamic reforms that would ensure greater disclosures, transparency and accountability. However, this is not uniformly observed. In a number of countries, the NGO operations are not significant rather it plays more of an oppositional role that might make the ruling governments highly suspicious on these nonprofits (Clark 1993).

2 Literature Review

In the era of neo-liberalism, the philosophy behind establishing welfare state or making provisions for public or welfare services by the state have been questioned and re-examined by the economists and social scientists. Barr (1998) and Anderson (2002) admitted that expenditures on welfare provision of government adversely affect on the fiscal structure of the state. Nonprofit (NP) sectors have been contributing as a significant game changer in transforming economy in parallel with the government and market forces. The growth of NPOs is the heterogeneous demands for products/services by the society i.e. when consumers have homogenous demand, public sector is preferred where as societies with heterogeneous demands necessitates NP sector for meeting the varied needs of the consumer (Weisbrod 1998). NPOs have been

functioning in diversified areas of public services catering to health care, education, research, women empowerment, environment, public awareness etc. (Hansmann 1980). These diversified domain of activities attract the NPIs to operate from the common platform along with all other contingents i.e. govt. agencies and for-profit players. All of them would have to target the same market segment. NP sector may comprise of government establishments as well as non government organizations (NGOs). The NPOs particularly in non government structure do not suffer from red-tapism, bureaucracy. The absence of profit motive makes customers to feel secure about the quality of goods and/or services provided.

According to Rose-Ackerman (1996) There may be three possibilities to describe the motivations and driving forces behind the emergence and rapid growth of NPOs on the demand side dimension i.e. (i) willingness of the donors (ii) the asymmetric information in some sectors (health care, education etc.) lacks transparency, creates confusions which leads customers to prefer non-profits & (iii) NPOs have a non government structure which increase capacity to deliver a set of diverse form of services in comparison with its public sector counterpart. Financial gain and creation of wealth for the stakeholder can never be the objective of a non-profit organization (Helmig et al. 2004). Irrespective of profit motive, all the organizations have to face the issues like declining customer (membership), uncontrollable price rise and increasing competition (Dolnicar and Lazarevski 2009). The performance, survival and sustainability issues are becoming important for a NPO especially they have to operate in the environment of increasing competition from the growing number of organizations who are targeting the same segment of donors (Kaplan 2001). Moreover, not for profit organizations are facing competition by their competitors both from for-profit and non-profit sectors (Seearam 2012).

3 Objectives of the Study

i. To prepare a smart, interactive & real time NGO Regulatory and Mentoring Platform through IoT Infrastructure.

4 Research Methodology

This research paper is developed using various reports, inputs from relevant research papers and information collected from reliable secondary sources. The growing impetus of IoT is witnessed everywhere. The study has attempted to develop a conceptual framework which would be able to mentor the NGOs on real time basis and help to instill regulations for the sector using the ecosystem of 'Internet of Things (IoT)'.

5 Analysis and Interpretation

The third sector needs reforms which would be dynamic in nature. A comprehensive and integrated conceptual model is developed where the state would devise a dedicated platform compounded with a software package which would be provided to all the NGOs free of cost. needs to be used by all the NGOs. This dedicated software package needs to be compulsorily used by every nonprofit firm and all sort of information regarding financial transactions, activities, assignments, list of beneficiaries, quantum of funds spent etc. are to be recorded on regular basis. All this information for each NGO shall be transferred and transmitted to the server instantly on real time basis when the system gets connected to the desired network loop.

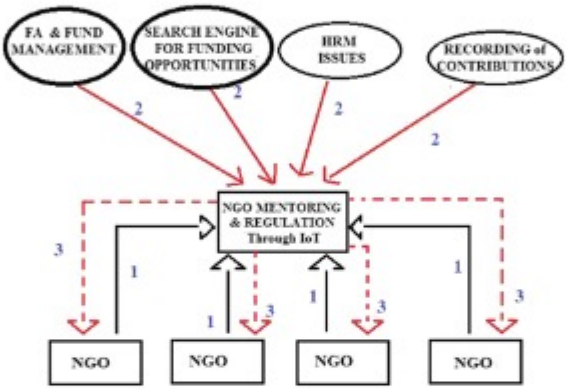

Fig. 1. Modus Operandi of proposed model

The information gets stored in the server and the same can be accessed, processed and analyzed by the Expert Agencies. In Fig. 1, the State-run Competent and Expert Agencies would provide consultancy services to the NGO firms. The devised IoT Enabled NGO Mentoring and Regulatory Framework would concentrate on two aspects i.e. it shall provide real time Consultancy support as a part Mentoring assignment and the model would enable to satisfactorily implement the stringent regulatory provisions and compliances thereof. The proposed model would serve the following assignment-

(i) **Financial Accounting and Fund Management:** The IoT platform would act as responsible instruments for capturing and recording all financial transactions. The issues of suspicion on NGOs depend on the level of transparency and disclosure particularly to the source and uses of funds that has been received from individual as well as institutional donors across the country and abroad. This instrument shall carry out appropriate means of financial accounting. If any discrepancy arises, the expert group would provide effective solution and the same shall be communicated to the respective NGO(s) case to case basis. It would enable greater transparency among the firms. On the other hand,

the Expert Group would analyze the financial health so that the NGO would be able to accomplish all the project assignment with due justice. The task of effective and efficient management of fund flow would be supported by the competent body.

(ii) **Search Engine for Funding Opportunities:** The 'IoT Enabled NGO Mentoring and Regulatory Framework' is expected to act as a dependable and dedicated 'Search Engine for Funding Opportunities'. This platform would gather adequate and exhaustive information about the Institutional funding opportunities from the world so that the NGOs networked into the platform can be benefitted for fundraising activities and execute social developmental projects/assignments as per the terms of reference. The platform may send links of relevant 'Expression of Interest (EOI)' or 'Request for Proposal (RFP)' documents based on the nature and expertise of NGOs on case to case basis.

(iii) **HRM Issues:** The devised virtual platform supported by the Consultancy/Experts team would study and analyze all the activities, SWOT, competency mapping etc. of every NGO. This agency may manage HRM function and frequently organize training programme for the employees/volunteers with the collaboration of the learned Institutions in the region. This would help the sector to efficiently manage HRM issues and could achieve competitive benchmarking strategy the context of HRM aspects.

(iv) **Recording of Substantive Contribution:** The 'IoT Enabled NGO Mentoring and Regulatory Framework' would record both qualitative and quantitative data with respect to the Substantive Contributions accomplished by each of the NGOs. This platform would attempt to record the level of social engineering initiatives like transfer of resources to the target of beneficiaries, no. of beneficiaries benefitted, creation of social assets, success of social development programmes (like health care/camp, capacity building measures, Child care, poverty alleviation etc.) quantum of funds utilized etc. for every NGO.

The model would essentially foster the third sector of the economy by augmenting and mentoring the system with the intervention of 'IoT Enabled NGO Mentoring and Regulatory Framework' which would streamline the NGOs and make them more competitive at par with the private firms operating in the segment.

Proposed Algorithm

Step 1: *All the NGOs would be connected in the network with IoT platform through Sensor nodes, Biometrics devices and web portal etc.*

Step 2: *This virtual platform is augmented with the 'State-run Competent and Expert Agencies' that would study and analyze all the information and build a Comprehensive, Interactive and real time platform i.e. 'IoT Enabled NGO Mentoring and Regulatory Framework'*

Step 3: *This IoT system retrieves all the information through its sensory nodes in the secure channel for recording financial transactions & fund management, HRM issues, substantive contributions for each of the NGO firms and would act as 'Search Engine for Funding Opportunities'.*

Step 4: *(a) If the IoT sensory nodes authenticate and validate that the select NGO is under performer, the system would devise its dedicated mentoring initiatives to improve its efficiency and quality function deployment (QFD) mechanism* (b) *If the IoT surveillance system authenticates and validates that the select NGO is deliberately performing misappropriation of resources or indulging in anti-state activities, the framework would reinforce as Stringent Regulatory mechanism.*

6 Conclusion

The development of a Nation can never be achieved by the State alone. Corporate sector upholds the growth of business and economy up to a certain extent. But the entire population cannot be included in the growth trajectory. The intervention of third sector is emergent to ensure inclusive growth. The NGOs suffer from many dimensions. It is the high time to strengthen the nonprofits by augmenting fund raising, marketing, training & development activities. A section of the sector is now under the scanner or surveillance of the State. This paper has attempted to design a model embedded with IoT infrastructure that would address all of these concerns. The dynamic reforms in the sector would envisage the paramount growth and holistic development for the people of this planet.

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A Novel Structure for Piezoelectric Based MEMS Energy Harvester

Anil Chamuah
Dept. of E.C.E.
Rajiv Gandhi University
Itanagar, India
chamuahanil@gmail.com

Kurmendra
Dept. of E.C.E.
Rajiv Gandhi University
Itanagar, India
kurmendra.nits@gmail.com

Rajesh Kumar
Dept. of E.C.E.
NERIST
Nirjuli, India
itsrk2006@gmail.com

***Abstract*— A novel structure has been designed to be used as piezoelectric Micro Electro Mechanical Systems (MEMS) energy harvester. A deep investigation has been made for the selection of the piezoelectric material and also for the design of the structure. Finally, the structure of a 'Jaw Harp' is used and 'Rochelle Salt' is applied as the piezoelectric material. Numerous simulations and analytical calculations have been performed in the process of optimizing the device performance by varying its various parameters. Towards the end, a very appreciable result have been achieved. A remarkable output electric potential of 0.12 V has been generated by the harvester on application of 1 Nm^{-2} pressure at the free vibrating end of the device.**

Keywords—energy harvester, jaw harp, MEMS, piezoelectric, rochelle salt

I. INTRODUCTION

Energy is everywhere surrounding us in various forms. Most of them are natural and some of them are because of various abiotic activities. As for some examples, wind energy, solar energy, the thermal energy, and mechanical energy. But the problem lies in the fact that the energy found in these are in such minute quantities that they can hardly be used for any viable purposes. In fact, until the recent development in modern high-end technologies, it was very difficult to capture these kind of energies for any viable applications. [1-2].

Energy Harvesting is considered to be the method of capturing very less amount of energy from one or more available natural energy sources, acquiring them and storing for later use in the applications like WSN (Wireless Sensor Network). In other words, an energy harvesting system is an electromechanical device that can provide power to various sensors and control circuitry for intermittent duty applications [2-3].

The main advantages of energy harvesting is that it is inexhaustible, free and less prone to maintenance. Energy harvesting can be applied to a wireless node which is placed to a remote site where a power plug or a battery is either unreliable or unavailable, a wireless node running on energy harvesting is a self-powered electronic system whose efficiency can be increased by means of using multiple energy sources which will significantly improve the reliability of the system also [1-3].

In the last decade, it is seen that MEMS technology has been widely used for energy harvesting application in various ways. As reported in [4-5], it is seen to be implemented for IoT (Internet of Things) which is ruling the world right now. The IoT requires for smart, integrated, miniaturised and wireless nodes running with low energy batteries which used to be exhausted after a certain period. Therefore, much researches are going on to make them self-powered standalone devices.

RF MEMS as reported in [6] can provide better efficiency in converting solar energy to charge as compared to photovoltaic cells.

The MEMS energy harvesters generate voltage in the range of mV and hence cannot be implemented for more power consuming devices. Therefore, array of such devices can be implemented, as seen in [7] for power conditioning circuits.

II. ARCHITECTURE OF THE PROPOSED MODEL

The architecture of the proposed model is shown Fig. 1 below. It has the structure of a 'Jaw Harp' which is a traditional musical instrument in the region of North-East India. It is an instrument which produces a musical sound because of very high vibration when a small force is applied to it. Since, a piezoelectric energy harvester needs to produce a large stress on application of a small amount of force, this particular structure is one of the best fit to serve the purpose.

The overall width of the proposed structure is 230µm, with first 155µm as movable part which can deflect in both upward and downward directions and the remaining part is defined as the fixed constraints. The overall depth is 10µm and also the overall height is 10µm. For better deflection the height of the main deflecting part is restricted to 2µm only.

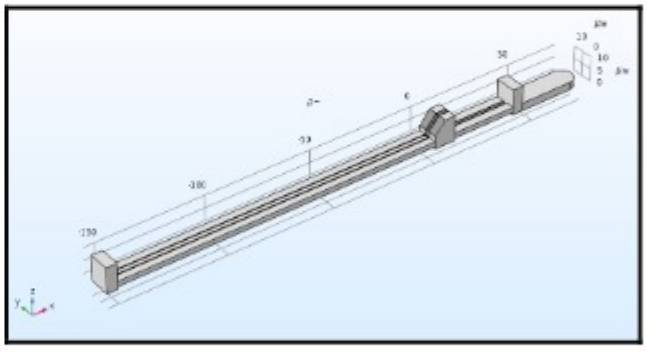

Fig. 1: Architecture of the proposed model

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III. WORKING PRINCIPLES

When the material parameters, the geometrical dimensions, and the external forces are known, the displacement of the beam can be found out. Once, the displacement is found, the stress can be calculated from it and finally from the stress, the electric potential developed in the structure can be calculated.

The architecture of the proposed model is similar to that of a rectangular cantilever and therefore its governing equations can be derived from it.

A. Deflection

For a rectangular cantilever beam structure (shown in Fig. 2), let the width, thickness and length be 'b', 'h' and 'L' respectively. Let 'F' be the force acting on the free end of the cantilever beam. For compensating the loading force 'F', a supporting force 'F_o' is produced at the clamped end in the opposite direction of the loading force. Meanwhile, a restrictive bending moment 'm_o' is produced at the clamped end of the beam to counteract the effect of bending moment caused by the loading force 'F'.

At the free end, the force moment 'FL' is in the downward direction, which as a result generates a balancing restrictive bending moment 'm_o' at the clamped end equal to 'FL' but is in upward direction.

From Fig. 2 at the position 'x', the bending moment at the left is ($-m_o+F_ox$) and the bending moment at the right is -F.(L-x). The bending moment on the left is equal to the bending moment on the right, i.e. M(x)=-F.(L-x). The differential equation for the displacement function 'w(x)' is given by:

$$-EIw''(x) = -F.(L-x) \quad (1)$$

where, E and I are the Young's modulus and moment of inertia of the beam respectively. The boundary conditions are:

$$w(0) = 0,\ w'(0) = 0 \text{ and } w''(L) = 0 \quad (2)$$

Using Equation (1) and (2), we have:

$$w(x) = (F(3L-x)x^2)/6EI = (2F(3L-x)x^2)/(Ebh^3) \quad (3)$$

The maximum displacement at the free end of the beam that is at x = L is given by:

$$w_{max} = w(L) = (FL^3)/3EI = (4FL^3)/(Ebh^3) \quad (4)$$

The Eqn. (4) is the required equation for the analytical calculations for maximum displacement produced in the proposed model on application of the applied pressure [1] [3].

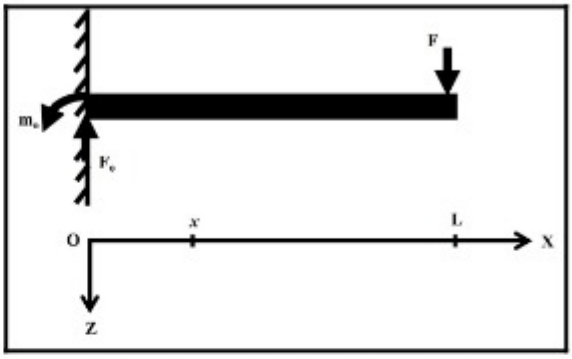

Fig. 2: Cantilever beam subjected to a force at the free end [3]

B. Stress

A miniaturized beam of a rectangular shape is shown in Fig. 3. The length 'L' is comparatively very large than the width 'b' and thickness 'h' of the beam. The length of the beam is taken along X-axis of a co-ordinate system considering its origin at the centre. If some force is acting perpendicularly in the middle of the beam, the top of the beam is compressed and the bottom of the beam is stretched (as shown in Fig. 4). There will also be a neutral plane along the middle of the cross section of the beam.

According to Hooke's Law, the stress in the layer at 'z' is given by:

$$T_{XX}(z) = Ez/r \quad (5)$$

Where r is the radius of curvature. When the beam is bent, the displacement of its central plane is a function of position, which is known as the displacement function 'w(x)'. As in mathematical concept, the absolute value of the second derivative of a curve w(x) will give the reciprocal of the radius of curvature of the curve w(x), which can be expressed as:

$$1/r = |w''(x)| \quad (6)$$

Equating equations (5) and (6) we have :

$$|T(x,z)| = Ez|w''(x)| \quad (7)$$

As shown in Fig. 4, for the bending up condition, we have $w''(x) < 0$. In the elemental section, for a layer with $z > 0$, it will be stretched, i.e. $T > 0$, and vice versa. Therefore, the algebraic relation for equation (7) is:

$$T(x,z) = -Ezw''(x) \quad (8)$$

Using Eq. (8), the stress on the top surface of the beam (at $z = -h/2$) is given by:

$$\begin{aligned} T(x) &= -E(h/2)\,w''(x) \\ &= (Fh(L-x))/2I \\ &= (6F(L-x))/(bh^2) \end{aligned} \quad (9)$$

The stress is maximum at x=0 and decreases linearly to zero at x=L. Using Eq. (9), the maximum stress is given by [1][3]:

$$\begin{aligned} T_{max} &= FhL/2I \\ &= 6FL/(bh^2) \end{aligned} \quad (10)$$

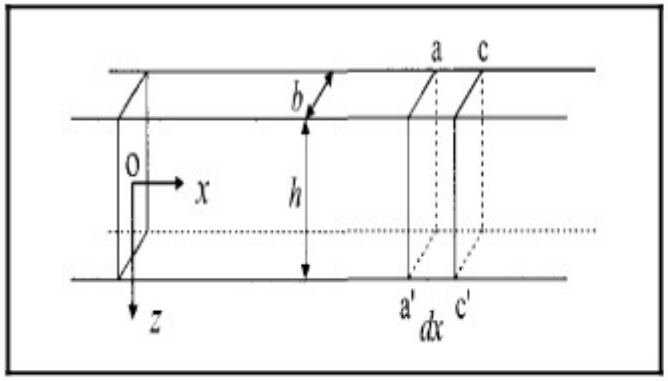

Fig. 3: An elemental section of the beam [3]

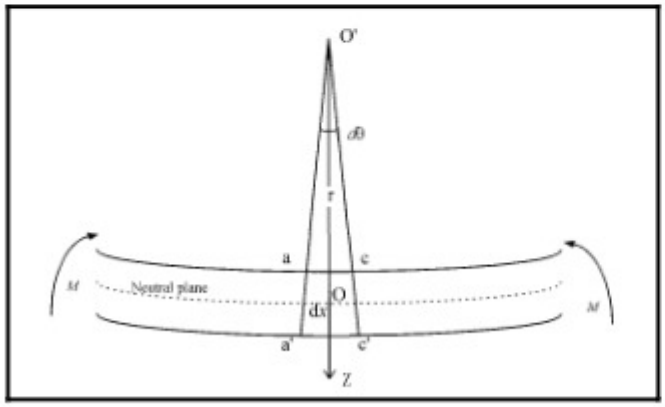

Fig. 4: Bending of the beam under bending moment [3]

C. *Electric Potential*

Piezoelectric material has used in the proposed work for the generation of electric potential on application of applied force or pressure. Piezoelectric materials are those where electric moments are created and aligned in a specific direction on application of mechanical strain, resulting as a electric dipole on application of mechanical strain, which is called the 'direct piezoelectric effect'. If deformation is created on the surface of the material on application of electric current, it is called 'inverse piezoelectric effect.

If we consider a simple one-dimensional case, a very simple equation can be used for the calculation of charge developed in the piezoelectric material and is given by:

$$q = (d_{33}\, T_{max}\, bh^2)/6L \qquad (11)$$

where q is the charge developed, d_{33} is a material property called the Piezoelectric Constant, and T_{max} is the maximum stress.

IV. RESULTS

For the modelling and simulation of the proposed structure, COMSOL Multiphysics (v5.3) is used which is based on Finite Element Method (FEM) analysis of structures and the following simulation results has been obtained. The analytical values are also calculated and placed in the tables below along with the simulation results.

The applied pressure is varied from 0 N/m^2 to 1 N/m^2 with a step size of 0.1 and the following results have been obtained:

A. *Displacement Occured*

TABLE I. ANALYTICAL AND SIMULATED RESULTS FOR DISPLACEMENT

S.L. No.	Applied Pressure (N/m^2)	Total Displacement (μm)	
		Analytical	***Simulated***
1	0	0.000000	0.000000
2	0.1	0.000140	0.000119
3	0.2	0.000280	0.000238
4	0.3	0.000420	0.000356
5	0.4	0.000560	0.000475
6	0.5	0.000700	0.000594
7	0.6	0.000840	0.000713
8	0.7	0.000979	0.000832
9	0.8	0.001119	0.000950
10	0.9	0.001259	0.001070
11	1.0	0.001399	0.001190

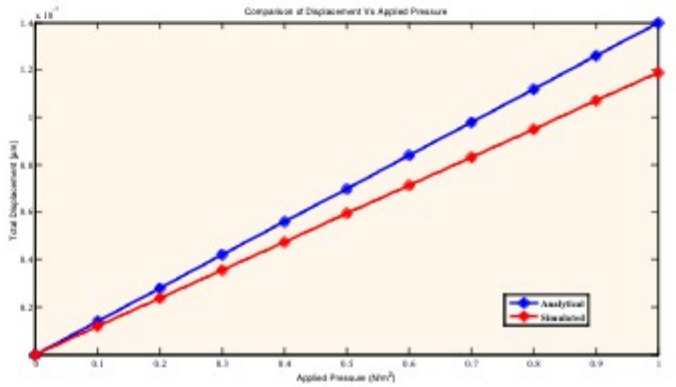

Fig. 5: Comparison of Displacement Occured Vs Applied Pressure

B. *Stress Developed*

TABLE II. ANALYTICAL AND SIMULATED RESULTS FOR STRESS

S.L. No.	Applied Pressure (N/m^2)	Stress (N/m^2)	
		Analytical	***Simulated***
1	0	0	0
2	0.1	183.75	190
3	0.2	367.50	380
4	0.3	551.25	569
5	0.4	735.00	759
6	0.5	918.75	949
7	0.6	1102.50	1140
8	0.7	1286.25	1330
9	0.8	1470.00	1520
10	0.9	1653.75	1710
11	1.0	1837.50	1900

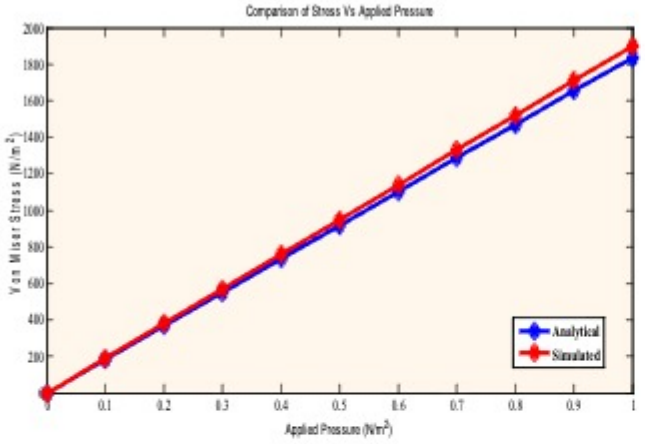

Fig. 6: Comparison of Stress Developed Vs Applied Pressure

C. *Electric Potential Generated*

TABLE III. ANALYTICAL AND SIMULATED RESULTS FOR ELECTRIC POTENTIAL

S.L. No.	Applied Pressure (N/m2)	Electric Potential (V)	
		Analytical	***Simulated***
1	0	0.000000	0.00
2	0.1	0.009923	0.01
3	0.2	0.019845	0.02
4	0.3	0.029768	0.04
5	0.4	0.039690	0.05
6	0.5	0.049613	0.06
7	0.6	0.059535	0.07
8	0.7	0.069458	0.08
9	0.8	0.079380	0.10
10	0.9	0.089303	0.11
11	1.0	0.099225	0.12

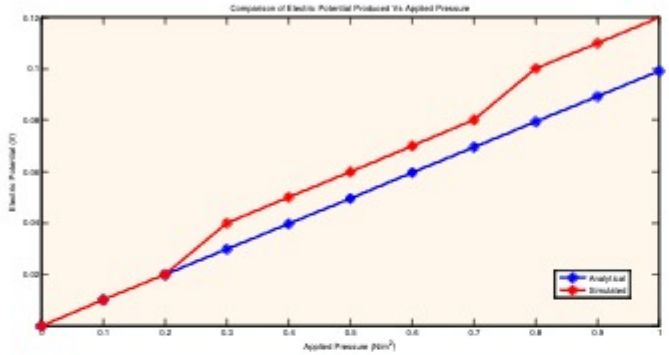

Fig. 7: Comparison of Electric Potential Generated Vs Applied Pressure

V. CONCLUSIONS

From the graphs shown above, it is clear that both the analytical and simulated results for the model are very close to each other which in turn verifies the project. Using Rochelle Salt as the Piezoelectric material and 150 µm as the length of the free vibrating end of the structure, electric potential in the range of ~ mV has been obtained. On varying the applied pressure from 0.1 to 1.0 Nm^{-2} a voltage range of 0.01 to 0.12 V has been generated as the output which can be used to power wireless nodes in a wireless sensor networks (WSN).

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Silver Metal Nanoparticles: Green Synthesis and Promising Bioactivities

Dwipen Kakati*, Manab Jyoti Goswami

Abstract

With the growing environmental awareness the world is rapidly moving towards nature derived or nature inspired products. Silver is one of the most used metals for its antimicrobial properties from ancient times. With the emergence of nano materials as a better alternative than the bulk metals, research across the globe is focused on application of metals in their nano forms. This review highlights the environmentally benign synthesis of silver metal nanoparticles using plant extracts and highlights their potent bioactivities.

Introduction

The European Commission defines a nanomaterial as a natural, an incidental, or a manufactured material containing particles in an unbound state or as an aggregate or agglomerate in which 50% of the particles in the number size distribution have one or more external dimensions in the size range from 1 to 100 nm.[1] Among different inorganic nanoparticles, noble metal nanoparticles such as gold (Au), silver (Ag), platinum (Pt) and palladium (Pd) have attracted great attention of researchers due to their size and shape dependent

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The Goal of Doubling Farmers' Income and Factor Markets in Indian Agriculture

Dr. Anup Kumar Das
Ex Student &
Assistant Professor in Economics,
Rajiv Gandhi University, Itanagar,
E-mail: anupdas97@gmail.com

1.The Goal of Doubling Farmers' Income

Despite the share of Agriculture is declining in the Indian economy, this sectorhas still akey role in the economy of the country.More than half of the population of the country depends on this sector for their livelihood. Recognising the importance of agriculture sector in the economy of the country, many strategies have been adopted by Government of India during the post-independence periodsfor the development of this sector. The land reform measures and the green revolution are such measures adopted in India for agricultural development. However, Chand (2016) pointed out that India's past strategies for agricultural development aims in enhancing agricultural output and achieving food security but ignored the need to increase the farmers' income. Chand (2016) also mentioned that such policies did not suggest any measures to improve farmers' welfare. According to Chand (2016), India's past strategies for agricultural development involves-

(a) An increase in productivity through better technology and verities and increased use of quality seed, fertilizer, irrigation and agro chemicals.

(b) Incentive structure in the form remunerative prices for some crops and subsidies on farm inputs.

Growing Urbanisation and Challenges of

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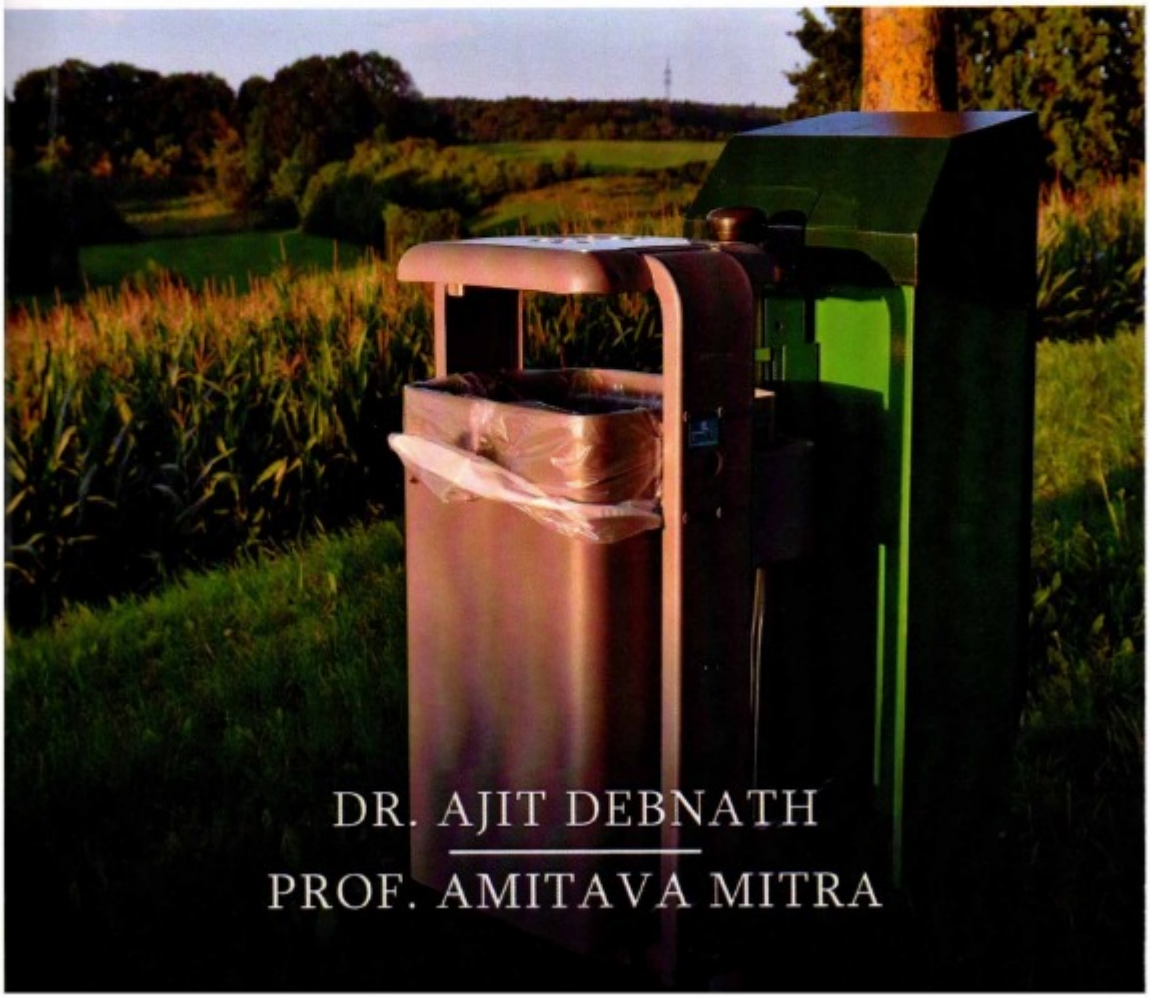

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Biodiversity of Fishes in Arunachal Himalaya

Systematics, Classification, and Taxonomic Identification

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Debangshu Narayan Das

POWER AND ITS DYNAMICS

A Critical Study of the Novels of Ngugi wa Thiong'o

Miazi Hazam

POWER AND ITS DYNAMICS

A Critical Study of the Novels of Ngugi wa Thiong'o

The book is an analysis of power as a theme and its manifestations in various forms in the seven novels of Ngugi written till date. The critical approach towards these seven novels incorporates the perspectives of theorists on power and includes the Postcolonial, Marxist, Feminist and Post-structuralist views on the issue of power and its implications in the context of colonial, postcolonial and neo-colonial eras in Kenya.

Miazi Hazam is assistant Professor in the Department of English, Rajiv Gandhi University (Arunachal Pradesh). He has published several research articles in national and international journals and is interested in Postcolonial Studies. At present he is actively engaged in guiding research in the mentioned area.

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SOCIAL MOVEMENTS IN NORTHEAST INDIA

Editor

Sarthak Sengupta

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CHAPTER - 3

RELIGIOUS REFORM MOVEMENTS IN ARUNACHAL PRADESH: UNDERSTANDING ADI AND MISHMI TRIBES

TARUN MENE AND S.K. CHAUDHURI

A movement or social movements are a type of group action with a common ideology who act together to achieve certain general goals relating to political issues, social issues, etc. It is generally designed to bring about or resist primary changes in an existing society or group. This may be of various types such as reform movement, radical movement, the environmental movement, tribal movement, caste movement, etc. Not intending to go deeper in defining the conceptual and typology of social movement as such which is beyond the frame of the present chapter, let it be clear at the very outset that the main discursive discourses will focus on the religious reform movements among the two selected ethnic tribal group of Arunachal Pradesh, such as, the Adis and the Idu Mishmis. It will precisely deal with the situation which arises as a result of a confrontation between traditional system of thought and practices and the values and the contradictory modern elements that have penetrated into the tribal world. And finally, try to generalize the results of such religious reform movement which are accelerated to redress the existing changes in the society and in this process of reform how the concerned ethnic group emulates certain elements of greater

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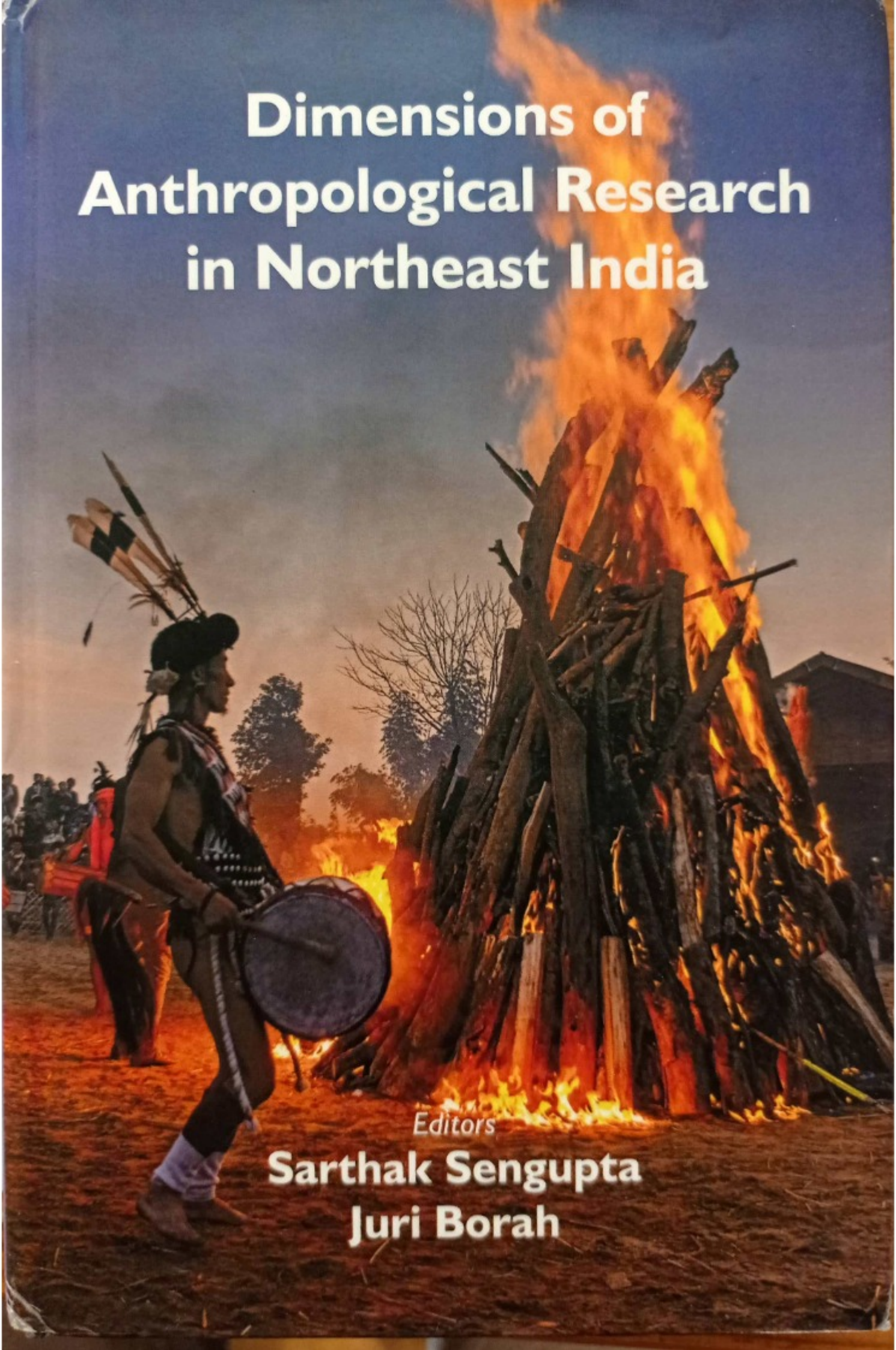

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Chapter - 5

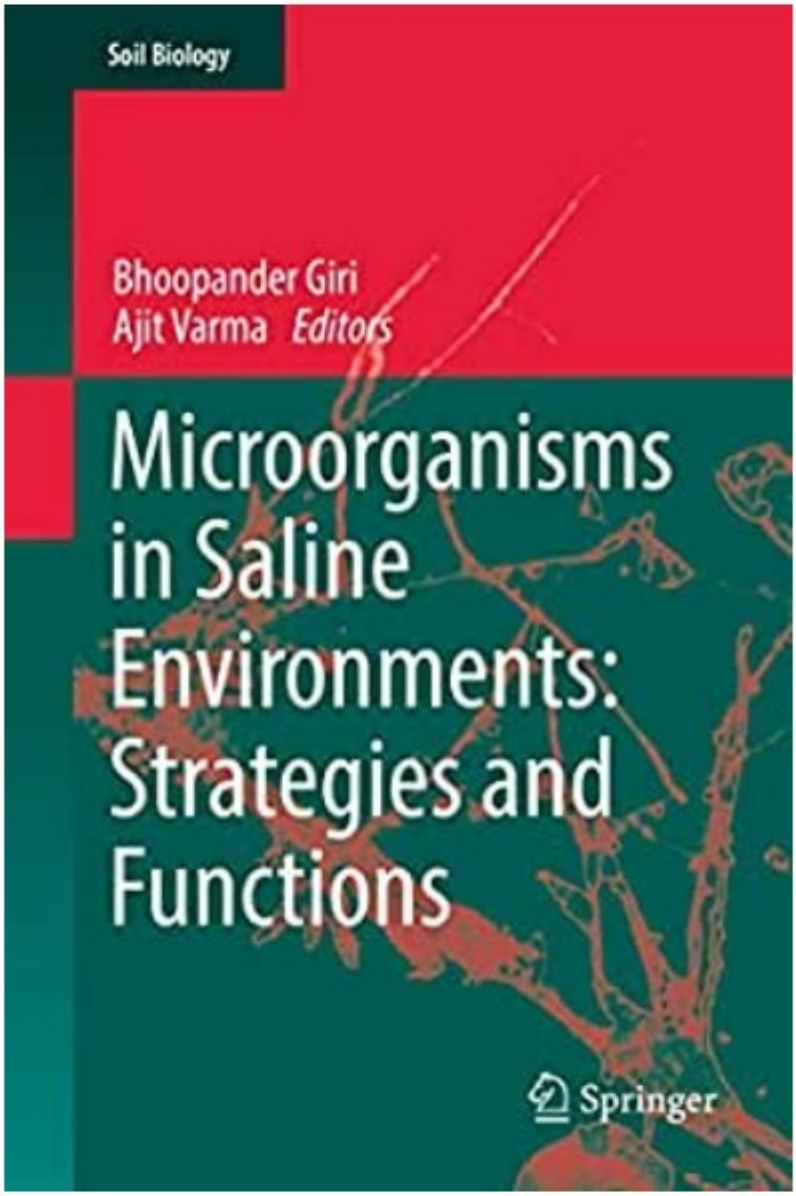
Suicide
A Public Health Issue with Special Reference to Arunachal Pradesh

— Tarun Mene

Introduction

Suicide is a complex phenomenon that has attracted the attention of philosophers, theologians, physicians, sociologists, anthropologists, and artists over the centuries. According to the French philosopher Albert Camus, in 'The Myth of Sisyphus', it is the only serious philosophical problem. As such, the task of academicians never concludes when it enters the realm of suicide.

Almost five decades back, Dublin (1963: v) claimed that 'The problem of suicide has so many aspects and such far-reaching implications, that no short treatise can possibly cover all of them. Any attempt to deal completely with a question that has so many ramifications would baffle the skill of the most thoughtful student of human affairs'. Firth (2000/1961) equally contended that 'Even the idea of suicide itself is both clear and susceptible to slippage, as there is no obvious line between where 'suicide' ends and 'risk-taking' behaviour or willful 'self-neglect' begins'. Similarly, Ian Hacking (2008: 1) noted, 'The meanings of suicide itself are so protean across time and space that it is not so clear that there is one thing, suicide'. As scholars from recent times, for example, Staples and Widger (2012) opined that 'It is a problem of enduring human interest, forcing us to ask questions about ourselves and our world that other human behaviours do not.' Munster and Broz (2015) simply concur, 'Suicide is a challenging object of study.' Minayo (2006) also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Chapter 19
Strategies for Reclamation of Saline Soils

Vinay Shankar and Heikham Evelin

Abstract Salinization of soil is one of the major constrains to food security. Salt deposition in the soil is a natural process; however, anthropogenic activities such as improper agricultural practices, poor drainage system, and inefficient water management have hastened the process of salinization. The increase in areas under salinity is coupled with the exponentially growing human population posing a huge challenge to mankind to ensure food security. It is therefore the need of the hour to reclaim these saline areas as well as improve the plant's ability to resist soil salinity. Many methods have been developed to desalinize the soils, such as leaching, growing halophytes, subsurface drainage, biomimicry, etc. This chapter deals with various strategies that are used for desalinization and also identifies the challenges in the application of these techniques.

Keywords Biomimicry · Desalinization · Halophytes · Leaching · Salinity

19.1 Introduction

Soil salinity is a major impediment to modern agriculture as it can adversely affect the growth, development, and yield of plants. The problem of salinity is enormous as it occurs in more than 100 countries covering approximately 1 billion hectares (ha) (FAO report 2015). Salinity problems are long-lasting and manifold—(1) it is rapidly increasing, with an estimated 0.3–1.5 million ha of farmland succumbing to salinity per year; (2) it causes a decline in crop productivity by 20%; (3) it decreases the production capacity of another 20–46 million ha; (4) it reduces diversity of flora; and (5) it increases soil erosion (Porcel et al. 2012; FAO 2015; Swallow and O'Sullivan 2019). Then again, the exponential increase of human population adding

V. Shankar
Department of Botany, Deshbandhu College, University of Delhi, New Delhi, India

H. Evelin (✉)
Department of Botany, Rajiv Gandhi University, Itanagar, India

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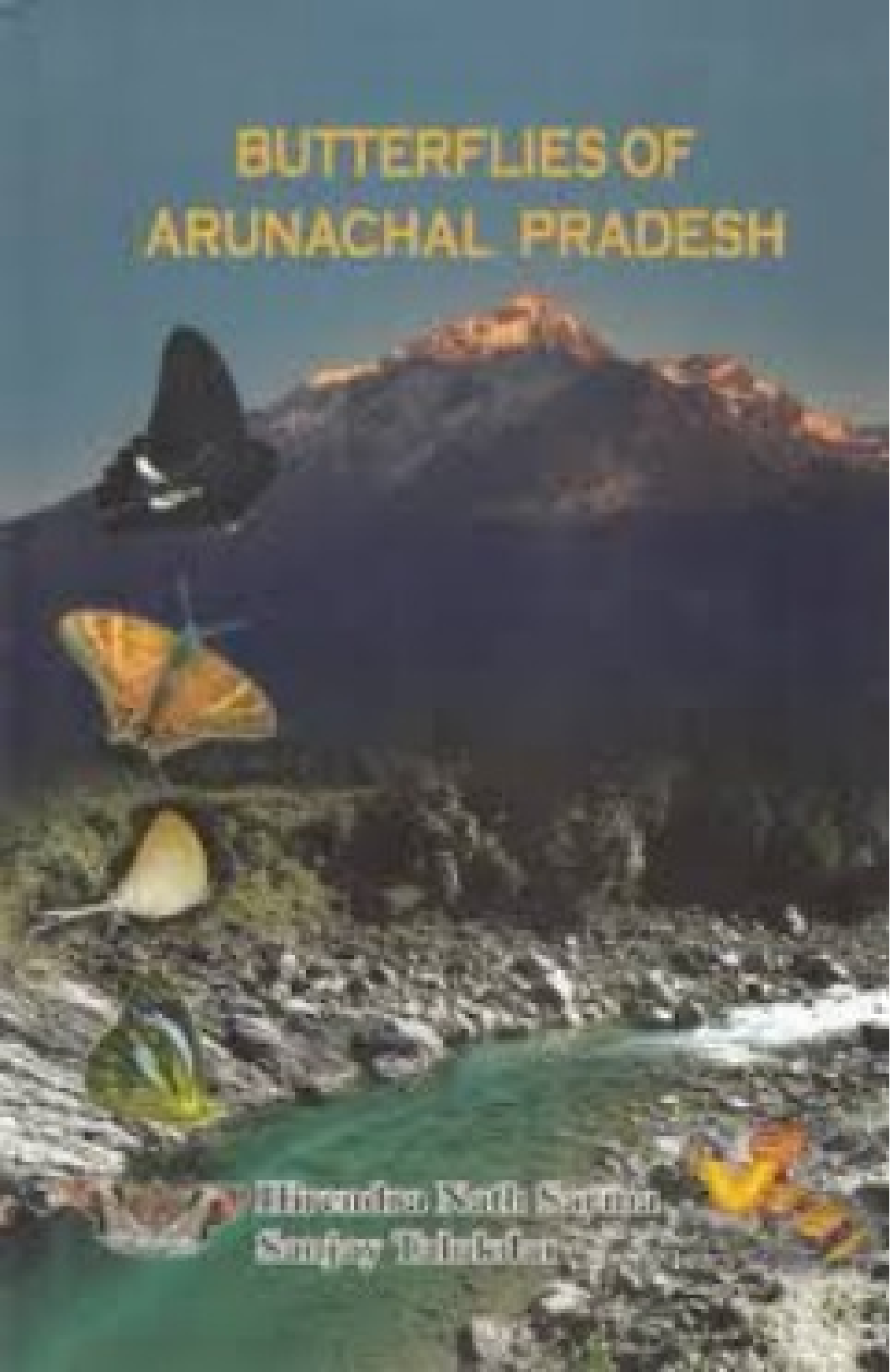
DISCOVERING EASTERN HIMALAYA

The Arunachal Pradesh

WEST KAMENG & TAWANG

Hirendra Nath Sarma

BUTTERFLIES OF ARUNACHAL PRADESH



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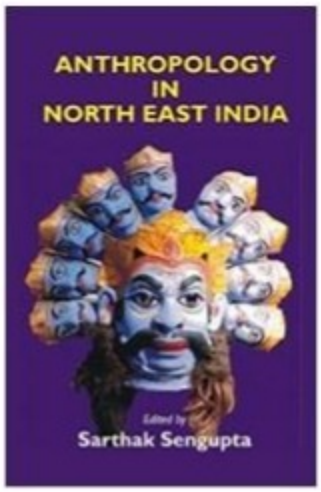

Authored By

Haobijam

Other Author

Scope of Book

Chapter Published in Book "**Anthropology in Northeast India**".

The inspiring collection of research articles accommodated in the present compilation includes eighteen contributions by eminent anthropologists focusing on various contemporary concerns relating to the status of women, gender and ethnicity, identity dynamics, cultural heritages, ethnoarchaeological aspects, the impact of Christianity, traditional village institutions, elderly health care perceptions, changes in tribal folklore, altitudinal stress among varied ethnic inhabitants of North East India. The volume covers an extensive canvass bringing together empirical research works and pinpoints the reality of the lifestyle of the people and is expected to grasp attention from a wide range of related academic disciplines and would provide information and inspiring thoughts to the academicians, researchers, administrators, policymakers and planners' about the region.

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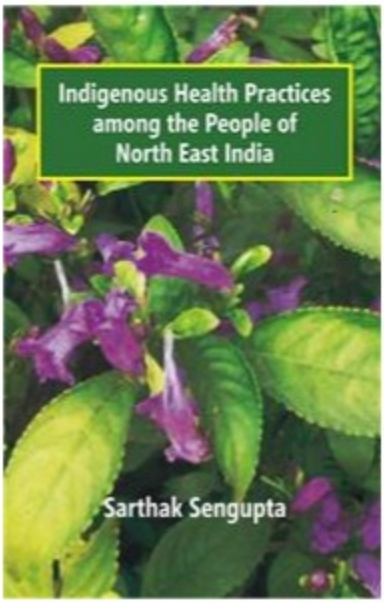

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Scope of Book

Chapter Published in Book "**Indigenous Health Practices Among the People of North East India**".

The impressive collection of papers accommodated in this volume offers a snapshot only through nineteen research contributions covering different issues related to indigenous health practices from different ethnic groups of North East India. The topics covered in the present treatise include indigenous notions of health care, healer and healing practices; ethno medicinal, ethno-botanical and ethnozoological knowledge; child-rearing and pregnancy care practices etc., prevailed in North East India. The compilation would provide a better understanding towards the key determinants of the health and wellbeing of the indigenous people in the context of public health. The book will be of extremely stimulus and serve as useful reference material for researchers, policy makers, and consultants in the field of health studies.

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Edible Insects in Sustainable Food Systems

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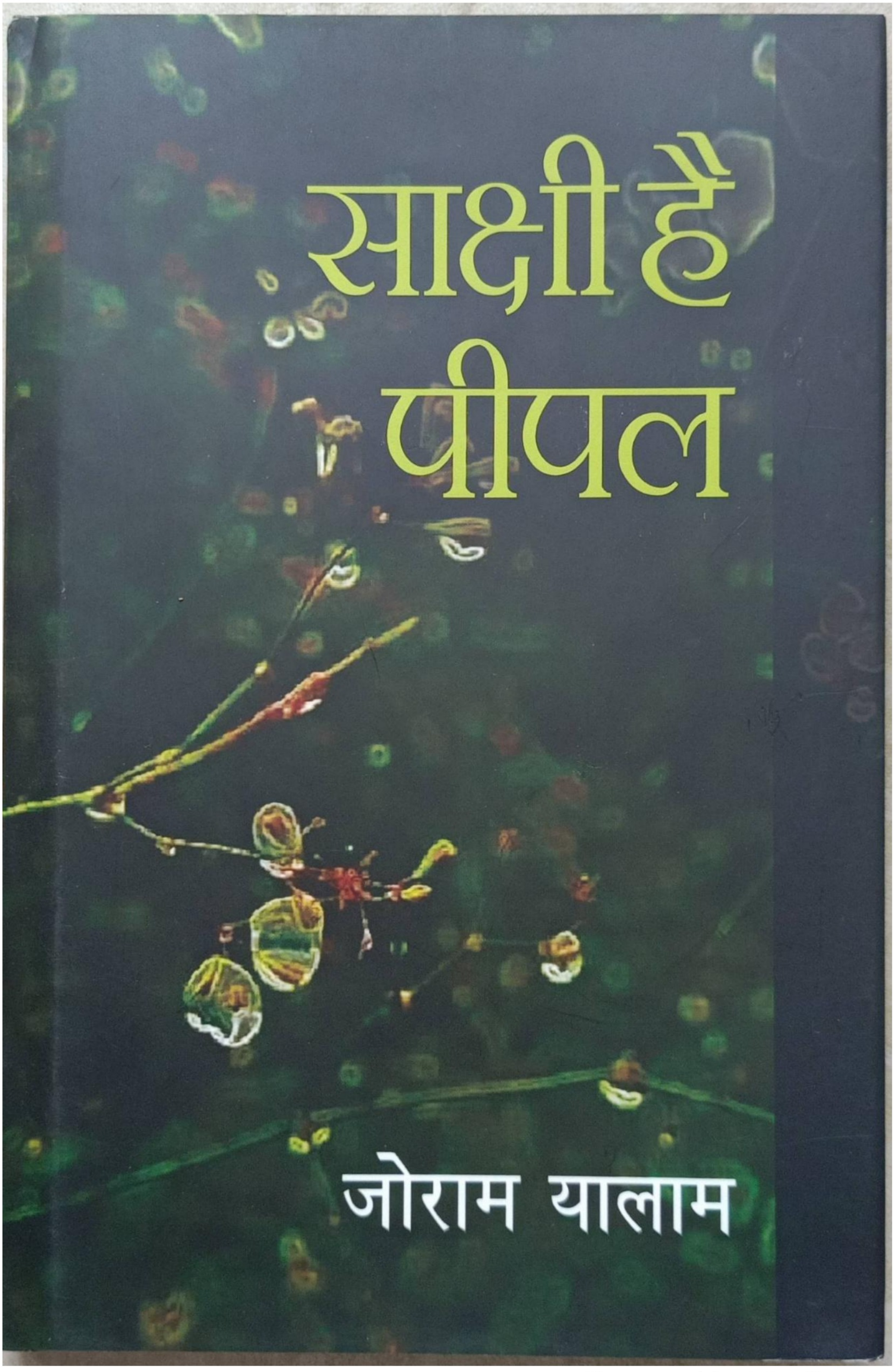

जोराम यालाम

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समय के साथ बच्चे बढ़ने लगे। बाँस, लकड़ी तथा घास-फूस का बना घर ऐसा लगता था, जैसे किसी ट्रेन का लम्बा कटा हुआ डिब्बा हो। एक ही लम्बा घर और उसमें सभी पत्नियों के अलग-अलग चूल्हे। बच्चों के तो बस मजे-ही-मजे। इतनी सारी माँएँ जो थीं उन्हें प्यार करने के लिए। एक ने खाना नहीं दिया, तो दूसरी ने खिला दिया। एक ने मारा तो दूसरी ने प्यार किया। पिता रात को पहली बीवी के साथ ही दिखते, परन्तु सुबह दूसरी, तीसरी या चौथी के साथ दिख जाते। बच्चे सकपकाने लगते। वे आँखें मीच-मीचकर उन्हें देखने लगते। अब तो बड़े लड़के खोदा से न रहा गया। उसने भी अपने पिता का अनुसरण करना शुरू कर दिया। वह भी हर रात अलग-अलग माँओं के साथ सोने लगा। उसकी माँ ने कहा, ''देखो देखो, इस लड़के को क्या हुआ है? अपने पिता के पीछे-पीछे चलने लगा है।'' इस पर नन्हें खोदा ने भोलेपन से कहा, ''पिताजी से तो कुछ कहती नहीं, सिर्फ मुझे डाँटती हो।'' घर में ठहाकों की आवाज गूँजने लगी पर खोदा को समझ में नहीं आया कि हुआ क्या है। अपमानित खोदा उन ठहाकों के बीच हुआँ...हुआँ... करके इतने जोर से रोने लगा कि सब एकदम से चुप हो गए, जैसे किसी ने व्हीसिल बजा दी हो और सभी उसकी तरफ प्रश्नसूचक नज़रों से देखने लगे। ''अरे बस भी करो, जब देखो हा, हा, ही, ही, हे, हे करके हँसती रहती हो। बेटी नहीं, बेटा है मेरा। मेरा वंश आगे ले जीएगा ये।'' ताजुम ने बेटे को गोद में प्यार से लेते हुए कहा था। रूखे-बिखरे बाल छोटी-छोटी उत्सुकता से भरी आँखें आबू की तरफ उठ गई, जो बहुत देर से आग जलाने की कोशिश कर रही थी। उसने सोचा, मैं तो मरने के बाद तितली बनकर जंगल-जंगल, पहाड़-पहाड़ उड़ती फिरूँगी। फिर मैं किसी की बेटी तो ऊँ हूँ...। कभी नहीं। यह थी ऐपा की दीदी यामी, जो समय से पहले ही परिपक्व हो गई थी।

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साक्षी है पीपल

जोराम यालाम

अनुज्ञा

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वैधानिक चेतावनी
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में उपयोग के लिए लेखक व प्रकाशक की लिखित अनुमति आवश्यक है।
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SAKSHI HAI PEEPAL
Short stories *by* Joram Yalam

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अनुक्रम

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भूमिका

पिछले बरस तीन महीनों के अरुणाचल प्रवास में मुझे जोराम यालाम नाबाम की हिन्दी कहानियाँ पढ़ने का अवसर मिला। इसके पूर्व में उन्हें लेखिका के रूप में नहीं, केवल हिन्दी साहित्य की कॉलेज प्राध्यापिका के रूप में जानता था। राजीव गाँधी विश्वविद्यालय के अतिथि भवन में जब वे मुझसे भेंट करने आईं, तो मैंने व्यक्तिगत और पारिवारिक कुशल-क्षेम के परिवृत्त तथा अरुणाचल के लोगों, वहाँ की प्रकृति, मौसम आदि तक सिमट आई बातचीत में कुछ नया जोड़ने के उद्देश्य से उनसे पूछ लिया, 'आप अपने कॉलेज में छात्रों को साहित्य पढ़ाकर सन्तुष्ट हो जाती हैं या कुछ अपना पढ़ना-लिखना भी करती हैं?'

'हाँ सर, मैंने अपने पी-एच.डी. के शोधपरक कार्य को पुस्तक रूप में छपवा लिया है।'

'बहुत अच्छा है! वह तो सामान्य आवश्यकता के अन्तर्गत भी होगी। एक उपाधि मिल गई होगी। लेकिन उसके बाद भी तो काम करते रहना चाहिए था। अरुणाचल के बारे में ही कुछ लिखतीं।'

'सर, बात दरअसल यह है कि एक तो कॉलेज में और वहाँ आने-जाने में ही काफी समय निकल जाता है। फिर आप जानते हैं, विवेक राजनीति में हैं। घर पर बहुत लोग आते-जाते रहते हैं। उन सबकी आवभगत भी करनी पड़ती है।'

विवेक जी यालाम के पति हैं। बहुत समझदार, सरल-हृदय, सेवाभावी और राजनीति में सक्रिय। अनाथ और निर्धन बालकों को शिक्षित बनाने के लिए अपने घर के निकट ही एक बड़ा आवासीय विद्यालय चला रहे हैं। इस विद्यालय के शिक्षक अधिकांशतः अरुणाचल के बाहर के हैं—सभी शिक्षा प्रसार के चुनौतियाँ स्वीकार करने को उद्यत, परिश्रम से मुँह न चुराने वाले, खुले विचारों वालें और मधुरभाषी। नाबाम विवेक की सूझबूझ से बहुत सारे मिशनरी भाव के मनुष्य एक स्थान पर आ जुटे हैं। इस विद्यालय की साप्ताहिक प्रार्थना

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सभा में बालक सभी प्रमुख धर्मों की प्रार्थनाओं का आवृत्तिपाठ करते हैं। गाँधी जयन्ती पर मैंने देखा कि एक बालक ने गाँधी वेश में अपने अनुयायियों के साथ हाथ में लाठी लिये बहुत दूर से चलकर मंच तक आया था। यालाम को अपना काफी समय इस विद्यालय की देखभाल में भी लगाना पड़ता है। मुझे यह सब बाद में पता चला। उस दिन तो यही लग रहा था कि अध्यापकी के कुएँ में विश्राम की आदत अपना चुके दूसरे लोगों के समान यालाम भी बहाने गढ़कर बच निकलने की कोशिश कर रही हैं। मैंने बात का सिरा हाथ से निकलने नहीं दिया, बोला, 'यह सब तो ठीक है, लेकिन जब आप उच्च शिक्षा से जुड़ गई हैं और आपमें कुछ लीक से हटकर करने की प्रतिभा है, तो समय निकालकर अपनी जिम्मेदारी भी निभानी चाहिए।'

'वह तो है सर, लेकिन समझ नहीं पाती कि क्या करूँ?'

'कुछ न हो, तो अरुणाचल की या अपनी न्यीशी लोक-कथाएँ ही एकत्र करके लिख डालिए। धीरे-धीरे तो यहाँ की लोक-सम्पदा विलुप्त ही हो रही है। उसे संरक्षित करना होगा। यह अरुणाचल का काम भी है और हिन्दी का भी।'

'सर बात तो ठीक है। मुझे कुछ करना चाहिए। अच्छा सर मैंने कुछ लिखा है, पता नहीं वह क्या है, आप पढ़ेंगे?'

'क्यों नहीं! आप लेकर आइए।'

'ठीक है सर, मैं अगले रविवार को आती हूँ।'

मैंने देखा, यालाम की झिझक थोड़ी कम हुई और चेहरे पर चमक दौड़ गई। रविवार को वे अपनी दो रचनाओं के साथ आ पहुँचीं। सामान्य शिष्टाचार निभाकर मैंने उन्हें विदा कर दिया और अवसर पते ही वे दोनों रचनाएँ पढ़ने बैठ गया। अन्त की ओर बढ़ते-बढ़ते मेरे आश्चर्य का ठिकाना नहीं रहा, वे यालाम की लिखी हिन्दी की दो मौलिक कहानियाँ थीं। दोनों में स्त्री-चरित्र केन्द्र में थे, जो बिना किसी लाग-लपेट या दाब-ढाँक के जीवन की त्रासदियों से गुजरते हुए अपने यथार्थ का परिचय दे रहे थे। इन स्त्रियों में कहीं भी दिखावा या बनावटीपन नहीं था। ये थी समाज में, परिवार में, स्कूल में, खेत-जंगल में, बारिश में, घाम में—कभी हँसती हुई, कभी किसी निर्णय पर पहुँचने का संकेत करती हुई। इन स्त्रियों के पास कभी-कभी मनकों की एक माला दिखाई देती थी जो इन्हें अपनी माँ से मिली थी, बड़ी मूल्यवान थी और आड़े वक़्त काम आती थी। एक कहानी में एक स्त्री इस ढंग से आत्महत्या का रास्ता चुनती है कि उस स्थिति की कल्पना से रोंगटे खड़े हो जाते हैं।

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कायरता भरा यह रास्ता चुनकर भी वह स्त्री जीवन से जुड़े काफी सारे तीखे सवाल छोड़ जाती है।

मैंने जल्दी ही यालाम को फ़ोन किया –

'आपकी दोनों रचनाएँ अच्छी लगीं।'

'धन्यवाद सर, लेकिन ये क्या हैं? मैंने तो, जो मन में आया, लिखती चली गई।'

'वह मैं बाद में बताऊँगा। पहले आप बताएँ, आपने ऐसी और रचनाएँ भी लिखी हैं या सिर्फ ये दो ही हैं?'

'और भी हैं सर।'

'किसी दिन लेकर आइए, पढ़ने की इच्छा है।'

अवकाश के एक दिन यालाम एक सुन्दर काले बैग में छः रचनाएँ लिये आईं। सबकी सब कहानियाँ। एक-एक को पढ़ता गया। किसी में पापुमपारे नदी क्षेत्र का वातावरण, किसी में जोराम गाँव, किसी में जीरो नामक जगह। स्त्री सभी कहानियों के केन्द्र में है। भिन्न-भिन्न भूमिकाएँ निभाती हुई, सबसे बड़ी पत्नी के रूप में भारी-भरकम जिम्मेदारी उठाती हुई, अपनी मर्जी दर्शाते हुए पति की एक के बाद एक शादियाँ करवाती हुई, दोनों वक़्त भोजन पकाती हुई, खेत-जंगल में हाड़तोड़ काम करती हुई, समूह-उत्सव में स्थानीय दारू का प्रबन्ध करती हुई, बार-बार छली जाकर टूटती हुई, सबसे छोटी पत्नी के रूप में अपमान सहते हुए भी जीती हुई, कभी-कभी किसी सौत के हमउम्र पुत्र की ओर आकृष्ट होती हुई। यही स्त्री अपने होने का अर्थ खोजती हुई भी मौजूद मिली यालाम की कहानियों में।

इन कहानियों के बच्चे भी विलक्षण थे। अनेक माँओं, किन्तु एक ही पुरुष की सन्तान होकर साथ-साथ रहते थे, सोते, खाते, शिकार करते, खेती में सहायता करते, शैतानी और मनोरंजन करते तथा अपनी जरूरतें खुद पूरी करने को आतुर होते हुए। ये बच्चे सिर्फ पिता से डरते हैं, माँ से कभी नहीं। यह स्थिति तब है, जब वह पिता पुरुष कोई बड़ा काम नहीं करता, बस कभी-कभी गुस्सा होकर दाव उठाए पत्नियों को धमकाने लगता है। बच्चे समझने लगे हैं कि उनका पिता अलग-अलग दिन अलग-अलग माँओं के पास जाता है, लेकिन उनके मन में कोई सवाल नहीं उभरता, वे जन्म से ही इसके अभ्यस्त हो चुके हैं। यह उनकी समाज-व्यवस्था का अंग बनकर सदियों से इसी तरह चली आ रही जीवन-शैली है। जहाँ शिक्षा पहुँच गई है, शहरीकरण का प्रभाव

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पड़ गया है, वहाँ इस चलन में बदलाव आया है। बच्चे इस बदलाव को भी जानने की कोशिश कर रहे हैं।

बाह्य संरचना की दृष्टि से मैंने पाया कि ये बतकही के काफी करीब। रचना के ढाँचे के बारे में कोई खास सावधानी दिखाई नहीं देती–ऐसी तो बिल्कुल नहीं, जो किसी लेखक को आशंका से भरे रखती है कि कहीं कोई उसकी कलात्मकता में कोई कमजोरी न खोज लें। यालाम को इसकी चिन्ता नहीं है। मुझे याद आ रहा है, एक कहानी में जब इन्दिरा गाँधी अरुणाचल जाकर पंडित नेहरू की प्रतिमा का अनावरण करती हैं, तो समारोह का संचालक हिन्दी के उस रूप में लोगों से तालियाँ बजाने का निवेदन करता है, जिसे आजकल अरुणाचल हिन्दी कहा जाने लगा है। हिन्दी कहानी के लिए यह एकदम नयी बात है।

एक रविवार को यालाम बिना पूर्व सूचना के आ गई और पूछा, 'सर, मैं जो सामग्री दे गई थी, उसे पढ़ लिया?'

'हाँ, वे सभी आपकी अच्छी कहानियाँ हैं। आप तो बहुत अच्छा लिखती हैं।'

'सर क्या ये सचमुच कहानियाँ कही जाएँगी? मुझे तो मालूम नहीं।'

(यह सवाल मेरे लिए बहुत कठिन था। मैं समझ चुका था कि यालाम भी पहले से जानती हैं कि उनकी रचनाएँ कहानियाँ हैं। पिछली सारी बैठकियों में या तो वे अपनी कहानियों की गुणवत्ता परखने की कोशिश कर रही थीं या मन-ही-मन मेरी अज्ञानता का आनन्द ले रही थीं। मुझे दूसरी बात का यकीन कुछ ज्यादा ही है। कारण यह है कि कहानी परखने की योग्यता मुझमें किसी भी स्तर पर नहीं है और शायद मैं अपनी अधिक आयु के अहम् में यालाम को शिक्षा देने की मूर्खता कर रहा था। जो भी बात सच हो–दूसरी ही सच होगी–मुझे अपनी इस मूर्खता पर भी गर्व है, क्योंकि उसी के सहारे में यालाम जैसी हिन्दी की एक नवोदित कहानीकार से परिचित हो सका। दूसरे किसी की भी बारी मेरे बाद ही आएगी।)

मैंने सवाल को टालते हुए कहा, 'यालाम, आप इन कहानियों को पुस्तकाकार छपवा सकें, तो अच्छा रहेगा।'

'ऐसा हो सकता है क्या सर?' कोई कुछ ऐसा-वैसा तो नहीं बोलेगा? मैं तो लिखती जाती हूँ और रखती जाती हूँ।'

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'आप लिखती जाइए, लेकिन रखती मत जाइए। अपनी कहानियाँ प्रकाशित कराइए।'

'कोशिश करती हूँ सर।'

आज जब ये कहानियाँ पुस्तकाकार छप रही हैं, तो आनन्द मिल रहा है, हिन्दी को एक नवोदित कहानीकार के पा जाने का आनन्द!

यालाम को शुभकामनाएँ।

स्वतन्त्रता दिवस, 2012

देवराज
पूर्व अधिष्ठाता : मानविकी संकाय
मणिपुर विश्वविद्यालय, इम्फाल

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Design of An Improved Micro-Electro-Mechanical-Systems Switch for RF Communication System

Kurmendra, Rajesh Kumar and Osor Pertin

Abstract This paper presents the design of improved MEMS shunt switch for RF communication applications. The switch was designed to provide a better performance in 10–100 GHz range. The switch was optimized in terms of width of the beam and air gap between the fixed type beam and dielectric layer to improve the isolation, insertion, and return loss. This study concludes that materials with high k-dielectrics and high Young's modulus are desirable for better performance in high-frequency range. The isolation, insertion, and return loss for the designed switch are obtained as –12 dB, –0.05 dB, and –45 dB, respectively.

Keywords MEMS · RF · Switch · Insertion · Isolation

1 Introduction

FET-based switches have failed to provide satisfactory performance when they are used for high-frequency applications such as microwave applications due to high power consumption and RF power-handling capability. Also, the demand of miniaturized devices is the reason for failing these FET-based switches. Micro-electro-mechanical systems (MEMSs)-based switches have been overcome all the problems associated with FET-based switches. MEMS switches have replaced FET switches due to their low power consumption with better RF performance in terms of iso-

Kurmendra (✉) · O. Pertin
Department of Electronics & Communication Engineering,
Rajiv Gandhi University (A Central University), Itanagar, India
e-mail: kurmendra.nits@gmail.com

O. Pertin
e-mail: pertinosor@gmail.com

Kurmendra · R. Kumar
Department of Electronics & Communication Engineering,
North Eastern Regional Institute of Science & Technology, Itanagar, India
e-mail: itsrk2006@gmail.com

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Table 1 Design parameters of the proposed switch

Serial number	Design parameter	Value (in μm)
1	Beam length	100
2	Beam width	5
	Beam thickness	1
3	Coplanar waveguide	50-10-1
4	Dielectric thickness	0.4
5	Substrate thickness	5
6	Air gap	0.6

lation, insertion, and return losses at GHz frequencies. These switches are also in demand since the fabrication of these MEMS-based switches does not require any new fabrication technology; they are compatible enough to the existing technology for the fabrication. MEMS switches are most successful designs among other MEMS-based designed devices, and they are capable of working efficiently in the range of 20–100 GHz [1–7]. MEMS switches with different designs are presented in the articles [3–7]. There are two types of MEMS switches which exist: (i) series MEMS switch and (ii) shunt MEMS switch. MEMS switches with cantilever beams are considered as series MEMS switch and those who employ fixed–fixed type of beams is considered as shunt type of MEMS switches. MEMS shunt-type switches are much popular due to their high performance in RF range, and many researchers have investigated that MEMS shunt-type switches are capable of providing a low pull-in voltage which is very important for RF MEMS switch designed for low-power applications [7–12]. Capacitance analysis of these shunt switches shows that they can also be used for tunable capacitor application. MEMS shunt type of switches is also designed with perforated holes in the beam for better Cd/Cu ratio. Cd/Cu ratio depends on width of the beam and the air gap between dielectric layer and beam. Many different ways of increasing capacitance ratio are given in the articles [12–20].

2 Design of the MEMS Switch

Figure 1 shows the designed MEMS switch. It consists of substrate (polysilicon), CPW (gold), dielectric (Si_3N_4), anchor (gold) both the side to support the beam (gold). The switch is designed along with CPW line to study the high-frequency characteristics. The CPW transmission line consists of two parts: (i) center conductor for signal transmission and (ii) two conductors which are connected to ground. The dimensions of each part of the switch are mentioned in Table 1.

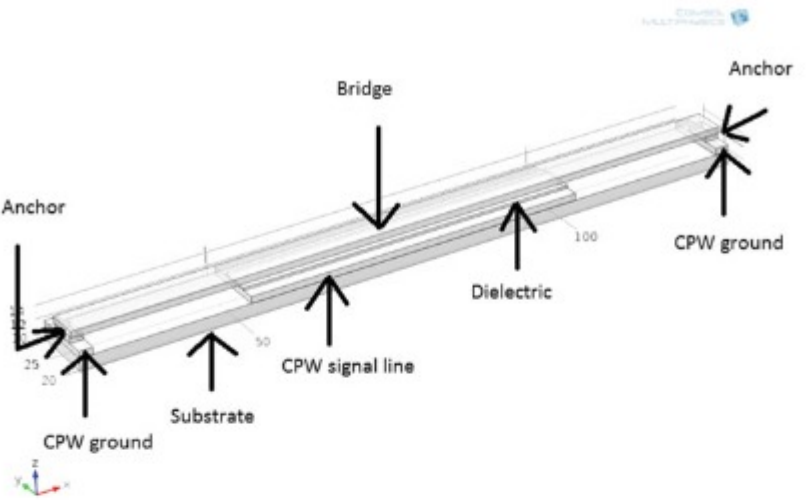

Fig. 1 Design of the MEMS switch

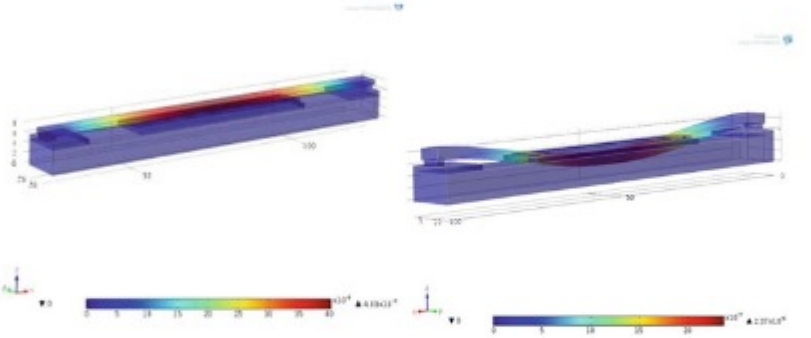

Fig. 2 Switch in upstate position and downstate position (FEM simulation using COMSOL)

2.1 Working Principle of the Designed Switch

When the switch is in upstate position, no electrostatic actuation is applied and the RF signal can transmit through the CPW transmission line. When an electrostatic voltage (actuation voltage) is applied, it creates electrostatic force to bend the beam in downstate. When the switch is biased with a voltage, the beam will bend down toward the substrate and keep in touch with dielectric, and then the RF signal will be connected to the beam and it will be transmitted to the ground lines in downstate position. In Fig. 2, the simulated graph for both the position can be seen. The equation for the actuation voltage can be given as [8]

$$V_p = \sqrt{\frac{8\ kg^3}{27\varepsilon_0\varepsilon_r Ww}} \tag{1}$$

where g is the air gap, k is the spring constant of the fixed–fixed beam, W is the beam width, w is the width of CPW signal line, and ε_0, ε_r are the permittivity of free space and dielectric, respectively.

2.2 *RF Parameters' Analysis*

The S parameters of CPW transmission line characteristics can be employed to do the performance analysis of the switch. In the upstate position, S_{11} parameter gives the return loss of the switch while S_{21} parameter decides the insertion loss [7, 12, 13]. In the downstate position, S_{21} gives the isolation of the switch. The S_{11} and S_{21} are calculated by using the following expressions [10]

$$S_{11} = \frac{j\omega CZ_0}{2 + \omega CZ_0} \tag{2}$$

$$S_{21} = \frac{2}{2 + \omega CZ_0} \tag{3}$$

The CPW characteristic impedance Z_0 is taken as 65.64 Ω, calculated by coplanar waveguide calculator [21]. The resonant frequency is 61.5 GHz calculated using the formula $\omega = \sqrt{\frac{K}{m}}$, where K is the spring constant and m is mass of the beam. The return loss, isolation, and insertion loss can be calculated in dB value by taking log 10 of S_{11} and S_{21} and multiplying by 20.

3 Result and Discussions

The MEMS shunt type of switch was designed considering the specification provided in Table 1. The switch was actuated by applying pull-in voltage and the study was done specifically for radio-frequency analysis such as insertion loss, isolation loss, and return loss. Figure 3 depicts the effect of up capacitance on insertion loss, and the insertion loss decreases as the formed-up capacitance increases. So, it is desirable to have high up capacitance for low value of insertion loss, and at the same time, Cu value should be less (for High Cd/Cu value), so trade-off should be there for a better performance.

Figure 4 shows the dependency of switch insertion loss on frequency, and it can be concluded that the insertion loss is low at higher frequency for the designed switch which is very much desirable for high-frequency application. Figure 5 shows the effect of beam width on insertion loss, and the switch was designed by considering

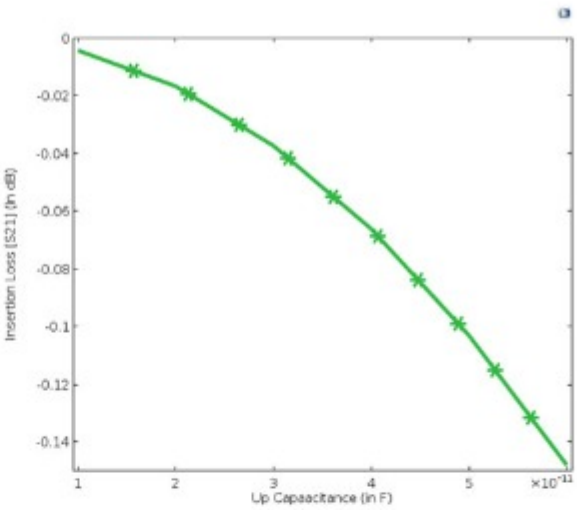

Fig. 3 Insertion loss as function of up capacitance

beam width as 5 and 7 μm. For high-frequency operation, switch designed with 5 μm is desirable compared to that of 7 μm. It also concludes that the trade-off between frequency of operation and insertion loss required. Figure 6 shows that the isolation loss is having a higher value for very low value of down capacitance (Cd). It is highly desirable to have a lower value of isolation loss (Cd should be high) since it assures that switch does not allow any signal in OFF state. Figure 7 depicts the isolation curve versus frequency, and the switch provides good isolation for the frequency range of 70–100 GHz with minimum loss and at frequencies lower than this range downgrades the isolation property of the switch. In Fig. 8, the effect of beam width on isolation can be seen. For better isolation, the switch should be optimized with shorter beam length.

Figure 9 shows the effect of up capacitance on return loss of the designed switch. The return loss should ideally be as minimum as possible. It can be concluded that the return loss increases as the up capacitance increases and since up capacitance is required to have a lower value for high Cd/Cu ratio. The trade-off is required to be done between return loss and up capacitance. The effect of frequency and beam width has also been shown in Fig. 10 and Fig. 11, respectively. They show a better performance for high frequency and smaller beam width.

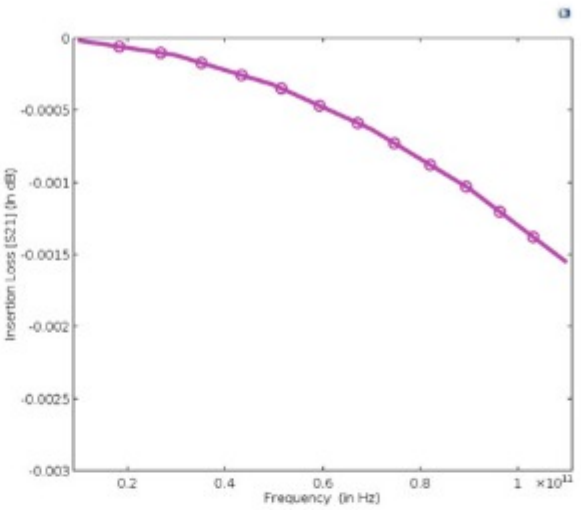

Fig. 4 Insertion loss as function of frequency

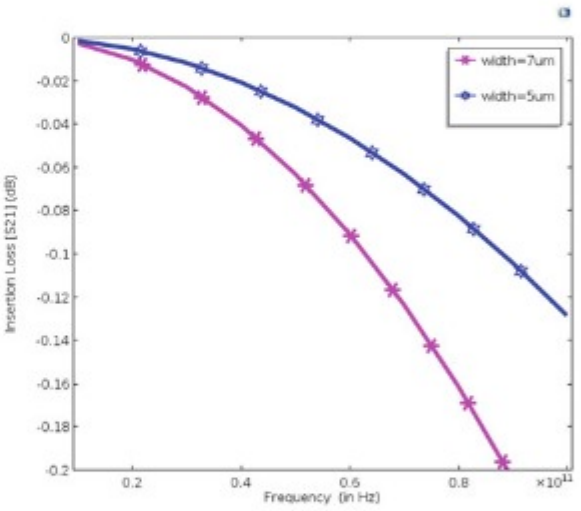

Fig. 5 Insertion loss as function of frequency at different beam widths

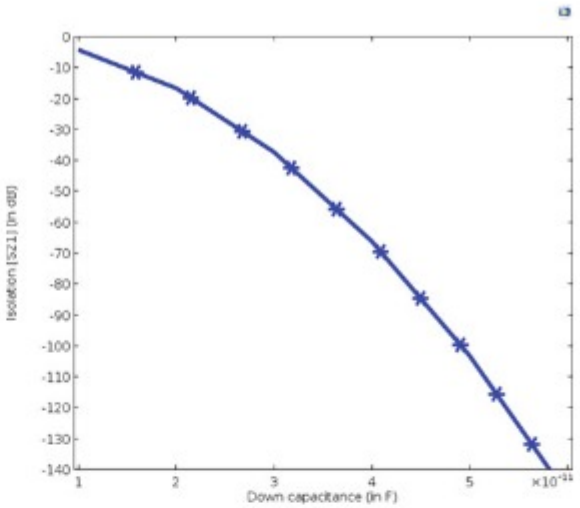

Fig. 6 Isolation as function of down capacitance

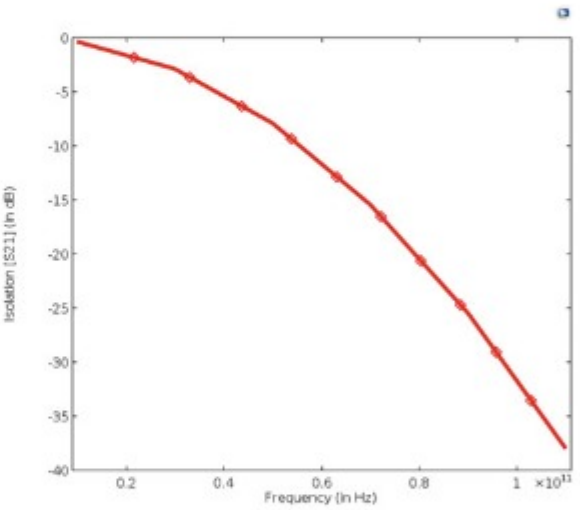

Fig. 7 Isolation as function of frequency

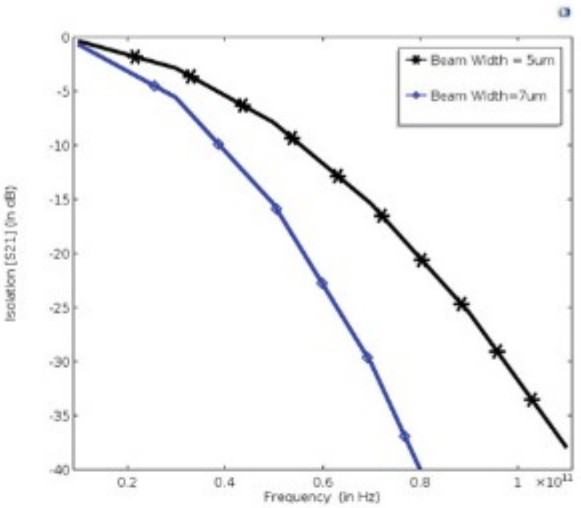

Fig. 8 Isolation as function of frequency at different beam widths

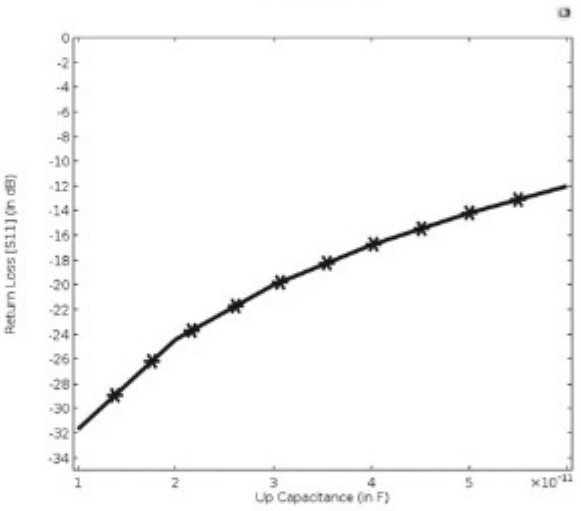

Fig. 9 Return loss as function of up capacitance

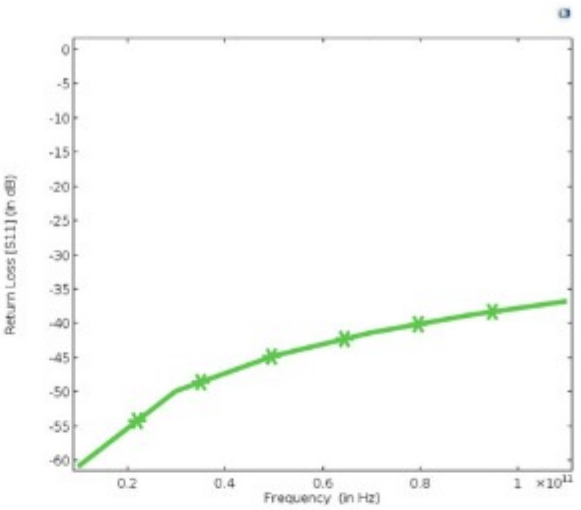

Fig. 10 Return loss as function of frequency

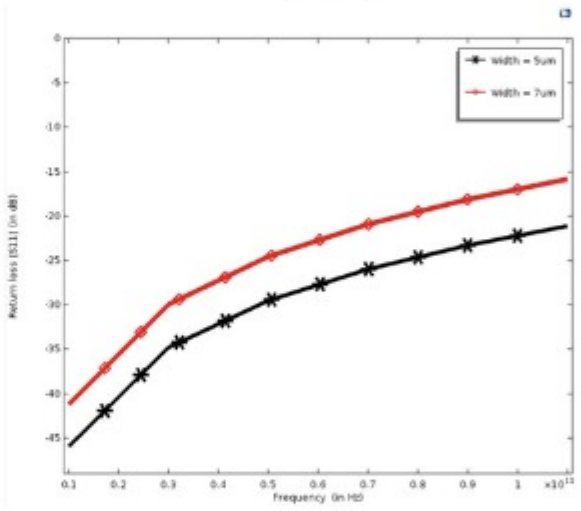

Fig. 11 Return loss as function of frequency at different beam widths

Table 2 Comparison of RF performance achieved by different MEMS switches

Authors	Used dielectric materials	Insertion loss	Isolation loss	Return loss	Pull-in voltage
Muhua Li et al. (2017) [22]	Si_3N_4	0.29 dB at 35 GHz	20.5 dB at 35 GHz	–	18.3 V
Guha et al. (2016) [23]	Si_3N_4 Hfo_2	−0.4 dB at 20 GHz	80 dB at 20 GHz	–	2.45 V 2.7 V
Our work	Si_3N_4	−0.05 dB at 62 GHz	−12 dB at 62 GHz	−45 dB at 62 GHz	10.5 V

4 Conclusion

In this paper, a MEMS switch was designed and study for high frequency was carried out. When the switch is supplied with actuation voltage of 10.5 V, then the S parameters can be plotted for different parameters such as frequency, beam width, and capacitance. It can be observed that isolation of switch in the downstate position of bridge decreases for increasing frequency sweep. It is also observed that as the frequency increases, insertion loss of the switch decreases. Insertion loss varies from −0.02 to −0.13 dB for a frequency sweep from 10 to 100 GHz. Comparison of RF performances for different designed switches is shown in Table 2. Proposed switch shows acceptable value of insertion, isolation, and return loss and operating frequency greater compared to other designed switches.

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DISTRIBUTION OF WETLANDS IN INDIA AND ECONOMIC VALUATION OF LESSER KNOWN WETLANDS IN EASTERN HIMALAYAS

Understanding The Nature

FAMES LINGGI | AMITAVA MITRA

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Wetlands are one of the most threatened ecosystems in the world. Whether they are mangroves, paddy fields or lakes, they are disappearing or are getting degraded due to urbanization, industrial and agricultural activities and other formal and informal encroachments from various economic agents. Wetland ecosystems provide innumerable tangible and intangible benefits to the economy but their contribution is ignored due to their public good/common property nature and as a result they are depleting and degrading overtime. With this background, this book reports on the distribution of wetlands in various states of the country. An attempt is also made to conduct the economic evaluation of a few wetlands in Eastern Himalayas.

This book will be relevant to the policy making in the Ministry of Environment and Forest, Tourism, DoNER etc. This book is also a valuable source of information for the environmentalists, environmental economists, environmental scientists and researchers.

Dr. Fames Linggi is currently working as Assistant Professor of Economics at Indira Gandhi Government College, Tezu. He has done his post graduation and Ph.D. from Rajiv Gandhi University, Rono Hills. He is currently associated with the research on environmental economics and household industry.

Prof. Amitava Mitra is currently a senior professor in the Department of Economics, Rajiv Gandhi University (Central), Itanagar. He has done his post graduation from the Centre of Economics Studies and Planning (CESP), Jawaharlal Nehru University, New Delhi and was awarded a Ph.D from Dibrugarh University, Assam. He has been associated with teaching and research, and has been a top level administrator at Rajiv Gandhi University for last thirty six years. He was also a Fulbright Fellow in Academic Administration in 2014. He has authored several books and a large number of research papers in reputed national and international journals in areas of environmental economics, policy, and development economics.

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Aditi Nath
Kamei Beeju
Ankur Saxena

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CHAPTER 1

Culture as a Factor in Spreading HIV/ AIDS

Mohammad Asghar

Introduction

Acquired Immune Deficiency Syndrome (AIDS), a condition caused by Human Immune-deficiency Virus (HIV), is one of the most notorious and multi-faceted disaster ever known to human history. It is much more than a medical problem. According to UNAIDS report (2016), in 2014, an estimated 36.9 million people were living with HIV (including 2.6 million children). Of this, roughly 2 million (including about 220,000 children) were newly infected. Many scientists have rightly assumed that there is an inextricable web of association between culture and HIV/ AIDS since the disease was first discovered in 1981. Apart from inadvertent modes of transmission like vertical transmission from mother to child, certain human behavior puts individuals at an increased risk for HIV/ AIDS. The present course of the epidemic is unlikely to change until and unless we adopt preventive measures by changing our behavior, as we neither have the means to cure it nor any vaccine to prevent it. Controlling of AIDS epidemic thus depends on the effective change in behavior and lifestyle to break the chain of transmission. However, this is more challenging because human behavior is shaped and influenced by the culture to where they belong. In recent years, increasing attention is being paid to understand these complex social and cultural variables that influences the risky behaviors related to HIV infection transmission.

Culture, in simple word means the traditions and customs held by a society or community based on their belief and value systems. Culture is the learned, shared and transmitted values, beliefs, norms and life ways carried by groups of people which guides their decisions, thinking and actions in patterned ways. Each member of this society is bound by their culture which might differ from one-another.

Seeking to influence cultural norms and practices to reduce people's risk of HIV will inevitably result in some kind of cultural adaptation. But it is not impossible to change a culture in a short time frame. Culture is a complex whole where each culture trait exists in a tangled web of relationships. It is because of this that a deep understanding of culture is required to understand a disease which is basically linked to human behavior in its causation, transmission and prevention. Any intervention policy to control an epidemic disease needs a proper understanding of each associated cultural trait. This chapter will discuss some of the social and cultural factors associated with the transmission of HIV/ AIDS. Besides the discussion on how cultural practice have lead to the emergence of AIDS as a human disease and how a once simian virus (SIV) became a human virus (HIV), this chapter will also discuss various cultural practice like cleansing rituals, sexual behaviors, wife inheritance, circumcision, etc. that have influenced

The book entitled "MHD Heat / Mass Transport in Fluid Flow" is the result of many years of facilitating, researching, and teaching in the field of Computational Fluid Dynamics. This book places a clear emphasis on the applications of various effects of thermophoresis in flow models based on rigorous and current research. To describe and explain the research methodology concepts on various flow model, this book uses realistic examples to help students get inside what research work is really like. In addition to examples, we have provided mathematical concepts of flow models so that students can learn the way of solving techniques uniquely. Different types of flow models will help students / scholars to distinguish between analytical and numerical solutions in practices, as well as help them to identify the practices they wish to adopt to improve their knowledge.

Dr. Nava Jyoti Hazarika is an Assistant Professor, THB College, Assam, India has 6 research papers. Dr. Sahin Ahmed is a Professor of Mathematics, Rajiv Gandhi University, Itanagar, India and published 100 papers & produced 6 PhD & 10 MPhil scholars & wrote 3 books. Their research domain: computer oriented MHD heat & mass transport in fluid flow.

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Dedicated

to

all the wonderful people of Computational Fluid Mechanics and hoping for desired aesthetic perfection in coming future by this work .....

And

Our beloved parents .....

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The beauty of Mathematics only shows itself to more patient followers .....

Maryam Mirzakhani

About the Book

The book entitled **"Applications of MHD Heat / Mass Transport in Porous Media"** is the result of many years of facilitating, researching, and teaching in the field of Computational Fluid Dynamics. This book places a clear emphasis on the applications of various effects of thermophoresis in flow models based on rigorous and current research.

To describe and explain the research methodology concepts on various flow model, this book uses realistic examples to help students get inside what research work is really like. In addition to examples, we have provided mathematical concepts of flow models so that students can learn the way of solving techniques uniquely. Different types of flow models will help students / scholars to distinguish between analytical and numerical solutions in practices, as well as help them to identify the practices they wish to adopt to improve their knowledge.

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Preface

Fluid Mechanics (FM) is an exciting and fascinating subject with unlimited practical applications ranging from microscopic biological systems to automobiles, airplanes, and spacecraft propulsion. Yet Fluid Mechanics has historically been one of the most challenging subjects for higher studies. Fluid Mechanics is a mature subject; the basic equations and approximations are well established and can be found in numerous introductory Fluid Mechanics books.

The objects of this books are:

- Understand the basic concepts of fluid mechanics and discuss the various types of fluid flow problems which are encountered in practice;
- Due attention has given towards setting up of physically realizable flow configurations and hence emphasis has been given to the form of non-dimensional substitutions, values of physical parameters and the initial and boundary conditions of flow problems under consideration;
- Concept of various solution techniques in different flow models;
- Model engineering problems and solve them in a systematic manner;
- Have a working knowledge of accuracy of the flow models and recognize the importance mathematical importance.

This book is organized into 10 chapters with fundamental concepts with fluid and fluid flows ending with bibliography.

- **Chapter – I** provide a basic introduction to principles and fundamental concepts of fluid mechanics associated with boundary layer theory and heat– mass transport. This introductory chapter also deals with brief review of the literature of the works carried out in the fields of fluid dynamics and problem solving techniques.
- **Chapter – II** is devoted for analytical solutions for unsteady Magnetohydrodynamic (MHD) flow for a rotating vertical porous plate immersed in a Darcian porous Regime in presence of a uniform transverse magnetic field with the first order homogeneous chemical

reaction. The effects of porosity of the medium, chemical reaction and magnetic body force are discussed through graphs.

- **Chapter – III** deals with the transient hydromagnetic flow over a semi-infinite vertical permeable moving plate embedded in a Darcian Porous medium subject to time-dependent wall suction in presence of heat generation/absorption with thermal and concentration buoyancy effects. The plate is assumed to move with a constant velocity in the direction of fluid flow while the free stream velocity is assumed to follow the exponentially increasing small perturbation law. The dimensionless governing equations for this investigation are solved analytically using two-term *Harmonic* and *Non-Harmonic* functions.
- **Chapter – IV** introduces the flow model on unsteady MHD flow of two-dimensional, laminar, incompressible, Newtonian, electrically-conducting and radiating fluid along a semi-infinite vertical permeable moving plate with periodic heat and mass transport by taking into account the effect of viscous dissipation. The plate moves with a constant velocity in the direction of the fluid flow while the free stream velocity follows an exponentially increasing small perturbation law subject to a constant suction velocity to the plate. Analytical solutions are obtained for velocity, temperature and concentration profiles within the boundary layer.
- **Chapter – V** investigated a three dimensional channel flow problem for a chemically, radiating and electrically conducting fluid in presence of external magnetic field and slip flow regime. In the channel, the stationary plate is subjected to a transverse sinusoidal injection velocity while the uniformly moving plate is subjected to a constant suction velocity and slip boundary conditions. Due to this type of injection velocity, the flow becomes three-dimensional. The acquired knowledge in this study can be used in the fields of chemical engineering for filtration and purification processes, in petroleum technology to study the movement of natural gas and oil.
- **Chapter – VI** covers the study of analytical solution for unsteady, hydromagnetic flow of a viscous incompressible, electrically conducting fluid over a vertical surface immersed in a Darcian porous regime with the effects of viscous dissipation and heat source / generation in presence of thermal radiation and first order chemical

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reaction. The Rosseland diffusion flux approximation is employed to simulate radiative heat transfer contribution. The study of convection fluid in presence of magnetic field and internal heat generation / absorption are useful application in different branches of Science and Technology such as geophysical science, cosmic science, fire engineering etc.

- **Chapter – VII** extends the analysis of analytical solutions for MHD boundary layer flow over a semi-infinite vertical porous plate in presence of Thermal Diffusion (Soret), Chemical reaction of first order under oscillatory suction and heat absorption. In the present flow model, the results would be useful in many practical areas related to the diffusion operations which involved molecular diffusion of species with chemical reaction.
- **Chapter – VIII** applies Laplace Transform Technique (LTT) for exact solution on *Ramped wall Temperature* (RWT) in free convection hydromagnetic flow past an impulsively started vertical infinite porous plate in a rotating conducting fluid filled with a saturated porous medium. The effects of the Ekman number, porosity and the Hall current on the flow characteristics are discussed. Both the primary and secondary velocities are escalated by the effects of Hall current. We feel that such a model is of importance in aero-dynamic cooling.
- **Chapter – IX** discusses the exact solution by Laplace Transform Technique for unsteady gravity-driven thermal convection flow of a viscous incompressible, electrically-conducting, absorbing-emitting, optically-thick gray gas along an inclined plane in saturated porous medium. The Rosseland diffusion flux model is employed to simulate thermal radiation effects. Velocity gradients at the plate are found to be enhanced with progression of porosity and with greater inclination of the plate. Applications of the model arise in high temperature materials operations exploiting magnetic fields and MHD (Magneto-Hydro-Dynamic) energy generators.
- **Chapter – X** reinforces the concept of an implicit finite difference scheme by Crank – Nicolson type for transient magnetohydrodynamic viscous dissipative flow of an electrically conducting fluid over an impulsively-started semi-infinite vertical plate adjacent to saturated porous medium in the presence of appreciable thermal radiation heat

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transfer and chemical reaction of first order. The fluid is assumed optically thin gray gas, absorbing-emitting radiation, but a non-scattering medium. A parametric study illustrating the effects of various physical parameters on the fluid velocity, temperature and concentration fields as well as skin-friction coefficient, the Nusselt and Sherwood numbers is conducted. Increasing Eckert number serves to accelerate the flow velocity, temperature, rate of heat and mass transfer. Such a study is found useful in magnetic control in the steel industry, liquid metal cooling in nuclear reactors, magnetic suppression of molten semi-conducting materials and meteorology.

Possible Applications:

It is expected that the present research work will have significant effect on medical sciences, environmental problems, industrial problems, missile technology, aeronautical engineering, petroleum engineering, agriculture engineering and many technological fields and for the generation of energy and it will attract many research workers to study in our field and the scholars may be benefited from this research.

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Dr. Nava Jyoti Hazarika
Prof. Sahin Ahmed

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NOMENCLATURE

A	Suction velocity parameter
B_0	Magnetic Induction
C	Dimensionless molar species concentration
$\overline{C}$	Molar species concentration in the boundary layer
$\overline{C}_0$	Molar species concentration at the stationary plate
$\overline{C}_1$	Molar species concentration at the plate in uniform motion
$\overline{C}_e$	Equilibrium molar species concentration of the fluid
$\overline{C}_r$	Chemical reaction
$\overline{C}_\infty$	Molar species concentration at the free stream
C_p	Specific heat at constant pressure
$\overline{C}_w$	Molar species concentration at the wall
C_f	Skin-friction
D	distance between the plates
D	The coefficient of chemical molecular diffusivity
D_m	Molecular diffusivity
D_T	Co-efficient of thermal diffusivity
Ec	Eckert number
G	Acceleration due to gravity
Gr	Grashof number for heat transfer

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Gm	Grashof number for mass transfer
Gc	Grashof number for mass transfer
H	Slip parameter
$\overline{K}$	Permeability of porous medium
K	Permeability parameter
$\overline{K}_1$	Permeability of porous medium
K_1	Permeability parameter
K^2	Rotation or Ekman number
K_0	Porosity Parameter
K_r	Chemical reaction parameter
M	Magnetic Body force or Hartmann number
M^2	Magnetic parameter
M	Wall thermal ratio
M	Hall current parameter
N	Wall mass ratio
N	Dimensionless exponential index
N	Dimensionless field parameter
Nu	Nusselt number
P	Pressure
Pr	Prandtl number
$\overline{q}$	Velocity vector of the fluid at $(\overline{x}, \overline{y}, \overline{z})$
$\overline{q}_r$	Radiative heat flux
q_r	Radiation parameter

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Q	Rate of heat absorption parameter
Q_0	Heat absorption coefficient
R	Rotational parameter
R	Thermal radiation
R_a	Thermal radiation parameter
Re	Reynolds number
Sc	Schmidt number
S_0	Soret number
Sh	Sherwood number
$\overline{t}$	Time
$\overline{T}$	Temperature of the fluid in the boundary layer
$\overline{T}_w$	Temperature of the fluid at the wall
$\overline{T}_\infty$	Temperature at the free stream
$\overline{T}_0$	Temperature at the stationary plate
$\overline{T}_1$	Temperature at the plate in uniform motion
$\overline{T}_e$	Equilibrium temperature of the fluid
$\overline{u}$	Components of velocity in $\overline{x}$ direction
$\overline{v}$	Components of velocity in $\overline{y}$ direction
$\overline{w}$	Components of velocity along $\overline{z}$ direction
$\overline{u}_p$	Dimensional plate velocity
$\overline{U}_\infty$	Dimensional free stream velocity
U	Uniform motion of the outer plane

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U_0 Scale of free stream velocity

U_p Dimensionless plate velocity

U_∞ Dimensionless free stream velocity

v_0 Injection velocity of the stationary plate

V_0 Scale of suction velocity

$\overline{x}$ Dimensional distances along the plate

$\overline{y}$ Dimensional distances perpendicular to the plate

$\overline{z}$ Dimensional distances normal to the plate

Greek Symbols

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α Fluid thermal diffusivity

β_T Thermal expansion co-efficient

β_C Concentration expansion co-efficient

ρ Fluid density

μ Co-efficient of viscosity of the fluid

ν Fluid kinematic viscosity

σ Fluid electrical conductivity

ω Frequency of oscillation

θ Dimensionless fluid temperature

ϕ Dimensionless species concentration of the fluid

τ Shearing stress

Ω Angular velocity

κ	Thermal conductivity
ε	Scalar constant (<< 1)

Subscripts

P	Plate condition
W	The wall condition
0	Conditions at the stationary plate
1	Conditions at the uniform motion plate
∞	Free stream conditions

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Abbreviation

1. Fluid dynamics (FM)
2. Magnetohydrodynamic (MHD)
3. Magneto-fluid-dynamics (MFD)
4. Magneto-gas-dynamics (MGD)
5. Computational Fluid Dynamics (CFD)
6. Classical Perturbation Technique (CPT)
7. Laplace Transform Technique (LTT)
8. Crank–Nicolson Method (CNM)
9. Runge-Kutta Method (RKM)

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Chapter - I

Introduction

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1.1 About Fluid Mechanics :

Mechanics is the oldest physical science that deals with both stationary and moving bodies under the influences of forces. The branch of mechanics that deals with bodies at rest is called **statics**, while the branch that deals with bodies in motion is called **dynamics**. The subcategory **fluid mechanics** is defined as the science that deals with the behaviour of fluids at rest (**fluid statics**) or in motion (**fluid dynamics**). Dynamics is the study of motion of matter. It may be divided in two parts – dynamics of rigid bodies and dynamics of non-rigid bodies. Further dynamics of non-rigid bodies is divided into two general classifications – **elasticity** and **fluid dynamics**. ***Fluid dynamics is that branch of science which deals with the study of the motion of fluids or that of bodies in contact with fluids***. Fluid dynamics itself is also divided into several categories. The study of the motion of fluids that are practically incompressible (such as liquids, specially water and gases at low speeds) is usually referred to as **hydrodynamics**. A subcategory of hydrodynamics is **hydraulics**, which deals with liquid flows in pipes and open channels. **Gas dynamics** deals with the flow of fluids that undergo significant density changes, such as the flow of gases through nozzles at high speeds. The category **aerodynamics** deals with the flow of gases (especially air) over bodies such as aircraft, rockets, and automobiles at high or low speeds. Some other specialized categories such as **metrology**, **oceanography** and **hydrology** deal with naturally occurring flows.

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It is well known that the matter is made up of molecules or atoms which are always in a state of random motion. In fluid dynamics, fluids are assumed to obey the ***"Continuum hypothesis"***. Fluids are composed of molecules that collide with one another and solid objects. However, the continuum hypothesis considers fluids to be continuously distributed in a given space, rather than discrete. Consequently, properties such as density, pressure and temperature and flow velocity are taken to be well defined at infinitesimally small points and are assumed to vary continuously from one point to another.

(a) Applications in Fluids Mechanics

Fluid mechanics is widely used both in everyday activities and in the design of modern engineering systems from vacuum cleaners to supersonic aircraft. Therefore, it is important to develop a good understanding of the basic principles of fluid mechanics. To begin with, fluid mechanics plays a vital role in the human body. The heart is constantly pumping blood to all parts of the human body through the arteries and veins and lungs are the sites of airflow in alternating directions. Needless to say, all artificial hearts, breathing machines and dialysis systems are designed using fluid dynamics.

An ordinary house is in some respects, an exhibition hall filled with applications of fluid mechanics. The piping systems for cold water, natural gas and sewage for an individual house and the entire city are designed primarily on the basis of fluid mechanics. The same is also true for the piping and ducting network of heating and air-conditioning systems. A refrigerator involves tubes through which the refrigerant flows, a compressor that pressurizes the refrigerant and two heat exchangers where the refrigerant absorbs and rejects heat. Fluid mechanics plays a major role in the design of all these components. Even the operation of ordinary faucets is based on fluid mechanics.

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We can also see numerous applications of fluid mechanics in an automobile. All components associated with the transportation of the fuel from fuel tank to the cylinders – the fuel line, fuel pump, fuel injectors or carburetors – as well as the mixing of the fuel and the air in the cylinders and the purging of combustion gases in exhaust pipes are analyzed using fluid mechanics. Fluid mechanics is also used in the design of the heating and air-conditioning system, the hydraulic brakes, the power steering, automatic transmission and lubrication systems, the cooling system of the engine block including the radiator and the water pump and even the tires. The sleek streamlined shape of recent model cars is the result of efforts to minimize drag by using extensive analysis of flow over surfaces.

On the broader scale, fluid mechanics plays a major part in the design and analysis of aircraft, boats, submarines, rockets, jet engines, wind turbines, bio-medical devices, the cooling of electronic components and the

transmission of water, crude oil and natural gas. It is also considered in the design of buildings, bridges and even billboards to make sure that the structures can withstand wind loading. Numerous natural phenomena such as the rain cycle, weather patterns, and the rise of ground water to the top of trees, winds, ocean waves and currents in large water bodies are also governed by the principles of fluid mechanics.

(b) A brief History of Fluid Mechanics

One of the first engineering problems humankind faced as cities were developed was the supply of water for domestic use and irrigation of crops. Our urban lifestyles can be retained only with abundant water and it is clear from archeology that every successful civilization of prehistory invested in the construction and maintenance of water systems. The Roman aqueducts, some of which are still in use, are the best known examples. However, perhaps the most impressive engineering from a technical viewpoint was done at the Hellenistic city of Pergamon in present day Turkey. There, from 283 to 133 BC, they built a series of pressurized lead and clay pipelines, up to 45 km long that operated at pressures exceeding 1.7 MPa (180m of head). Unfortunately, the names of almost all these early builders are lost to history. The earliest recognized contribution to fluid mechanics theory was made by the Greek mathematician Archimedes (285 – 212 BC). He formulated and applied the **"buoyancy principle"** in history's first nondestructive test to determine the Gold contest of the crown of King Hiero I. The Romans built great aqueducts and educated many conquered people on the benefits of clean water, but overall had a poor understanding of fluids theory.

Up to the Renaissance, there was a steady improvement in the design of such flow systems as ships, canals and water conduits, but no recorded evidence of fundamental developments in flow analysis was discovered. The Leonardo Da Vinci (1452-1519) derived the equations of **Conservation of mass** in one-dimensional flow. Leonardo was an excellent experimentalist, and his notes contain accurate descriptions of waves, jets, hydraulic jumps, eddy formation, and both low-drags (streamlined) and high-drag (parachute) designs.

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During the Middle age the application of fluid machinery slowly but steadily expanded. Elegant piston pumps were developed for dewatering mines, the watermill and windmill were perfected to grind grain, forge metal and for other tasks. For the first time in recorded human history significant work was being done without the power of a muscle supplied by a person or animal and these inventions are generally credited with enabling the later industrial revolution. Again the creators of most of the progress are unknown, but the devices themselves were well documented by several technical writers such as Georgius Agricola, De Re Metalica, Basel, 1556.

The Renaissance brought continued development of fluid systems and machines, but more importantly, the scientific method was perfected and adopted throughout Europe. Simon Stevin (1548-1617), Galileo Galilei (1564-1642), Edme Mariotte (1620-1684) and Evangelista Torricelli (1608-1647) were among the first to apply the method to fluids as they investigated hydrostatic pressure distributions and vacuums. That work was integrated and refined by the brilliant mathematician, Blaise Pascal (1623-1662). Edme Mariotte (1620-1684) built the first wind tunnel. At the same time, Italian mathematician and physicist Evangelista Torricelli with the invention of the Barometer (1643) contributed in the development of the subject. He also formulated a law; known as Torricelli's law.

A new era in the history of fluid mechanics had started in 1687, when English mathematician and physicist Sir Isaac Newton (1642-1727) formulated the laws of motion and law of viscosity of linear fluids. Newton devoted his second book on **"Principia Mathematica"** exclusively for the study of fluid dynamics and fluid statics. That effort was built upon by the Swiss Daniel Bernoulli (1700-1782) and his associate Leonard Euler (1707-1783). Together, their work defined the **energy and momentum equations**. Bernoulli's 1738 classic treatise "***Hydrodynamics***" may be considered the first fluid mechanics text. Finally, Jean D' Alembert (1717-1789) developed the idea of velocity and acceleration components, a differential expression of continuity, and his "***Paradox***" of zero resistance to steady uniform motion.

The development of fluid mechanics theory up through the end of the Eighteenth century had little impact on engineering since fluid properties

and parameters were poorly quantified and most theories were abstractions that could not be quantified for design purposes. That was to change with the development of the French school of engineering led by Riche de Prony (1755-1839). Prony and his associates in Paris at the Ecole Polytechnic and the Ecole Ponts et Chaussees were the first to integrate calculus and scientific theory into the engineering curriculum, which became the model for the rest of the world. Antonie Chezy (1718-1798), Louis Navier (1785-1836), Gaspard Coriolis (1792-1843), Henry Darcy (1803-1858) and many other contributors to fluid engineering and theory were students and / or instructors at the schools.

By the mid nineteenth century fundamental advances were coming on several fronts. The physician Jean Poiseuille (1799-1869) had accurately measured flow in capillary tubes for multiple fluids, while in Germany Gotthilf Hagen (1797-1884) had differentiated between laminar and turbulent flow in pipes. In England, Lord Osborn Reynolds (1842-1912) published the classic pipe experiment in 1883 and developed the dimensionless **Reynolds number (*Re*)** that bears his name. Reynolds developed the concept of turbulent flows. He established that at higher velocities, fluid flow breaks up into a fluctuating velocity pattern known as the turbulent flow. With the help of Reynolds number he successfully characterizes to what degree a fluid flow is laminar or turbulent. Similarly, in parallel to the early work of Navier, George Stokes (1819-1903) completed the general equations of fluid motion with friction that are called ***Navier-Stokes Equations***. Almost 150 years later, the Navier-Stokes equations are still the fundamental equations used to analyze a viscous fluid flow. Moreover, they are the subject of many research and application in the field of computational fluid dynamics today.

The late nineteenth century was notable for the expansion of fluid theory by Irish and English scientists and engineers, including in addition to Reynolds and Stokes, William Thomson, Lord Kelvin (1824-1907), William Strutt, Lord Rayleigh (1842-1919) and Sir Horace Lamb (1849-1934). These individuals investigated a large number of problems including dimensional analysis, **irrotational flow**, **votex motion**, **cavitation** and **waves**. In a broader sense their work also explored the links between fluid mechanics, thermodynamics and heat transfer.

The dawn of the twentieth century brought two monumental developments. First in 1903, the self-taught Wright brothers (Wilbur, 1867-1912; Orville, 1871-1948) through application of theory and determined experimentation perfected the **airplane**. Their primitive invention was complete and contained all the major aspects of modern craft. The Navier-Stokes equations were of little use up to this time because they were too difficult to solve. In a pioneering paper in 1904, the Garman Ludwig Prandtl (1875-1953) showed that fluid flows can be divided into a layer near the walls, the ***boundary layer***, where the friction effects are significant and an outer layer where such effects are negligible and the simplified Euler and Bernoulli equations are applicable. His students, Theodore Von Karman (1881-1963), Paul Blasius (1883-1970), Johann Nikuradse (1894-1979) and others built on that theory in both **hydraulic** and **aerodynamic** applications.

The mid twentieth century could be considered a **"Golden age"** of fluid mechanics applications. Existing theories were adequate for the tasks at hand, fluid properties and parameters were well defined. These supported a huge expansion of the **aeronautical**, **chemical**, **industrial** and **water resources** sectors; each of which pushed fluid mechanics in new directions. Fluid mechanics research and work in the late twentieth century were dominated by the development of the digital computer in America. The ability to solve large complex problems, such as global climate modeling or to optimize the design of a **turbine blade** has provided a benefit to our society that the eighteenth-century developers of fluid mechanics could never have imagined.

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For most of the nineteenth and twentieth century there were two approaches to the study of fluid flow: one is theoretical and other is experimental. Many contributions to our understanding of fluid behavior were made through the year by these two methods. But today, because of the power of modern digital computers, there is yet a third way to study fluid dynamics: **Computational Fluid Dynamics (CFD)**. In this modern industrialization system CFD is used more and more for fluid flow analysis. The modern computer system costs have continued to decrease; CFD has becoming to the forefront in the various engineering analysis of fluid flow. The development of aeronautical, chemical and mechanical engineering during the past few decades and the exploration of space from 1960s

immensely increased the interest of fluid mechanics with tremendous application of CFD.

1.2 Definitions :

(a) Fluid

A substance exists in three primary phases: **Solid**, **Liquid** and **Gas**. At very high temperature, it also exists as **Plasma**. ***A substance in the liquid or gas phase is referred to as a fluid***. Distinction between a solid and a fluid is made on the basis of the substance's ability to resist an applied shear (or tangential) stress that tends to change its shape. A solid can resist an applied shear stress by deforming, whereas a fluid deforms continuously under the influence of shear stress, no matter how small. In solid shear stress is proportional to strain, but in fluids stress is proportional to strain rate when a constant shear force is applied, a solid eventually stops deforming, at some fixed strain angle, whereas a fluid never stops deforming and approaches a certain rate of strain.

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(b) Pressure

The force per unit area exerted by the fluid at each point of the surface of contact is defined as fluid pressure. Mathematically, the pressure 'p' at a point in the fluid is the limit of the ratio of normal force δF over an area δA by the surrounding fluid particles as the area approaches zero. It is defined as

$$p = \lim_{\delta A \to 0} \frac{\delta F}{\delta A} \tag{1.2.1}$$

(c) Density

The density of a fluid is defined as the mass per unit volume. If δm is the mass of the fluid in a small volume δv surrounding a given point, then the density 'ρ' of the fluid at that point is given by

$$\rho = \lim_{\delta v \to 0} \frac{\delta m}{\delta v} \tag{1.2.2}$$

(d) Temperature

If two bodies of different heat content are brought into contact while isolated from all other bodies, then some thermal energy will exchange between these two bodies. The body from where thermal energy moves is said to be at higher temperature, while the body into which the energy flows is said to be at lower temperature. When two bodies have in thermal equilibrium state then they are said to a common property, which is known as temperature. In fluid dynamics, the temperature is direct indication to have a Kinetic energy of the continuous random motion of the molecules.

(e) Specific Heat

The specific heat C of a fluid is defined as the amount of heat required to raise the temperature of a unit mass of the fluid by one degree. Thus specific heat (C) is defined by

$$C = \frac{\partial Q}{\partial T}, \tag{1.2.3}$$

where δQ is the amount of heat added to raise the temperature by δT. The value of the specific heat depends on two well-known processes – one is the constant volume process and other is the constant pressure process. These two are denoted and defined as –

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Specific heat at constant volume:

$$C_v = \left(\frac{\partial Q}{\partial T}\right)_v \tag{1.2.4}$$

Specific heat at constant pressure:

$$C_p = \left(\frac{\partial Q}{\partial T}\right)_p \tag{1.2.5}$$

Ratio of these two specific heats is denoted by γ.

Thus $\gamma = C_p/C_v$.

(f) Viscosity

When two fluid layers move relatively to each other, a friction force develops between them and the slower layer tries to slow down the faster layer. This internal resistance to flow is quantified by the fluid property **viscosity**. It is a measure of internal stickiness of the fluid. Viscosity is caused by cohesive forces between the molecules in liquids and by molecular collisions in gases. There is no fluid with zero viscosity, and thus all fluid flows involve viscous effects to some degree. For the property of viscosity the flow of water and air is much easier than the heavy oil.

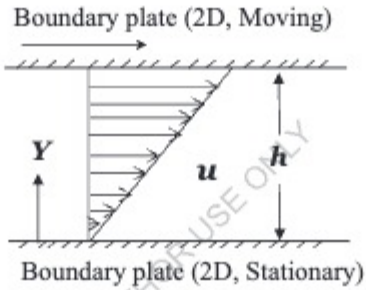

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Fig. 1.1: Velocity distribution of a viscous fluid between two parallel flat plates (Couette flow)

In general, in any flow, layers move at different velocities and the fluid's viscosity arises from the shear stress between the layers that ultimately oppose any applied force. The relationship between the shear stress and the velocity gradient can be obtained by considering two plates closely spaced at a distance y, and separated by a homogeneous substance. Assuming that the plates are very large, with a large area A, such that edge effects may be ignored, and that the lower plate is fixed, let a force F be applied to the upper plate. If this force causes the substance between the plates to undergo shear flow with a velocity gradient u/y (as opposed to just shearing elastically until the shear stress in the substance balances the applied force), the substance is called a fluid.

The applied force is proportional to the area and velocity gradient in the fluid:

$$F = \mu A \frac{u}{y} \tag{1.2.6}$$

This equation can be expressed in terms of shear stress as

$$\tau = \frac{F}{A} \tag{1.2.7}$$

Thus as expressed in differential form by Sir Isaac Newton (1713) for straight, parallel and uniform flow, the shear stress between layers is proportional to the velocity gradient in the direction perpendicular to the layers:

$$\tau = \mu \frac{\partial u}{\partial y}, \tag{1.2.8}$$

where τ is the tangential stress or shear stress, μ is the co-efficient of viscosity, $\frac{du}{dy}$ is the velocity gradient. Newton assumed the fluid to be confined in between two horizontal plates and the y – axis is perpendicular to the plates. The shear stress is maximum at the surface where the fluid is in contact with it, due to no slip condition. This equation is known as **Newton's law of Viscosity**.

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(g) Kinematic Viscosity

The ratio of co-efficient of viscosity μ to the mass density ρ of the fluid is known as the co-efficient of viscosity or simply kinematic viscosity and it is represented by

$$\upsilon = \frac{\mu}{\rho} \tag{1.2.9}$$

1.3 Different Types of Fluid :

(a) Viscous (or Real) and Inviscid (or Ideal) Fluid

An infinitesimal fluid element is acted upon by two types of forces, namely body forces and surface forces. The body force which is proportional to the mass of the body on which it acts and the surface force acts on a surface element and is proportional to the surface area. The surface may be resolved into two components, one normal and the other tangential to the area. The normal force per unit area is said to be the normal stress or pressure while the tangential force per unit area is said to be the shearing stress.

A fluid is said to be **viscous (or real)** when normal as well as shearing stresses exist. On the other hand, a fluid is said to be **inviscid (or ideal)** when it does not exert any shearing stress, whether at rest or in motion. Clearly the pressure exerted by an inviscid fluid on any surface is always along the normal to the surface at that point. Due to shearing stress a viscous fluid produces resistance to the body moving through it as well as between the particles of the fluid itself. Syrup, heavy oil, coal tar, paint etc. example of viscous fluids whereas water and air are treated as inviscid fluids.

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(b) Incompressible and compressible Fluids

A fluid is said to be classified as being compressible or incompressible, depending on the level of variation of density during flow. Incompressibility is an approximation, and a fluid is said to be incompressible if a large variation of pressure is requiring to produce some appreciable change in its density. Therefore, the volume of every portion of fluid remains unchanged over the course of its motion when the fluid is incompressible. On the other hand, a compressible fluid is one whose density changes readily with temperature and pressure for example gases.

Liquids, on the other hand, are rather difficult to compress and for most problems we can treat them incompressible. The study of incompressible flows may be used to explain many realistic situations like the flight of an airplane, various types of channel flows etc.

(c) Newtonian and Non-Newtonian Fluids

Fluids that obey Newton's law of viscosity are called Newtonian fluids whereas fluids which do not obey Newton's law of viscosity are called Non-Newtonian fluids. In other word, a fluid is said to be Newtonian if its viscosity not change with the rate of deformation and in the case of Non-Newtonian fluid the viscosity varies with the rate of deformation.

The equation $\tau = \mu \frac{du}{dy}$ is similar to the equation $y = mx$, where $y = \tau$, $m = \mu$ and $x = \frac{du}{dy}$. Hence Newtonian fluid represents a straight line. But in case of Non-Newtonian fluid all the terms represent variable, so Non-Newtonian fluid represent a curve.

(d) Laminar and Turbulent Flow

Some flows are smooth and orderly while others are rather chaotic. The highly ordered fluid motion characterized by smooth layers of fluid is called laminar. Laminar flow, sometimes known as streamline flow, occurs when a fluid flows in parallel layers, with no disruption between the layers. At low velocities the fluid tends to flow without lateral mixing, and adjacent layers' slide past one another like playing cards. There are no cross currents perpendiculars to the direction of flow. The word laminar comes from the movement of adjacent fluid particles together in **'laminates'**. In laminar flow the motion of the particles of fluid is very orderly with all particles moving in straight lines parallel to the pipe walls. In fluid dynamics, laminar flow is a flow regime characterized by high momentum diffusion and low momentum convection. The flow of high viscosity fluids such as oils at low velocities is typically laminar.

On the other hand, turbulent flow is opposite of laminar flow which occurs at high velocities. The high discovered fluid motion that typically occurs at high velocities and is characterized by velocity fluctuations is called turbulent. The flow of low-viscosity fluids such as air at high velocities is typically turbulent. In nonscientific terms laminar flow is "smooth", while turbulent flow is "rough."

(e) Steady and Unsteady Flow

A flow, in which properties and conditions associated with the motion of the fluid are independent of the time so that the flow pattern remains unchanged with the time is said to be steady. Mathematically, for a steady flow, $\frac{\partial P}{\partial t} = 0$, P may represent as velocity, temperature, pressure etc. On the other hand, a flow in which properties and conditions associated with the motion of the fluid depend on the time so that the flow pattern varies with time is said to be unsteady.

The term periodic refers to the kind of unsteady flow in which the flow oscillates about a steady mean. Unsteady flows are especially important in technological applications like nuclear reactors, metallurgy, turbo machinery, chemical processes industries, and aerospace technology. Many devices such as turbines, compressor, boilers, condensers and heat exchangers operate for long periods of time under the same conditions, and they are classified as steady-flow devices. During steady flow, the fluid properties can change from to point within a device, but at any fixed point they remain constant.

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(f) Rotational and Irrotational Flow

A flow, in which the fluid particles go on rotation about their own axes, while flowing, is said to be rotational. On the other hand, a flow in which the fluid particles do not rotate about their own axes, while flowing, is said to irrotational.

1.4 Boundary Layer Theory :

During the week of 8th August 1904, a small group of Mathematician and Scientists gathered in Heidelberg, Germany. Germany's oldest university, which was founded in 1386, Heidelberg was a natural venue for the third International Mathematics Congress. One of the presenters at the congress was Ludwig Prandtl, a 29 years old professor at the US technical university in Hanover. Prandtl's presentation was only 10 minutes long, but that was all the time needed to describe a new concept that would revolutionize the understanding and analysis of fluid dynamics. His presentation, and the

subsequent paper that was published in the congress's proceedings in1905, introduced the concept of the boundary layer in a fluid flow over a surface.

(a) The Boundary Layer Concept

The Prandtl's paper entitled **"On the motion of fluids with very little friction"** was only eight pages long, but it would prove to be one of the most important fluid dynamics papers ever written. This paper gave the first description of boundary layer concept. He theorized that an effect of friction was to cause the fluid immediately adjacent to the surface to stick to the surface – in other words, he assumed the no-slip condition at the surface and that frictional effect were experienced only in a boundary layer, a thin region near the surface. Outside the boundary layer, the flow was essentially the inviscid flow that had been studied for the previous two centuries.

Another marked result according to Prandtl is flow separation. In the boundary layer the decelerated fluid particles, in all the cases do not remain in the thin layer which adheres to the body along the whole wetted length of the wall. In some cases, the boundary layer increases its thickness considerably in the downstream direction and the flow in the boundary layer becomes reversed, this causes the decelerated fluid particle to be forced outwards, which means that the boundary layer is separated from the wall. This phenomenon is known as boundary layer separation. The pressure distribution over the surface of the body is radically changed once the flow separation. The altered distribution creates a pressure drag due to flow separation, that is, a large unbalanced force that acts in the direction of the free-stream flow. When the flow separation is extensive that is, when the separation flow region is large, the pressure drag is usually much larger than the skin-friction drag.

Prandtl showed that for the boundary layer, the Navier-Stokes equations can be reduced to a simple form. The Navier-Stokes equations have elliptic behaviour. The complete flow field must be solved simultaneously, in accord with specific boundary conditions defined along the entire boundary of the flow. In contrast, the boundary-layer equations have parabolic behaviour, which affords tremendous analytical and computational simplification. They can be solved step-by-step by marching

downstream from where the flow encounters a body, subject to specified inflow conditions at the encounter and specified boundary conditions at the outer edge of the boundary layer. The systematic calculation yields the flow variables in the boundary layer, including the velocity gradient at the wall surface. The shear stress at the wall, hence the skin-friction drag on the surface, is obtained directly from those velocity gradients.

(b) Velocity Boundary layer

To understand the boundary layer concept, we consider flow over the flat plate as shown in Fig. 1.2. As the fluid particles make contact with the surface, they assume zero velocity. These particles then act to retard the motion of the particles in the adjoining layer, which act to retard the motion of the particles in the next layer, and so on until, at a distance $y = \delta$ from the surface, the effect becomes negligible. This retardation of fluid motion is associated with shear stress τ acting in planes that are parallel to the fluid velocity. With increasing distance y from the surface, the x-component of the fluid velocity u, must then increase until it approaches the free stream velocity u_∞.

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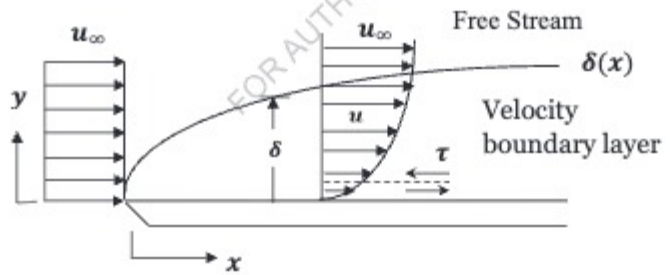

Fig. 1.2: Velocity boundary layer development on a flat plate

The quantity δ is termed the boundary layer thickness, and it is typically defined as the value of y for which $u = 0.99\,u_\infty$. The boundary layer velocity profile refers to the manner in which u varies with y through the boundary layer. Accordingly, the fluid flow is characterized by two distinct regions, a thin fluid layer called boundary layer in which velocity gradients and shrear stresses are large and a region outside the boundary layer in which

velocity gradient and shear stresses are negligible. With increasing distance from the leading edge, the effects of viscosity penetrate further into the free stream and the boundary layer grows (δ-increases with x).

As it pertains to the fluid velocity, the foregoing boundary layer may be referred to more specifically as the velocity boundary layer. It develops whenever there is fluid flow over a surface and it is of fundamental importance to problems involving convection transport. In fluid mechanics its significance to the engineer stems from its relation to the surface shear stress τ_s, and hence the surface frictional effects. For external flows it provides the basis for determining the local friction co-efficient

$$C_f = \frac{\tau_s}{\rho u_\infty^2 / 2} \tag{1.4.1}$$

a key non-dimensional parameter from which the surface frictional drag may be determined. For a Newtonian fluid, from the knowledge of the velocity gradient at the surface, the surface shear stress τ_s acting on the plate at any location 's' is defined as

$$\tau_s = \mu \left(\frac{\partial u}{\partial y}\right)_{y=0}, \tag{1.4.2}$$

where μ is a fluid property known as the co-efficient of viscosity. In a velocity boundary layer, the velocity gradients at the surface depends on the distance x from the leading edge of the plate. Therefore, the surface shear stress and friction co-efficient also depend on x.

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(c) Thermal Boundary Layer

Just as velocity boundary layer develops when there is fluid flow over a surface, a thermal boundary layer must develop if the fluid free stream and surface temperatures differ. We consider a flow over an isothermal flat plate as shown in Fig. 1.3. At the leading edge the temperature profile is uniform, with $T(y) = T_\infty$. The fluid particles adjacent to the surface get the same temperature that of the surface. These fluid particles exchange heat energy with particles in adjoining layers and this continues till the adjoining layers have no temperature difference which happens at large distance away from the surface. As a result, a temperature gradient is developed in the fluid

layers and temperature variation occurs in the fluid flow from T_s to T_∞. The flow region over the surface in which the temperature variation in the direction normal to the surface is observed, is called thermal boundary layer.

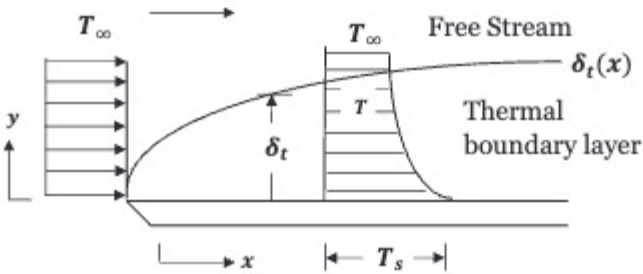

Fig. 1.3: Thermal boundary layer development on an isothermal flate plate

The thickness of the thermal boundary layer δ_t is typically defined as the value of y for which the ratio $[(T_s - T)/(T_s - T_\infty)] = 0.99$. With the increasing distance from the leading edge, the effects of heat transfer penetrate further into the free stream and the thermal boundary layer grows. At any distance x from the leading edge, the local surface heat flux q_s'' may be obtained by appling Fourier's law of heat conduction at $y = 0$ as

$$q_s'' = -k_f \left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{1.4.3}$$

This expression is appropriate because, at the surface, there is no fluid motion and energy transfer occurs only by conduction. Also, from Newton's law of cooling, we get

$$q_s'' = h(T_s - T_\infty)\,, \tag{1.4.4}$$

where h is called the heat transfer co-efficient with units and its value depends on the units used. The dimensionless form of h is the Nusselt number '*Nu*'.

Combining Eqs. (1.4.3) and (1.4.4) we have

$$h = \frac{-k_f \left(\frac{\partial T}{\partial y}\right)_{y=0}}{(T_s - T_\infty)} \tag{1.4.5}$$

Hence, conditions in the thermal boundary layer, which strongly influence the wall temperature gradient $\left(\frac{\partial T}{\partial y}\right)_{y=0}$, determine the rate of heat transfer across the boundary layer. Since $(T_s - T_\infty)$ is constant, independent of x, while δ_t increases with increasing x, temperature gradient in the boundary layer must decrease with increasing x. Accordingly, the magnitude of $\left(\frac{\partial T}{\partial y}\right)_{y=0}$ decreases with increasing x, and it follows that q_s'' and h decrease with increasing x.

(d) Concentration Boundary Layer

We consider a binary mixture of two chemical spices A and B that flows over a surface as shown in Fig. 1.4. The molar concentration of the species A at the surface is $C_{A,S}$ and in the free stream it is $C_{A,\infty}$. If $C_{A,S}$ differs from $C_{A,\infty}$, transfer of species of A by convection will occur. The concentration boundary layer is the region of the fluid where concentration gradients exist. The thickness of this boundary layer δ_c is typically defined as the value of y for which $\left[(C_{A,S} - C_A)/(C_{A,S} - C_{A,\infty})\right] = 0.99$. With increasing distance from the leading edge, the effects of species transfer penetrate further into the free stream and the concentration boundary layer grows.

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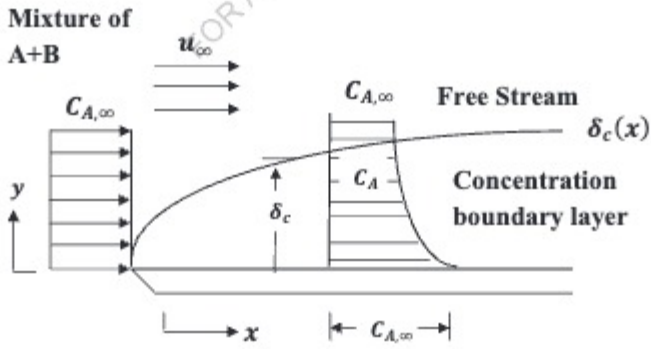

Fig.1.4: Species concentration boundary layer development on a flate plate

The molar flux of species A, N_A'' associated with species transfer by diffusion is determined by an expression which is termed as Fick's law, is given by

$$N_A'' = -D_{AB}\frac{\partial C_A}{\partial y}, \tag{1.4.6}$$

where D_{AB} is property of the binary mixture known as binary diffusion co-efficient. At any point corresponding to $y > 0$ in the concentration boundary layer of Fig. 1.4, species transfer is due to both bulk fluid motion and diffusion. Moreover, there is no fluid motion at $y = 0$ and thus species transfer is by diffusion only. Applying Fick's law at $y = 0$, the molar flux at the surface at any distance from the leading edge is

$$N_{A,S}'' = -D_{AB}\left(\frac{\partial C_A}{\partial y}\right)_{y=o} \tag{1.4.7}$$

Also, the molar flux to the concentration difference across the boundary layer is given by

$$N_{A,S}'' = h_m\left(C_{A,S} - C_{A,\infty}\right), \tag{1.4.8}$$

where h_m is called the convection mass transfer co-efficient. The dimensionless form of h_m is called the Sherwood number.

Combining Eqs. (1.4.7) and (1.4.8), we have

$$h_m = \frac{-D_{AB}\left(\frac{\partial C_A}{\partial y}\right)_{y=o}}{\left(C_{A,S} - C_{A,\infty}\right)} \tag{1.4.9}$$

Thus, conditions in the concentration boundary layer, which strongly influence the surface concentration gradient $\left(\frac{\partial C_A}{\partial y}\right)_{y=o}$, also influence the convection mass transfer co-efficient, and so the rate of species transfer in the boundary layer.

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1.5 Heat Transfer :

Heat transfer is the process of transmission of thermal energy due to temperature gradient or temperature difference. Heat is a vector quantity; it follows in the direction of decreasing temperature, with a negative temperature gradient. Transmission of heat can also be defined as heat exchange or heat flow. It is a spontaneous process which takes place due to the temperature gradient i.e. when there is a temperature difference between

the two bodies or regions with its surrounding. According to the second law of thermodynamics the process of heat exchange takes place from the region of higher temperature to the region of lower temperature and the process continues spontaneously till the two regions or bodies reach the state of thermal equilibrium.

Heat transfer is a phenomenon associated with both Newtonian and Non-Newtonian fluids. In the phenomena of nature, exchange of heat takes place in many geophysical and environmental processes such as rising of water in seas, melting of ice, increasing of hot in the atmosphere etc. In our day to day life we use innumerable machines such as boilers, heaters, refrigerators, air-conditioners etc. where exchange of heat occurs.

Heat transfer process is common to the discipline of engineering such as nuclear, chemical, bio-chemical, metallurgy etc. The design of cooling systems for motors, generators and transformers are many applications of engineering science that concerning with heat transfer. Chemical engineering is concerned with the evaporation, condensation and heating and cooling of fluids. In civil engineering an understanding of the laws of heat flow is important in the construction of dams. Many metallurgical and industrial mechanism or operations like extracting metals involve the study of heat transfer. In agriculture to develop better variety of seeds have to need importance on the heat transfer. Various foods processing concern with the lots of knowledge of heat transfer.

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(a) Various Modes of Heat Transfer

There are three basic modes of heat transfer:

1. Conduction
2. Convection
3. Radiation

Conduction

Each of the fluid molecules in the flow contains thermal energy by virtue of the fact that the absolute temperature is greater than zero. In the collision of fluid particles with different levels of thermal energy will result in a net transport of heat from the higher energy or temperature particles to the lower

energy or temperature particles. The flux of heat due to this inter particle transfer mechanism, is called heat conduction.

Heat conduction may occur through two mechanisms:

1. By molecular interactions whereby the exchange of thermal energy occurs due to the kinetic motion or direct impact of molecules. Molecules at a relatively higher temperature impact energy to adjacent molecules at a lower temperature. Such type of energy transfer always exists so long that there is a temperature difference in a system comprising molecules of a solid, liquid or gas.
2. By the drift of **"free electrons"** as in the case of metallic solids. The concentrations of electrons differ in different metallic alloys. Hence, the ability of metallic alloys to conduct heat varies directly with the concentration of free electrons in them. Non metals have a very low concentration of free electrons and hence they are bad conductors of heat. Pure conductor is found only in solids like solid metals, which are good conductor of heat.

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In 1822, Baron Jean Baptise Joseph Fourier (1768-1830) formulated the theory of heat conduction known as **"Fourier's Law of Conduction"** states that the heat flux q, resulting from thermal conduction is proportional to the magnitude of the temperature gradient and opposite to it sign. If the proportionality constant is denoted by k, then we have

$$q = -k\frac{dT}{dx}, \tag{1.5.1}$$

where k is called the thermal conductivity. The (– ve) sign shows that heat is transferred in the direction of decreasing temperature. If the temperature T decreases with x then q will be positive and it will flow in the x-direction. If T increases with x then q will be negative and it will flow opposite to x-direction. In either case, q will flow from higher temperature to lower temperature. The thermal conductivity of a material depends on its state and is a function of its pressure, temperature, humidity and structure. Pure metals have the highest values of thermal conductivities while gases and vapors have the lowest. Some materials like aluminum have a very high thermal conductivity at very low temperatures and these are called super conductors.

Convection

Heat transfer that occurs between two mediums which are in relative motions is known as convection heat transfer. Convection heat transfer occurs between a fluid in motion and a bounding surface when the two are at different temperatures. The convection of heat transfer has comprised by two mechanisms:

1. Transfer of energy due to random molecular motion of the fluid is called **diffusion**.
2. Transfer of energy due to bulk or macroscopic motion of the fluid is called **advection**.

The transport of thermal energy is inseparably linked with the movement of the fluid itself. Thus convection is possible only in the presence of a fluid medium.

We can estimate convection (q) using the formula

$$q = hA(T_s - T_\infty)\,, \tag{1.5.2}$$

where h is the convection heat transfer co-efficient, A is the area implied in the heat transfer process, T_s is the temperature of the system, T_∞ is a reference temperature.

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Convection of heat transfer is classified according to the nature of the flow. They classified as: **Natural convection**, **Forced convection** and **Mixed convection**.

Natural Convection

If the fluid motion is set up by buoyancy effects resulting from the density variation caused by the temperature difference in the fluid, the heat transfer is said to be natural or free convection. This case occurs at very small velocities of the motion in presence of large temperature differences. Natural convection is the principle mode of heat transfer from pipes, refrigerating coils, electric baseboard heaters, transmission lines, hot radiators and several practical applications in everyday life. In free convection the flow velocity in general is very small; hence Reynolds number has no significance. But the Grashof number, which is the ratio of buoyancy force to viscous flow, is

important in case of free convection. Natural convection is often preferred to forced convection in situation that demands the minimization of heat transfer rate or the minimization of operational costs.

Forced Convection

When the fluid motion is produced by some superimposed velocity field such as fans, by stirring and pumps creating an artificially induced convection heat, such type of energy transport is called forced convection. In forced convection the velocity field is independent of temperature field and so it is possible to obtain velocity independently. Forced convection occurs in a variety of flow configuration, such as flow of liquids through pipe, flow fluids over surfaces, flow of water through nuclear heating elements, flow of the liquid through heating tubes of a solar collector etc.

Mixed Convection

The combined forced convection and natural convection or mixed convection arises simultaneously and it becomes necessary to evaluate the total heat transfer by adding the heat transfer due to forced and free convections. If both the natural and forced convective heat transfer mechanisms act together to transfer heat and are equally important in the flow system, then such flows are called mixed convection. Nuclear reactor technology and some aspects of electronic cooling are the examples of mixed convection.

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Radiation

Thermal radiation is the creation or emission of electromagnetic waves from all matter by virtue of the fact that the temperature of the matter is greater than absolute zero. Therefore, radiation is the process of transfer of energy from material into surrounding space in the form of electromagnetic waves. Two bodies radiating heat may exchange heat and no medium is required for thermal energy to be exchanged by the radiating bodies.

Stefan-Boltzman's law states that the total emissive power of a black body (E_b) is proportional to the fourth power of its absolute temperature.

$$E_b = \sigma T^4 \ , \qquad (1.5.3)$$

where T is the absolute temperature and σ is the Stefen-Boltzman constant with $\sigma = 5.67 \times 10^{-8}\, Wm^{-2}k^{-4}$.

Some examples of thermal radiation are the visible light and infrared light emitted by an incandescent light bulb, the infrared radiation emitted by animals and detectable with an infrared camera and the cosmic microwave background radiation. Sunlight is thermal radiation generated by the hot plasma of the sun. The earth also emits thermal radiation, but at a much lower intensity and different spectral distribution because it is cooler. The earth's absorption of solar radiation, followed by its outgoing thermal radiation is the two most important processes that determine the temperature and climate of the earth.

1.6 Mass Transfer :

It is a process of transfer of mass due to the concentration difference of spices in a mixture. In the mixture, consisting of two or more components having different concentrations at different points, the molecular motions will cause the transfer of mass by diffusion to minimize the concentration differences within the system. So long there exists concentration difference of spices, mass transfer will occur.

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Like heat transfer, mass transfer considerations are also very important to the modern engineering design. Some common examples of mass transfer processes are the purification of blood in the kidneys and liver, the distillation of alcohol, evaporation of water from a point to the atmosphere, evaporation of petrol in carburetor, diffusion of smoke through tall chimneys into the environment, drying, chemical reaction, absorption, adsorption, distillation etc.

The mechanism of mass transfer depends greatly on the dynamics of the system in which it occurs. There are two different modes of transfer of mass: **Mass diffusion** and **Convective mass transfer**.

(a) Mass Diffusion

If mass is transfer by random molecular motion in stagnant or laminar flowing fluids, the process of transportation of mass is known as molecular diffusion. It is interesting to observe that both conduct of heat transfer and

mass diffusion are transport processes which are originating from molecular activity. Mass diffusion occurs in liquids and solids as well as in gases. However, mass transfer is strongly influenced by molecular spacing diffusion, occurs more readily in gases that in liquids and more spontaneously in liquids than in solids.

A relation between the flux of the diffusion substance and the concentration gradient responsible for this mass transfer was put forward by **Fick** (1855) and is known as **Fick's first law of diffusion**. The Fick rate equation for the transfer of spices A in x-direction in a binary mixture of spices A and B may be expressed as

$$J_{Ax} = -D_{AB}\frac{dC_A}{dx}, \tag{1.6.1}$$

where J_{Ax} denotes the molar flux in the x-direction relative to the molar average velocity, $\frac{dC_A}{dx}$ is the molar concentration gradient in the x-direction, D_{AB} is the mass diffusion co-efficient or mass diffusivity for component A diffusing through component B, C_A is the molar concentration of spices A. The negative sign indicates that the mass diffusion is taking place in the direction of decreasing concentration. Diffusion co-efficient D_{AB} is a physical property of a specific system and depends upon its temperature, pressure and the nature or state of system components. Fick's law of diffusion is very much similar to Fourier's law of heat conduction and Newton's law of viscosity.

(b) Convective mass transfer

Convective mass transfer occurs in cases where the bulk velocity is appreciable or when both the species, in a binary mixture, are moving with sufficient velocity. Convective mass transfer is analogous to the convective heat transfer. Mass transfer by convection depends on both the transport properties and dynamic characteristics of the moving fluid.

Just as in heat convection, mass convection is also take place under the natural and forced convections form. An example of free convection mass transfer is the evaporation of alcohol. The forced convection mass transfer takes place due to presence of some external agencies which carries

the mass to transport. An example of forced convection mass transfer is the evaporation of water from an ocean when air blows over it.

1.7 Magnetohydrodynamic (MHD) :

The first historically documented MHD experiment was performed by none other than Michal Faraday in 1832. In terms of his MHD work, knowing that salt water was a conductor and that flowing salt water is constantly interacting with the Earth's magnetic field, he tried to measure the voltage difference between banks in the Thames River. Unfortunately, his equipment was not able to pick up the potential difference, due to the inefficiencies in equipment in the 1830s, but his prediction about an induced current was later confirmed by Dr. William Wollaston, who measured the voltage difference across the English Channel in 1851.

Fluid dynamics and Electromagnetic theory were developed independently of each other almost up to first half of the 20th century. A systematic study of the hydrodynamic of a conducting fluid immersed in a magnetic field was started in 1942 by Hannes Alfven, the study is known as "Magnetohydrodynamics (MHD)" or 'Hydromagnetics', for which he received the Nobel Prize in Physics in 1970. Hydromagnetics is the union of two fully developed fields – Electromagnetic theory and dynamics of fluid. Consequently, ***Magnetohydrodynamics (MHD) is the science, which deals with the motion of electrically conducting fluid in the presence of a magnetic field***. The set of equations which describe MHD are a combination of Navier-Stokes equations of fluid dynamics and Maxwell's equations of electromagnetism.

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It is concerned with physical systems specified by the equations that result from the fusion of those of hydrodynamics and electromagnetic theory. It is well known fact that when a conductor moves in a magnetic field, electric current is induced in it. These currents experience a mechanical force, called the Lorentz force $(\vec{J} \times \vec{B})$, where $\vec{J}$ the electric current density and $\vec{B}$ is the magnetic induction in the fluid region, due to the presence of the magnetic field. This force tends to modify the initial motion of the conductor. Moreover, a magnetic field which is generated by the induced currents is added on to the applied magnetic field. Thus there is

a coupling between the motion of the conductor and electromagnetic field, which is exhibited in a more pronounced form in liquid and gas conductors. This is due to the fact that the molecules composing the liquids and gases enjoy more freedom of movement than those of solid conductors.

Matter is composed of atoms and molecules and has necessarily a discrete structure in MHD, as in fluid dynamics, we shall through adopt a continuum picture. The subject of MHD is traditionally studied as a continuum theory i.e. attempts at studying discrete particles in the flows are not at a level such that computation in these regards is realistic. To run "realistic simulations" would require computations of flows with many more particles that current computers are able to handle. Thus, the only way to study MHD seems to be its continuum form.

The hydrodynamic equations are basically non-linear and electrodynamic equations are linear. The coupling of two systems of equations: Hydrodynamic and Electrodynamic causes the non-linear aspect to be carried over into the resulting MHD equations. MHD effects in conducting liquids have been studied in the laboratory by Williams (1930) and Hartmann (1937). There are two basic phenomena in MHD. They are:

1. An induced magnetic field associated with current appears perturbing the original magnetic field.
2. An electromagnetic force due to interaction of current and field appears perturbing the original motion.

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Applications of MHD

MHD as a science has its application in Geophysics as well in Astrophysics. MHD is related to Engineering problems as well as also in Medical Sciences.

Geophysics

In Geophysics MHD generators are used as sources of sounding signals, for the purpose of depth sounding of Earth which is required for several geological investigations, particularly for the practical exploration and assessment of underground petroleum deposits and natural gas fields.

Astrophysics

MHD applies quite well to astrophysics since over 99% of baryonic matter content of the universe is made up of plasma, including stars, the interplanetary medium, the interstellar medium, the intergalactic medium, nebulae and jets. The solar wind is governed by MHD. The differential solar rotation may be the long term effect of magnetic drag at the poles of the sun. MHD is known to be the cause of solar flares, the largest explosions in the solar system.

Engineering

MHD has attached the attention of large number of scholars due to its diverse applications in engineering. MHD is related to engineering applications such as creation and containment of hot plasmas by electromagnetic forces in thermonuclear reactors, design of MHD pumps, MHD generators, MHD bearings, MHD flow meters, MHD spectroscopy, creation of MHD propulsion force, liquid-metal cooling of nuclear fission reactors, electromagnetic casting, welding, crystal growth, fusion reactors, jet printers, the processing of melting, refining and solidification of metals and metallurgy, creation of electromagnetic stirring, microelectronics, MHD dynamo and electromagnetic valves, aerospace applications, design of heat exchangers, bracks etc. MHD is also used in stabilizing a flow against the transition from laminar to turbulent flow and in the reduction of turbulent drag, suppression of flow separation and even lift and thrust production (MHD flow control).

Medical Science

An application is biomedical engineering includes Cardiac MRI, ECG etc. The concept of electromagnetic fields in medical research was initiated by Kolin (1936). Later Korchevskii *et al*. (1965) discussed the possibility of regulating blood flow by the application of magnetic fields.

Maxwell's equations

Magnetohydrodynamics is dependent on Maxwell's equations of electromagnetism and Navier-Stokes equations of fluid dynamics. MHD is

a continuum theory and hence it cannot treat kinetic phenomena. Maxwell's equations describe the properties of electric and magnetic fields and connect them to their sources, charge density and current density. There are four Maxwell's equations in matter. These are:

Gauss's law of electrostatics:

$$\vec{\nabla}.\vec{E} = \frac{\rho_0}{\varepsilon}, \tag{1.7.1}$$

where $\vec{E}$ is the electric field intensity, ε is permittivity of the medium, ρ_0 is the charge density of the medium

Gauss's law of magnetism:

$$\vec{\nabla}.\vec{B} = 0, \tag{1.7.2}$$

where $\vec{B}$ is the magnetic induction vector

Faraday's law of electromagnetic induction:

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{1.7.3}$$

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Ampere's law with Maxwell's correction:

$$\vec{\nabla} \times \vec{B} = \mu_e \vec{J} + \mu_e \varepsilon \frac{\partial \vec{E}}{\partial t}, \tag{1.7.4}$$

where $\vec{J}$ is the electric current density vector, μ_e is the magnetic permeability of the medium.

Further

Ohm's law:

$$\vec{J} = \sigma\left[\vec{E} + \vec{q} \times \vec{B}\right], \tag{1.7.5}$$

where $\vec{q}$ is the velocity of the moving charge, σ is the electrical conductivity of the medium.

Lorentz's force:

$$\vec{F} = e\left[\vec{E} + \vec{q} \times \vec{B}\right] , \tag{1.7.6}$$

where $\vec{F}$ is the Lorentz force per unit volume, e is the electric charge.

Magnetic induction equations:

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times \left(\vec{q} \times \vec{B}\right) + \frac{1}{\mu_e \sigma} \vec{\nabla}^2 \vec{B} \tag{1.7.7}$$

1.8 Porous Medium :

The material consisting of a solid matrix with an inter-connected void (pore) is called **porous medium**. This inter-connectedness of the void allows the flow of one or more fluid through the material. Many natural substances such as soils, rocks, biological tissues and man-made materials such as cement, ceramics, foams, fibrous aggregates, filter paper, sand filters can be considered as porous media. The fraction of the total volume of the medium that is occupied by void space is called the **porosity** of a porous medium. **Permeability** measures quantitatively the ability of a porous medium to conduct fluid flow, under the action of an applied pressure gradient.

Porosity is a macroscopic porous medium property. Total porosity is defined as the ratio of volume of the void space (U_v) to the bulk volume (U_b) of a porous medium. Then we have

$$Porosity = \frac{U_v}{U_b} = \frac{U_b - U_s}{U_b} = 1 - \frac{U_s}{U_b},$$

where U_s is the volume of the solids within U_b.

The porosity, a dimensionless quantity, usually is expressed either as a fraction or as percentage. Two out of the three terms are required to calculate porosity.

Flows through porous media are encountered while investigating transport phenomena in underground rocks, filters and catalyst beds. Studies of flows through porous media are important in investigating underground water, oil and natural gas resources. Porous media theories play an important

role in many branches of engineering, including material science, the petroleum industry, hydrology, chemical engineering, geophysics and soil mechanics, as well as in biomechanics.

In 1762, Leonhard Euler gave the first description of a porous body. On his book **"Anleitung Zur Naturlehre"**, which was published after his death, he imputed the elasticity of a solid to a certain subtile is closed pores. His remarks on porous bodies are: "All bodies in the world are composed of rough and subtile matter, where of the first is called the characteristic matter whereas the other due to its real infinity small density contributes nothing to the increase of their mass. Since the mixture of the both matters extends to the smallest parts, those parts of the space, in which no rough matter contained, are called the pores of the bodies, and there are different kinds concerning the size, because also the smallest parts are still filled up with pores. The most distinct difference however, which must be considered for the pores of anybody, is that some form of an open path to the others, whereas other once are surrounded by the rough matter in such a way that the subtile matter there in contained cannot escape. In order to denote this difference, we will call the first open pores and the last closed pores."

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Reinhard Woltman (1757-1837) was a harbor construction director from Hamburg; he expanded an idea on soil mechanics and porous bodies and introduced the volume fraction concept, an essential part of the theory of porous medium. Henry Philibert Gaspard Darcy (1803-1858) a French Hydraulic Engineer, first did experimental investigations regarding fluid flow through porous media.

In 1856, Darcy observed, in tests with natural sand, the proportionality of the total volume of water running through the sand and the loss of pressure. These investigations were of a purely experimental nature, Darcy's results are essential for a continuous mechanical treatment of the motion of a liquid in a porous solid. He formulated and published an empirical law called Darcy's law that gives a proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance. Darcy took water as the experimental fluid. The porous medium is in fact a non-homogeneous medium. For the sake of analysis, it is possible to describe the

flow in terms of a homogeneous fluid with averaged dynamic properties having some effects on the locally non-homogeneous continuum. Then, it is possible to investigate the motion of the hypothetical homogeneous fluid under the action of the property averaged external forces. On the basis of this hypothesis a complicated problem of flow through a porous medium reduces to the flow problem of a homogenous fluid with some additional resistance.

For a homogenous medium the Darcy's law is expressed in vector form as

$$\vec{q} = -\frac{K}{\mu}\vec{\nabla}p\,, \tag{1.8.1}$$

where $\vec{q}$ is the volume flow rate or filter velocity, K is the permeability which is in general second order tensor, μ is the co-efficient of viscosity and p is the pressure.

For the case of an isotropic medium the permeability is a scalar. Then the above equation simplifies to

$$\vec{\nabla}p = -\frac{\mu}{K}\vec{q} \tag{1.8.2}$$

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Following Wooding (1957) and many authors on convection in porous media used an extensive of Eq. (1.8.2) of the form

$$\rho\left[\frac{\partial\vec{q}}{\partial t} + (\vec{q}.\vec{\nabla})\vec{q}\right] = -\vec{\nabla}p - \frac{\mu}{K}\vec{q} \tag{1.8.3}$$

This equation was obtained by analogy with the Navier-Stokes equation.

An alternative to Darcy's law is commonly known as Brinkman's equation. In 1947, H. C. Brinkman added a term to Darcy's law, in order to account for the transitional flow between the boundaries. This correction term called Brinkman term, accounts for flow through a medium where the grains of the media are porous themselves. With inertial terms omitted the Brinkman's equation takes the form

$$\vec{\nabla}p = -\frac{\mu}{K}\vec{q} + \bar{\mu}\nabla^2\vec{q}\,, \tag{1.8.4}$$

where μ is the co-efficient of viscosity and $\tilde{\mu}$ is an effective viscosity. The first is the usual Darcy term and the second is analogous to the Laplacian term that appears in the Navier-Stokes equation. In Brinkman's set μ and $\tilde{\mu}$ are equal to each other.

Combining the Eqs (1.8.3) and (1.8.4), the Navier-Stokes equation for flow of an incompressible viscous fluid through porous media takes the form

$$\rho\left[\frac{\partial \bar{q}}{\partial t} + (\bar{q}.\bar{\nabla})\bar{q}\right] = -\bar{\nabla}\mathrm{p} - \frac{\mu}{\mathrm{K}}\bar{q} + \mu\nabla^2\bar{q} + \rho\bar{F}\,, \qquad (1.8.5)$$

where $\bar{F}$ is the external force acting in the fluid per unit mass.

1.9 Non-dimensional Parameters :

Dimensional analysis of any problem enables us to know the qualitative behaviour of the physical problem. The dimensionless parameters facilitate to understand the physical significance of a particular phenomenon associated with the problem. The purpose of dimensional analysis is to determine certain fundamental relationships between the variables viz. velocity, acceleration, rotation, length, mass, density, force, temperature, viscosity, stress etc. These qualities are fundamentally different from one another although they possess certain quantities in common. The major advantage of the use of dimensional analysis is most apparent where complete analytical solution of the physical problem is not possible. The solution of the problem is considerably simplified using the method of dimensional analysis.

The inertia force always exists in all flow problems. Besides the inertia force, there always exist some additional forces which are responsible for fluid motion. The required conditions for dynamic similarity can always be obtained by considering the ratio of the inertia force and any one of the remaining forces (e.g. viscous force, gravity force, pressure force and so on).

There are several non-dimensional quantities of great significance. Some of the dimensionless quantities relevant to our study are mentioned here.

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(a) Reynolds Number (*Re*)

Reynolds number is a dimensionless number, named after British Mathematician Osborne Reynolds (1842-1912). It is defined as the ratio of inertia force to viscous force and consequently quantifies the relative importance of these two forces occurring in a flow. If for a flow problem the *Re* is small then we can neglect the inertia force whereas for large *Re* the viscous force can be neglected and the fluid may be treated as non-viscous fluid. However, if *Re* is very large the effect of viscosity can be considered to be confined within the boundary layer and the flow becomes turbulent.

Mathematically, the Reynolds number (*Re*) is defined as,

$$Re = \frac{Inertia\ force}{Viscous\ force} = \frac{\rho U^2/_L}{\mu U/_{L^2}} = \frac{UL}{\nu}$$

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(b) Grashof number for heat transfer or thermal Grashof number (*Gr*)

The ratio of buoyancy force due to temperature difference to the hydrodynamic viscous force acting on the fluid is known as thermal Grashof number or simply Grashof number, named after the German engineer Prof. Franz Grashof (1826-1893). It is a very important dimensionless parameter in analyzing Natural or Free convection.

The Grashof number (*Gr*) is defined as

$$Gr = \frac{g\beta(T_w - T_\infty)L^3}{\nu^2}$$

The Grashof number in free convection plays the same role as the Reynolds number in forced convection. For example, in forced convection the transition from laminar to turbulent flow is governed by the critical value of Reynolds number. Similarly, in free convection the transition from laminar to turbulent flow is governed by the critical value of thermal Grashof number, which lies within the range $10^8 < Gr < 10^9$.

(c) Grashof number for mass transfer or solutal Grashof number (*Gm*)

Similar to thermal Grashof number, solutal Grashof number defines as the ratio of buoyancy force due to concentration difference to viscous force. The Grashof number (*Gm*) is defined as

$$Gm = \frac{g\overline{\beta}(C_w - C_\infty)L^3}{\nu^2}$$

It is signifies in free convection flows involving mass transfer. This is because the density variation in free convection mass transfer is due to spices concentration difference, and hence the buoyancy force in natural convection mass transfer is incorporated into Grashof number.

(d) Hartmann Number (Magnetic parameter, *M*)

Hartmann number of a fluid is defined as the ratio of electromagnetic force to the viscous force. German scientist Franz Hartmann (1838-1912) first studied the flow of an incompressible fluid between parallel plates theoretically and experimentally by imposing a magnetic in transverse direction. He gave the concept of Hartmann number denoted by *M*.

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Mathematically it is defined as,

$$M = \frac{\sigma L^2 B_0^2}{\mu}$$

The magnitude of Hartmann number indicates the relative effects of magnetic and viscous drag. Hence it determines the velocity profiles of such flows.

(e) Prandtl Number (*Pr*)

It is an important dimensional parameter dealing with the properties of a fluid. It refers to the relative thickness of momentum (velocity) boundary layer and thermal boundary layer. The ratio of the Kinematical viscosity to the thermal diffusivity of a fluid is defined as the Prandtl number, named after the German scientist Ludwig Prandtl (1875-1953).

Mathematically, Prandtl number is defined as,

$$Pr = \frac{Kinematic\ viscosity}{Thermal\ diffusivity} = \frac{\nu}{\alpha} = \frac{{}^{\mu}/_{\rho}}{{}^{\kappa}/_{\rho C_p}} = \frac{\mu C_p}{\kappa}$$

For the substances with very small value of Prandtl number the thickness of the thermal boundary layer is much bigger than that of the velocity boundary layer. Thus, for the fluids with $Pr >> 1$ the momentum diffusion is much greater than the energy diffusion, but for the fluids with $Pr << 1$ the situation is reversed. Liquid metals have very small Prandtl number (Pr = 0.004 approx.) and glycerin is one of the substances bearing a very high value of Prandtl number (Pr = 7250).

(f) Schmidt Number (*Sc*)

Schmidt number is a dimensionless quantity defined as the ratio of momentum diffusivity (Viscosity) and mass diffusivity. The concept of Schmidt number was introduced by German engineer Ernst Heinrich Wilhelm Schmidt (1892-1975).

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Mathematically Schmidt number is defined as,

$$Sc = \frac{Momentum\ diffusivity}{Mass\ diffusivity} = \frac{\nu}{D} = \frac{\mu}{\rho D}$$

The Schmidt number provides a measure of the relative effectiveness of momentum and mass transport by diffusion in a fluid medium, for a given fluid flow involving convection mass transfer. The Schmidt number compares the relative thickness of velocity and concentration boundary layers.

(g) Eckert Number (*Ec*)

The Eckert number is a measure of the viscous dissipation effects in the flow. Since this grows in proportion to the square of the velocity, it can be neglected for every small velocity.

Mathematically the Eckert number is defined as,

$$Ec = \frac{U^2}{C_p \Delta T}$$

The Eckert number also indicates the Kinetic energy of the flow relative to some enthalpy difference.

(h) Nusselt Number (*Nu*)

In fluid dynamics, it is important to know the quantity of heat exchanged between the body and the fluid. The quality of heat transfer can be calculated with the help of a co-efficient of heat transfer$\alpha(x)$, which is defined by Newton's law of cooling as,

$$q(x) = \alpha(x)(T_w - T_\infty)$$

But at the boundary, the heat exchange between the body and the fluid takes place only due to conduction. Hence, according to Fourier's law we get,

$$q(x) = -k\left(\frac{\partial T}{\partial y}\right)_{y=0}$$

From these two laws, dimensionless co-efficient of heat transfer which is generally known as the Nusselt number, can be defined as,

$$Nu = \frac{L\alpha(x)}{k} = -\frac{L}{(T_w - T_\infty)}\left(\frac{\partial T}{\partial y}\right)_{y=0}$$

(i) Sherwood Number (*Sh*)

Sherwood number is defined as the ratio of the convective mass transport to the diffusive mass transport. This dimensionless quantity is named in honour of American chemical engineer Thomas Kilgore Sherwood. Sherwood number is used in mass transfer mechanism. Mathematically Sherwood number is defined as,

$$Sh = -\frac{L}{(C_w - C_\infty)}\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

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1.10 Mathematical Formulation :

The foundational axioms of fluid mechanics are the laws of conservation of mass, conservation of momentum (also known as Newton's second law) and conservation of energy. These are based on Classical mechanics and modified in Relativistic mechanics. The central equations for fluid mechanics are the Navier-Stokes equations which are non-linear differential equations describing the flow of a fluid whose stress depends linearly on pressure and velocity. In this section of the book, fundamental equations and the boundary conditions of a viscous incompressible electrical fluid motion through a porous medium with constant fluid properties in the presence of a magnetic field and heat sources and sinks in vector form are presented.

I. Governing Equations of Flow

(a) Equation of continuity

$$div\ \vec{q} = 0\,, \tag{1.10.1}$$

where $\vec{q}$ is the fluid velocity for all incompressible fluid.

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(b) Navier-Stock's equation in modified form

$$\frac{\partial \vec{q}}{\partial t} + (\vec{q}.\vec{\nabla})\vec{q} = \vec{F} - \frac{1}{\rho}\nabla p + \vec{J}X\vec{B} + \nu\nabla^2\vec{q} - \frac{\nu}{K}\vec{q}\ , \tag{1.10.2}$$

where $\vec{F}$ is the external body force, ρ is the fluid density, p is the pressure, $\vec{J}$ is the current density, $\vec{B}$ is the magnetic field intensity, ν is the kinematic viscosity and K is the permeability of the porous medium.

(c) Energy equation

$$\rho C_P\left[\frac{\partial T}{\partial t} + (\vec{q}.\vec{\nabla})T\right] = \kappa\nabla^2 T + \mu\Phi - \frac{\vec{J}^2}{\sigma} + Q\,, \tag{1.10.3}$$

where T is the temperature, κ is the thermal conductivity, μ is the coefficient of viscosity, Q is the heat absorption/generation, C_P is the specific heat at constant pressure and in rectangular Cartesian co-ordinates

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\,, \tag{1.10.4}$$

$$\Phi \equiv \begin{bmatrix} 2\left\{\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right\} \\ +\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2 \end{bmatrix}, \quad (1.10.5)$$

Φ is called the *dissipation function*.

(d) Concentration equation

$$\left[\frac{\partial C}{\partial t} + (\vec{q}.\vec{\nabla})C\right] = D\nabla^2 C - C_r(C - C_\infty) + D_m\nabla^2 T\,, \quad (1.10.6)$$

where D is molecular diffusivity and D_m is thermal diffusivity.

II. Boundary Conditions

The boundary conditions of a flow of an incompressible viscous electrically conducting fluid through a porous medium in presence of a transverse magnetic field are:

(a) There is no slip of fluid on the boundary;

(b) $T = 0$ or $\frac{\partial T}{\partial n} = 0$ or $T = T_w$ on the boundary ;

(c) $T \to T_\infty$ at a large distance from the boundary ;

(d) $C \to C_\infty$ at a large distance from the boundary ;

(e) The normal component of the magnetic induction is continuous across the interface;

(f) If none of the regions (fluid, solid or vacuum) adjoining the boundary is perfectly conducting, the tangential component of the magnetic field $\vec{H} = \vec{B}/\mu_e$ is continuous across the interface. If, however, at least one of two media in contact is perfectly conducting, then the magnetic field $\vec{H} = \vec{B}/\mu_e$ must satisfy the condition $\vec{n}\,X\,(\vec{H}_2 - \vec{H}_1) = \vec{J}_s$, where $\vec{n}$ is the unit vector normal to the surface, $\vec{H}_1$, $\vec{H}_1$ are the values of the magnetic field on two sides of the interfaces and $\vec{J}_s$ is the surface current density.

The tangential component of the electric field is continuous across the interface. The equation of continuity, motion and energy can be simplified with usual boundary layer approximations whenever a problem of boundary layer flow and heat transfer is considered.

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III. Research Methodology

(a) Classical Perturbation Technique

The fluid dynamic and Magneto-fluid dynamic equations can be solved by different methods like Laplace transform method, series method, numerical techniques and perturbation techniques etc. To obtain the solutions of some physical problems, we have used perturbation technique in this thesis. Problems in non-steady boundary layers involve an essentially steady flow on which there is superimposed a small non-steady perturbation. If it is assumed that the perturbation is small compared with the steady basic flow, it is possible to split the equations into non-linear equation for the steady part.

The essential idea is that the problem has a small parameter (say ε) in either the governing equations or in the boundary conditions. In a flow at high Reynolds number, the small parameter is $\varepsilon = \frac{1}{Re}$, in a creeping flow $\varepsilon = Re$, and in flow around an airfoil ε is the ratio of thickness to chord length. The solutions of these problems can frequently be written in terms of a series involving the small parameter, the higher order terms acting as a perturbation on the lower order terms. These methods are called perturbation techniques.

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A well-known example is that for which the external stream has the form

$$U(x,t) = \bar{U}(x) + \varepsilon\, U_1(x,t) + \cdots\cdots, \tag{1.10.7}$$

where ε denotes a very small number. The most important special case when the external perturbation is purely Harmonic, was studied by Lighthill (1954). The same type of linearization can be employed when the perturbation at the wall is represented by the expression

$$T_w(x,t) = \bar{T}_w(x) + \varepsilon T_{w1}(x,t) \tag{1.10.8}$$

or when the wall itself performs small, non-steady, perturbing motions (oscillating bodies).

In such cases we start with the assumption that the solutions for the dynamics as well as for the thermal boundary layer are of the following forms:

$$\left.\begin{aligned} u(x,y,t) &= u_0(x,y) + \varepsilon u_1(x,y,t) + \varepsilon^2 u_2(x,y,t) + \cdots\cdots \\ v(x,y,t) &= v_0(x,y) + \varepsilon v_1(x,y,t) + \varepsilon^2 v_2(x,y,t) + \cdots\cdots \\ T(x,y,t) &= T_0(x,y) + \varepsilon T_1(x,y,t) + \varepsilon^2 T_2(x,y,t) + \cdots\cdots \\ C(x,y,t) &= C_0(x,y) + \varepsilon C_1(x,y,t) + \varepsilon^2 C_2(x,y,t) + \cdots\cdots \end{aligned}\right\} \quad (1.10.9)$$

The postulated forms from equations are introduced into the governing equations of the flow and the resulting terms are ordered with respect to the powers of ε. From the requirement that the differential expressions, which multiply each power of ε must vanish separately, we obtain a cascade of differential equations. All the sets of differential equations except those of order zero will be linear and can be solved. The method can also be applied to the calculation of periodic boundary layers.

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(b) Laplace Transform Technique

The knowledge of "Laplace transforms" is an essential part of mathematical background required by scientists and engineers. This is because the transform methods provide an easy and effective means for the solutions of many problems arising in science and engineering. For example, the Laplace transformation replaces a given function $F(t)$ by another function $f(s)$. The Laplace transformation converts an ordinary differential equation with some given initial conditions into an algebraic equation in terms of $f(s)$. Finally, using inverse Laplace transformation we recover the original function $F(t)$. Thus, the method of Laplace transformation is especially useful for initial value problem, as it enables us to solve the problem without the trouble of finding the general solution first and then evaluating the arbitrary constants. In the case of partial differential equation in two independent variables, the Laplace transformation gives rise to an ordinary differential equation for the transform.

Definition of the Laplace Transform

Let $F(t)$ be a function of t specified for $t > 0$. Then the *Laplace transform* of $F(t)$, denoted by $\mathcal{L}\{F(t)\}$, is given by

$$\mathcal{L}\{F(t)\} = f(s) = \int_0^\infty e^{-st}F(t)dt$$

Some important properties of Laplace Transform

i. *First translation or shifting property:*
If $\mathcal{L}\{F(t)\} = f(s)$ then
$$\mathcal{L}\{e^{at}F(t)\} = f(s-a)$$

ii. *Change of Scale property:*
If $\mathcal{L}\{F(t)\} = f(s)$ then
$$\mathcal{L}\{F(at)\} = \frac{1}{a}f\left(\frac{s}{a}\right)$$

iii. *Laplace transform of derivative:*
If $\mathcal{L}\{F(t)\} = f(s)$ then
$$\mathcal{L}\{F'(t)\} = sf(s) - F(0)$$
$$\mathcal{L}\{F''(t)\} = s^2f(s) - sF(0) - F'(0)$$

iv. *Division by t:*
If $\mathcal{L}\{F(t)\} = f(s)$ then
$$\mathcal{L}\left\{\frac{F(t)}{t}\right\} = \int_s^\infty f(u)du$$

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Some special function

i. The *Error function* is defined as:
$$erf(t) = \frac{2}{\sqrt{\pi}}\int_0^t e^{-u^2}\,du$$

ii. The *Complementary Error function* is defined as:
$$erfc(t) = 1 - erf(t) = \frac{2}{\sqrt{\pi}}\int_t^\infty e^{-u^2}$$

Definition of the Inverse Laplace Transform

If the Laplace transform of a function $F(t)$ is $f(s)$, i.e. if $\mathcal{L}\{F(t)\} = f(s)$, then $F(t)$ is called an inverse Laplace transform of $f(s)$ and we write symbolically

$$F(t) = \mathcal{L}^{-1}\{f(s)\}$$

where $\mathcal{L}^{-1}$ is called the inverse laplace transformation operator.

Some important properties of Inverse Laplace Transform

i. *Shifting Property*:

If $\mathcal{L}^{-1}\{f(s)\} = F(t)$, then

$$\mathcal{L}^{-1}\{f(s-a)\} = e^{at}F(t)$$

ii. *Change of scale Property:*

If $\mathcal{L}^{-1}\{f(s)\} = F(t)$, then

$$\mathcal{L}^{-1}\{f(ks)\} = \frac{1}{k}F\left(\frac{t}{k}\right)$$

iii. *Division by s:*

If $\mathcal{L}^{-1}\{f(s)\} = F(t)$, then

$$\mathcal{L}^{-1}\left\{\frac{f(s)}{s}\right\} = \int F(u)du$$

iv. *Convolution Property*:

If $\mathcal{L}^{-1}\{f(s)\} = F(t)$ and $\mathcal{L}^{-1}\{g(s)\} = G(t)$, then

$$\mathcal{L}^{-1}\{f(s)g(s)\} = \int_0^t F(u)G(t-u)du$$

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(c) Crank–Nicolson Method (CNM)

In numerical analysis, the **Crank–Nicolson Method** is a finite difference method used for numerically solving the heat equation and similar partial differential equations (2002). It is a second-order method in time. It is implicit in time and can be written as an implicit Runge–Kutta method, and it is numerically stable. The method was developed by John Crank and Phyllis Nicolson in the mid-20th century (1947).

The Crank–Nicolson method is based on the trapezoidal rule, giving second-order convergence in time. For example, in one dimension, if the partial differential equation is

$$\frac{\partial u}{\partial t} = F\left(u,\ x,\ t,\ \frac{\partial u}{\partial x},\ \frac{\partial^2 u}{\partial x^2}\right) \qquad (1.10.10)$$

then, letting $u(i\Delta x, n\Delta t)$, the equation for Crank–Nicolson method is a combination of the forward Euler method at n and the backward Euler

method at $(n+1)$ (note, however, that the method itself is *not* simply the average of those two methods, as the equation has an implicit dependence on the solution):

$$\frac{u_i^{n+1}-u_i^n}{\Delta t}=F_i^n\left(u,\ x,\ t,\ \frac{\partial u}{\partial x},\ \frac{\partial^2 u}{\partial x^2}\right)\ \text{(Forward Euler)}\ (1.10.11)$$

$$\frac{u_i^{n+1}-u_i^n}{\Delta t}=F_i^{n+1}\left(u,\ x,\ t,\ \frac{\partial u}{\partial x},\ \frac{\partial^2 u}{\partial x^2}\right)\text{(Backward Euler)}(1.10.12)$$

$$\frac{u_i^{n+1}-u_i^n}{\Delta t}=F_i^n\frac{1}{2}\left[\begin{matrix}F_i^{n+1}\left(\begin{matrix}u,\ x,\ t,\\ \frac{\partial u}{\partial x},\ \frac{\partial^2 u}{\partial x^2}\end{matrix}\right)\\ +F_i^n\left(\begin{matrix}u,\ x,\ t,\\ \frac{\partial u}{\partial x},\ \frac{\partial^2 u}{\partial x^2}\end{matrix}\right)\end{matrix}\right]\text{(Crank}-\text{Nicolson)}(1.10.13)$$

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Note that this is an *implicit method*: to get the "next" value of u in time, a system of algebraic equations must be solved. If the partial differential equation is nonlinear, the discretization will also be nonlinear so that advancing in time will involve the solution of a system of nonlinear algebraic equations, though linearizations are possible. In many problems, especially linear diffusion, the algebraic problem is tridiagonal and may be efficiently solved with the tridiagonal matrix algorithm, which gives a fast $O(n)$ direct solution as opposed to the usual $O(n^3)$ for a full matrix.

Thomas Algorithm

Let us call the three non-zero diagonals of $\boldsymbol{A}$ as a, b and c where b has the elements of the principal diagonal, a has the elements of the diagonal before the principle diagonal with zero as the first element and c has the elements of the diagonal which lie after the principal diagonal with a zero as the last element then the order of a, b and c is equal to the number of unknowns for any time level with the known vector $\boldsymbol{B}$. Then the Thomas algorithm can be written as

Do $i = 2$ to N (if N is the number of unknowns)

$$b_i = b_i - a_i \frac{b_{i-1}}{a_{i-1}}$$

$$d_i = d_i - a_i \frac{d_{i-1}}{a_{i-1}}$$

end do

$$u_N = \frac{d_N}{b_N}$$

Do $i = N - 1$ to 1

$$u_i = \frac{d_i - c_i u_{i+1}}{b_i}$$

end do

Stability Analysis

The Crank-Nicolson scheme to the one-dimensional diffusion equation with zero boundary conditions and some known initial conditions is

$$\frac{u_i^{n+1} - u_i^n}{\Delta t} = \frac{a}{2(\Delta x)^2}[\{u_{i-1}^{n+1} - 2u_i^{n+1} + u_{i+1}^{n+1}\} + \{u_{i-1}^n - 2u_i^n + u_{i+1}^n\}]$$

$$\Rightarrow -\frac{r}{2}u_{i+1}^{n+1} + (1+r)u_i^{n+1} - \frac{r}{2}u_{i-1}^{n+1} = \begin{Bmatrix} \frac{r}{2}u_{i+1}^n + (1-r)u_i^n \\ + \frac{r}{2}u_{i-1}^n \end{Bmatrix} \quad (1.10.14)$$

where $r = \dfrac{a\,\Delta t}{(\Delta x)^2}$, for $i = 1, 2, 3 \ldots (N-1)$ and $n = 0, 1, 2, 3 \ldots\ldots$

$$\begin{pmatrix} 1+r & -r/2 & \cdot \\ -r/2 & 1+r & \cdot \\ \cdot & \cdot & 1+r \end{pmatrix} \begin{pmatrix} u_1^{n+1} \\ u_2^{n+1} \\ \cdot \\ u_{N-1}^{n+1} \end{pmatrix} = \begin{pmatrix} 1-r & -r/2 & \cdot \\ r/2 & 1-r & \cdot \\ \cdot & \cdot & 1-r \end{pmatrix} \begin{pmatrix} u_1^n \\ u_2^n \\ \cdot \\ u_{N-1}^n \end{pmatrix}$$

$$\Rightarrow \left(I - \frac{r}{2}T_{N-1}\right)\overline{u}^{n+1} = \left(I + \frac{r}{2}T_{N-1}\right)\overline{u}^n$$

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$$\Rightarrow \overline{u}^{n+1} = \left(\frac{I + \frac{r}{2}T_{N-1}}{I - \frac{r}{2}T_{N-1}}\right)\overline{u}^{n}$$

Therefore the iterative matrix for the present scheme is

$$\overline{A} = \frac{I + \frac{r}{2}T_{N-1}}{I - \frac{r}{2}T_{N-1}} \tag{1.10.15}$$

and the Eigen values of this matrix are

$$\frac{1 - 2rsin^2\frac{i\pi}{2N}}{1 + 2rsin^2\frac{i\pi}{2N}}, i = 1, 2, \ldots\ldots\ldots\ldots(N-1) \quad (1.10.16)$$

In Eq. (1.10.15) for all positive values of r the denominator is greater than the numerator makes modulus of eigenvalues of $\overline{A}$ less than one. Hence Crank-Nicolson scheme is unconditionally stable.

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$$\frac{u_i^{n+1} - u_i^n}{\Delta t} = \frac{a}{2(\Delta x)^2}[\{u_{i-1}^{n+1} - 2u_i^{n+1} + u_{i+1}^{n+1}\} + \{u_{i-1}^n - 2u_i^n + u_{i+1}^n\}]$$

$$\Rightarrow -\frac{r}{2}u_{i+1}^{n+1} + (1+r)u_i^{n+1} - \frac{r}{2}u_{i-1}^{n+1} = \begin{Bmatrix} \frac{r}{2}u_{i+1}^n + (1-r)u_i^n \\ + \frac{r}{2}u_{i-1}^n \end{Bmatrix} \quad (1.10.17)$$

where $r = \frac{a\,\Delta t}{(\Delta x)^2}$, for $i = 1, 2, 3\ldots.(N-1)$ and $n = 0, 1, 2, 3\ldots\ldots..$

1.11 Review of Relevant Literature :

(a) Channel / Couette Flow

In fluid dynamics, Couette flow refers to the laminar flow of a viscous fluid in the space between two parallel plates, one of which moving relative to the other. The flow is driven by virtue of viscous drag force acting on the fluid and the applied pressure gradient parallel to the plates. This type of flow is

named in honour of **Maurice Marie Alfred Couette**, a professor of physics at the France University of Angers in the late 19th century. Some important application areas of Couette motion are Magnetohydrodynamics power generators and pumps, polymer technology, petroleum industry and purification of crude oil, nuclear reactors etc.

Mixed convection in a vertical parallel-plate channel with uniform wall temperature has been initially studied by Tao (1960a). Habchi and Acharya (1986) extended the work of Tao (1960b) to asymmetric heating where one plate is heated and other plate is adiabatic. Some of the published papers such as, Aung and Worku (1986), Cheng *et al.* (1990), Hamadah and Wirtz (1991), Vajravelu and Sastri (1977), Ingham *et al.* (1998), Barletta (2002) and Boulama and Galanes (2004) deals with the mixed convection in a vertical parallel-plate channel with symmetric heating or asymmetric heating under different physical situations. Vajravelu and Sastry (1978) have analyzed the free convection heat transfer in a viscous, incompressible fluid confined between long vertical wavy walls in the presence of constant heat source. Kaviany (1985) used a numerical solution of laminar flow in a porous channel bounded by isothermal parallel plates and his work was based on the Darcy model. Using finite-volume techniques Kim *et al.* (1994) investigated a numerical study which is made of heat transfer characteristics from forced pulsating flow in a channel filled with fluid-saturated porous media. In this study the Brinkman-Forchheimer-extended Darcy model was employed. Vafai and Kim (1989) studied porous forced convection between two parallel plates. Hassanien and Mansour (1990) investigated about a problem of two-dimensional unsteady flow of a viscous, incompressible, electrically-conducting fluid through a porous medium bounded by two infinite parallel plates under the action of a transverse magnetic field.

Chamkha (2001) has studied the unsteady laminar Hydromagnetic flow and heat transfer in porous channel with temperature-dependent properties and inertial effects on the convection regime. **Leong** and Jin (2005) studied on heat transfer of oscillating flow through a channel filled with aluminum foam subjected to a constant wall heat flux. Barletta *et al.* (2007) studied on fully developed laminar mixed convection flow in a vertical plane parallel channel filled with a porous medium and subject to isoflux-isothermal wall conditions is investigated assuming that (i) the

Darcy law and the Boussinesq approximation hold, (ii) the effect of viscous dissipation is significant. Hooman and Gurgenci (2007) investigated numerically the forced convection with viscous dissipation in a parallel plate channel filled by a saturated porous medium. The natural convection in unsteady Couette flow between two vertical parallel plates in the presence of constant heat flux and radiation has been presented by Narahari (2009). Narahari (2010) has investigated the effects of thermal radiation and free convection currents on the unsteady Couette flow between two vertical parallel plates with constant heat flux at one boundary. Unsteady MHD Couette Flow of a viscous incompressible electrically conducting fluid, in the presence of a transverse magnetic field, between two parallel porous plates has studied by Seth *et al.* (2011). Electrically conducting fluid confined between two infinite vertical walls heated/ cooled asymmetrically was considered by Sarkar *et al.* (2012). Kar *et al.* (2013) study the effect of heat source and chemical reaction on a three-dimensional free convective MHD flow in a vertical channel through a porous medium. Using finite difference technique, Hazarika (2012-2013) studied the Hall effects in a rotating system of transient hydromagnetic Couette flow.

Recently, Ahmed *et al.* (2017) analyzed the hydromagnetic effect on three-dimensional Couette flow of viscous incompressible, electrically conducting and Newtonian fluid through a porous medium bounded by two horizontal parallel porous flat plates with transverse sinusoidal injection of the fluid at the stationary plate and its corresponding removal by periodic suction through the plate in uniform motion. In this study the results show that methods, perturbation and electrical network schemes provides excellent approximations to the solution of this nonlinear system with high accuracy. Using the Laplace transform technique Kalita and Ahmed (2017) have presented the effects of the buoyancy force and magnetic drag force on an unsteady hydromagnetic Couette flow of a viscous, incompressible, electrically conducting fluid through a vertical channel in the presence of thermal radiation and mass diffusion. The phenomenon of forced convective heat transfer with internal heat generation in a micro-channel filled with a porous material saturated with a rarefied gas and using finite element method by varying wall heat flux and wall temperature ratio under local thermal non-equilibrium (LTNE) conditions have been investigated by Seetharamu *et al.* (2017). Numerical solutions are obtained in this adopted

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model for both the fluid and solid temperature distributions by considering the case A for variable wall heat fluxes, case B for variable wall temperature ratio and case C for temperature jump coefficient.

(b) Laminar Boundary Layer Flows with Thermal and Mass Diffusion

The study of laminar boundary layers in the presence of an oscillatory flow with a steady mean component was first undertaken by Lighthill (1954). He considered the effects of small fluctuations in the free stream velocity on the skin-friction and heat transfer for plates and cylinders by employing the Karman-Pohlhausen approximate integral method. Nanda and Sharma (1963) and Eshghy *et al.* (1965) later extended Lighthill's theory for free convective flows. Muhuri and Maiti (1967) and Singh *et al.* (1978) investigated the free-convection flow and heat transfer along a semi-infinite horizontal plate with a small amplitude surface temperature oscillation about a non-zero mean by using the approximate integral method.

Sakiadis (1961) was the first author to analyze the boundary layer flow on a continuous surface. Cheng and Minkowycz (1977) also studied free convection from a vertical flat plate with applications to heat transfer from a dick. The unsteady free convection flow past an infinite porous plate and semi-infinite plate were studied by Nanda and Sharma (1962). In their first paper they assumed the suction velocity at the plate varying in time as $t^{-\frac{1}{2}}$, whereas in the second paper the plate temperature was assumed to oscillate in time about a constant nonzero mean. Free convective flow past a vertical plate has been studied extensively by Ostrach (1953) and many others. The free convective heat transfer on vertical semi-infinite plate was investigated by Berezovsky *et al.* (1977). Martynenko *et al.* (1984) investigated the laminar free convection from a vertical plate.

Eckert (1958) studied the effect of mass transfer cooling of foreign gas injected to the boundary layer, the case of uniform suction and blowing through an isothermal vertical wall was treated by Sparrow and Cess (1961). Using suitable perturbation techniques Kelleher and Yang (1968) investigated the heat transfer response of laminar free convection boundary layers along vertical heated plates to surface-temperature oscillations. In this

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work the solutions of the governing non-similar equations for the fluctuating flow and heat transfer were obtained for both small and large frequencies. With an oscillating surface heat flux, the problem of natural convective flow from a vertical surface has been investigated by Hossain *et al*. (1998). They also investigated the additional effects of a transverse magnetic field on the problem posed by Kelleher and Yang. In all the above studies solutions were obtained for both small and large frequencies by using suitable perturbation techniques. For intermediate frequencies the equations governing the fluctuating flow and heat transfer were obtained by using both an implicit finite difference method and the local non-similarity method by Minkowycz and Sparrow (1978). Merkin (1975) obtained asymptotic solutions valid at large distances from the leading edge with suction or blowing. Clarke (1973) extended the range of suction or injection parameter using the method of matched asymptotic expansions. Lin and Yu (1976) studied the permeable wall heat transfer problem.

There are many transport processes in industry and in the environment in which buoyancy forces arise for both thermal and mass diffusion as a result of the co-existence of thermal and concentration gradients. Somers (1965), Wilcox (1961), and Gill *et al*. (1965) studied the effects of mass transfer on free convection. Similarity analysis of the natural convection flows adjacent to both vertical and horizontal surfaces which result from the combined buoyancy effects of thermal and mass diffusion was first investigated by Gebhart and Pera (1971) and Pera and Gebhart (1972). Hossain and Begum (1984) studied the combined effect of heat and mass transfer to unsteady convection flow from a doubly infinite vertical permeable surface with small-amplitude fluctuations in the free stream, the surface temperature, and the surface species concentration. Hossain (1988) investigated the effect of a fluctuating surface temperature on the unsteady two dimensional natural convection flows with uniform species concentration at the surface by the use of the Karman-Pohlhausen approximate integral method.

Combined effects of thermal and mass diffusion on the natural convection flow of a viscous incompressible fluid along a vertical wavy surface have been investigated by Hossain and Rees (1999). Again Hossain *et al*. (2001) has investigated a linearized theory how a free double-diffusive

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boundary layer flow is affected by small amplitude temporal variations in the surface temperature and species concentration and the mean temperature and the mean species concentration are assumed to vary as a power 'n' of the distance measured from the leading edge. In this analysis, three distinct methods, namely, a perturbation method for low frequencies, an asymptotic series expansion for high frequencies, and a finite difference method for intermediate frequencies, are used. Muthucumaraswamy and Ganesan (2002) have considered diffusion and first-order chemical reaction effects on impulsively-started infinite vertical plate with variable temperature. Anjali Devi and Kandasamy (2002) have studied the effects of chemical reaction, heat and mass transfer on non-linear MHD laminar boundary-layer flow over a wedge with suction or injection.

Muthucumaraswamy and Meenakshisundaram (2006) theoretical studied the chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion. Shrama and Singh (2010) investigated the effect of temperature dependent electrical conductivity on steady natural convection flow of a viscous incompressible low Prandtl ($Pr << 1$) electrically conducting fluid along an isothermal vertical non-conducting plate in the presence of transverse magnetic field and exponentially decaying heat generation. Cheng *et al*. (1988) studied the steady forced convection problem in packed sphere beds. **Makinde** and Chinyoka (2010) studied the unsteady flow and heat transfer of a dusty fluid between two parallel plates with variable viscosity and electric conductivity.

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(c) Convective MHD Flow

The study of forced and free convection flow and heat transfer for electrically conducting fluids past a semi-infinite porous plate under the influence of a magnetic field has attracted the interest of many investigators in view of its applications in many engineering problems such as geophysics, astrophysics, boundary layer control in the field of aerodynamics. Engineers employ MHD principle, in the design of heat exchangers pumps and flow meters, in space vehicle propulsion, thermal protection, braking, control and re-entry, in creating novel power generating systems etc. Because of the above practical importance of such problems

many researchers have been working in this field and some of these are mentioned here.

In recent years, the analysis of hydromagnetic flow involving heat and mass transfer in porous medium has attracted the attention of many scholars because of its possible applications in diverse fields of science and technology. The Magneto hydrodynamics in the present form is due to the contributions of several notable authors like Hartmann (1937), Shercliff (1965), Ferraro and Plumpton (1966), Hughes and Young (1966), Crammer and Pai (1973) etc.

Singh and Cowling (1963) have considered the effect of magnetic field on free convective flow of electrically conducting fluids past a semi-infinite flat plate. Soundalgekar (1974) studied the effects of free convection currents on steady MHD flow past a vertical porous plate. Sacheti *et al.* (1994) derived an exact solution for the unsteady MHD problem. Soundalgekar (1965) investigated the Hydromagnetic flow of a viscous incompressible fluid due to uniformly accelerated motion of an infinite flat plate in the presence of a magnetic field fixed relative to the plate and he found that velocity at any point and at any instant decreases when the strength of the magnetic field is increased. Usual Laplace transform technique, Kafousias and Georgantopoulos (1982) studied the transverse magnetic effects on the free convective flow of an incompressible, electrically conducting fluid past a non-conducting and non-magnetic, vertical limiting surface. Raptis and Soundalgekar (1984) determined the effects of mass transfer on the flow of an electrically conducting fluid past a steadily moving infinite vertical porous plate under the action of a transverse magnetic field. The hydromagnetic channel flow and temperature field was investigated by Attia and Kotb (1996). Greenspan and Carrier (1959) and Singh (1990, 1991) have studied extensively the hydromagnetic effects on the flow past a plate with or without injection/suction. Hossain *et al.* (1998) have studied the MHD free convection flow when the surface is kept at oscillating heat flux. The problem of the free convection flow of an electrically conducting fluid along a vertical plate embedded in a thermally stratified porous medium in the presence of a uniform normal magnetic field investigated by Chamkha (1997).

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Sharma and Chaudhary (2004) investigate the hydromagnetic effect on viscous incompressible flow between two horizontal parallel porous flat plates with transverse sinusoidal injection of the fluid at the stationary plate and its corresponding removal by periodic suction through the plate in uniform motion. Bég *et al.* (2009) obtained local non-similarity numerical solutions for the velocity, temperature and induced magnetic field distributions in forced convection hydromagnetic boundary layers, over an extensive range of magnetic Prandtl numbers and Hartmann numbers. Abdelkhalek (2009) presented for heat and mass transfer effect on hydromagnetic flow of a moving permeable vertical surface. Poonia and Chaudhary (2010) presented an unsteady, two-dimensional, hydromagnetic, laminar mixed convective boundary layer flow of an incompressible and electrically-conducting fluid along an infinite vertical plate embedded in the porous medium with heat and mass transfer by taking into account the effect of viscous dissipation. They also observed that increased cooling ($Gr > 0$) of the plate and the Eckert number leads to a rise in the velocity profile. Ahmed (2010) investigated the influence of thermal radiation and magnetic Prandtl number on the steady MHD heat and mass transfer by mixed convection flow of a viscous, incompressible, electrically-conducting, Newtonian fluid which is an optically thin gray gas over a vertical porous plate taking into account the induced magnetic field. Ahmed (2010) deals with the mixed convection hydromagnetic oscillatory flow and periodic heat transfer of a viscous incompressible and electrically conducting fluid past an infinite vertical porous plate.

The transient MHD free convective viscous flow occupying a semi-infinite porous regime adjacent to an infinite moving hot vertical plate with constant velocity has been analyzed by Ahmed and Kalita (2013). Mishra *et al.* (2013) have studied free convective fluctuating MHD flow through porous media past a vertical porous plate with variable temperature. Ahmed and Sinha (2014) presented the effects of the applied magnetic field on a three dimensional MHD time dependent flow of a viscous incompressible electrically conducting fluid bounded by an infinite vertical isothermal plate. Ahmed and Das (2013) discussed MHD mass transfer flow past a vertical porous plate embedded in a porous medium in a slip flow regime with thermal radiation and chemical reaction. MHD transient flows with hall

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current past an accelerated horizontal porous plate in a rotating system have been investigated by Ahmed *et al*. (2013). Das *et al*. (2015) considered Hall effects on unsteady hydromagnetic flow past an accelerated porous plate in a rotating system in view of the significance of the thermal diffusion.

The flow model of steady free convective MHD flow of an incompressible viscous electrically-conducting fluid over an infinite vertical isothermal porous plate with mass convection is investigated by Ahmed and Batin (2014). Ahmed *et al.* (2014) investigated for the model of unsteady MHD thermal convection flow of a viscous incompressible absorbing-emitting optically thin gray gas along an impulsively-started semi-infinite vertical plate adjacent to the *Darcian* porous regime in presence of a first order chemical reaction and significant thermal radiation effects. The study of the thermal radiation and chemical reaction effects on an unsteady MHD free convective mass transfer flow past an accelerated infinite vertical plate embedded in a porous medium was performed by Sarma *et al.* (2014). An investigation is performed for unsteady MHD boundary layer flow and heat transfer through a Darcian porous medium bounded by a uniformly moving semi-infinite isothermal vertical plate in presence of thermal radiation by Khatun and Ahmed (2015).

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Recently, Kowsalya and Begam (2016) analyzed the effects of hall current and thermal diffusion on MHD unsteady mass transfer flow past a semi-infinite vertical porous plate embedded in a porous medium in a slip flow regime in presences of Variable Suction, thermal Radiation and Chemical Reaction. Moreover, an analytical solution of a Magnetohydrodynamic steady mixed convective flow of an incompressible, viscous, Newtonian, electrically-conducting and chemically-reacting fluid over an infinite vertical porous plate with combined heat and mass transfer is presented by Ahmed *et al*. (2017).

(d) Flow through Porous Medium

Porous media theories play an important role in many branches of engineering, including material science, chemical engineering and petroleum industry, soil mechanics as well as in biomechanics. Studied of

flow through porous media are important in investigating underground water, oil and natural gas resources.

The study of origin of flow through porous media is heavily based on Darcy's experimental law (1856). Wooding (1956) and Brinkman (1947a, 1947b) have modified Darcy's law, which is used by a number of scholars to investigate convective flows through porous media. On some unsteady motions of a liquid and a gas in a porous medium studied by Barenblatt (1952). Aronson (1969) presented the regularity properties of flows through porous media. On a class of similarity solutions of the porous media equation have been investigated by Gilding and Peletier (1976). Simultaneous heat, mass and momentum transfer in porous studied by Whitaker (1977). Many authors have been worked on flow through porous media like Atkinson and Peletier (1971), Ghaboussi and Wilson (1973), Gilding and Peletier (1976), Vafai and Tien (1980, 1981), Varshney (1979), Whitaker (1986), Homsy (1987), Tung and Dhir (1988), Hassanizadeh and Gray (1990), Horvath (1991), Vadasz (1993), Olbricht (1996) and Yih (1998) etc.

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Hsiao and Luo (1996) investigated nonlinear diffusive phenomena of solutions for the system of compressible adiabatic flow through porous media. Many researchers have studied MHD free convective heat and mass transfer flow in a porous medium with different configurations; some of them are Raptis and Kafoussias (1982), Sattar (1993) and Kim (2004). Jaiswal and Soundalgekar (2001) obtained an approximate solution to the problem of an unsteady flow past an infinite vertical plate with constant suction and embedded in a porous medium with oscillating plate temperature. Kuwahara *et al.* (2001) investigated a numerical study in two-energy equation model for convection in porous media.

Alazmi and Vafai (2000, 2004) was analyzed the variants within the porous media transport models. The unsteady flow through a highly porous medium in the presence of radiation was studied by Raptis and Perdikis (2004). Choudhary and Jain (2007) presented combined heat and mass transfer effects on MHD free convection flow in porous medium. Non-Newtonian flow in porous media was presented by Sochi (2010). Chamkha *et al*. (2011) carried out a boundary layer analysis for the natural convection

past an isothermal sphere in a Darcy porous medium saturated with a nanofluid. A boundary layer analysis for the natural convection past a horizontal plate in a porous medium saturated with a nanofluid is analyzed by Gorla and Chamkha (2011). The problems of Magnetohydrodynamics (MHD) flows of porous media (Darcian and non-Darcian) saturated with Newtonian as well as non-Newtonian fluids studied by Chamkha and Aly (2010). Singh *et al*. (2013) was presented the periodic solution of oscillatory Couette MHD flow through porous medium. Chamkha *et al*. (2014) investigated the viscous dissipation and magnetic field effect in a Non-Darcy porous medium.

The radiating heat and mass transport in Darcian porous regime is analyzed by Ahmed *et al.* (2015). Guvindarajan *et al*. (2015) discussed combined effect of heat and mass transport through a porous medium. Pattnaik and Biswal (2015) studied the effects of MHD free convective flow through porous media with time dependent temperature and concentration. MHD mass transfer flow past a vertical porous plate embedded in a porous medium was presented by Kowsalya and Begam (2016). Seshaiah and Varma (2016) presented the chemical reaction effects on MHD free convective flow through porous medium. The effects of temperature-dependent viscosity and thermal conductivity on free convection magnetohydro-dynamic flow of an optically thin gray, viscous, and incompressible micropolar fluid and heat transfer past a stretching plate through porous medium in the presence of radiation, heat generation, and Joule dissipation presented by Hazarika and Phukan (2016) and solved numerically for prescribed boundary conditions using the shooting method.

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(e) Boundary Layer Flow for Thermal Radiation with or without Soret and Dufour Effect

In the context of space technology and in the process involving high temperature, the effects of radiations are vital importance. Recent developments in hypersonic flights, missile re-entry, combustion chambers, power plants for inter planetary flight and gas-cooled nuclear reactors have focused attention on thermal radiation as a mode of energy transfer and emphasized the need from improved understanding of radiative transfer in this process.

In the year 1969, a landmark work on radiation has been developed by England and Emery and in this paper they investigated the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Thermal radiation of a gray fluid which is emitting and absorbing radiation in a non-scattering medium has been investigated by Ali *et al*. (1984), Ibrahim and Hady (1990), Mansour (1990), Abdus-Sattar and Hamid Kalim (1996). Hossain and Takhar (1996) analyzed the effect of radiation using the Rosseland diffusion approximation which leads to non-similar solutions for the forced and free convection flow of an optically dense fluid from vertical surfaces with constant free stream velocity and surface temperature.

Korycki (2006) described radiative heat transfer as an important fundamental phenomena existing in practical engineering such as those found in solar radiation in buildings, foundry engineering and solidification processes, chemical engineering, composite structures applied in industry. Bakier (2001) presented an analysis to investigate the effect of radiation on mixed convection from a vertical flat plate in a saturated porous medium. In this study both a hot surface facing upward and a cold surface facing downward considered. Raptis *et al*. (2004) presented the effect of thermal radiation on MHD flow. Makinde and Mhone (2005) analyzed the force convection flow with thermal radiation and mass transfer past a moving vertical porous plate. The radiation effects on boundary layer flow with and without applying a magnetic field under different situations has been studied by many investigators, for examples: Israel-Cookey *et al*. (2003), Mahmoud and Ali (2007), Hayat *et al*. (2007).

Ferdows *et al*. (2004) analyzed free convection flow with variable suction in presence of thermal radiation. The effects of radiation on heat transfer in MHD mixed convection flow and mass transfer past an infinite vertical plate with Ohmic heating and viscous dissipation have been discussed Chaudhary *et al*. (2006). Using an implicit finite-difference method of Crank–Nicolson type, the interaction of free convection with thermal Radiation of a viscous incompressible unsteady flow past an impulsively started vertical plate with heat and mass transfer analyzed Prasad *et al*. (2007). Ogulu and Makinde (2009) are to consider unsteady hydromagnetic free convection flow for a dissipative and radiating fluid

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applying a simple perturbation technique. Prasad *et al.* (2010) studied the radiation and mass transfer effects on unsteady MHD free convection flow past a vertical porous plate embedded in porous medium. Pal and Talukdar (2010) studied Perturbation analysis of unsteady Magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Continuum equations governing mixed convection from a vertical surface embedded in a non-Darcy porous medium with aiding and opposing external flows in the presence of melting, radiation and heat generation or absorption effects for non-Newtonian fluids are developed by Chamkha *et al*. (2010). Analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting and heat generation/ absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, a first-order homogeneous chemical reaction and the mass flux are reported by Kesavaiah *et al.* (2011). Ahmed and Goswami (2011) have analyzed the effect of thermal diffusion on an oscillatory three dimensional flow with mass transfer past an infinite vertical porous plate in presence of a heat sink. Ibrahim *et al*. (2012) proposed the radiation and chemical reaction effects on MHD free convection flow past a moving vertical plate.

In view of the applications in geophysics, astrophysics and also in the design of high temperature industrial processing systems, Das *et al*. (2013) adopted an implicit finite difference scheme of Crank-Nicolson's type for the effects of radiation on unsteady free convection flow of a viscous incompressible fluid past a moving vertical plate embedded in a porous medium on taking into account viscous dissipative heat. The effects of Radiation and thermal diffusion on heat and mass transfer in MHD free convective flow through a porous medium in a vertical porous channel in the presence of Hall current have been presented Manglesh and Gorla (2013). The radiation and viscous dissipation effects on an unsteady MHD free convection heat and mass transfer flow of an in-compressible, electrically conducting, fluid past an infinite vertical porous plate with Hall current in the presence of chemical reaction has been carried out Reddy (2014). Etwire (2014) investigates the effects of Radiation and Chemical Reaction on magneto hydrodynamic stagnation point flow over a porous stretching surface with convective thermal boundary condition. Guria *et al*. (2015) investigate the effect of radiation on three dimensional flows past a

vertical porous plate subject to the periodic suction velocity distribution through porous medium. Das *et al*. (2017) have analyzed numerically for axi-symmetric laminar boundary-layer slip flow of a viscous incompressible rarefied gas in a convectively heated vertical cylinder in the presence of thermal radiation by the fourth order Runge-Kutta method with shooting technique.

On the other hand, when the heat and mass transfer occurs simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are more complicated. It was found that an energy flux can be generated not only by the temperature gradients but also by the composition gradients. The Soret and Dufour effects were neglected in many reported research studies, since they are of a smaller order of magnitude than the effects described by Fourier's and Fick's laws. However, such effects become crucial when the density difference exists in the flow regimes. The Soret effect, for instance, has been utilized for isotope separation. The Dufour effect was found to be of considerable magnitude such that it cannot be neglected [Eckert and Drake (1972)]. The Dufour and Soret effects were studied by many researchers. Some of them are Dursunkaya and Worek (1992), Kafoussias and Williams (1995), Anghel *et al*. (2000) etc. Ahmed (2010) investigated the Soret and Dufour effects of a magnetohydrodynamic three-dimensional convection flow past an infinite vertical porous plate. Due to the importance of Soret and Dufour effects for the fluids with very light molecular weight as well as medium molecular weight many investigators have studied and reported results for these flows of whom the names are Chamkha and Ben-Nakhi (2008), Reddy *et al*. (2010), Chamkha *et al*. (2011).

Rao *et al*. (2007) studied the radiation effect on an unsteady magnetohydrodynamic free convective flow past a vertical porous plate in the presence of Soret and Galerkin finite element method has been adopted for its solution, which is more economical from computational point of view. Bég *et al*. (2009) examined the combined effects of Soret and Dufour diffusion and porous impedance on laminar magnetohydrodynamic mixed convection heat and mass transfer of an electrically-conducting fluid, they applying two equal and opposing forces along the x-axis, the sheet is

stretched with a speed proportional to the distance from the fixed origin $x = 0$.

Ahmed and Sengupta (2011) have studied the Soret and Dufour effects on a three dimensional MHD mixed convection flow past an infinite vertical porous plate with thermal radiation. A two-dimensional unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical porous plate in a porous medium in presence of thermal radiation and chemical reaction has been studied numerically including the Dufour and Soret effects by Ibrahim (2014). Reddy *et al.* (2013) have investigated the effects of first-order homogeneous chemical reaction and thermal radiation on hydromagnetic free convection heat and mass transfer for a micropolar fluid past a semi-infinite vertical moving porous plate in the presence of thermal diffusion and Rosseland approximation is used to describe the radiative heat flux in the energy equation.

An implicit finite difference scheme was considered by Gadipally and Gundagani (2014) for the Soret and Dufour effects on unsteady MHD mixed convective boundary layer flow of a viscous incompressible, electrically conducting fluid past a semi-infinite vertical porous moving plate taking into account the mass transfer with variable viscosity and thermal conductivity. Srinivasacharya *et al.* (2015) presented the results of Soret and Dufour on mixed flow along a wavy surface in a Darcy porous medium in the presence of cross diffusion effects with the variable viscosity and thermal conductivity. By shooting method along with Runge-Kutta fourth order integration scheme, Vedavathi *et al.* (2015) studied with the effects of Dufour and Soret on two-dimensional unsteady MHD free convection flow past a vertical porous plate in a porous medium in the presence of thermal conductivity. The homotopy analysis method (HAM) with two auxiliary parameters is employed to examine heat and mass transfer in a steady two-dimensional magneto hydrodynamic viscoelastic fluid flow over a stretching vertical surface by considering Soret and Dufour effects have been presented by Rashidi *et al*. (2015).

Recently, Reddy and Chamkha (2016) is focused on the study of heat and mass transfer characteristics of an unsteady MHD boundary layer flow through porous medium over a stretching sheet in the presence of thermo-

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diffusion and diffusion-thermo effects with thermophoresis. Heat and mass transfer characteristics of MHD forced convection flow over a non-isothermal stretching sheet embedded in a porous medium subjected to a heat source is investigated numerically by taking into account the Soret and Dufour effects by Sharma and Aich (2016). Zueco *et al.* (2017) has been analyzed the steady-state solutions of unsteady MHD free convective heat and mass transfer flow of an electrically conducting viscous incompressible and Newtonian fluid past a continuously moving semi-infinite vertical porous plate under the action of strong magnetic field and Soret effects taking into account the induced magnetic field with thermal diffusion. In this study, numerical solutions are obtained using two numerical methods: Finite Difference and Network Simulation methods where stability and convergence of the explicit finite difference scheme are established.

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Chapter - II

Analytical study of Unsteady Magnetohydrodynamic Chemically reacting fluid over a Vertical Porous Plate in a Darcian Porous Regime: A Rotating system

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2.1. Introduction :

The hydrodynamic rotating flow of electrically conducting viscous incompressible fluids has gained considerable attention because of its numerous applications in physics and engineering which are directly governed by the action of Coriolis and magnetic forces. In geophysics it is applied to measure and study the positions and velocities with respect to a fixed frame of reference on the surface of earth which rotate with respect to an inertial frame in the presence of its magnetic field. The subject of geophysical dynamics now a day has become an important branch of fluid dynamics due to the increasing interest to study environment. In astrophysics it is applied to study the stellar and solar structure, inter planetary and inter stellar matter, solar storms and flares etc. In engineering it finds its application in MHD generators, ion propulsion, MHD bearings, MHD pumps, MHD boundary layer control of reentry vehicles etc. Several scholars viz. Crammer and Pai (1973), Ferraro and Plumpton (1966), Shercliff (1965) have studied such flows on account of their varied importance.

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Several investigations are carried out on the problem of hydrodynamic flow of a viscous incompressible fluid in rotating medium considering various variations in the problem. Mention may be made of the studies Greenspan and Howard (1963), Holton (1965), Walin (1969), Siegmann (1971), Hayat and Hutter (2004), Singh *et al*. (2005). The problem of Magnetohydrodynamic flow of a viscous incompressible electrically conducting fluid in a rotating medium is studied by many researchers, namely, Ghosh (2001), Singh (2000), Hossain *et al*. (2001), Ghosh and Pop (2002), Hayat *et al*. (2008), Hayat and Abelman (2007), Abelman *et al*. (2009), Wang and Hayat (2004) under different conditions and configurations to analyze various aspects of the problem and to find its application in Science and Engineering. Seth *et al*. (2011) studied the unsteady hydromagnetic Couette flow of a viscous incompressible electrically conducting fluid in a rotating system in the presence of a uniform transverse magnetic field.

Greenspan (1990) carried out a pioneer work on the theory of rotating fluid, and Thronley (1968) gave theoretical presentation of Stokes and

Rayleigh layers in rotating systems. Mahato and Maiti (1988) investigated a flow model on unsteady free Convective flow and mass transfer in a Rotating Porous Medium. A rich variety of important analytical, numerical and experimental investigations concerning the rotating system of fluid are available in the literatures based on the basic work of Greenspan, Batchelor (1967), Cowling (1957), Gupta (1972), Pop and Soundalgekar (1973), Puri (1975), El-Kabeir *et al*. (2007) and Gebhart *et al*. (1988). Vidyanidhi and Nigam (1967) considered viscous flow between rotating parallel plates under constant pressure gradient. Free convection effects on flow past an accelerated vertical plate with variable suction and uniform heat flux in presents of magnetic field was studied by Raptis *et al*. (1981). Mass transfer effects on flow past a uniformly accelerated vertical plate was analyzed by Soundalgekar (1982). MHD effects on flow past an infinite vertical plate for both the classes of impulse as well as accelerated motion of the plate presented by Raptis and Singh (1985). Magnetohydrodynamic oscillatory convective flow of a viscous, incompressible and electrically conducting fluid in a rotating vertical porous channel is analytically investigated by Singh (2012).

Moreover, natural convection in a fluid-saturated porous medium is of fundamental importance in many industrial and environmental problems. On the other hand, heat and mass transfer from a vertical flat plate is encountered in various applications such as heat exchangers, cooling systems and electronic equipment. In addition, Non-Newtonian fluids such as molten plastics, polymers, glues, ink, pulps, foodstuffs or slurries are increasingly used in various manufacturing, industrial and engineering applications especially in the chemical engineering processes. Singh (2011) obtained an exact solution of an oscillatory MHD flow in a channel filled with porous medium. Ahmed (2008) investigated the effect of transverse periodic permeability oscillating with time on heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate, by means of series solution method. The effect of transverse periodic permeability oscillating with time on the free convective heat transfer flow of a viscous incompressible fluid through highly porous medium bounded by an infinite vertical porous plate subjected to a periodic suction velocity was presented by Ahmed (2010). The transient natural convection-radiation flow of viscous dissipation fluid along an

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infinite vertical surface embedded in a porous medium, by means of network simulation method, investigated by Zueco (2008). The study of vertical channel flow bounded by a wavy wall and a vertical flat plate filled with porous medium was presented by Ahmed (2008). Later on Ahmed (2009) also investigated the effects of free convection heat transfer on the three-dimensional channel flow through a porous medium with periodic injection velocity. Fasogbon (2010) studied the simultaneous buoyancy force effects of thermal and species diffusion through a vertical irregular channel by using parameter perturbation technique. Ahmed and Zueco (2011) investigated the effects Hall current, magnetic field on the oscillatory free convective MHD flow in a rotating vertical porous channel when the entire system rotates about an axis normal to the channel plates and a strong magnetic field of uniform strength is applied along the axis of rotation.

Also, Ahmed (2010) investigated the effects of periodic heat transfer on unsteady MHD mixed convection flow past a vertical porous flat plate with constant suction and heat sink when the free stream velocity oscillates in about a non-zero constant mean. The steady Magnetohydrodynamic (MHD) mixed convection stagnation point flow over a vertical flat plate is investigated by Ali *et al*. (2011). A numerical simulation on unsteady hydromagnetic free convection near a moving infinite flat plate in a rotating medium is presented by Harouna (2010). Muthucumaraswamy *et al*. (2011) studied the effects of rotation on the hydromagnetic free convection flow of an incompressible viscous and electrically conducting fluid past a uniform accelerated infinite vertical plate in the presence of variable temperature and uniform mass diffusion.

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The present work is focuses on the rotating system in a Darcian porous regime with the effect of unsteady hydromagnetic first order chemically reacting fluid in presence of variable heat and mass transport. The boundary layer equations are solved analytically and the numerical results are presented graphically.

2.2 Mathematical Formulation :

We consider an infinite vertical porous plate rotates in unison with a viscous fluid occupying the porous region with the constant angular velocity Ω about an axis which is perpendicular to the vertical plane surface. The Cartesian Co-ordinate system is chosen such that x, y - axes respectively are in the vertical upward and perpendicular directions on the plane of the vertical Porous surface z = 0 while z - axis is normal to it as shown in Fig. 2.1. With the above frame of reference and assumptions, and physical variables, except the pressure p, are functions of z and time t only.

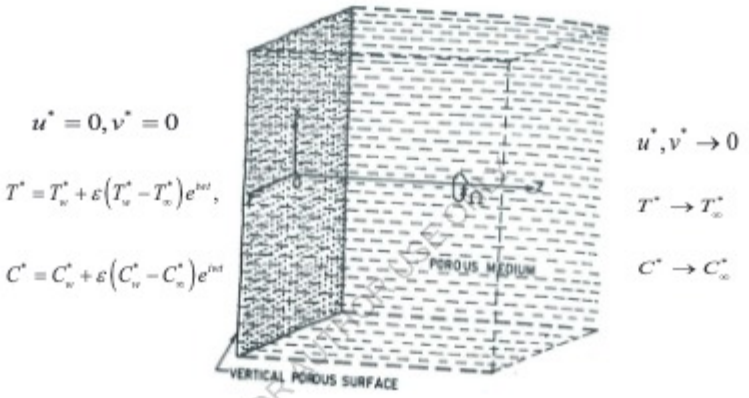

Fig. 2.1: Flow configuration

The boundary layer equations expressing the conservation of mass, momentum and energy and the equation of mass transfer, neglecting the heat due to viscous dissipation which is valid for small velocities are:

$$\frac{\partial w^*}{\partial z^*} = 0 \tag{2.2.1}$$

$$\frac{\partial u^*}{\partial t^*} + w^* \frac{\partial u^*}{\partial z^*} - 2\Omega v^* = \left\{ \begin{matrix} g\beta(T^* - T_\infty^*) + g\beta^*(C^* - C_\infty^*) \\ + \nu \frac{\partial^2 u^*}{\partial z^{*2}} - \frac{\nu}{K^*} u^* - \frac{\sigma B_0^2 u^*}{\rho} \end{matrix} \right\} \tag{2.2.2}$$

$$\frac{\partial v^*}{\partial t^*} + w^* \frac{\partial v^*}{\partial z^*} + 2\Omega u^* = \nu \frac{\partial^2 v^*}{\partial z^{*2}} - \frac{\nu}{K^*} v^* - \frac{\sigma B_0^2 v^*}{\rho} \tag{2.2.3}$$

$$0 = -\frac{1}{\rho}\frac{\partial p^*}{\partial z^*} - \frac{\nu}{K^*}w^* \tag{2.2.4}$$

$$\frac{\partial T^*}{\partial t^*} + w^*\frac{\partial T^*}{\partial z^*} = \frac{k}{\rho\, C_p}\frac{\partial^2 T^*}{\partial z^{*2}} \tag{2.2.5}$$

$$\frac{\partial C^*}{\partial t^*} + w^*\frac{\partial C^*}{\partial z^*} = D\frac{\partial^2 C^*}{\partial z^{*2}} - C_r^*\,(C^* - C_\infty^*) \tag{2.2.6}$$

The corresponding boundary conditions are:

$$\left[\begin{array}{l} \left.\begin{array}{l} u^* = 0\,, v^* = 0\,,\; T^* = T_w^* + \varepsilon\,(T_w^* - T_\infty^*)\,e^{i\omega^* t^*}, \\ \qquad C^* = C_w^* + \varepsilon\,(C_w^* - C_\infty^*)\,e^{i\omega^* t^*}, \end{array}\right\} \text{at } z^* = 0 \\ \\ u^*, v^* \to 0\,, T^* \to T_\infty^*, C^* \to C_\infty^* \qquad as \quad z^* \to \infty \end{array}\right] \tag{2.2.7}$$

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In physically realistic situation, we cannot ensure perfect insulation in any experimental setup. There will always be some fluctuations in the temperature. The plate temperature is assumed to vary harmonically with time. It varies from $T_w^* \pm \varepsilon\,(T_w^* - T_\infty^*)$ as t varies from 0 to $\frac{2\pi}{\omega}$. Since ε is small, the plate temperature varies only slightly from the mean value T_w^*.

For constant suction, we have from Eq. (2.2.1) in view of conditions (2.2.7)

$$w^* = -w_0 \tag{2.2.8}$$

Considering $u^* + iv^* = U^*$ and taking into account Eq. (2.2.8), then Eqs. (2.2.2) and (2.2.3) can written as

$$\frac{\partial U^*}{\partial t^*} - w_0\frac{\partial U^*}{\partial z^*} + 2\Omega i U^* = \left\{\begin{array}{l} g\beta(T^* - T_\infty^*) + g\beta^*(C^* - C_\infty^*) \\ +\nu\dfrac{\partial^2 U^*}{\partial z^{*2}} - \dfrac{\nu}{K^*}U^* - \dfrac{\sigma B_0^2\, U^*}{\rho} \end{array}\right\} \tag{2.2.9}$$

We introduce the following non-dimensional quantities:

$$\left.\begin{array}{c} z = \frac{w_0\, z^*}{\nu}\,,\quad U = \frac{U^*}{w_0}\,,\quad t = \frac{t^*\, w_0^2}{\nu}\,,\quad \omega = \frac{\nu\,\omega^*}{w_0^2}, \\ M^2 = \frac{\sigma B_0^2\,\nu}{\rho w_0^2},\quad K_0 = \frac{w_0^2\,K^*}{\nu^2}, T = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*},\quad C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, \\ Pr = \frac{\rho\,\nu C_p}{k},\quad Sc = \frac{\nu}{D}\,,\quad Gr = \frac{\nu g\beta(T_w^* - T_\infty^*)}{w_0^3}\,, \\ Gm = \frac{\nu g\beta^*(C_w^* - C_\infty^*)}{w_0^3}\,,\quad R = \frac{\Omega\nu}{w_0^2}\,,\quad C_r = \frac{\nu C_r^*}{w_0^2} \end{array}\right\} \quad (2.2.10)$$

In view of the non-dimensional quantities (2.2.10), Eqs (2.2.9), (2.2.5), and (2.2.6) reduce respectively to,

$$\frac{\partial U}{\partial t} - \frac{\partial U}{\partial z} + 2RiU = GrT + GmC + \frac{\partial^2 U}{\partial z^2} - \left(\frac{1}{K_0} + M^2\right)U \qquad (2.2.11)$$

$$\frac{\partial T}{\partial t} - \frac{\partial T}{\partial z} = \frac{1}{Pr}\frac{\partial^2 T}{\partial z^2} \qquad (2.2.12)$$

$$\frac{\partial C}{\partial t} - \frac{\partial C}{\partial z} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - C_r C \qquad (2.2.13)$$

and boundary condition (2.2.7) becomes

$$\left.\begin{array}{c} U = 0\,,\ T = 1 + \varepsilon e^{i\omega t}\,,\ C = 1 + \varepsilon e^{i\omega t} \ \text{ at } \ z = 0 \\ U \to 0\,,\ T \to 0,\ C \to 0 \quad \text{as} \quad z \to \infty \end{array}\right\} \quad (2.2.14)$$

2.3 Method of Solution :

In order to reduce the system of partial differential Eqs (2.2.11) to (2.2.13) under the boundary conditions (2.2.14), to a system of ordinary differential equations in the non-dimensional form, we assume the following for velocities, temperature and concentration of the flow field as the amplitude ε ($\ll 1$) of the permeability variations is very small.

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$$\left.\begin{aligned} U(z,t) &= U_0(z) + \varepsilon e^{i\omega t} U_1(z) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \\ T(z,t) &= T_0(z) + \varepsilon e^{i\omega t} T_1(z) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \\ C(z,t) &= C_0(z) + \varepsilon e^{i\omega t} C_1(z) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \end{aligned}\right\} \quad (2.3.15)$$

Substituting Eq. (2.3.15) into the system Eqs (2.2.11) to (2.2.13) and equating harmonic and non- harmonic terms, we get

$$U_0'' + U_0' - 2iRU_0 - (K_0^{-1} + M^2)U_0 = -(GrT_0 + GmC_0) \quad (2.3.16)$$

$$U_1'' + U_1' - U_1\left(K_0^{-1} + M^2 + i(\omega + 2R)\right) = -(GrT_1 + GmC_1) \quad (2.3.17)$$

$$T_0'' + PrT_0' = 0 \quad (2.3.18)$$

$$T_1'' + PrT_1' - i\omega PrT_1 = 0 \quad (2.3.19)$$

$$C_0'' + ScC_0' - ScC_rC_0 = 0 \quad (2.3.20)$$

$$C_1'' + ScC_1' - (i\omega + C_r)\,ScC_1 = 0 \quad (2.3.21)$$

The appropriate boundary conditions reduce to

$$\left.\begin{aligned} &U_0(0) = 0, \quad T_0(0) = 1, \quad C_0(0) = 1 \\ &U_1(0) = 0, \quad T_1(0) = 1, \quad C_1(0) = 1 \\ &U_0(\infty) \to 0, \quad T_0(\infty) \to 0, \quad C_0(\infty) \to 0 \\ &U_1(\infty) \to 0, \quad T_1(\infty) \to 0, \quad C_1(\infty) \to 0 \end{aligned}\right\} \quad (2.3.22)$$

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without going details, the solutions of Eqs (2.3.16) to (2.3.21) subject to the conditions (2.3.22) can be shown as

$$U_0(z) = -L_1e^{-Prz} - L_1e^{-\eta_1 z} + L_3e^{-\lambda_1 z} \quad (2.3.23)$$

$$U_1(z) = -L_4e^{-\xi z} - L_5e^{-\eta_2 z} + L_6e^{-\lambda_2 z} \quad (2.3.24)$$

$$T_0(z) = e^{-Prz} \quad (2.3.25)$$

$$T_1(z) = e^{-\xi z} \quad (2.3.26)$$

$$C_0(z) = e^{-\eta_1 z} \quad (2.3.27)$$

$$C_1(z) = e^{-\eta_2 z} \quad (2.3.28)$$

In the view of the above solutions, the velocity, temperature and concentration of the boundary layer become

$$U(z,t) = \begin{Bmatrix} -L_1 e^{-Prz} - L_1 e^{-\eta_1 z} + L_3 e^{-\lambda_1 z} \\ +\varepsilon e^{i\omega t}\left(-L_4 e^{-\xi z} - L_5 e^{-\eta_2 z} + L_6 e^{-\lambda_2 z}\right) \end{Bmatrix}$$

$$T(z,t) = e^{-Prz} + \varepsilon e^{i\omega t} e^{-\xi z}$$

$$C(z,t) = e^{-\eta_1 z} + \varepsilon e^{i\omega t} e^{-\eta_2 z}$$

2.3.1 Skin-Friction

The Skin-Friction at the plate z = 0 is given by

$$\tau = \left(\frac{\partial U}{\partial z}\right)_{z=0} = \left(\frac{\partial U_0}{\partial z}\right)_{z=0} + \varepsilon e^{i\omega t}\left(\frac{\partial U_1}{\partial z}\right)_{z=0}$$

$$= (PrL_1 + \eta_1 L_2 - \lambda_1 L_3) + \varepsilon e^{i\omega t}(\xi L_4 + \eta_2 L_5 - \lambda_2 L_6)$$

$$= \tau_0 + \varepsilon(cos\omega t + sin\omega t)\tau_1$$

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2.3.2 Rate of mass transfer

The rate of mass transfer in terms of Sherwood number (Sh) is given by

$$Sh = \left(\frac{\partial C}{\partial z}\right)_{z=0} = \left(\frac{\partial C_0}{\partial z}\right)_{z=0} + \varepsilon e^{i\omega t}\left(\frac{\partial C_1}{\partial z}\right)_{z=0}$$

$$= -\eta_1 - \varepsilon e^{i\omega t}\eta_2$$

2.4 Validity :

In order to validate the accuracy of the calculated present numerical values, the present numerical results are compared with Mahato and Maiti (1988).

Table – 1: Comparison of values of the Primary flow velocity (u) for the Rotation parameter (R) with those obtained by Mahato and Maiti (1988) when $Pr = 0.71$, $Sc = 0.78$, $M = 5$, $K_0 = 0.1$, $Gr = Gm = 5$, $\omega = 5$, $t = 0.2$ and $\varepsilon = 0.02$.

	Present Work			**Mahato and Maiti (1988)**		
z	$R = 0$	$R = 5$	$R = 10$	$R = 0$	$R = 5$	$R = 10$
0	0	0	0	0	0	0
2	0.0558548	0.0516316	0.0421268	0.0574566	0.0531155	0.0433424
4	0.0115506	0.0106874	0.0087290	0.0120562	0.011555	0.0091117
6	0.0024974	0.0023106	0.0018873	0.0026166	0.0024209	0.0019773
8	0.0005591	0.0005173	0.0004225	0.0005840	0.0005404	0.0004414
10	0.0001284	0.0001188	0.0009705	0.0001333	0.0001233	0.0001008

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Table – 2: Comparison of values of the Primary flow velocity (u) for the Magnetic body force (M) with those obtained by Mahato and Maiti (1988) when $Pr = 0.71$, $Sc = 0.78$, $R = 5$, $K_0 = 0.1$, $Gr = Gm = 5$, $\omega = 5$, $t = 0.2$ and $\varepsilon = 0.02$.

	Present Work			**Mahato and Maiti (1988)**		
z	$M = 0$	$M = 5$	$M = 10$	$M = 0$	$M = 5$	$M = 10$
0	0	0	0	0	0	0
2	0.0980921	0.0516316	0.0176741	0.0991812	0.0522003	0.0178697
4	0.0203117	0.0106874	0.0036568	0.020646	0.0108628	0.0037169
6	0.00439148	0.0023106	0.0007908	0.0044683	0.0023510	0.0008047
8	0.00098335	0.0005173	0.0001771	0.0009905	0.0005255	0.0001799
10	0.00022589	0.0001188	0.0000407	0.0002289	0.0001204	0.0000412

2.5 Results and Discussion :

The effects of flow parameters such as the Magnetic Parameter (M), Rotation parameter (R), Porosity parameter (K_0), Chemical reaction (C_r), Prandtl number (Pr), Schmidt number(Sc) on Primary, Secondary velocity field, Concentration, Skin-friction and Sherwood number have been studied analytically and presented with the help of Figs. 2.2 to 2.13 The dimensionless Primary and Secondary velocity components for different values of $Gr = 5 = Gm$, $K_0 = 0.1$, $R = 5$, $M = 5$, $\varepsilon = 0.02$, $Sc = 0.78$ (Ammonia), $Pr = 0.71$(air), $t = 0.2$ are shown in Figs. 2.2 to 2.9.

The primary velocity profiles (u) are plotted in **figure 2.2** for various values of Magnetic body force (M). It is obvious that the existence of the magnetic field is to decrease the velocity in the momentum boundary layer because the application of the transverse magnetic field results in a resisting type of force called Lorentz force, similar to drag force that resists the fluid flow which results in reducing the velocity of the fluid in the boundary layer.

In **figure 2.3** it has also been observed that, the Primary Velocity decelerated with the increase of Rotation Parameter (R). The primary velocity profiles across the boundary layer are shown in **figure 2.4** for various values of the Porosity parameter (K_0). It is clearly seen that as K_0 increases the velocity profiles across the boundary layer increases since the resistance offered by the porous medium decreases as the permeability of the porous medium increases. But with the existence of porosity the Primary Velocity gradually increases near the plate and then decreases to zero at the free stream. Inspection of **figure 2.5** shows that an increase in the Chemical reaction (C_r) induces a significant deceleration in the flow velocity (u)

In **figure 2.6** the influence of Magnetic body force (M) on secondary velocity (v) evolution through the boundary layer is plotted. With an increase in M, there is a strong deceleration in the flow in magnitude. **Figure 2.7** illustrates the influence of the Rotation Parameter (R) on the secondary velocity profiles. It is seen that the secondary velocity is accelerated in magnitude with the increase of Rotation Parameter (R).

In **figure 2.8** we observe that with an increase in Porosity Parameter (K_0) (over 0.1 through 0.3, 0.5, 0.7 to 0.9) there is a considerable increase in magnitude of the secondary velocity (v). The effects of Chemical Reaction (C_r) on secondary velocity profiles are presented in **figure 2.9**. From this figure we observe that, as the value of C_r increases, the flow velocity decelerated in the momentum boundary layer. Moreover, all the profiles of secondary flow velocities for the influence of M, R, K_0 and C_r are highly negative from the plate, and hence there is significant flow reversal.

The Skin-Friction (τ_u) for primary velocity profiles have been plotted for Rotation parameter (R) and Magnetic body force (M) in **figure 2.10.** It is seen that the skin-friction reduces with the increase of M or R near the plate $z = 0$, but away the plate the profiles approaches to a converging point 0.48375.

The Primary Skin-friction (τ_u) distribution for the effect of porosity (K_0) and magnetic body force (M) is presented in **figure 2.11**. Near the plate $z = 0$, it is seen that the porosity suppressed the skin-friction, while this trend is reversed away the plate. Moreover, the values of skin-friction reduce for the bigger values of Hartmann number and all the profiles reduce to a converging point.

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The effect of generative chemical reaction parameter (C_r) on the species concentration profiles is illustrated in **figure 2.12**. It is noticed from this graph that there is marked effect of increasing the values of the chemical reaction (C_r) on the solutal boundary layer. It is observed that for increasing values of the chemical reaction decreases the concentration of species in the boundary layer.

Figure 2.13 depicts the Sherwood number (Sh) for various values of Chemical reaction (C_r) and Schmidt number (Sc) in the boundary layer. It is seen that the effect of C_r or Sc is to increase the Sherwood number in the boundary layer. All the profiles of Sherwood number are negative due to foreign species of concentration in presence of generative chemical reaction.

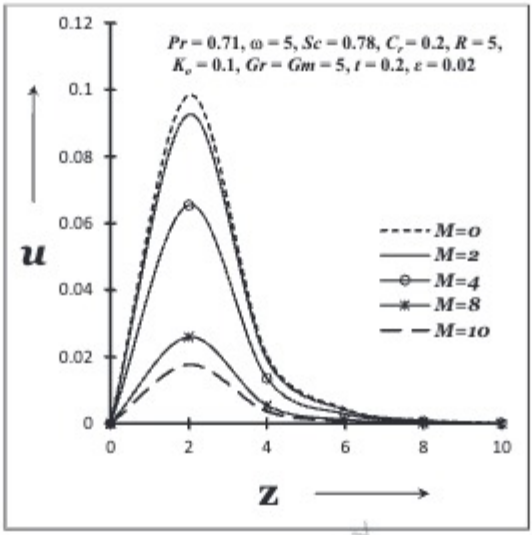

Fig. 2.2: Primary velocity distribution for Magnetic field

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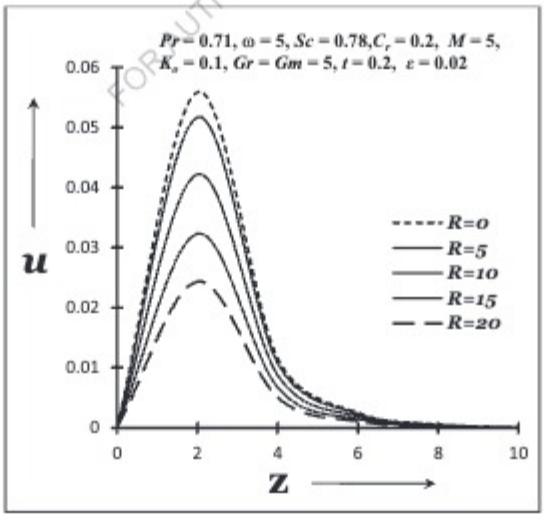

Fig. 2.3: Primary velocity distribution for Rotation parameter

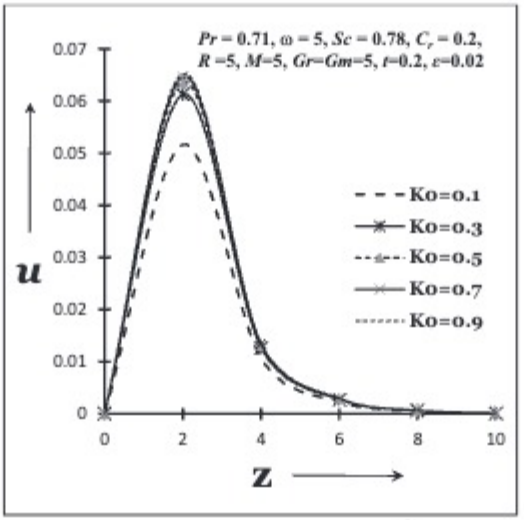

Fig. 2.4: Primary velocity distribution for Porosity

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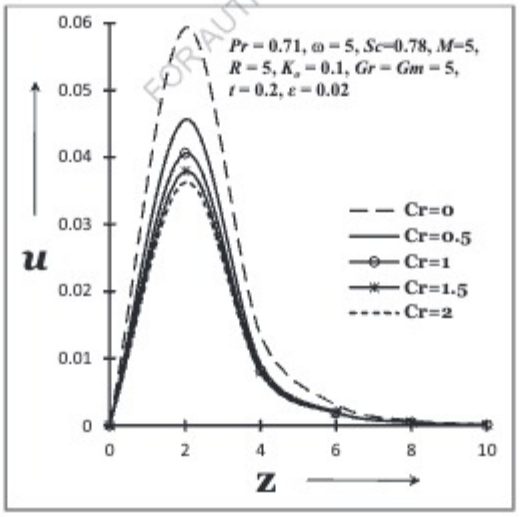

Fig. 2.5: Primary velocity distribution for Chemical Reaction

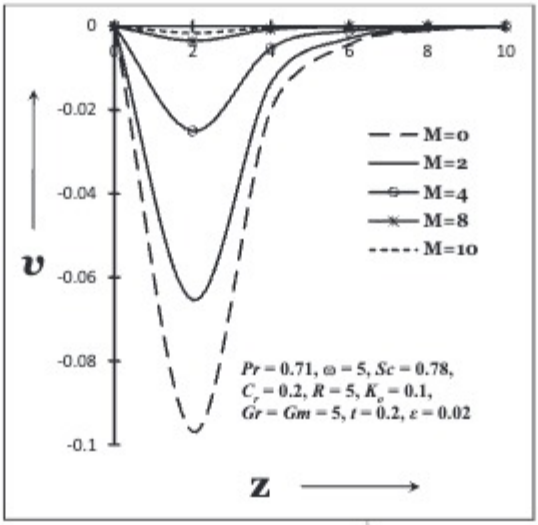

Fig. 2.6: Secondary velocity distribution for Magnetic Field

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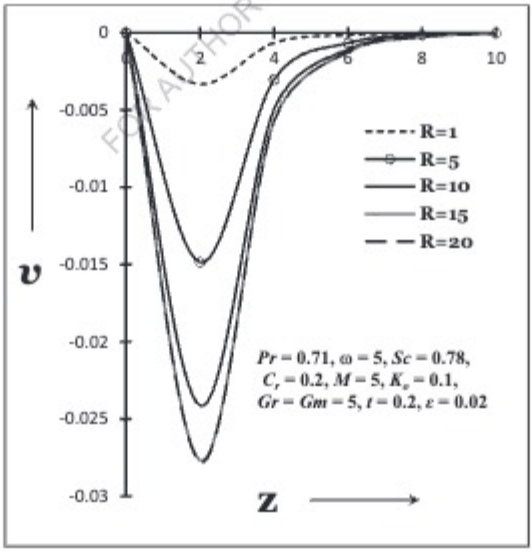

Fig. 2.7: Secondary velocity distribution for Rotation Parameter

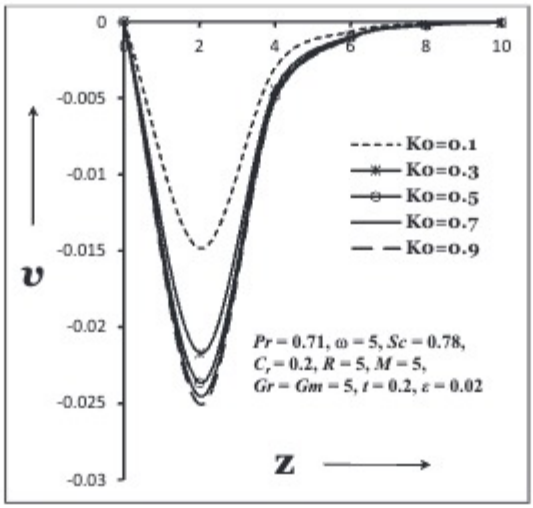

Fig. 2.8: Secondary velocity distribution for Porosity

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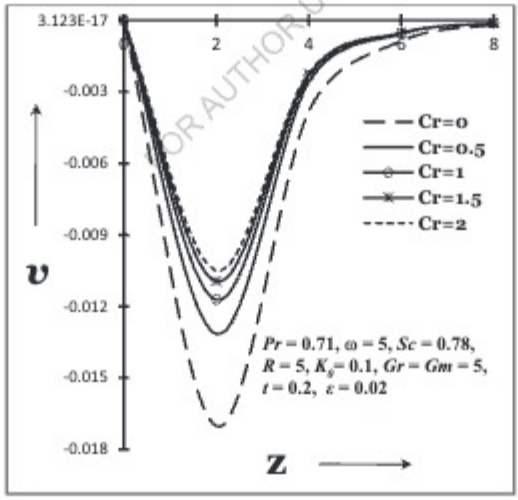

Fig. 2.9: Secondary velocity distribution for Chemical Reaction

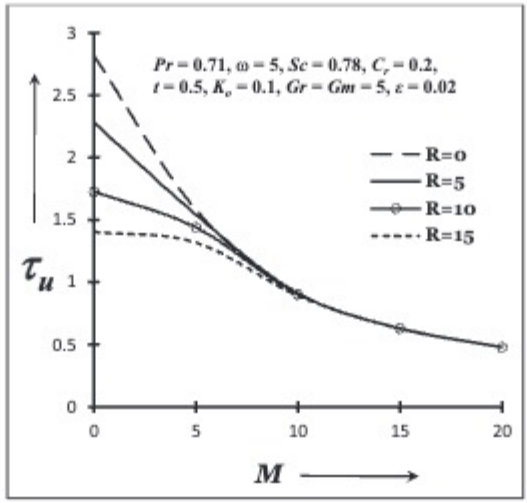

Fig. 2.10: Primary Skin-friction for Rotation Parameter and Magnetic field

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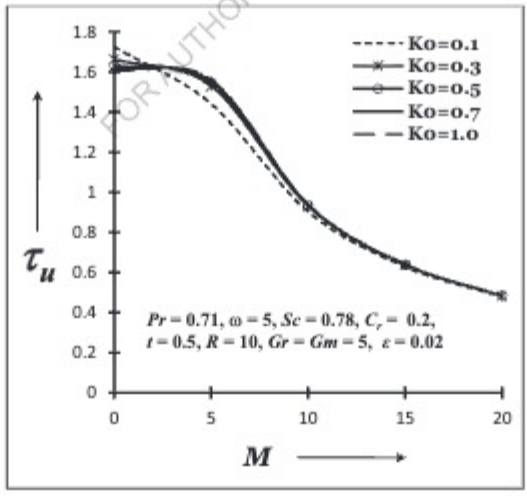

Fig. 2.11: Primary Skin-friction distribution for Porosity and Magnetic field

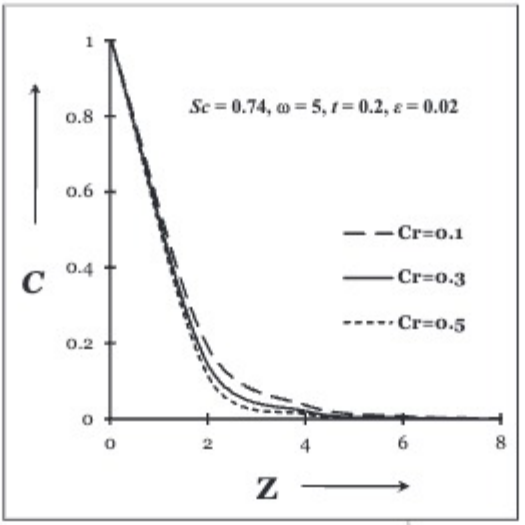

Fig. 2.12: Concentration distribution for Chemical Reaction

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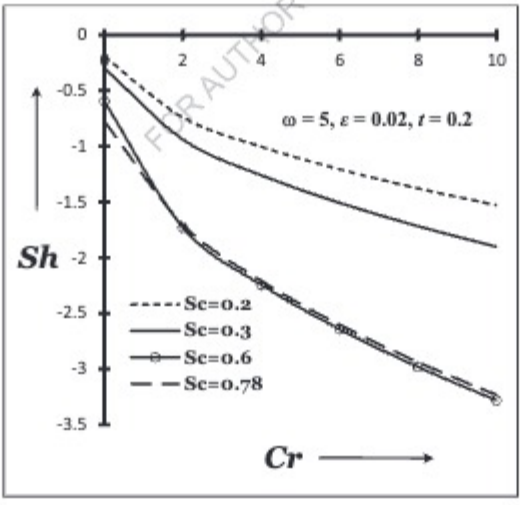

Fig. 2.13: Sherwood number for Chemical Reaction and Schmidt number.

2.6 Conclusion :

The Problem of unsteady MHD free convective flow with heat and mass transfer effects in a rotating porous medium in presence of first order Chemical reaction has been considered. The solutions for Primary and Secondary velocity field and Concentration profiles are obtained using the perturbation technique. All numerical calculation has been done through Mathematica Code 8.0. The above analysis brings out the following results.

- It is observed that existence of Magnetic body force, Rotation Parameter and Chemical reaction decreases the Primary Velocity;
- It is observed that in the presence of Magnetic body force and Chemical reaction, the Secondary velocity decreases but in the existence of Rotation Parameter and Porosity, the secondary velocity increases. For all the values of secondary velocity (v) are negative, so back flow has been observed;
- The Permeability parameter (K_0) and Magnetic body force (M) have the influence of increasing the Primary Skin-friction;
- The Concentration boundary layer decreases with increasing values of the Chemical reaction parameter (C_r);
- The Chemical reaction (C_r) and Schmidt number (Sc) have the influence of decreasing the Rate of Shear Stress.

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Chapter - III

Analytical Study of Darcian drag forced and Heat absorption on a periodic Heat and Mass Transport along a Vertical surface in presence of Magnetic field

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3.1 Introduction :

Heat and mass transport with chemical reaction occurs almost in many branches of science and engineering. There are two types of chemical reactions, homogeneous and heterogeneous. In a mixed system, a reaction is said to be homogeneous if it takes place uniformly in the entire given phase and heterogeneous if it takes place in a restricted region or within the boundary of the phase. In most chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be first order if the rate of reaction is directly proportional to concentration. In many chemical engineering processes, chemical reaction occurs between a foreign mass of the fluid. This type of chemical reaction may change the temperature and the heat content of the fluid and may affect the free convection process.

In many chemical engineering processes, the chemical reaction does occur between a mass and fluid in which plate is moving. These processes take place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing. In the light of the fact that, the combination of heat and mass transfer problems with chemical reaction are of importance in many processes, and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electricity is one in which electrical energy is extracted directly from moving conducting fluid. Kumar and Gupta (2008) investigated the effect of variable permeability on unsteady two-dimensional free convective flow through a porous medium bounded by a vertical porous surface. Sharma *et al.* (2011) have studied the influence of chemical reaction on unsteady MHD free convective flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in the presence of heat source. Muthucumaraswamy and Ganesan (2001) studied the effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate.

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Simultaneous heat and mass transfer from different geometries embedded in porous media has many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors and underground energy transport. Cheng and Minkowycz (1977) have presented similarity solutions for free thermal convection from a vertical plate in a fluid-saturated porous medium. The Problem of combined thermal convection from a semi-infinite vertical plate in the presence or absence of a porous medium has been studied by many authors. Nakayama and Koyama (1987) have studied pure, combined and forced convection in Darcian and non-Darcian porous medium. Lai and Kulacki (1991) have investigated coupled heat and mass transfer by mixed convection from an isothermal vertical plate in a porous medium. Hsieh *et al.* (1993) has presented non-similar solutions for combined convection in porous medium. Chamkha (1997) has investigated hydrodynamic natural convection from an isothermal inclined surface adjacent to a thermally stratified porous medium.

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Magnetohydrodynamic (MHD) transient convective flow with heat and mass transfer has been a subject of interest of many researchers because of its varied applications in science and technology, which involves the interaction of several phenomena. The phenomena of free convection arise in the fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. In natural process and industrial applications many transport processes exist where transfer of heat and mass takes place simultaneously as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. The process of heat and mass transfer is encountered in fluid fuel nuclear reactor, chemical process industries and many engineering applications in which fluid is considered to be working medium. Chen and Strobal (1980) analyzed the nature of convective flows resulting from buoyancy induced pressure gradient in a laminar boundary layer of a stretched sheet with constant velocity and temperature. Soundalgekar (1972) analyzed the viscous dissipation effects on unsteady free convective flows past and infinite vertical porous plate with constant suction. It was assumed that the plate temperature oscillates in such a way that its amplitude is small.

Chamkha (2004) analyzed the unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. An effect of heat and mass transfer on MHD free convection along a moving permeable vertical surface has been studied by Abdulkhalek (2009). Ahmed and Liu (2010) analyzed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity. Ahmed (2010) investigated the effect of periodic heat transfer on unsteady MHD mixed convection flow past a vertical porous flat plate with constant suction and heat sink when the free stream velocity oscillates in about a non-zero constant mean. Chamkha (2000a) considered the problem of steady, hydromagnetic boundary layer flow over an accelerating semi-infinite porous surface in the presence of thermal radiation, buoyancy and heat generation or absorption effects.

In fact, flows of fluids through porous media have possible applications in many branches of science and technology. In fact, flows of fluids through porous media have attracted the attention of a number of scholars because of their possible applications in many branches of sciences and technology. Classically the Darcian model is used to simulate the bulk effects of porous materials on flow dynamics and is valid for Reynolds numbers based on the pore radius, up to approximately 10. Chamkha (2000b) studied transient-free convection Magnetohydrodynamic boundary layer flow in a fluid-saturated porous medium channel. Bég *et al.* (2005) presented perturbation solutions for the transient oscillatory hydromagnetic convection in a Darcian porous media with a heat source present. Ahmed and Kalita (2013) presented the Magnetohydrodynamic transient convective radiative heat transfer one-dimensional flow in an isotropic, homogeneous porous regime adjacent to a hot vertical plate.

The present chapter is to investigate the effects of Magnetic body force and Chemical reaction of first order for the unsteady mixed convection boundary layer flow along a vertical permeable surface which is immersed in a Darcian porous regime in presents of mass blowing or suction and absorption. It is assumed that the surface is moving uniformly with constant

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velocity and the free stream velocity varying with time. The flow model is solved analytically.

3.2 Problem formulation :

Consider unsteady two-dimensional flow of a laminar, incompressible, viscous, electrically conducting and heat-absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field with effects of homogeneous first order chemical reaction in presence of thermal and concentration buoyancy forces. It is assumed that there is no applied voltage which implies the absence of an electrical field. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall effects are negligible. A consequence of the small magnetic Reynolds number is the uncoupling of the Navier-Stokes equations from Maxwell's equations. The governing equations for this investigation are based on the balances of mass, linear momentum, energy and concentration species. Taking into consideration the assumption made above, these equations can be written in Cartesian frame of reference, as follows:

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$$\frac{\partial v^*}{\partial y^*} = 0 \tag{3.2.1}$$

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = \left\{ \begin{matrix} -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T (T - T_\infty) \\ +g\beta_c (C - C_\infty) - \left(\frac{\nu}{K^*} + \frac{\sigma}{\rho} B_0^2\right) u^* \end{matrix} \right\} \tag{3.2.2}$$

$$\frac{\partial T}{\partial t^*} + v^* \frac{\partial T}{\partial y^*} = \alpha \frac{\partial^2 T}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T - T_\infty) \tag{3.2.3}$$

$$\frac{\partial C}{\partial t^*} + v^* \frac{\partial C}{\partial y^*} = D \frac{\partial^2 C}{\partial y^{*2}} - C_r^* (C - C_\infty) \tag{3.2.4}$$

The viscous dissipation effects are neglected in this study. The third and fourth terms on the RHS of the momentum Eq. (3.2.2) denote the thermal and concentration buoyancy effects respectively. Also the last term of the energy Eq. (3.2.3) is the heat absorption effects. It is assumed that the permeable plate moves with a constant velocity in the direction of fluid flow,

and the free stream velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and the concentration at the wall as well as the suction velocity are exponentially varying with time.

Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration fields are

$$\left[\begin{array}{c} \left\{\begin{array}{c} u^* = u_p^*,\ T = T_w + \varepsilon(T_w - T_\infty)e^{n^*t^*}, \\ C = C_w + \varepsilon(C_w - C_\infty)e^{n^*t^*} \end{array}\right\}\ y^* = 0 \\ u^* \to U_\infty^* = U_0\left(1 + \varepsilon e^{n^*t^*}\right),\ T \to T_\infty,\ C \to C_\infty,\ y^* \to \infty \end{array}\right] \quad (3.2.5)$$

It is clear from Eq. (3.2.1) that the suction velocity at the plate surface is a function of time only. Assuming that it takes the following exponential form:

$$v^* = -V_0\left(1 + \varepsilon A e^{n^*t^*}\right) \quad (3.2.6)$$

Outside the boundary layer, Eq. (3.2.2) gives,

$$-\frac{1}{\rho}\frac{dp^*}{dx^*} = \frac{dU_\infty^*}{dt^*} + \frac{\nu}{\kappa^*}U_\infty^* + \frac{\sigma}{\rho}B_0^2U_\infty^* \quad (3.2.7)$$

It is convenient to employ the following dimensionless variables:

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$$\left\{\begin{array}{c} u = \frac{u^*}{U_0},\ v = \frac{v^*}{V_0}, y = \frac{V_0y^*}{\nu}, U_\infty = \frac{U_\infty^*}{U_0}, U_p = \frac{u_p^*}{U_0}, t = \frac{t^*V_0^2}{\nu} \\ \theta = \frac{T - T_\infty}{T_w - T_\infty},\ C = \frac{C - C_\infty}{C_w - C_\infty},\ n = \frac{n^*\nu}{V_0^2}, K = \frac{K^*V_0^*}{\nu^2}, \\ Pr = \frac{\nu\rho C_p}{k} = \frac{\nu}{\alpha},\ Sc = \frac{\nu}{D},\ M = \frac{\sigma B_0^2\nu}{\rho V_0^2}, C_r = \frac{\nu C_r^*}{V_0^2} \\ Gr = \frac{\nu\beta_T g(T_w - T_\infty)}{U_0V_0^2},\ Gc = \frac{\nu\beta_C g(C_w - C_\infty)}{U_0V_0^2}, \phi = \frac{\nu Q_0}{\rho C_pV_0^2} \end{array}\right\} \quad (3.2.8)$$

In view of Eqs (3.2.6) – (3.2.8), the Eqs (3.2.2) – (3.2.4) reduces to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + Gr\theta + GcC + N(U_\infty - u) \quad (3.2.9)$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - \phi\theta \quad (3.2.10)$$

$$\frac{\partial C}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - C_r C \quad (3.2.11)$$

where

$$N = \left(M + \frac{1}{K}\right)$$

Thus the dimensionless form of the boundary conditions (3.2.5) become

$$\left.\begin{array}{llll} u = U_p, & \theta = 1 + \varepsilon e^{nt}, & C = 1 + \varepsilon e^{nt} & at \;\; y = 0 \\ u \to U_\infty, & \theta \to 0, & C \to 0 & as \;\; y \to \infty \end{array}\right\} \quad (3.2.12)$$

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3.3 Problem Solution :

Eqs (3.2.9) – (3.2.11) represent a set of partial differential equations that cannot be solved in closed form. However, it can be reduced to a set of ordinary differential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as

$$\left.\begin{array}{l} u(y,t) = u_0(y) + \varepsilon e^{nt} u_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \\ \theta(y,t) = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \\ C(y,t) = C_0(y) + \varepsilon e^{nt} C_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \end{array}\right\} \quad (3.3.13)$$

Substituting Eq. (3.3.13) into Eqs (3.2.9) – (3.2.11), equating the harmonic and non-harmonic terms and neglecting the higher-order terms of $O(\varepsilon^2)$

$$u_0'' + u_0' - Nu_0 = -N - Gr\theta_0 - GcC_0 \tag{3.3.14}$$

$$u_1'' + u_1' - (N+n)u_1 = -(N+n) - Au_0' - Gr\theta_1 - GcC_1 \tag{3.3.15}$$

$$\theta_0'' + Pr\theta_0' - Pr\phi\theta_0 = 0 \tag{3.3.16}$$

$$\theta_1'' + Pr\theta_1' - \Pr(\phi + n)\,\theta_1 = -APr\theta_0' \tag{3.3.17}$$

$$C_o'' + ScC_0' - ScC_rC_0 = 0 \tag{3.3.18}$$

$$C_1'' + ScC_1' - nScC_1 = -AScC_0' \tag{3.3.19}$$

The corresponding boundary conditions can be written as

$$\left.\begin{array}{l} u_0 = U_p,\ u_1 = 0, \theta_0 = 1,\ \theta_1 = 1, C_0 = 1, C_1 = 1\ at\ y = 0 \\ u_0 = 1, u_1 = 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0\ as\ y \to \infty \end{array}\right\} \tag{3.3.20}$$

The solutions of Eqs (3.3.14) – (3.3.19) subjects to condition (3.3.20) can be shown as

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$$u_0(y) = 1 + C_3e^{-\xi_1 y} + B_2e^{-m_1 y} + B_3e^{-\lambda_1 y} \tag{3.3.21}$$

$$u_1(y) = \left.\begin{array}{l} 1 + C_4e^{-\xi_2 y} + B_4e^{-\xi_1 y} + B_5e^{-m_1 y} \\ +B_6e^{-\lambda_1 y} + B_7\,e^{-m_2 y} + B_8e^{-\lambda_2 y} \end{array}\right\} \tag{3.3.22}$$

$$\theta_0(y) = e^{-m_1 y} \tag{3.3.23}$$

$$\theta_1(y) = e^{-m_2 y} + B_1(e^{-m_1 y} - e^{-m_2 y}) \tag{3.3.24}$$

$$C_0(y) = e^{-\lambda_1 y} \tag{3.3.25}$$

$$C_1(y) = e^{-\lambda_2 y} + B\left(e^{-\lambda_1 y} - e^{-\lambda_2 y}\right) \tag{3.3.26}$$

In view of the above solutions, the velocity, temperature and concentration distribution in the boundary layer becomes,

$$u(y,t) = \left\{ \begin{matrix} 1 + C_3 e^{-\xi_1 y} + B_2 e^{-m_1 y} + B_3 e^{-\lambda_1 y} \\ +\varepsilon e^{nt} \begin{pmatrix} 1 + C_4 e^{-\xi_2 y} + B_4 e^{-\xi_1 y} + B_5 e^{-m_1 y} + B_6 e^{-\lambda_1 y} \\ +B_7 e^{-m_2 y} + B_8 e^{-\lambda_2 y} \end{pmatrix} \end{matrix} \right\}$$

$$\theta(y,t) = e^{-m_1 y} + \varepsilon e^{nt}[e^{-m_2 y} + B_1(e^{-m_1 y} - e^{-m_2 y})]$$

$$C(y,t) = e^{-\lambda_1 y} + \varepsilon e^{nt}\left[e^{-\lambda_2 y} + B\left(e^{-\lambda_1 y} - e^{-\lambda_2 y}\right)\right]$$

3.3.1 Rate of Skin-friction

The Skin-friction at the plate $y = 0$ is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y}\right)_{y=0} + \varepsilon e^{nt}\left(\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$= 1 - \xi_1 C_3 - m_1 B_2 - \lambda_1 B_3 + \varepsilon e^{nt} \begin{pmatrix} 1 - \xi_2 C_4 - \xi_1 B_4 - m_1 B_5 \\ -\lambda_1 B_6 - m_2 B_7 - \lambda_2 B_8 \end{pmatrix}$$

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3.3.2 Rate of heat transfer

The rate of heat transfer in terms of Nusselt number '*Nu*' is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(\frac{\partial \theta_0}{\partial y}\right)_{y=0} + \varepsilon e^{nt}\left(\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$= -m_1 + \varepsilon e^{nt}[-m_2 + B_1(m_2 - m_1)]$$

3.3.3 Rate of mass transfer

The rate of mass transfer in terms of Sherwood number '*Sh*' is given by

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = \left(\frac{\partial C_0}{\partial y}\right)_{y=0} + \varepsilon e^{nt}\left(\frac{\partial C_1}{\partial y}\right)_{y=0}$$

$$= -\lambda_1 + \varepsilon e^{nt}[-\lambda_2 + B(\lambda_2 - \lambda_1)]$$

3.4 Validity :

1. When $M = 0$ and $C_r = 0$, the present paper reduces to the work which is done by Chamkha (2004).
2. When $M = 0$, $\phi = 0$, and $C_r = 0$ the present paper reduces to the work which is done by Kim (2000).

Table - 3.1 Comparison of present results for velocity (u) with those of Chamkha (2000) with different values of Gr when $n = 0.1$, $Pr = 0.7$, $Sc = 0.6$, $Gc = 1$, $Up = 0.5$, A = 0.5, $t = 1$, $\varepsilon = 0.2$

	Present work			Chamkha (2004)		
y	$Gr = 0$	$Gr = 1$	$Gr = 2$	$Gr = 0$	$Gr = 1$	$Gr = 2$
0	0.5	0.5	0.5	0.5	0.5	0.5
2	1.22171	1.20558	1.18945	1.26008	1.24122	1.22235
4	1.23069	1.22677	1.22286	1.24886	1.24393	1.23901
6	1.22382	1.22316	1.22249	1.23040	1.22941	1.22841
8	1.22165	1.22154	1.22144	1.22380	1.22358	1.22338
10	1.22115	1.22113	1.22112	1.22182	1.22177	1.22172

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Table - 3.2 Comparison of present results for velocity (u) with those of Kim (2000) with different values of Gr when $n = 0.1$, $Pr = 0.71$, $Sc = 0.6$, $Gc = 1$, $Up = 0.5$, A = 0.005, $t = 0.2$, $\varepsilon = 0.001$

	Present work			Kim (2000)		
y	$Gr = 0$	$Gr = 1$	$Gr = 2$	$Gr = 0$	$Gr = 1$	$Gr = 2$
0	0.5	0.5	0.5	0.5	0.5	0.5
2	0.98957	0.97270	0.955829	1.02892	1.08960	1.15027
4	1.00958	1.00631	1.00304	1.02953	1.05131	1.07310
6	1.00415	1.00367	1.00319	1.01187	1.01801	1.02415
8	1.00185	1.00178	1.00172	1.00454	1.00614	1.00774
10	1.00122	1.00121	1. .0012	1.00211	1.00251	1.00292

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3.5 Results and discussion :

The effects of flow parameters such as the Magnetic parameter (M), Heat absorption (ϕ), Porosity parameter (K), Chemical reaction (C_r), Prandtl number (Pr), Schmidt number (Sc) on velocity field, temperature, concentration, Skin-friction (τ), Nusselt number (Nu) and Sherwood number (Sh) have been studied analytically and presented with the help of Figs. 3.1 to 3.10.

The typical velocity profiles in the boundary layer represents in Fig. 3.1 for various values of Magnetic body force (M). It is obvious that an increase in M reduces the velocity. The application of a transverse magnetic field to an electrically conducting field gives rise to a resistive type of force called Lorentz force. This force has the tendency to slow down the fluid. This trend is evident in this figure.

Figs. 3.2 and 3.3 illustrate the influence of the heat absorption coefficient ϕ on the velocity and temperature profiles respectively. Physically speaking, the presents of heat absorption effects has the tendency to reduce the fluid temperature. This causes the thermal buoyancy effects to decrease resulting in a net reduction in the fluid velocity. These behaviors are clearly obvious from Figs. 3.2 and 3.3 in which both the velocity and temperature distribution decrease as ϕ increases. It is also observed that both the velocity and the thermal boundary layers decrease as the heat absorption coefficient effects increase.

The opposite trend is observed in Fig. 3.4 for the case when the value of the porosity (K = 0.1, 0.3, 0.5, 0.7 and 0.9) is increased. As depicted in this figure, the effects of increasing the values of porous permeability is to enhance the value of the velocity component in the boundary layer due to the fact that drag is reduced by increasing the values of the porous permeability on the fluid flow which results in increased velocity. The trend shows that the velocity is accelerated with increasing porosity parameter.

Figs. 3.5 and 3.6 illustrate the influence of Chemical reaction (C_r) on the velocity and concentration distribution respectively. It is clear that for increasing values of Chemical reaction tends to decrease the velocity as well as species concentration of the fluid. This means that in the case of suction, the Chemical reaction decelerates the fluid motion. In turn, this causes the concentration buoyancy effects to decrease as chemical reaction increases. Consequently less flow is induced along the plate resulting in decrease in the fluid velocity in the boundary layer.

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Fig. 3.7 displays the effects of the Schmidt number Sc on the concentration profiles. It is noticed that effect of increasing values of Sc is to decrease concentration profile. This is consistent with the fact that, increase in Sc means decrease of molecular diffusivity D those results in decrease of concentration boundary layer. Hence concentration of species is higher for smaller values of Sc and lower for lager values of Sc.

In Fig. 3.8 the Skin-friction distribution for the effects of Chemical reaction (C_r) and Magnetic body force (M) are presented. The maximum values of shear stress (τ) is observed at the plate $y = 0$ for the effects of M and C_r. Moreover, when M increases the shear stresses becomes small in

magnitude. While a substantial depression of shear stress has been observed when the Chemical reaction increases from 0 through 0.3, 0.6 to 0.9.

Fig. 3.9 depicts the behavior of rate of heat transfer (Nu) at the plate $y = 0$ for the effects heat absorption (ϕ) and Prandtl number (Pr). An increase in heat absorption leads to increase the rate of heat transfer throughout the thermal boundary layer. The minimum values of Nu occurred near the plate $y = 0$ for different values of ϕ and Pr. Due to the negative values of Nu, the heat of the fluid is diffused to the vertical wall $y = 0$. Moreover, increasing values of Pr enhanced the rate of heat transfer.

The variation of rate of mass transfer (Sh) for different values of Chemical reaction (C_r) and time (t) has analyses Fig. 3.10. It is marked that increasing C_r and t enhanced the Sherwood number. Also it is seen that due to negativity of Sh the mass is diffused to the vertical wall $y = 0$. Moreover, minimum values of Sh occurred near $y = 0$ when time is small and maximum values of Sh is observed for large values of time.

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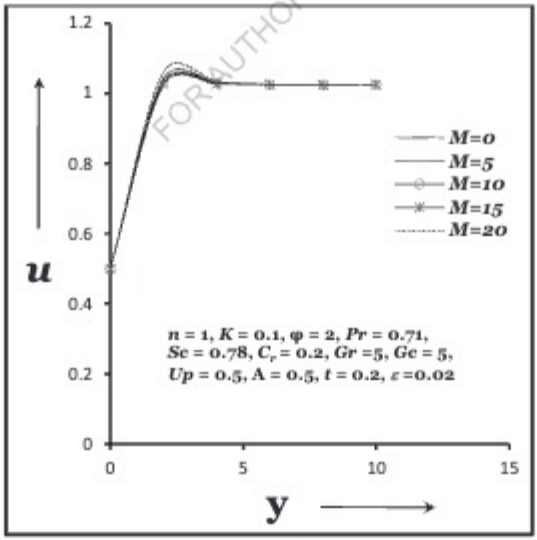

Fig. 3.1: Velocity distribution for Magnetic field

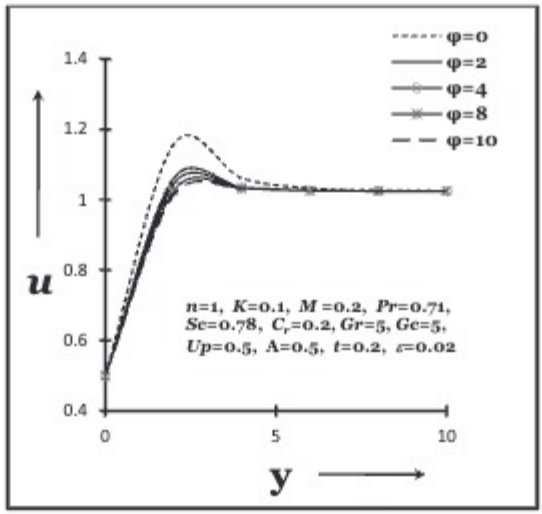

Fig. 3.2: Velocity distribution for Heat absorption

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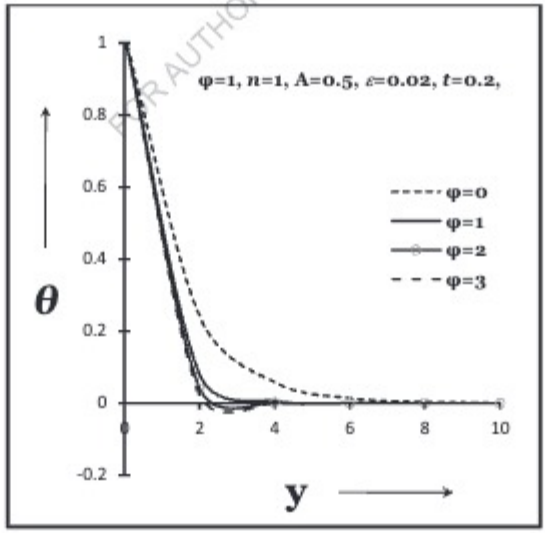

Fig. 3.3: Temperature distribution for Heat Absorption

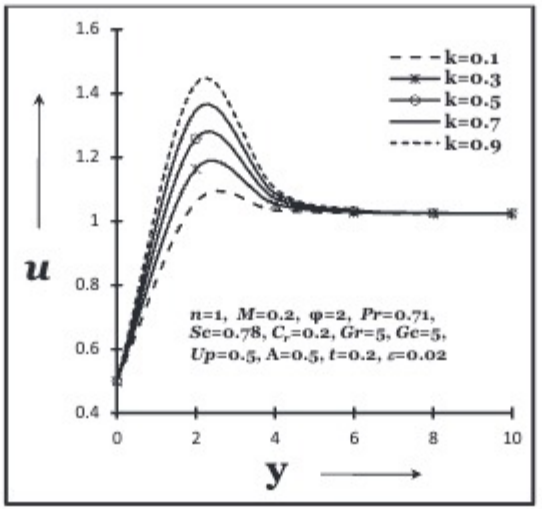

Fig. 3.4: Velocity distribution for Porosity parameter

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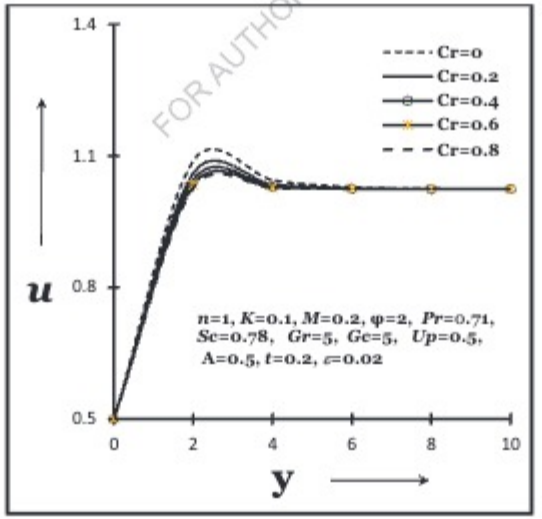

Fig. 3.5: Velocity distribution for Chemical reaction

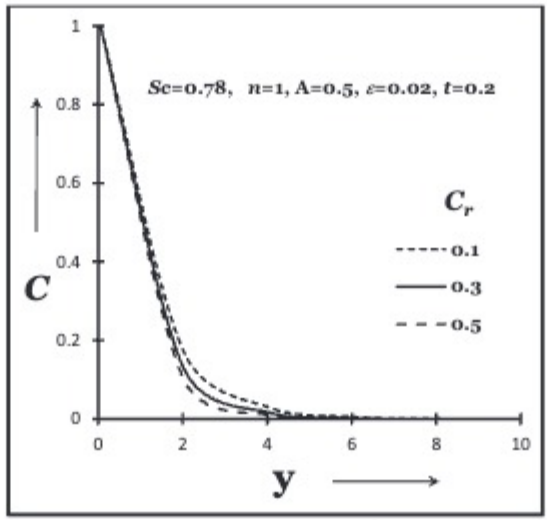

Fig. 3.6: Concentration distribution for Chemical Reaction

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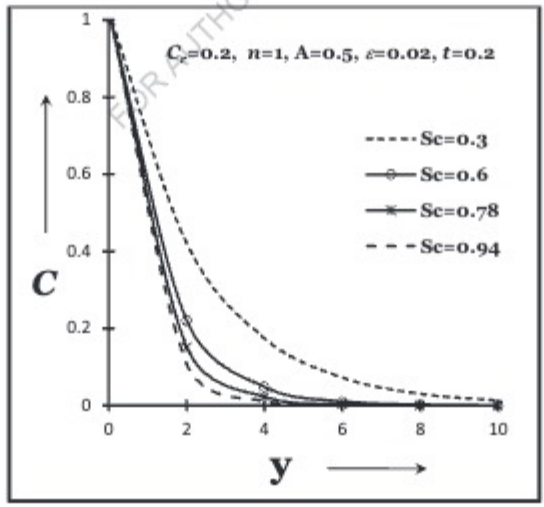

Fig. 3.7: Concentration distribution for Schmidt number

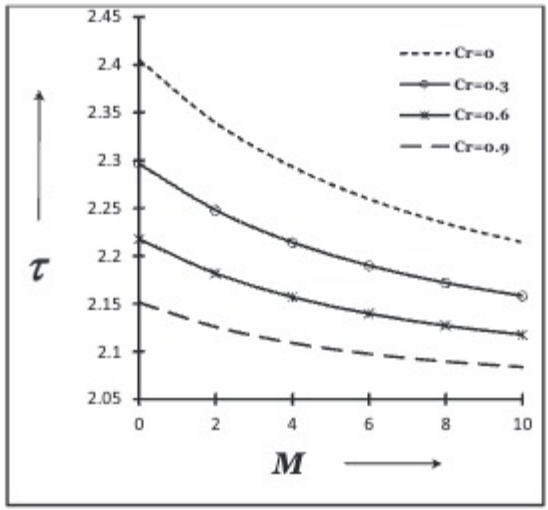

Fig. 3.8: Skin Friction for Chemical Reaction and Magnetic field

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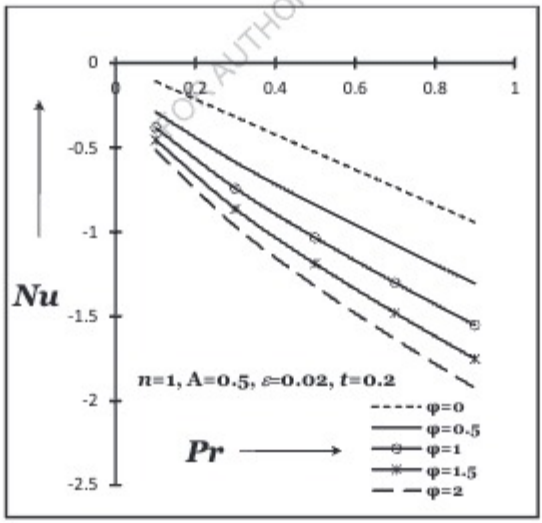

Fig. 3.9: Nusselt Number for Heat Absorption and Prandtl number

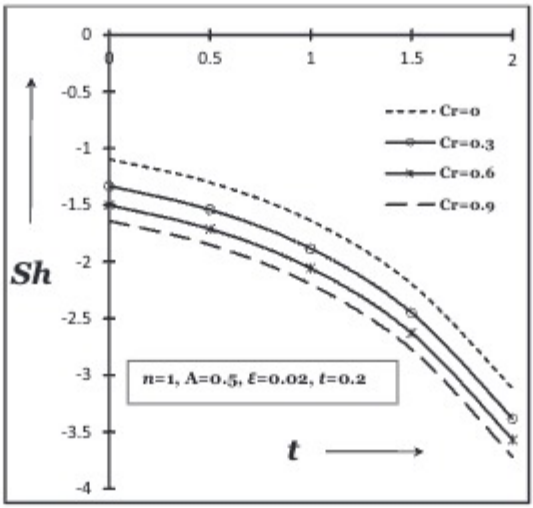

Fig. 3.10: Sherwood Number for Chemical reaction and time.

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3.6 Conclusion :

The Governing equations for unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat absorption and first order chemical reaction was formulated. The plate velocity was maintained at a constant value and the flow was subjected to a transverse magnetic field. The resulting partial differential equations were transformed into a set of ordinary differential equations using two-term series and solved in closed form. Numerical evaluations of the closed form results were performed and some graphical results were obtained to some of the physical parameters. The above analysis brings out the following results.

- It is observed that existence of Magnetic body force, Heat absorption coefficient and Chemical reaction decreases the velocity.
- It is observed that the existence of Porosity parameter increases the velocity.
- The Heat absorption co-efficient have the influence of decreasing the Temperature and Nusselt number.

- The Concentration boundary layer decreases with the increasing values of Chemical reaction and Schmidt number.
- The Chemical reaction has the influence of decreasing the Skin-friction and Sherwood number.

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Chapter - IV

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Mathematical Analysis for optically thin Radiating / Chemically reacting fluid in a Darcian Porous Regime

4.1 Introduction :

The study of heat and mass transfer to chemical reacting MHD free convection flow with radiation effects on a vertical plate has received a growing interest during the last decades. Accurate knowledge of the overall convection heat transfer has vital importance in several fields such as thermal insulation, dying of porous solid materials, heat exchangers, stream pipes, water heaters, refrigerators, electrical conductors and industrial, geophysical and astrophysical applications such as polymer production, manufacturing of ceramic, packed-bed catalytic reactor, food processing, cooling of nuclear reactor, enhanced oil recovery, underground energy transport, magnetized plasma flow, high speed plasma wind, cosmic jets and stellar system. For some industrial application such as glass production, furnace design, propulsion systems, plasma physics and spacecraft re-entry aerothermodynamics which operate at higher temperatures and radiation effect can also be significant. Consolidated effects of heat and mass transfer problems are of importance in many chemical formulations and reactive chemicals. Therefore, considerable attention had been paid in recent years to study the influence of the participating parameters on the velocity fields. More such engineering application can be seeing in electrical power generation system when the electrical energy is extracted directly from a moving conducting fluid.

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There has been a renewed interest in studying Magnetohydrodynamic (MHD) flow and heat transfer in porous and non-porous media due to the effect of magnetic fields on the boundary layer flow control and on the performance of many systems using electrically conducting fluids. In addition, this type of flow finds applications in many engineering problems such as MHD generators, plasma studies, nuclear reactors and geothermal energy extractors. Chamkha (2004) presented an unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. An analysis of an unsteady MHD convective flow past a vertical moving plate embedded in a porous medium in the presence of transverse magnetic field a reported by Kim (2000). Singh (2003) studied the effects of mass transfer on free convection in MHD flow of viscous fluid. Ahmed (2007) looked the effects of unsteady free convective MHD flow

through a porous medium bounded by an infinite vertical porous plate. Raptis (1986) studied mathematically the case of unsteady two-dimensional natural convective heat transfer of an incompressible, electrically conducting viscous fluid in a highly porous medium bound by an infinite vertical porous plate. Soundalgekar (1973) obtained approximate solutions for the two-dimensional, incompressible, viscous fluid past an infinite porous vertical plate with constant suction velocity normal to the plate, the difference between the temperature of the plate and the free stream is moderately large causing the free convection currents. Zueco and Ahmed (2010) proposed the mixed convection MHD flow along a porous plate with chemical reaction in presence of heat source. Recently, free convective fluctuating MHD flow through porous media past a vertical porous plate with variable temperature and heat source was studied by Acharya *et al.* (2014). Rao *et al.* (2015) was discussed the heat transfer on steady MHD rotating flow through porous medium in a parallel plate channel. Pattnaik and Biswal (2015) studied the analytical solution of MHD free convective flow through porous media with time dependent temperature and concentration. Recently, Hazarika and Ahmed (2016) have investigated the analytical study of unsteady MHD chemically reacting fluid over a vertical porous plate in a Darcian porous Regime. Chemical reaction effects on MHD free convective flow through porous medium with constant suction and heat flux has been discussed by Seshaiah and Varma (2016).

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All the above investigations are restricted to MHD flow and heat transfer problems only. However, of the late the effects of radiation on MHD flow, heat and mass transfer have become more important industrially. The radiation flows of an electrically conducting fluid with high temperature, in the presence of magnetic fields, are encountered in electrical power generation, astrophysical flows, solar power technology, space vehicle re-entry, nuclear engineering applications and other industrial areas. Radiative heat and mass transfer plays an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. Radiation effects on mixed convection along an isothermal vertical plate were studied by Hossain and Takhar (1996). The radiation effects on boundary layer flow with and

without applying a magnetic field under different situations have been studied by many investigators. Prasad *et al.* (2010) studied the radiation and mass transfer effects on unsteady MHD free convection flow past a vertical porous plate embedded in porous medium. Ibrahim *et al.* (2012) proposed the radiation and chemical reaction effects on MHD free convection flow past a moving vertical plate. Rao *et al.* (2013) investigate the effects of unsteady MHD free convection heat and mass transfer flow past a semi-infinite vertical plate with Radiation, Chemical reaction and Soret effects. The transient MHD free convective flow of a viscous, incompressible, electrically conducting, gray, absorbing-emitting, but not scattering, optically thick fluid medium which occupies a semi-infinite porous region adjacent to an infinite hot vertical plate moving with constant velocity was presented by Ahmed and Kalita (2013). The effects of chemical reaction as well as magnetic field on the heat and mass transfer of Newtonian two-dimensional flow over an infinite vertical oscillating plate with variable mass diffusion investigated by Ahmed and Kalita (2013). Ahmed (2014) presented the effects of conduction-radiation, porosity and chemical reaction on unsteady hydromagnetic free convection flow past an impulsively started semi-infinite vertical plate embedded in a porous medium in presence of thermal radiation. The thermal radiation and Darcian drag force MHD unsteady thermal-convection flow past a semi-infinite vertical plate immersed in a semi-infinite saturated porous regime with variable surface temperature in the presence of transversal uniform magnetic field have been discussed by Ahmed *et al.* (2014). Radiation effects on MHD free convective heat and mass transfer past a vertical porous plate studied by Reddy *et al.* (2014). Radiation and mass transfer on unsteady MHD convective flow past an infinite vertical plate in presence of Dufour and Soret effects studied by Vedavathi *et al.* (2015).

In all these investigations, the viscous dissipation is neglected. Gebhart (1962) had shown the importance of viscous dissipative heat in free convection flow in the case of isothermal and constant heat flux at the plate. Soundalgekar (1972) analyzed the viscous dissipative heat on the two-dimensional unsteady free convective flow past an infinite vertical porous plate when the temperature oscillates in time and there is constant suction at the plate. Cookey *et al.* (2003) had investigated the influence of viscous

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dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction. Prasad and Reddy (2008) had discussed about the Radiation and Mass transfer effects on an unsteady MHD convection flow with viscous dissipation. Radiation effects on an unsteady MHD convective flow past a vertical plate in porous medium with viscous dissipation analyzed by Gundagani *et al*. (2013). Venkateswarlu *et al*. (2013) discussed the effects of chemical reaction and heat generation on MHD boundary layer flow of a moving vertical plate with suction and dissipation. Ibrahim *et al*. (2014) studied the radiation effects on unsteady MHD free convective heat and mass transfer flow with viscous dissipation. Radiation and viscous dissipation effects on unsteady MHD flow with hall current in presence of chemical reaction had analyzed by Reddy (2014). The effects MHD with viscous dissipation by considering double diffusive convection in the presence of chemical reaction investigated by Reddy (2015). Very recently, effects of chemical reaction over a MHD steady mixed convective flow in an infinite vertical porous plate with combined heat and mass transfer and viscous dissipation using perturbation technique has been presented by Ahmed *et al*. (2017).

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In this chapter the effects of Chemical reaction and thermal Radiation of optically thin gray gas on a mixed convective boundary layer flow of an electrically conducting fluid over a semi-infinite porous surface embedded in a Darcian porous regime in presence of viscous dissipative heat is investigated. The governing equations are solved by using a regular perturbation theory.

4.2 Mathematical Analysis :

In this flow model, we consider two-dimensional unsteady hydromagnetic laminar mixed convective boundary layer flow of a viscous, incompressible, electrically conducting and radiating fluid in an optically thin environment, past a semi-infinite vertical permeable moving plate embedded in a Darcian porous medium, in presents of thermal and concentration buoyancy effects with chemical reaction of first order. The $\overline{x}$ -axis is taken in the upward direction along the plate and $\overline{y}$ -axis normal to it. A uniform magnetic field is applied in the direction perpendicular to the plate. The transverse applied

magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field is negligible. Also, it is assumed that there is no applied voltage, so that the electric field is absent. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species which are present, and hence the Soret and Dufour effects are negligible. Further, due to semi-infinite plane surface assumption, the flow variables are functions of normal distance $\overline{y}$ and $\overline{t}$ only. Now, under the usual Boussinesq's approximation, the governing boundary layer equations are:

$$\frac{\partial \overline{v}}{\partial \overline{y}} = 0 \tag{4.2.1}$$

$$\frac{\partial \overline{u}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{u}}{\partial \overline{y}} = \left\{ \begin{array}{l} -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{x}} + \nu\frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + g\beta_T\left(\overline{T} - \overline{T}_\infty\right) \\ +g\beta_C\left(\overline{C} - \overline{C}_\infty\right) - \left(\frac{\nu}{\overline{K}} + \frac{\sigma B_0^2}{\rho}\right)\overline{u} \end{array} \right\} \tag{4.2.2}$$

$$\frac{\partial \overline{T}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} = \frac{k}{\rho c_p}\left[\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{1}{k}\frac{\partial \overline{q}}{\partial \overline{y}}\right] + \frac{\nu}{c_p}\left(\frac{\partial \overline{u}}{\partial \overline{y}}\right)^2 \tag{4.2.3}$$

$$\frac{\partial^2 \overline{q}}{\partial \overline{y}^2} - 3\alpha^2 \overline{q} - 16\sigma^* \alpha \overline{T}_\infty^3 \frac{\partial \overline{T}}{\partial \overline{y}} = 0 \tag{4.2.4}$$

$$\frac{\partial \overline{C}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{C}}{\partial \overline{y}} = D\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} - \overline{C}_r\left(\overline{C} - \overline{C}_\infty\right) \tag{4.2.5}$$

The third and fourth terms on the right hand side of momentum Eq. (4.2.2) denote the thermal and concentration buoyancy effects respectively. The second and third terms on right hand side of energy Eq. (4.2.3) represent the radiative heat flux and viscous dissipation respectively. Also the second term on right hand of concentration Eq. (4.2.5) represents the chemical reaction effect.

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It is assumed that the permeable plate moves with a constant velocity in the direction of fluid flow and the free steam velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and concentration at the wall as well as the suction velocity are exponentially varying with time. Eq. (4.2.4) is the differential approximation for radiation and the radiative heat flux $\overline{q}$ satisfies this non-linear differential equation (1998).

The boundary conditions for the velocity, temperature and concentration fields are:

$$\left.\begin{array}{c} \overline{u} = \overline{u}_p, \quad \overline{T} = \overline{T}_w + \varepsilon\left(\overline{T}_w - \overline{T}_\infty\right)e^{\overline{n}\overline{t}}, \\ \overline{C} = \overline{C}_w + \varepsilon\left(\overline{C}_w - \overline{C}_\infty\right)e^{\overline{n}\overline{t}} \quad at \quad \overline{y} = 0 \\ \\ \overline{u} \to \overline{U}_\infty = U_0\left(1 + \varepsilon e^{\overline{n}\overline{t}}\right), \quad \overline{T} \to \overline{T}_\infty, \\ \overline{C} \to \overline{C}_\infty \quad as \quad \overline{y} \to \infty \end{array}\right\} \tag{4.2.6}$$

It is clear from the Eq. (4.2.1) that the suction velocity at the plate is either a constant or function of time only. Hence, the suction velocity normal to the plate is assumed in the form:

$$\overline{v} = -V_0\left(1 + \varepsilon A e^{\overline{n}\overline{t}}\right) \tag{4.2.7}$$

The negative sign indicates that the suction is towards the plate.

Outside the boundary layer, Eq. (4.2.2) gives:

$$-\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{x}} = \frac{d\overline{U}_\infty}{d\overline{t}} + \frac{\nu}{\overline{K}}\,\overline{U}_\infty + \frac{\sigma}{\rho}\,B_0^2\overline{U}_\infty \tag{4.2.8}$$

Since the medium is optically thin with relatively low density and $\alpha \ll 1$, the radiative heat flux given by Eq. (4.2.3), in the spirit of Cogley *et al.* (1968) becomes:

$$\frac{\partial \overline{q}}{\partial \overline{y}} = 4\alpha^2\left(\overline{T} - \overline{T}_\infty\right) \tag{4.2.9}$$

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where

$$\alpha^2 = \int_0^\infty \delta\lambda \frac{\partial B}{\partial \overline{T}}$$

where B is Planck's function.

In order to write the governing equations and boundary conditions in dimensionless form, the following non-dimensional quantities are introduced.

$$\left.\begin{aligned}
&u = \frac{\overline{u}}{U_0},\ v = \frac{\overline{v}}{V_0},\ y = \frac{V_0 \overline{y}}{\nu},\ U_\infty = \frac{\overline{U}_\infty}{U_0},\ U_p = \frac{\overline{u}_p}{U_0},\\
&t = \frac{\overline{t}\, V_0^2}{\nu},\ \theta = \frac{\overline{T} - \overline{T}_\infty}{\overline{T}_w - \overline{T}_\infty},\ \phi = \frac{\overline{C} - \overline{C}_\infty}{\overline{C}_w - \overline{C}_\infty},\ n = \frac{\overline{n}\,\nu}{V_0^2},\\
&K = \frac{\overline{K}\, V_0^2}{\nu^2},\ Pr = \frac{\nu \rho C_p}{k},\ Sc = \frac{\nu}{D},\ M = \frac{\sigma B_0^2 \nu}{\rho V_0^2},\\
&Gr = \frac{\nu \beta_T g\left(\overline{T}_w - \overline{T}_\infty\right)}{U_0 V_0^2},\ Gm = \frac{\nu \beta_C g\left(\overline{C}_w - \overline{C}_\infty\right)}{U_0 V_0^2},\\
&Ec = \frac{U_0^2}{C_p\left(\overline{T}_w - \overline{T}_\infty\right)},\ R^2 = \frac{\alpha^2\left(\overline{T}_w - \overline{T}_\infty\right)}{\rho C_p k U_0^2},\ C_r = \frac{\nu \overline{C}_r}{V_0^2}
\end{aligned}\right\} \quad (4.2.10)$$

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In view of Eqs (4.2.4) and (4.2.7- 4.2.10), Eqs (4.2.2), (4.2.3) and (4.2.5) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{nt}) \frac{\partial u}{\partial y} = \left\{ \begin{aligned} &\frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + Gr\theta \\ &+ Gm\phi + N(U_\infty - u) \end{aligned} \right\} \quad (4.2.11)$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon A e^{nt}) \frac{\partial \theta}{\partial y} = \frac{1}{Pr}\left[\frac{\partial^2 \theta}{\partial y^2} - R^2 \theta\right] + Ec\left(\frac{\partial u}{\partial y}\right)^2 \quad (4.2.12)$$

$$\frac{\partial \phi}{\partial t} - (1 + \varepsilon A e^{nt}) \frac{\partial \phi}{\partial y} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial y^2} - C_r \phi \quad (4.2.13)$$

where $N = M + K^{-1}$

The corresponding dimensionless boundary conditions are:

$$\left.\begin{cases} u = U_p, \quad \theta = 1 + \varepsilon e^{nt}, \quad \phi = 1 + \varepsilon e^{nt}, \quad at \quad y = 0 \\ u \to U_\infty = 1 + \varepsilon e^{nt}, \quad \theta \longrightarrow 0, \quad \phi \longrightarrow 0, \quad as \quad y \longrightarrow \infty \end{cases}\right\} \quad (4.2.14)$$

4.3 Solution of the Problem :

The Eqs (4.2.11- 4.2.13) are coupled, non-linear partial differential equations and these cannot be solved in closed-form. However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighbourhood of the plate as:

$$\left.\begin{cases} u(y,t) = u_0(y) + \varepsilon e^{nt} u_1(y) + O(\varepsilon^2) + \cdots \cdots \cdots \\ \theta(y,t) = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + O(\varepsilon^2) + \cdots \cdots \cdots \\ \phi(y,t) = \phi_0(y) + \varepsilon e^{nt} \phi_1(y) + O(\varepsilon^2) + \cdots \cdots \cdots \end{cases}\right\} \quad (4.3.15)$$

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Substituting Eq. (4.3.15) in Eqs (4.2.11- 4.2.13) and equating the harmonic and non-harmonic terms, and neglecting the higher order terms of $O(\varepsilon^2)$, we obtain:

$$u_0''(y) + u_0'(y) - N u_0(y) = -N - Gr\theta_0(y) - Gm\phi_0(y) \quad (4.3.16)$$

$$u_1''(y) + u_1'(y) - (N+n)u_1(y) = \left.\begin{cases} -(N+n) - Au_0'(y) \\ -Gr\theta_1(y) - Gm\phi_1(y) \end{cases}\right\} \quad (4.3.17)$$

$$\theta_0''(y) + Pr\,\theta_0'(y) - R^2\,\theta_0(y) = -PrEc\,[u_0'(y)]^2 \quad (4.3.18)$$

$$\left.\begin{cases} \theta_1''(y) + Pr\,\theta_1'(y) \\ -(R^2 + nPr)\theta_1(y) \end{cases}\right\} = \left\{\begin{matrix} -PrA\,\theta_0'(y) - \\ -2PrEc\,u_0'(y)u_1{}'(y) \end{matrix}\right\} \quad (4.3.19)$$

$$\phi_0''(y) + Sc\,\phi_0'(y) - Sc\,C_r\phi_0(y) = 0 \quad (4.3.20)$$

$$\phi_1''(y) + Sc\,\phi_1'(y) - Sc(n + C_r)\phi_1(y) = -ASc\,\phi_0'(y) \quad (4.3.21)$$

where prime denotes ordinary differentiation with respect to y.

The corresponding boundary conditions can be written as:

$$\left\{\begin{array}{c} u_0 = U_p,\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 1,\ \phi_0 = 1, \\ \phi_1 = 1 \ at\ y = 0 \\ \\ u_0 = 1, u_1 = 1,\ \theta_0 \longrightarrow 0,\ \theta_1 \longrightarrow 0,\ \phi_0 \longrightarrow 0, \\ \phi_1 \longrightarrow 0 \ as\ y \longrightarrow \infty \end{array}\right\} \tag{4.3.22}$$

The Eqs (4.3.16) – (4.3.21) are still coupled and non-linear, whose exact solutions are not possible. So we expand u_0, u_1, θ_0, θ_1, ϕ_0, ϕ_1 in terms of *Ec* in the following form, as the Eckert number is very small for incompressible flows.

$$F(y) = F_0(y) + Ec\ F_1(y) + O(Ec^2) \tag{4.3.23}$$

where *F* stands for any u_0, u_1, θ_0, θ_1, ϕ_0, ϕ_1.

Substituting Eq. (4.3.23) into Eqs (4.3.16) – (4.3.21), equating the co-efficient of *Ec* to zero and neglecting the terms in Ec^2 and higher order, we get the following equations:

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The zeroth order equations are:

$$u_{01}''(y) + u_{01}'(y) - Nu_{01}(y) = -N - Gr\ \theta_{01}(y) - Gm\ \phi_{01}(y) \tag{4.3.24}$$

$$u_{02}''(y) + u_{02}'(y) - Nu_{02}(y) = -Gr\ \theta_{02}(y) - Gm\ \phi_{02}(y) \tag{4.3.25}$$

$$\theta_{01}''(y) + Pr\ \theta_{01}'(y) - R^2\ \theta_{01}(y) = 0 \tag{4.3.26}$$

$$\theta_{02}''(y) + Pr\ \theta_{02}'(y) - R^2\ \theta_{02}(y) = -Pr[u_{01}'(y)]^2 \tag{4.3.27}$$

$$\phi_{01}''(y) + Sc\ \phi_{01}'(y) - Sc\ C_r\ \phi_{01}(y) = 0 \tag{4.3.28}$$

$$\phi_{02}''(y) + Sc\ \phi_{02}'(y) - Sc\ C_r\ \phi_{02}(y) = 0 \tag{4.3.29}$$

and the respective boundary conditions are:

$$\left\{\begin{matrix} u_{01} = U_p,\ u_{02} = 0,\quad \theta_{01} = 1,\quad \theta_{02} = 0, \\ \phi_{01} = 1,\ \phi_{02} = 0\ at\ y = 0 \\ \\ u_{01} \longrightarrow 1, u_{02} \longrightarrow 0, \theta_{01} \longrightarrow 0, \theta_{02} \longrightarrow 0, \\ \phi_{01} \longrightarrow 0, \phi_{02} \longrightarrow 0\ at\ y \longrightarrow \infty \end{matrix}\right\} \tag{4.3.30}$$

The first order equations are:

$$\begin{Bmatrix} u_{11}''(y) + u_{11}'(y) \\ -(N+n)u_{11}(y) \end{Bmatrix} = \begin{Bmatrix} -(N+n) - Gr\ \theta_{11}(y) \\ -Gm\ \phi_{11}(y) - A\ u_{01}'(y) \end{Bmatrix} \tag{4.3.31}$$

$$\begin{Bmatrix} u_{12}''(y) + u_{12}'(y) \\ -(N+n)u_{12}(y) \end{Bmatrix} = \begin{Bmatrix} -Gr\ \theta_{12}(y) - Gm\ \phi_{12}(y) \\ -A\ u_{02}'(y) \end{Bmatrix} \tag{4.3.32}$$

$$\theta_{11}''(y) + Pr\ \theta_{11}'(y) - N_1\theta_{11}(y) = -PrA\ \theta_{01}'(y) \tag{4.3.33}$$

$$\theta_{12}''(y) + Pr\ \theta_{12}'(y) - N_1\theta_{12}(y) = \begin{Bmatrix} -PrA\ \theta_{02}'(y) - \\ 2Pr\ u_{01}'(y)u_{11}'(y) \end{Bmatrix} \tag{4.3.34}$$

$$\phi_{11}''(y) + Sc\ \phi_{11}'(y) - Sc(n + C_r)\phi_{11}(y) = -ASc\ \phi_{01}'(y) \tag{4.3.35}$$

$$\phi_{12}''(y) + Sc\ \phi_{12}'(y) - Sc(n + C_r)\phi_{12}(y) = -ASc\ \phi_{02}'(y) \tag{4.3.36}$$

where $N_1 = R^2 + nPr$.

and respective boundary conditions are:

$$\left\{\begin{matrix} u_{11} = 0,\ u_{12} = 0,\quad \theta_{11} = 1,\quad \theta_{12} = 0, \\ \phi_{11} = 1,\ \phi_{12} = 0\ at\ \ y = 0 \\ \\ u_{11} \longrightarrow 1,\ u_{12} \longrightarrow 0,\ \theta_{11} \longrightarrow 0, \theta_{12} \longrightarrow 0, \\ \phi_{11} \longrightarrow 0, \phi_{12} \longrightarrow 0\ at\ \ y \longrightarrow \infty \end{matrix}\right\} \tag{4.3.37}$$

Solving Eqs (4.3.24) – (4.3.29) under the boundary condition (4.3.30) and Eqs (4.3.31) – (4.3.36) under the boundary condition (4.3.37) and using Eqs (4.3.15) and (4.3.23), we obtain the Velocity, Temperature and Concentration distributions in the boundary layer as:

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$$u(y,t)=\left\{\begin{array}{l} P_3e^{-m_3y}+P_1e^{-m_2y}+P_2e^{-m_1y}+1 \\ +Ec\left\{\begin{array}{c} J_8e^{-m_3y}+J_1e^{-m_2y}+J_2e^{-2m_3y}+ \\ J_3e^{-2m_2y}+J_4e^{-2m_1y} \\ +J_5e^{-(m_2+m_3)y}+J_6e^{-(m_1+m_2)y} \\ +J_7e^{-(m_1+m_3)y}G_6e^{-m_6y}+ \end{array}\right\} \\ +\varepsilon e^{nt}\left[\begin{array}{l} \left\{\begin{array}{c} G_1e^{-m_5y}+G_2e^{-m_2y}+G_3e^{-m_4y} \\ +G_4e^{-m_1y}+G_5e^{-m_3y}+1 \end{array}\right\} \\ +Ec\left\{\begin{array}{c} L_{19}e^{-m_6y}+L_1e^{-m_5y}+L_2e^{-m_2y} \\ +L_3e^{-2m_3y}+L_4e^{-2m_2y} \\ +L_5e^{-2m_1y}+L_6e^{-(m_2+m_3)y} \\ +L_7e^{-(m_1+m_2)y}+L_8e^{-(m_1+m_3)y} \\ +L_9e^{-(m_3+m_6)y}+L_{10}e^{-(m_3+m_5)y} \\ +L_{11}e^{-(m_3+m_4)y}+L_{12}e^{-(m_2+m_6)y} \\ +L_{13}e^{-(m_2+m_5)y}+L_{14}e^{-(m_2+m_4)y} \\ +L_{15}e^{-(m_1+m_6)y}+L_{16}e^{-(m_1+m_5)y} \\ +L_{17}e^{-(m_1+m_4)y}+L_{18}e^{-m_3y} \end{array}\right\} \end{array}\right] \end{array}\right\}$$

$$\theta(y,t)=\left\{\begin{array}{l} e^{-m_2y}+Ec\left\{\begin{array}{c} S_7e^{-m_2y}+S_1e^{-2m_3y}+S_2e^{-2m_2y} \\ +S_3e^{-2m_1y}+S_4e^{-(m_2+m_3)y} \\ +S_5e^{-(m_1+m_2)y}+S_6e^{-(m_1+m_3)y} \end{array}\right\} \\ \left\{D_2e^{-m_5y}+D_1e^{-m_2y}\right\}+ \\ +\varepsilon e^{nt}\left[Ec\left\{\begin{array}{c} R_{17}e^{-m_5y}+R_1e^{-m_2y}+R_2e^{-2m_3y} \\ +R_3e^{-2m_2y}+R_4e^{-2m_1y}+ \\ R_5e^{-(m_2+m_3)y}+R_6e^{-(m_1+m_2)y} \\ +R_7e^{-(m_1+m_3)y}+R_8e^{-(m_3+m_6)y} \\ +R_9e^{-(m_3+m_5)y}+R_{10}e^{-(m_3+m_4)y} \\ +R_{11}e^{-(m_2+m_6)y}+R_{12}e^{-(m_2+m_5)y} \\ +R_{13}e^{-(m_2+m_4)y}+R_{14}e^{-(m_1+m_6)y} \\ +R_{15}e^{-(m_1+m_5)y}+R_{16}e^{-(m_1+m_4)y} \end{array}\right\}\right] \end{array}\right\}$$

$$\phi(y,t)=e^{-m_1y}+\varepsilon e^{nt}\{Z_2e^{-m_4y}+Z_1e^{-m_1y}\}$$

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4.3.1 The Skin-Friction

Knowing the velocity field, the Skin-friction at the plate can be obtained, which in non-dimensional form is given by:

$$C_f = \frac{\overline{\tau}_w}{\rho U_0 V_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$= \begin{bmatrix} -m_3P_3 - m_2P_1 - m_1P_2 + Ec\begin{Bmatrix} -m_3J_8 - m_2J_1 - 2m_3J_2 - \\ 2m_2J_3 - 2m_1J_4 - (m_2+m_3)J_5 \\ -(m_1+m_2)J_6 - (m_1+m_3)J_7 \end{Bmatrix} \\ +\varepsilon e^{nt}\begin{bmatrix} \begin{pmatrix} -m_6G_6 - m_5G_1 - m_2G_2 - \\ m_4G_3 - m_1G_4 - m_3G_5 \end{pmatrix} \\ +Ec\begin{Bmatrix} -m_6L_{19} - m_5L_1 - m_2L_2 - 2m_3L_3 \\ -2m_2L_4 - 2m_1L_5 - (m_2+m_3)L_6 \\ -(m_1+m_2)L_7 - (m_1+m_3)L_8 \\ -(m_3+m_6)L_9 - (m_3+m_5)L_{10} \\ -(m_3+m_4)L_{11} - (m_2+m_6)L_{12} \\ -(m_2+m_5)L_{13} - (m_2+m_4)L_{14} \\ -(m_1+m_6)L_{15} - (m_1+m_5)L_{16} \\ -(m_1+m_4)L_{17} - m_3L_{18} \end{Bmatrix} \end{bmatrix} \end{bmatrix}$$

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4.3.2 Rate of Heat Transfer

Knowing the temperature field, the rate of heat transfer co-efficient can be obtained, which in the non-dimensional form, in terms of the Nusselt number is given by:

$$Nu = -x\frac{\left(\partial T/\partial \overline{y}\right)_{\overline{y}=0}}{\overline{T}_w - \overline{T}_\infty}$$

$$NuRe_x^{-1} = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -\left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$= -\left[\begin{array}{c} -m_2 + Ec\left\{\begin{array}{c} -m_2S_7 - 2m_3S_1 - 2m_2S_2 - \\ 2m_1S_3 - (m_2 + m_3)S_4 \\ -(m_1 + m_2)S_5 - (m_1 + m_3)S_6 \end{array}\right\} \\ +\varepsilon e^{nt}\left[\begin{array}{c} (-m_5D_2 - m_2D_1) \\ +Ec\left\{\begin{array}{c} -m_5R_{17} - m_2R_1 - 2m_3R_2 \\ -2m_2R_3 - 2m_1R_4 - (m_2 + m_3)R_5 \\ -(m_1 + m_2)R_6 - (m_1 + m_3)R_7 \\ -(m_3 + m_6)R_8 - (m_3 + m_5)R_9 \\ -(m_3 + m_4)R_{10} - (m_2 + m_6)R_{11} \\ -(m_2 + m_5)R_{12} - (m_2 + m_4)R_{13} \\ -(m_1 + m_6)R_{14} - (m_1 + m_5)R_{15} \\ -(m_1 + m_4)R_{16} \end{array}\right\} \end{array}\right] \end{array}\right]$$

where $Re_x = \frac{V_0 x}{\nu}$ is the local Reynolds number.

4.3.3 Rate of Mass Transfer

Knowing the concentration field, the rate of mass transfer co-efficient can be obtained, which in the non-dimensional form, in terms of the Sherwood number is given by:

$$Sh = -x\frac{\left(\partial\overline{C}/\partial\overline{y}\right)_{\overline{y}=0}}{\overline{C}_w - \overline{C}_\infty}$$

$$ShRe_x^{-1} = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = -\left(\frac{\partial C_0}{\partial y} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\right)_{y=0}$$

$$= -[-m_1 + \varepsilon e^{nt}(-m_4Z_2 - m_1Z_1)]$$

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4.4 Validity :

When $C_r = 0$, the present paper reduces to the work which was done by Prasad and Reddy (2008).

Table – 4.1: Comparison of the present results with those of Prasad and Reddy (2008) with effects of Gr and Gm on C_f when $Pr = 0.71$, $Sc = 0.6$, $M = 1.0$, $R = 0.5$, $K = 0.5$, $n = 0.1$, $Up = 0.5$, A = 0.5, $C_r = 0.2$, $t = 1.0$, $Ec = 0.001$, $\varepsilon = 0.001$.

Gr	*Gm*	Prasad and Reddy (2008)		Present Work	
		Effect of *Gr* on C_f	Effect of *Gm* on C_f	Effect of *Gr* on C_f	Effect of *Gm* on C_f
0	0	1.6877	1.9741	1.60691	2.03578
1	1	2.0974	2.5123	2.04773	2.48857
2	2	2.5123	3.0515	2.48857	2.94137
3	3	2.9345	3.5918	2.92944	3.39418
4	4	3.3660	4.1331	3.37035	3.84699

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The table - 4.1 shows the accuracy of the present model in comparison with the previous model studied by Prasad and Reddy (2008) and this comparison is validated the present study.

4.5 Results and Discussion :

The formulation of the problem that accounts for the effects of radiation and viscous dissipation on the flow of an incompressible, viscous and chemically reacting fluid along a semi-infinite, vertically moving porous plate embedded in a porous medium in the presence of transverse magnetic field was accomplished. Following Cogley *et al.* (1968) approximation for the radiative heat flux in the optically thin environment, the governing equations

on the flow field were solved analytically, using a perturbation method and the expressions for the velocity, temperature, concentration, Skin-friction, Nusselt number and Sherwood number were obtained. In order to get a physical insight of the problem, the above physical quantities are computed numerically for different values of the governing parameters viz. Thermal Grashof number *Gr*, the Solutal Grashof number *Gm*, Radiation parameter *R*, Magnetic parameter *M*, Permeability parameter *K*, Plate velocity *Up*, Prandtl number *Pr*, Schmidt number *Sc*, Eckert number *Ec* and Chemical reaction C_r.

Figure 4.1 shows the typical velocity profiles in the boundary layer for various values of the thermal Grashof number. It is observed that an increase in *Gr*, leads to a rise in the values of the velocity due to enhancement in the buoyancy force. Here, the positive values of *Gr* correspond to cooling of the plate. In addition, it is observed that the velocity increases rapidly near the wall of the porous plate as Grashof number increases and then decays to the free stream velocity.

Figure 4.2 depicts the typical velocity profiles in the boundary layer for distinct values of the solutal Grashof number *Gm*. The velocity distribution attaints a distinctive maximum value in the region of the plate surface and then decrease properly to approach the free stream value. As expected, the fluid velocity increases and the peak value becomes more distinctive due to increase in the buoyancy force represented by *Gm*.

For different values of thermal radiation parameter *R* on the velocity and temperature profiles are shown in **Figure 4.3(a) and 4.3(b).** It is noticed that an increase in the radiation parameter results a decrease in the velocity and temperature within the boundary layer, as well as decreased the thickness of the velocity and temperature boundary layers.

The effect of magnetic field on velocity profiles in the boundary layer is depicted in **Figure 4.4.** It is obvious that the existence of the magnetic field is to decrease the velocity in the momentum boundary layer because the application of the transverse magnetic field results in a resisting type of force called Lorentz force, which results in reducing the velocity of the fluid in the boundary layer. **Figure 4.5** shows the effect of the permeability of the

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porous medium parameter K on the velocity distribution. It is found that the velocity increases with an increase in K.

The velocity distribution across the boundary layer for several values of plate moving velocity Up in the direction of the fluid flow is depicted in **Figure 4.6**. Although we have different initial plate moving velocities, the velocity decreases to a constant value for given material parameters.

Figure 4.7(a) and 4.7(b) shows the behaviour of velocity and temperature for different values of Prandtl number Pr. The numerical results show the effect of increasing values of Prandtl number results in the decreasing velocity. From **Figure 4.7(b)**, it is observed that an increase in the Prandtl number results a decrease in the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of Pr are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Pr. Hence in the case of smaller Prandtl numbers as the thermal boundary layer is thicker and the rate of heat transfer is reduced.

Figure 4.8(a) and 4.8(b) shows the effects of Schmidt number on the velocity and concentration respectively. As the Schmidt number increases, the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. Reductions in the velocity and concentration distributions are accompanied by simultaneous reductions in the velocity and concentration boundary layers.

The effects of chemical reaction on velocity and concentration are depicted by **Figure 4.9(a) and 4.9(b)**. It is noticed that an increase in the chemical reaction parameter results a decrease in the velocity and concentration within the boundary layer.

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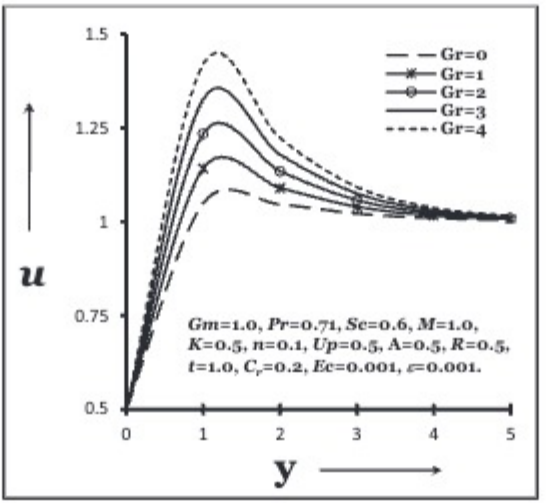

Fig. 4.1: Effects of *Gr* on Velocity

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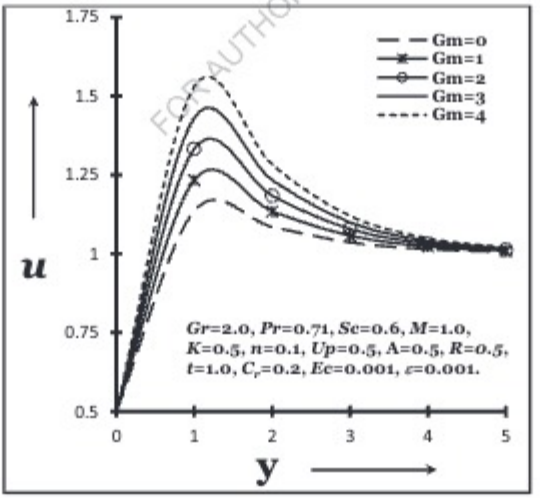

Fig. 4.2: Effects of *Gm* on Velocity

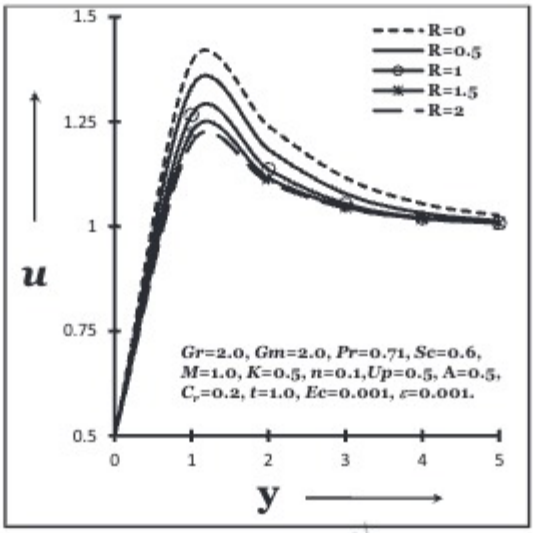

Fig. 4.3(a): Effects of Radiation on Velocity

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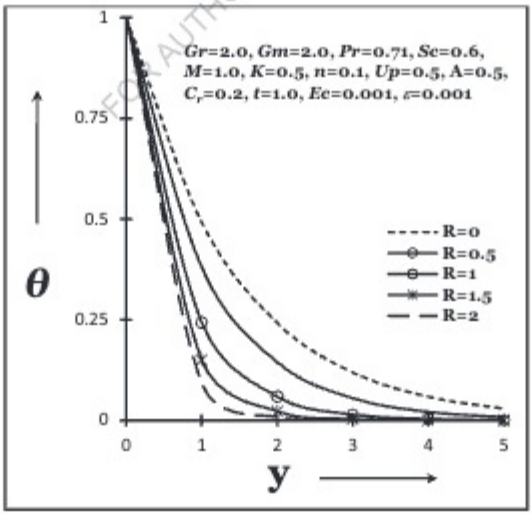

Fig. 4.3(b): Effects of Radiation on Temperature

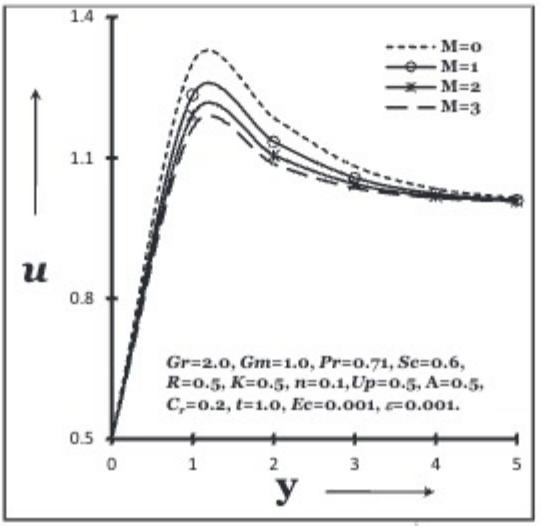

Fig. 4.4: Effects of Magnetic field on velocity

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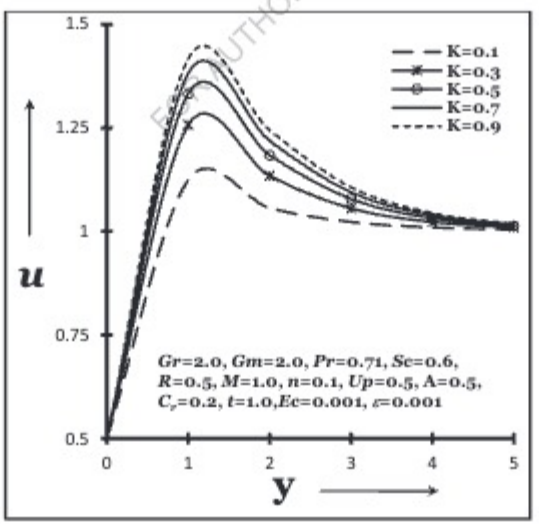

Fig. 4.5: Effects of Permeability parameter on velocity

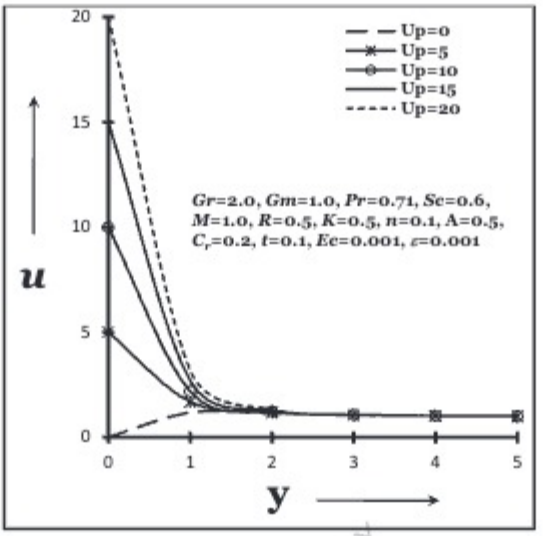

Fig. 4.6: Effects of *Up* on velocity

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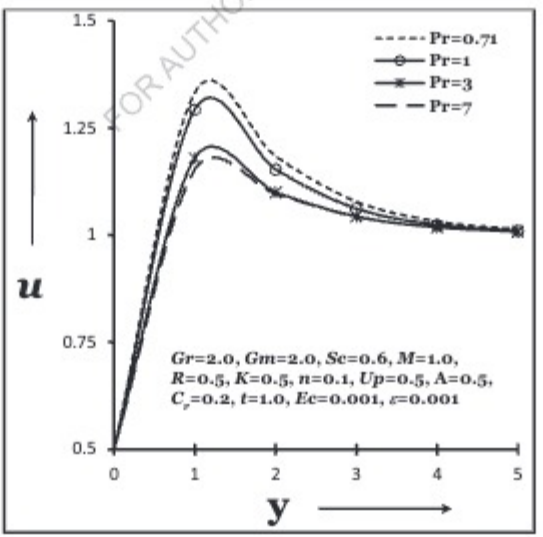

Fig. 4.7(a): Effects of *Pr* on velocity

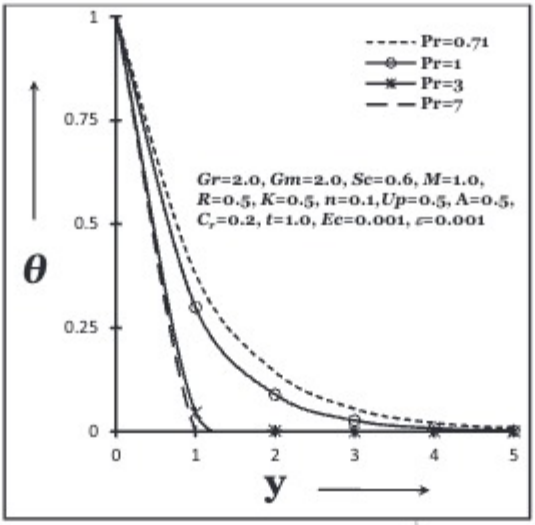

Fig. 4.7(b): Effects of *Pr* on Temperature

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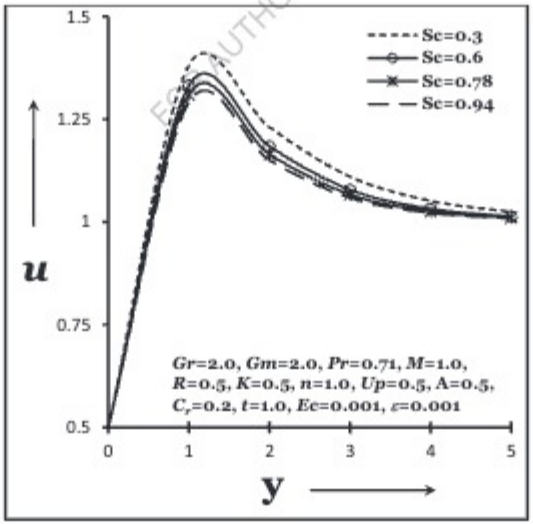

Fig. 4.8(a): Effects of *Sc* on velocity

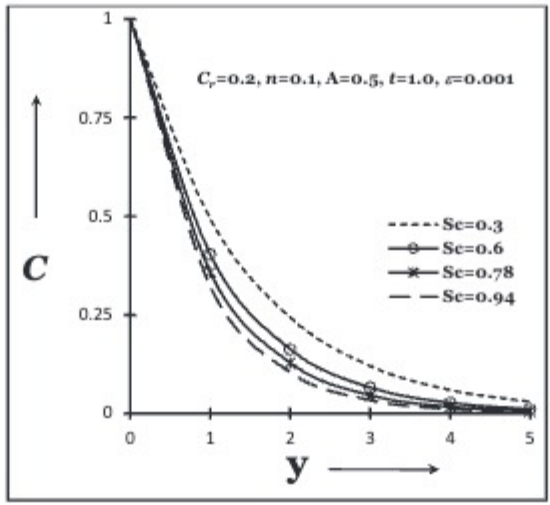

Fig. 4.8(b): Effects of *Sc* on concentration

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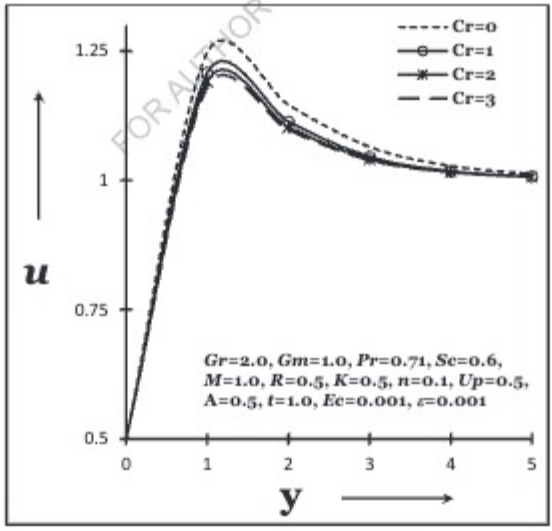

Fig. 4.9(a): Effects of C_r on velocity

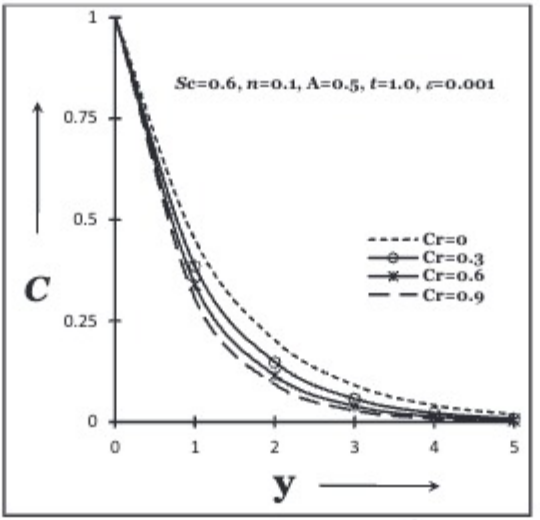

Fig. 4.9(b): Effects of C_r on Concentration.

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4.6 Conclusion :

The governing equations for unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with radiation and viscous dissipation effects were formulated. Chemical reaction effect is also included in the present work. The plate velocity is maintained at constant value and the flow is subjected to a transverse magnetic field. The present investigation brings out the following conclusions of physical interest on the velocity, temperature and concentration distribution of the flow field.

- It is found that when thermal and solutal Grashof number is increased, the thermal and concentration buoyancy effects are enhanced and thus the fluid velocity increased;
- However, the presence of radiation effects caused reductions in the fluid temperature, which resulted in decrease in the fluid velocity;
- It is observed that the existence of magnetic body force and chemical reaction decreases the fluid velocity;

- The permeability parameter and plate velocity have the influence of increasing the fluid velocity;
- As Prandtl number increased the velocity and temperature are both decreased;
- When Schmidt number increased, the concentration level decreased resulting in decreased fluid velocity.

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Chapter - V

Steady Three-Dimensional Channel Flow for Radiating/Chemically Reacting Fluid with Sinusoidal Injection: Analytical Approach

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5.1 Introduction :

The dynamics of fluids through porous channel has been a popular area of research regarding to numerous increasing applications in chemical, mechanical and materials process engineering. Examples of such fluids include clay coating, coal, oil slurries, shampoo, paints and suspensions, cosmetic products, grease, custard physiological liquids etc. The channel flows through porous medium have numerous engineering and geophysical applications, for example in the fields of chemical engineering for filtration and purification processes, in the fields of agriculture engineering to study the underground water resources, in petroleum technology to study the movement of natural gas, oil and water through the oil channels/reservoirs.

Magnetohydrodynamics deals with the dynamics of an electrically conducting fluid, which interacts with a magnetic field. The study of heat transfer and flow, through and across porous media, is of great theoretical interest because it has been applied to a variety of geophysical and astrophysical phenomena. Practical interest of such study includes applications in electromagnetic lubrication, boundary cooling, bio-physical systems and in many branches of engineering and science. In engineering, it finds its application in MHD pumps, MHD bearing, nuclear reactors, geothermal energy extraction and boundary layer control in the field of aerodynamics.

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Suction and injection at the plate also play a fundamental role in the plane Couette flow. It remains two-dimensional if the suction and injection applied at the porous parallel plate are uniform, but by the application of the transverse sinusoidal injection at the stationary plate and constant suction at the moving plate, the flow remains three-dimensional as studied by Singh (1990). A similar problem of three-dimensional Couette flow of dusty viscous fluid was investigated by Govindarajan *et al.* (2007) with transpiration cooling. Such flow problems are important for studies of transpiration cooling process by investigating associated heat transfer problems. Das *et at.* (2008) studied the three-dimensional Couette flow of a viscous incompressible electrically conducting fluid between two infinite horizontal parallel porous flat plates in presence of a transverse magnetic field. Sharma and Saini (2008) investigated the effect of injection/suction

between two horizontal parallel porous flat plates, with transverse sinusoidal injection of fluid at the stationary plate and its corresponding removal by periodic suction through the plate in motion, assuming the sinusoidal injection at the lower plate and its corresponding removal by the upper plate in motion. A three- dimensional Couette flow through a porous medium with heat transfer has also been investigated by Ahmed (2009). Fasogbon (2010) studied the simultaneous buoyancy force effects of thermal and species diffusion through a vertical irregular channel by using parameter perturbation technique. The study of heat and mass transfer on the free convective flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity and a constant free stream velocity was presented by Ahmed (2009). The effect of transverse sinusoidal injection velocity distribution on the three-dimensional free convective Couette flow of a viscous incompressible fluid in slip flow regime under the influence of heat source has been studied by Jain and Gupta (2006). Ahmed *et al.* (2006) have obtained an analytical solution to the problem of three-dimensional free convective flow of an incompressible viscous fluid past a porous vertical plate with the transverse sinusoidal suction velocity taking into account the presence of species concentration. The effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity analyzed by Ahmed and Liu (2010). Ahmed and Zueco (2011) investigated the effects of Hall current, magnetic fields, rotation of the channel and suction-injection on the oscillatory free convective MHD flow in a rotating vertical porous channel when the entire system rotates about an axis normal to the channel plates and a strong magnetic field of uniform strength is applied along the axis of rotation. Ahmed *et al.* (2015) analyzed an analytical and numerical solution of three-dimensional channel flow in presence of a sinusoidal fluid injection and chemical reaction.

Radiation effects on free convection flow have become very important due to its applications in space technology, processes having high temperature, and design of pertinent equipments. Moreover, heat transfer with thermal radiation on convection flows is very important due to its

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significant role in the surface heat transfer. Recent developments in gas cooled nuclear reactors, nuclear power plants, gas turbines, space vehicles, hypersonic flights, missiles and satellites have attached research in this field. The effects of radiation on MHD flow, heat and mass transfer become more important industrially. Many processes in engineering areas occur in high temperature and knowledge of radiation heat transfer becomes very important for design of pertinent equipment. The quality of final product depends to a great extent on the heat controlling factors and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. At high operating temperature, radiation effects quite significant. Sparrow (1978) explained a parameter named Rosseland approximation to describe the radiation heat flux in the energy equation in his book. England and Emery (1969) have studied the thermal radiation effects of an optically thin gray gas bounded by stationary vertical plate. Radiation effects on mixed convection along an isothermal vertical plate were studied by Hossain and Takhar (1996). Bég *et al*. (2003) presented a non-Darcy model for mixed convection flow of an optically dense viscous fluid along a vertical surface in a porous regime with the effects of thermal radiation. An analysis of the thermal radiation effects on stationary mixed convection from vertical surfaces in saturated porous media for both a hot and a cold surface has been presented by Bakier (2001). The effects of radiation and viscous dissipation on the transient natural convection-radiation flow of viscous dissipation fluid along an infinite vertical surface embedded in a porous medium, by means of network simulation method, investigation by Zueco (2008). The effects of radiation and chemical reaction on natural convection flows of a Newtonian fluid along a vertical surface embedded in a porous medium presented by Mahmoud and Chamkha (2010).

Ahmed and Chamkha (2010) has been presented the effects of chemical reaction and conduction radiation on heat and mass transfer flow over a porous vertical plate with induced magnetic field. The porosity and Magnetohydrodynamic effects on a horizontal channel flow of a viscous incompressible electrically conducting, Newtonian and radiating fluid through a porous medium in the presence of thermal radiation and transverse magnetic field were studied by Ahmed and Kalita (2013). The modal of

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Magnetohydrodynamic transient convective radiating heat transfers in an isotropic, homogenous porous regime adjacent to a hot vertical plate using the Laplace transform method were studied by Ahmed and Kalita (2013). Ahmed and Chamkha (2014) analyzed the effect of Hartmann Newtonian radiating MHD flow for a rotating vertical porous channel. The effects of conduction-radiation, porosity and chemical reaction on unsteady hydromagnetic free convection flow past an impulsively-started semi-infinite vertical plate embedded in a porous medium in the presence of first order chemical reaction and thermal radiation were analyzed by Ahmed (2014) and the boundary layer equation are solved by an efficient, accurate, extensively validated and unconditionally stable finite difference scheme of the Crack-Nicolson type. Recently, Seth *at el.* (2016) has been presented heat and mass transfer effects on unsteady MHD natural convection flow of a chemically reacting and radiating fluid.

The main objective of this chapter is to study the channel flow for the thermal radiation effects on heat and mass transfer in presence of external magnetic field associated with chemical reaction of first order and suction/injection. The main flow and cross flow skin-frictions at the plate $y = 0$ are presented with the effects of radiation, magnetic field and Reynolds number. Moreover, the behaviour of main flow velocity, fluid temperature and species concentration has been investigated.

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5.2 Basic Equations :

Introducing a coordinate system (Fig. 5.1) with the plates oriented vertically parallel to the $\overline{x} - \overline{z}$ plane, such that the $\overline{x}$ - axis is oriented along the length of the plates in the direction of the buoyancy force and the $\overline{y}$ - axis is perpendicular to the plates and directed into the fluid region.

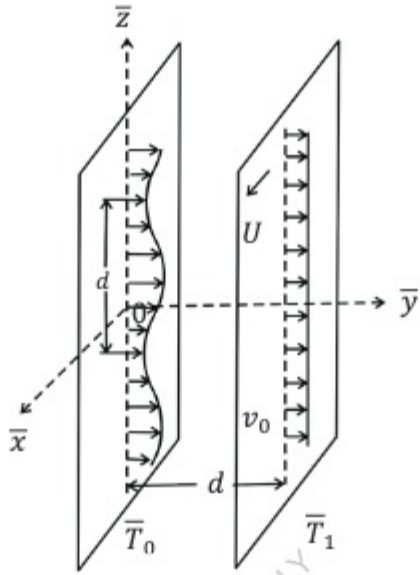

Fig. 5.1: Couette flow with periodic injection and constant suction

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The plate at rest is subject to a transverse sinusoidal injection velocity distribution of the form

$$\overline{v} = v_0\left[1 + \varepsilon cos\left(\frac{\pi\overline{z}}{d}\right)\right] \tag{5.2.1}$$

where $v_0 > 0$ and $0 \leq \varepsilon \ll 1$. Here v_0 is the undistributed part of the injection velocity, d is the wavelength of the periodic injection velocity and ε is the preference parameter. The outer plate has a uniform motion U in the $\overline{x}$-direction and is subjected to a constant suction, v_0 under the first-order velocity slip conditions. Without loss of generality, the distance between the plates may be taken equal to the wavelength, d of the suction velocity. A uniform magnetic field is applied normal to the plane of the plates. The contributions of the viscous and Joulean dissipation in the energy equation are small and can be neglected. This assumption has been shown to be applicable to a similar problem when no external electric field is imposed on the flow. All the fluid properties are assumed to be independent of $\overline{x}$, except possibly the pressure. However, the flow remains three dimensional due to the form of suction velocity distribution and the constant suction at

the respective plates, as assumed above. Let $\overline{T}_0, \overline{C}_0$ be the respectively the temperature and the molar species concentration of the fluid at the plate at rest. Further, let the temperature and molar species concentration at the plate in uniform motion are $\overline{T}_1, \overline{C}_1$ respectively. Let $\vec{q} = \overline{u}\hat{\imath} + \overline{v}\hat{\jmath} + \overline{w}\hat{k}$ be the velocity vector of the fluid at the point $(\overline{x}, \overline{y}, \overline{z})$, where $\hat{\imath}, \hat{\jmath}, \hat{k}$ are the unit vectors along the coordinate axes. Let $\vec{B} = B_0\hat{\jmath}$ be the applied magnetic field, where B_0 is the magnetic field component along $\overline{y}$-axis. Let $\overline{T}, \overline{C}$ be respectively the temperature and molar species concentration of the field. Let $\overline{T}_e, \overline{C}_e$ be respectively the equilibrium temperature and molar species concentration of the field. The magnetic Reynolds number is assumed to be small so that the induced magnetic field can be neglected. The level of species concentration in the field is very low so that the Soret and Dufour effects can be neglected.

The equations governing steady heat mass transfer by natural convective motion of an incompressible viscous electrically conducting fluid through a vertical channel in presence of a magnetic field are given by:

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Equation of Continuity

$$\frac{\partial \overline{v}}{\partial \overline{y}} + \frac{\partial \overline{w}}{\partial \overline{z}} = 0 \tag{5.2.2}$$

Equation of Momentum

$$\overline{v}\frac{\partial \overline{u}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{u}}{\partial \overline{z}} = \left\{ \begin{matrix} g\beta(\overline{T} - \overline{T}_e) + g\overline{\beta}(\overline{C} - \overline{C}_e) + \\ \nu\left(\frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{u}}{\partial \overline{z}^2}\right) - \frac{\sigma B_0^2 \overline{u}}{\rho} \end{matrix} \right\} \tag{5.2.3}$$

$$\overline{v}\frac{\partial \overline{v}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{v}}{\partial \overline{z}} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{y}} + \nu\left(\frac{\partial^2 \overline{v}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{v}}{\partial \overline{z}^2}\right) \tag{5.2.4}$$

$$\overline{v}\frac{\partial \overline{w}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{w}}{\partial \overline{z}} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{z}} + \nu\left(\frac{\partial^2 \overline{w}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{w}}{\partial \overline{z}^2}\right) - \frac{\sigma B_0^2 \overline{w}}{\rho} \tag{5.2.5}$$

Equation of Energy

$$\overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{T}}{\partial \overline{z}} = \frac{\kappa}{\rho C_p}\left(\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{T}}{\partial \overline{z}^2}\right) + \frac{Q}{\rho C_p}\left(\overline{T} - \overline{T}_e\right) - \frac{1}{\rho C_p}\frac{\partial \overline{q}_r}{\partial \overline{y}} \quad (5.2.6)$$

Equation of mass diffusion

$$\overline{v}\frac{\partial \overline{C}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{C}}{\partial \overline{z}} = D\left(\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{C}}{\partial \overline{z}^2}\right) - \overline{K}\left(\overline{C} - \overline{C}_e\right) \quad (5.2.7)$$

The corresponding boundary conditions are

$$\left\{\begin{array}{c} \overline{y} = 0: \ \overline{u} = 0, \ \overline{v} = v_0\left\{1 + \varepsilon cos\left(\frac{\pi \overline{z}}{d}\right)\right\}, \\ \overline{w} = 0, \ \overline{T} = \overline{T}_0, \ \overline{C} = \overline{C}_0 \\ \overline{y} = d: \quad \overline{u} = U + L_1\frac{\partial \overline{u}}{\partial \overline{y}}, \ \overline{v} = v_0, \\ \overline{w} = 0, \ \overline{T} = \overline{T}_1, \ \overline{C} = \overline{C}_1 \end{array}\right\} \quad (5.2.8)$$

where $L_1 = \left(\frac{2-m_1}{m_1}\right)L$, L is the mean free path and m_1 being the Maxwell's reflection coefficient.

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Since the medium is optically thin with relatively low density and $\alpha \ll 1$, the radiative heat flux given by Eq. (5.2.6) becomes,

$$\frac{\partial \overline{q}_r}{\partial \overline{y}} = 4\alpha^2\left(\overline{T} - \overline{T}_e\right) \quad (5.2.9)$$

where

$$\alpha^2 = \int_0^\infty \delta\lambda \frac{\partial B}{\partial \overline{T}}$$

where B is the Planck's function.

In order to write the governing equations and boundary conditions in dimensionless form, the following non-dimensional quantities are introduced.

$$\left\{\begin{array}{c} y=\frac{\overline{y}}{d}, z=\frac{\overline{z}}{d}, p=\frac{\overline{p}}{\rho v_0^2}, u=\frac{\overline{u}}{U}, v=\frac{\overline{v}}{v_0}, w=\frac{\overline{w}}{v_0}, \\ Pr=\frac{\mu C_p}{\kappa}, m=\frac{\overline{T}_1-\overline{T}_e}{\overline{T}_0-\overline{T}_e}, Sc=\frac{\nu}{D}, h=\frac{L_1}{d}, \\ Re=\frac{v_0 d}{\nu}, M=\frac{\sigma B_0^2 d}{\rho v_0} \quad \theta=\frac{\overline{T}-\overline{T}_e}{\overline{T}_0-\overline{T}_e}, n=\frac{\overline{C}_1-\overline{C}_e}{\overline{C}_0-\overline{C}_e}, \\ \phi=\frac{\overline{C}-\overline{C}_e}{\overline{C}_0-\overline{C}_e}, Gr=\frac{g\beta d\left(\overline{T}_0-\overline{T}_e\right)}{U v_0}, A=\frac{Q v d}{v_0 \kappa}, \\ Gm=\frac{g\overline{\beta} d\left(\overline{C}_0-\overline{C}_e\right)}{U v_0}, K=\frac{\overline{K} d}{v_0}, R_a=\frac{4 d \alpha^2}{v_0 \rho C_p} \end{array}\right\} \quad (5.2.10)$$

In view of Eqs (5.2.9) and (5.2.10), Eqs (5.2.2 – 5.2.7) obtains in the following non-dimensional form:

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$$\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (5.2.11)$$

$$v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=Gr\theta+Gm\phi+\frac{1}{Re}\left(\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-Mu \quad (5.2.12)$$

$$v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{Re}\left(\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \quad (5.2.13)$$

$$v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{Re}\left(\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-Mw \quad (5.2.14)$$

$$v\frac{\partial \theta}{\partial y}+w\frac{\partial \theta}{\partial z}=\frac{1}{PrRe}\left(\frac{\partial^2 \theta}{\partial y^2}+\frac{\partial^2 \theta}{\partial z^2}\right)+\frac{A\theta}{Pr}-R_a\theta \quad (5.2.15)$$

$$v\frac{\partial \phi}{\partial y}+w\frac{\partial \phi}{\partial z}=\frac{1}{ScRe}\left(\frac{\partial^2 \phi}{\partial y^2}+\frac{\partial^2 \phi}{\partial z^2}\right)-K\phi \quad (5.2.16)$$

The corresponding non-dimension boundary conditions become:

$$\left.\begin{cases} y = 0 : u = 0, v = 1 + \varepsilon cos(\pi z), w = 0, \ \theta = 1, \phi = 1 \\ y = 1 : \ u = 1 + h\dfrac{\partial u}{\partial y}, \ v = 1, \ w = 0, \ \theta = m, \ \phi = n \end{cases}\right\} \quad (5.2.17)$$

5.3 Method of Solution :

It is noted that, the amplitude ε of the injection is very small and hence using a perturbation technique, the solution to this heat and mass transfer problem may be assumed to be of the following form

$$\left.\begin{cases} u(y,z) = u_0(y) + \varepsilon u_1(y,z) + \varepsilon^2 u_2(y,z) + \cdots\cdots\cdots\cdots \\ v(y,z) = v_0(y) + \varepsilon v_1(y,z) + \varepsilon^2 v_2(y,z) + \cdots\cdots\cdots\cdots \\ w(y,z) = w_0(y) + \varepsilon w_1(y,z) + \varepsilon^2 w_2(y,z) + \cdots\cdots\cdots\cdots \\ p(y,z) = p_0(y) + \varepsilon p_1(y,z) + \varepsilon^2 p_2(y,z) + \cdots\cdots\cdots\cdots \\ \theta(y,z) = \theta_0(y) + \varepsilon \theta_1(y,z) + \varepsilon^2 \theta_2(y,z) + \cdots\cdots\cdots\cdots \\ \phi(y,z) = \phi_0(y) + \varepsilon \phi_1(y,z) + \varepsilon^2 \phi_2(y,z) + \cdots\cdots\cdots\cdots \end{cases}\right\} \quad (5.3.18)$$

When $\varepsilon = 0$, the problem reduces to a two-dimensional flow and is governed by the following equations obtained from Eqs. (5.2.11– 5.2.16) using (5.3.18)

$$v_0' = 0 \quad (5.3.19)$$

$$u_0'' - Reu_0' - ReMu_0 + Re(Gr\theta_0 + Gm\phi_0) = 0 \quad (5.3.20)$$

$$p_0' = 0 \quad (5.3.21)$$

$$w_0'' - Rew_0' - ReMw_0 = 0 \quad (5.3.22)$$

$$\theta_0'' - PrRe\theta_0' + Re(A - PrR_a)\theta_0 = 0 \quad (5.3.23)$$

$$\phi_0'' - ScRe\phi_0' - ScReK\phi_0 = 0 \quad (5.3.24)$$

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The corresponding boundary conditions are

$$\left.\begin{array}{l} y=0:\ u_0=0,\ v_0=1,\ w_0=0,\ \theta_0=1,\quad \phi_0=1 \\ y=1:\ u_0=1+hu_0',\ v_0=1,\ w_0=0,\ \theta_0=m,\ \phi_0=n \end{array}\right\} \quad (5.3.25)$$

The solutions of Eqs (5.3.19 – 5.3.24) subject to the boundary conditions (5.3.25) are

$$v_0 = 1, \quad p_0 = constant, \quad w_0 = 0 \quad (5.3.26)$$

$$\theta_0(y) = C_1 e^{J_1 y} + C_2 e^{J_2 y} \quad (5.3.27)$$

$$\phi_0(y) = C_3 e^{J_3 y} + C_4 e^{J_4 y} \quad (5.3.28)$$

$$u_0(y) = \left\{\begin{array}{l} C_5 e^{J_5 y} + C_6 e^{J_6 y} + C_7 e^{J_1 y} + \\ C_8 e^{J_2 y} + C_9 e^{J_3 y} + C_{10} e^{J_4 y} \end{array}\right\} \quad (5.3.29)$$

When $\varepsilon \neq 0$, substituting (5.3.18) into Eqs (5.2.11 – 5.2.16) and equating the co-efficient of like powers of ε on both sides and neglecting higher order terms of $\varepsilon^2, \varepsilon^3$ ect., we obtain the following equations

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$$\frac{\partial v_1}{\partial y} + \frac{\partial w_1}{\partial z} = 0 \quad (5.3.30)$$

$$\frac{\partial u_1}{\partial y} + v_1 \frac{\partial u_0}{\partial y} = \frac{1}{Re}\left(\frac{\partial^2 u_1}{\partial y^2} + \frac{\partial^2 u_1}{\partial z^2}\right) + Gr\theta_1 + Gm\phi_1 - Mu_1 \quad (5.3.31)$$

$$\frac{\partial v_1}{\partial y} = -\frac{\partial p_1}{\partial y} + \frac{1}{Re}\left(\frac{\partial^2 v_1}{\partial y^2} + \frac{\partial^2 v_1}{\partial z^2}\right) \quad (5.3.32)$$

$$\frac{\partial w_1}{\partial y} = -\frac{\partial p_1}{\partial z} + \frac{1}{Re}\left(\frac{\partial^2 w_1}{\partial y^2} + \frac{\partial^2 w_1}{\partial z^2}\right) - Mw_1 \quad (5.3.33)$$

$$\frac{\partial \theta_1}{\partial y} + v_1 \frac{\partial \theta_0}{\partial y} = \frac{1}{PrRe}\left(\frac{\partial^2 \theta_1}{\partial y^2} + \frac{\partial^2 \theta_1}{\partial z^2}\right) + \frac{A\theta_1}{Pr} - R_a\theta_1 \quad (5.3.34)$$

$$\frac{\partial \phi_1}{\partial y} + v_1 \frac{\partial \phi_0}{\partial y} = \frac{1}{ScRe}\left(\frac{\partial^2 \phi_1}{\partial y^2} + \frac{\partial^2 \phi_1}{\partial z^2}\right) - K\phi_1 \quad (5.3.35)$$

The corresponding boundary conditions for this case are

$$\left.\begin{matrix} y = 0: \;\; u_1 = 0, \;\; v_1 = cos\pi z \,, \;\; w_1 = 0, \;\; \theta_1 = 0, \;\; \phi_1 = 0 \\ y = 1: \;\; u_1 = hu_1{}', \;\; v_1 = 0, \;\; w_1 = 0, \;\; \theta_1 = 0, \;\; \phi_1 = 0 \end{matrix}\right\} \quad (5.3.36)$$

5.4 Cross Flow solution :

For the solution purpose, it is first assumed that the Eqs (5.3.30), (5.3.32) and (5.3.33) being independent of the main flow, temperature and concentration fields. The solutions for v_1, w_1, p_1 are considered to be the following form

$$\left.\begin{matrix} v_1(y,z) = v_{11}(y)cos\pi z \\ w_1(y,z) = -\frac{1}{\pi} v_{11}{}'(y)sin\pi z \\ p_1(y,z) = p_{11}(y)cos\pi z \end{matrix}\right\} \quad (5.4.37)$$

Where $v_{11}{}'(y)$ denotes differentiation of $v_{11}(y)$ with respect to y. Expressions $v_1(y,z)$ and $w_1(y,z)$ have been chosen so that the Eq. of continuity (5.3.30) is satisfied. Substituting Eq. (5.4.37) into the Eqs (5.3.32) and (5.3.33) leads to

$$v_{11}'' - Rev_{11}' - \pi^2 v_{11} = Rep_{11}' \quad (5.4.38)$$

$$v_{11}''' - Rev_{11}'' - (\pi^2 + ReM)v_{11}{}' = \pi^2 Rep_{11} \quad (5.4.39)$$

Eliminating p_{11} from the Eqs (5.4.38) and (5.4.39) yields

$$v_{11}^{IV} - Rev_{11}''' - (2\pi^2 + ReM)v_{11}{}'' + \pi^2 Rev_{11}' + \pi^4 v_{11} = 0 \quad (5.4.40)$$

The corresponding boundary conditions become

$$\left.\begin{matrix} y = 0 \;\; : \;\; v_{11} = 1 \,, \;\; v_{11}' = 0 \\ y = 1 \;\; : \;\; v_{11} = 0 \,, \;\; v_{11}' = 0 \end{matrix}\right\} \quad (5.4.41)$$

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The solutions of v_1, w_1 and p_1 with the help of Eq. (5.4.40) under the boundary condition (5.4.41) are respectively

$$v_1(y,z) = \frac{1}{D}\left[D_1 e^{\lambda_1 y} + D_2 e^{\lambda_2 y} + D_3 e^{\pi y} + D_4 e^{-\pi y}\right] cos\pi z$$

$$w_1(y,z) = -\frac{1}{\pi D}\left[\lambda_1 D_1 e^{\lambda_1 y} + \lambda_2 D_2 e^{\lambda_2 y} + \pi D_3 e^{\pi y} - \pi D_4 e^{-\pi y}\right] sin\pi z$$

$$p_1(y,z) = -\frac{1}{Re\pi D}[D_5 e^{\pi y} + D_6 e^{-\pi y}] cos\pi z$$

5.5. Solutions for the Main flow, Temperature and the Concentration fields :

The solutions to Eqs (5.3.31), (5.3.34) and (5.3.35) may be assumed u_1, θ_1, ϕ_1 as

$$\left.\begin{matrix} u_1(y,z) = u_{11}(y) cos\pi z \\ \theta_1(y,z) = \theta_{11}(y) cos\pi z \\ \phi_1(y,z) = \phi_{11}(y) cos\pi z \end{matrix}\right\} \quad (5.5.42)$$

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Substituting Eq. (5.5.42) into Eqs (5.3.31), (5.3.34) and (5.3.35), the following ordinary differential equations are obtained.

$$\left.\begin{matrix} u_{11}'' - Reu_{11}' - (\pi^2 + ReM)u_{11} - Reu_0' v_{11} \\ +Re(Gr\theta_{11} + Gm\phi_{11}) \end{matrix}\right\} = 0 \quad (5.5.43)$$

$$\theta_{11}'' - PrRe\theta_{11}' + (ARe - \pi^2 - PrReR_a)\theta_{11} - PrRe\theta_0' v_{11} = 0 \quad (5.5.44)$$

$$\phi_{11}'' - ScRe\phi_{11}' - (\pi^2 + ScReK)\phi_{11} - ScRe\phi_0' v_{11} = 0 \quad (5.5.45)$$

The corresponding boundary conditions are

$$\left.\begin{matrix} y = 0 : & u_{11} = 0, & \theta_{11} = 0, & \phi_{11} = 0 \\ y = 1 : & u_{11} = hu_{11}', & \theta_{11} = 0, & \phi_{11} = 0 \end{matrix}\right\} \quad (5.5.46)$$

The solutions of u_1 , θ_1 and ϕ_1 under the boundary condition (5.5.46) are respectively

$$u_1(y,z) = \left[\begin{array}{l} \left\{ \begin{matrix} D_{27}e^{\lambda_1 y} \\ +D_{28}e^{\lambda_2 y} \end{matrix} \right\} + \frac{Re}{D} \left[\begin{matrix} D_{29}e^{(J_5+\lambda_1)y} + D_{30}e^{(J_5+\lambda_2)y} + \\ D_{31}e^{(J_5+\pi)y} + D_{32}e^{(J_5-\pi)y} + \\ D_{33}e^{(J_6+\lambda_1)y} + D_{34}e^{(J_6+\lambda_2)y} + \\ D_{35}e^{(J_6+\pi)y} + D_{36}e^{(J_6-\pi)y} + \\ D_{37}e^{(J_1+\lambda_1)y} + D_{38}e^{(J_1+\lambda_2)y} + \\ D_{39}e^{(J_1+\pi)y} + D_{40}e^{(J_1-\pi)y} + \\ D_{41}e^{(J_2+\lambda_1)y} + D_{42}e^{(J_2+\lambda_2)y} + \\ D_{43}e^{(J_2+\pi)y} + D_{44}e^{(J_2-\pi)y} + \\ D_{45}e^{(J_3+\lambda_1)y} + D_{46}e^{(J_3+\lambda_2)y} + \\ D_{47}e^{(J_3+\pi)y} + D_{48}e^{(J_3-\pi)y} + \\ D_{49}e^{(J_4+\lambda_1)y} + D_{50}e^{(J_4+\lambda_2)y} + \\ D_{51}e^{(J_4+\pi)y} + D_{52}e^{(J_4-\pi)y} \end{matrix} \right] \\ -ReGr \left[\begin{matrix} D_{53}e^{\lambda_5 y} + D_{54}e^{\lambda_6 y} + \\ \frac{PrRe}{D} \left\{ \begin{matrix} D_{55}e^{(J_1+\lambda_1)y} + D_{56}e^{(J_1+\lambda_2)y} + \\ D_{57}e^{(J_1+\pi)y} + D_{58}e^{(J_1-\pi)y} + \\ D_{59}e^{(J_2+\lambda_1)y} + D_{60}e^{(J_2+\lambda_2)y} + \\ D_{61}e^{(J_2+\pi)y} + D_{62}e^{(J_2-\pi)y} \end{matrix} \right\} \end{matrix} \right] \\ -ReGm \left[\begin{matrix} D_{63}e^{\lambda_3 y} + D_{64}e^{\lambda_4 y} + \\ \frac{ScRe}{D} \left\{ \begin{matrix} D_{65}e^{(J_3+\lambda_1)y} + D_{66}e^{(J_3+\lambda_2)y} + \\ D_{67}e^{(J_3+\pi)y} + D_{68}e^{(J_3-\pi)y} + \\ D_{69}e^{(J_4+\lambda_1)y} + D_{70}e^{(J_4+\lambda_2)y} + \\ D_{71}e^{(J_4+\pi)y} + D_{72}e^{(J_4-\pi)y} \end{matrix} \right\} \end{matrix} \right] \end{array} \right] cos\pi z$$

$$\theta_1(y,z) = \left[\begin{array}{l} \left\{ \begin{matrix} D_{17}e^{\lambda_5 y} \\ +D_{18}e^{\lambda_6 y} \end{matrix} \right\} + \frac{PrRe}{D} \left[\begin{matrix} D_{19}e^{(J_1+\lambda_1)y} + D_{20}e^{(J_1+\lambda_2)y} + \\ D_{21}e^{(J_1+\pi)y} + D_{22}e^{(J_1-\pi)y} + \\ D_{23}e^{(J_2+\lambda_1)y} + D_{24}e^{(J_2+\lambda_2)y} + \\ D_{25}e^{(J_2+\pi)y} + + D_{26}e^{(J_2-\pi)y} \end{matrix} \right] \end{array} \right] cos\pi z$$

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$$\phi_1(y,z) = \left[\begin{Bmatrix} D_7 e^{\lambda_3 y} \\ D_7 e^{\lambda_3 y} \end{Bmatrix} + \frac{ScRe}{D} \begin{bmatrix} D_9 e^{(J_3+\lambda_1)y} + D_{10} e^{(J_3+\lambda_2)y} + \\ D_{11} e^{(J_3+\pi)y} + D_{12} e^{(J_3-\pi)y} + \\ D_{13} e^{(J_4+\lambda_1)y} + D_{14} e^{(J_4+\lambda_2)y} + \\ D_{15} e^{(J_4+\pi)y} + + D_{16} e^{(J_4-\pi)y} \end{bmatrix} \right] cos\pi z$$

5.6 Skin-friction Co-efficient

The non-dimensional skin-friction coefficients in the main flow direction at the plates

$(y = 0, 1)$ are given by

$$\tau_{x0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = u_0'(0) + \varepsilon u_{11}'(0) cos\pi z\,, \tag{5.6.47}$$

$$\tau_{x1} = \left(\frac{\partial u}{\partial y}\right)_{y=1} = u_0'(1) + \varepsilon u_{11}'(1) cos\pi z\,. \tag{5.6.48}$$

In addition, the non-dimensional skin-friction coefficients in the transverse directions at the plates $(y = 0, 1)$ are given by

$$\tau_{z0} = \left(\frac{\partial w}{\partial y}\right)_{y=0} = -\frac{\varepsilon}{\pi} v_{11}''(0) sin\pi z\,, \tag{5.6.49}$$

$$\tau_{z1} = \left(\frac{\partial w}{\partial y}\right)_{y=1} = -\frac{\varepsilon}{\pi} v_{11}''(1) sin\pi z\,. \tag{5.6.50}$$

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5.7 Rate of Heat Transfer

The non-dimensional heat flux at the plates $(y = 0, 1)$ in terms of the Nusselt numbers is given by

$$Nu_0 = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \theta_0'(0) + \varepsilon \theta_{11}'(0) cos\pi z\,, \tag{5.7.51}$$

$$Nu_1 = \left(\frac{\partial \theta}{\partial y}\right)_{y=1} = \theta_0'(1) + \varepsilon \theta_{11}'(1) cos\pi z\,. \tag{5.7.52}$$

5.8 Rate of Mass Transfer

The non-dimensional mass flux at the plates $(y = 0, 1)$ in terms of the Sherwood numbers is given by

$$Sh_0 = \left(\frac{\partial \phi}{\partial y}\right)_{y=0} = \phi_0'(0) + \varepsilon \phi_{11}'(0) cos\pi z\,, \tag{5.8.53}$$

$$Sh_1 = \left(\frac{\partial \phi}{\partial y}\right)_{y=1} = \phi_0'(1) + \varepsilon \phi_{11}'(1) cos\pi z\,. \tag{5.8.54}$$

5.9 Accuracy :

In order to check the accuracy of the employed perturbation method, comparisons with the previously published work of Ahmed *et al*. (2015) are performed. Table - 5.1 and 5.2 show comparison of the present results for the cross flow w and fluid temperature θ for various Reynolds number (Re).

Table - 5.1: Comparison of the present results with the results of Ahmed *et al.* (2015) for the cross flow w when $Pr = 0.71$, $Sc = 0.78$, $M = 5$, $h = 0.2$, A = -1.5, $m = 2 = n$, $K = 1$, z = 0.3, $\varepsilon = 0.005$.

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	Present work		**Ahmed *et al.* (2015)**	
y	$Re = 0.5$	$Re = 1.0$	$Re = 0.5$	$Re = 1.0$
0.0	0.00000000	0.00000000	0.00000000	0.00000000
0.2	0.00379178	0.00315629	0.00361143	0.00318550
0.4	0.00465926	0.00442443	0.00460571	0.00435311
0.6	0.00372425	0.00392053	0.00367247	0.00387362
0.8	0.00215156	0.00252823	0.00213583	0.00248731
1.0	0.00000000	0.00000000	0.00000000	0.00000000

Table - 5.2: Comparison of the present results with the results of Ahmed *et al.* (2015) for the temperature profiles θ when $Pr = 0.71$, A = -1.5, $m = 2$, $K = 1$, z = 0.3, $\varepsilon = 0.005$.

y	Present work		Ahmed *et al.* (2015)	
	$Re = 0.5$	$Re = 1.0$	$Re = 0.5$	$Re = 1.0$
0.0	1.000000	1.000000	1.000000	1.000000
0.2	1.060172	1.175762	1.058798	1.170987
0.4	1.141370	1.354621	1.135608	1.351539
0.6	1.332976	1.550760	1.327254	1.545700
0.8	1.597813	1.774175	1.596509	1.769840
1.0	2.000000	2.000000	2.000000	2.000000

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5.10 Results and Discussion :

In this chapter all the numerical calculation through the Mathematica code 8 have been done with respect to the values $Pr = 0.71$ (air), $Sc = 0.78$ (ammonia), $Gr = 2 = Gm$ (heat is conveying from fluid to the wall), $h = 0.5$, $K = 1$ (endothermic reaction), A = -2, z = 2, $\varepsilon = 0.005$.

Table - 5.3 and 5.4 depict the nature of cross flow velocity in y-direction (v) and cross flow velocity in z-direction (w) under the influence of Hartmann number (M) and Reynolds number (Re). From Table - 5.3 it is seen that v decreases throughout the channel as the fluid move from the plate at rest ($y = 0$) toward the plate in motion ($y = 1$). Further, in the regions of the channel close to the plate at rest it seems that v decreases with an increase in Hartmann number, but as the fluid move further out into the channel toward the plate in motion, it is seen that v increases as Hartmann number increases. Also, it is seen that w initially increases from zero value (starting from the plate at rest) to some maximum value attainable at possibly the middle of the channel and again decreases thereafter to zero when one

approaches the plate in motion. It is also observed that starting from the region very close to the plate at rest, w initially increases with increasing in Hartmann number till about the middle of the channel and then decreases thereafter with increasing values of Hartmann number when one gradually nears the plane in motion.

Table - 5.3: Effects of M on v and w when $Re = 0.5$.

y	v ($M = 5$)	v ($M = 10$)	w ($M = 5$)	w ($M = 10$)
0.0	1.005	1.005	0	0
0.2	1.00422	1.00418	0.00201472	0.00209178
0.4	1.00283	1.00276	0.00225515	0.00225926
0.6	1.0015	1.00145	0.00192441	0.00187425
0.8	1.00047	1.00045	0.00130038	0.00125156
1.0	1	1	0	0

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Table - 5.4: The effects of Re on v and w when $M = 5$.

y	v ($Re = 0.5$)	v ($Re = 1$)	w ($Re = 0.5$)	w ($Re = 1$)
0.0	1.005	1.005	0	0
0.2	1.0042	1.0041	0.00201472	0.0020163
0.4	1.00283	1.00283	0.00225515	0.00223585
0.6	1.0015	1.00151	0.00192441	0.00191043
0.8	1.00047	1.00048	0.00130038	0.00131899
1.0	1	1	0	0

From Table – 5.4 it has been seen that v decreases throughout the channel as the fluid move from the plate at rest ($y = 0$) towards the plate in motion

($y = 1$). With increasing values of Reynolds number in the region of the channel v decreases near the plate at rest and thereafter slightly increases from the middle of the channel. Eventually, w increases with increasing values of Re in the regions of the channel close to the plate at rest, and then middle of the channel w decreases. From both the tables, it has been seen that the magnitude of v is greatest at the plate at rest and least at the plate in motion. It is also observed that the effects of M and Re on v are greatest at the plate at rest and are least at the plate in motion. Further, it is also been seen that the influence of Re and M on w is most significant at middle of the channel.

The effects of external magnetic field on the main flow velocity (u) for conducting air ($Pr = 0.71$) in case of plate cooling ($Gr > 0$) is presented in Fig. 5.2. In this figure it has been observed a velocity peak arises closed to the plate in motion for all profiles. With an increase in Hartmann number, there is a clear increase in the fluid velocity. In the momentum Eqs (5.2.12) and (5.2.14), the hydromagnetic terms, $-Mu$ and $-Mw$ derived from classical MHD flat-plate boundary layer flow owing to the presence of a negative magnetic term. The applied magnetic field, B_0, is therefore, effectively moving with the free stream. The resulting Lorentzian body force will therefore not act as a drag force as in conventional MHD flows, but as an aiding body force. This will serve to accelerate the flow and boost velocities in the channel near the plate in motion.

Fig. 5.3 represents the main flow velocity distribution (u) for the effects of thermal radiation (R_a). An increasing the thermal radiation elevated the velocity distribution near the plate $y = 1$.

The behaviour of the chemical reaction (K) on the main flow velocity (u) has been shown in Fig. 5.4. The imposition of the endothermic chemical reaction causes an increase the value of u throughout the channel.

Fig. 5.5 depicts the influence of Reynolds number (Re) on the fluid temperature (θ). It has been observed that the fluid temperature is depressed when the Reynolds number (Re) increases from 0.1 through 0.3, 0.5, 0.7 to 0.9.

The effects of thermal radiation (R_a) on the fluid temperature have been presented in Fig. 5.6. It is seen that an increasing thermal radiation (R_a) reduced the fluid temperature and this reduction of the fluid temperature is occurred in the middle of the channel.

Fig. 5.7 shows the influence of wall-mass ratio (n) on concentration. When n takes the positive integer values (n = 0, 1, 2), the concentration is sharply increased at the plate y = 1, whereas n takes the negative values (n = -1, 0) the concentration has been depressed.

The endothermic chemical reaction (K) on the species concentration has been plotted in Fig. 5.8. Due to the cause of endothermic rate, the species concentration is reduced throughout the channel. Also it shows that the maximum effects have been counted in the middle of the channel when K = 3.

The main flow skin-friction distribution (τ_{x0}) at y = 0 for the variation of Radiation (R_a) and the magnetic field (M) is presented in Fig. 5.9. In the region $0 \leq M \leq 6$, the skin-friction has increased when R_a increases from 0 through 2, 4 to 6. Maximum elevation of τ_{x0} for R_a has been observed in the neighbourhood of M = 4. However, there is a reversed trend to the skin-friction when $M > 6$ for the thermal radiation. When magnetic field M increases within the interval (0, 4), all the values of τ_{x0} are increased at the maximum height. However, the values of τ_{x0} are decreased when $M \geq 4$.

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In Fig. 5.10 it is marked that the cross flow skin-friction (τ_{z0}) at y = 0 is increased when M varies from 2, 5 to 10. At M = 2, the values of τ_{z0} have been falling down when Re increased. At M = 10 (large magnetic application) the values of τ_{z0} have been grown up when Re increased. But at M = 5 there is no significant effects of Re.

The Nusselt number (Nu_0) is presented for the various values of suction parameter (A) and Reynolds number (Re) in the Fig. 5.11. When Re increases, all the distribution of Nu_0 are highly falling down, it means that the heat is defused to the fluid region from the wall y = 0. Moreover, the

Nusselt number is decreased when the suction parameter A takes negative values.

The effects of wall-mass ratio (n) and Reynolds number (Re) on the Sherwood number (Sh_0) have been shown in the Fig. 5.12. For the positive integer values of n = 0, 1, 2 the Sherwood number elevated and for the negative integer values of n = -1, 0 the Sherwood number depressed.

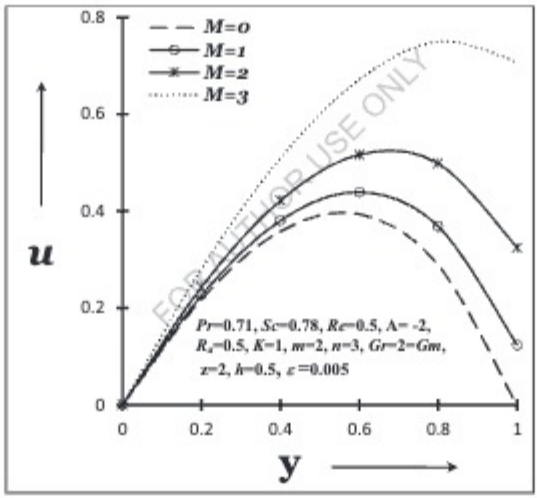

Fig. 5.2: Main flow velocity profiles for M

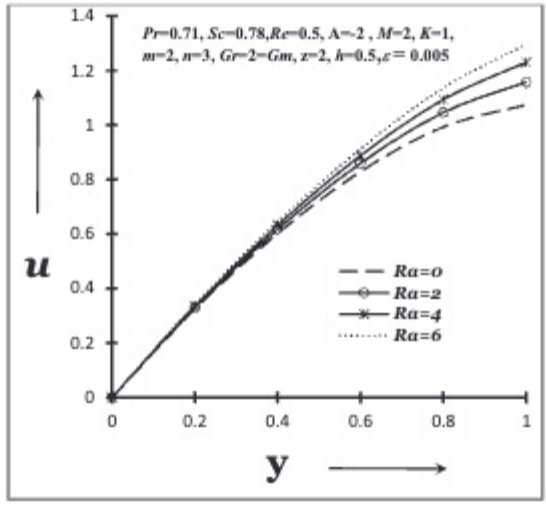

Fig. 5.3: Main flow velocity profiles for R_a

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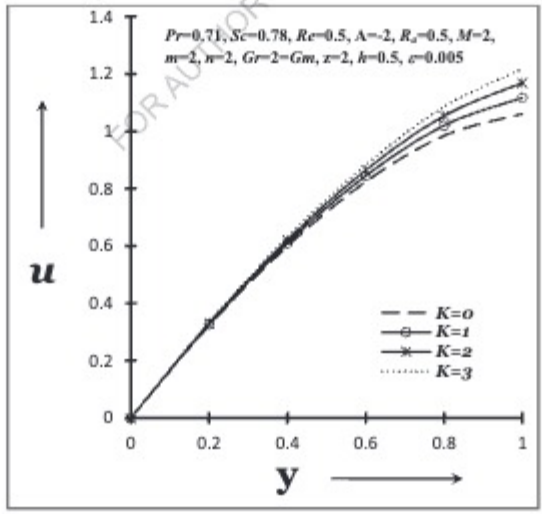

Fig. 5.4: Main flow velocity profiles for K

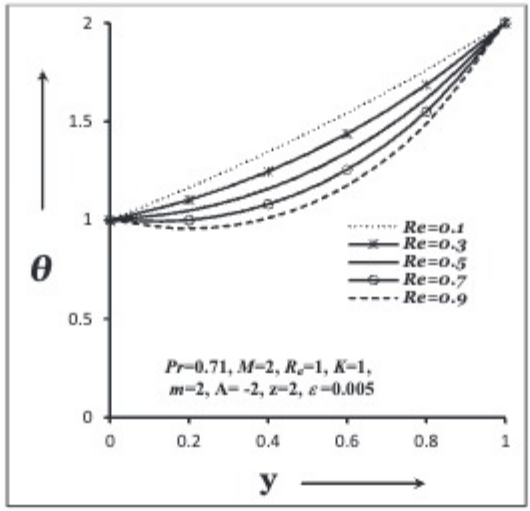

Fig. 5.5: Temperature profiles for *Re*

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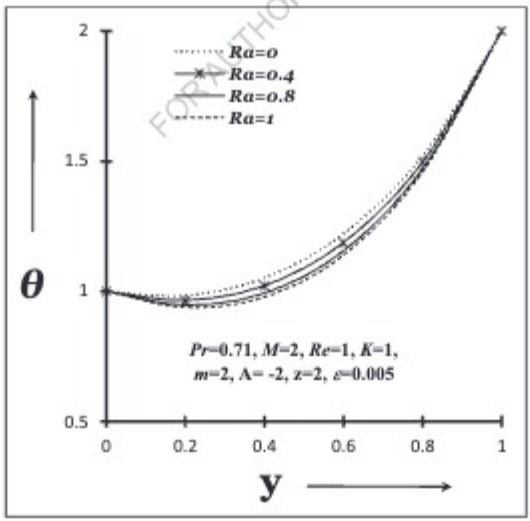

Fig. 5.6: Temperature profiles for R_a

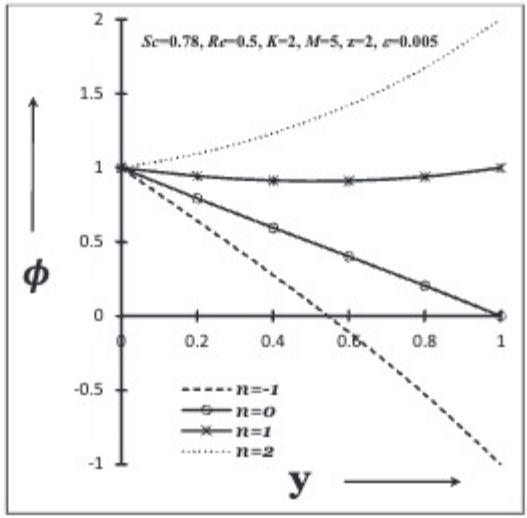

Fig. 5.7: Concentration profiles for *n*

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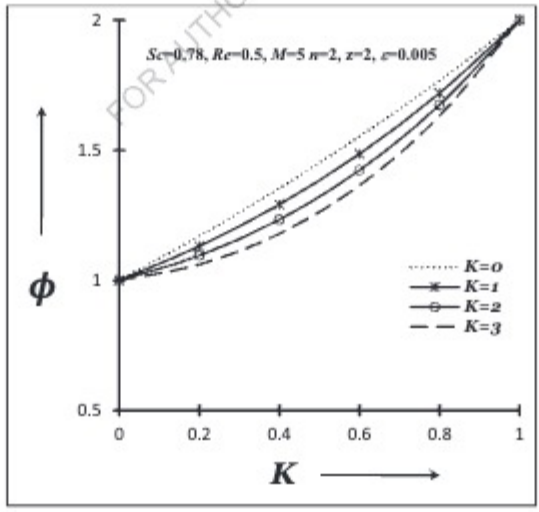

Fig. 5.8: Concentration profiles for *K*

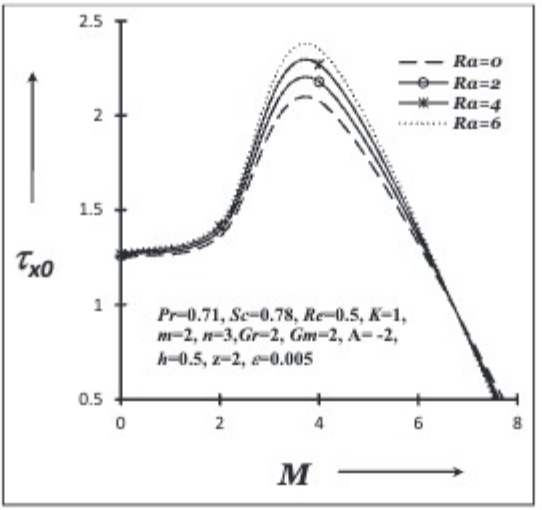

Fig. 5.9: Skin-friction profiles for R_a and M

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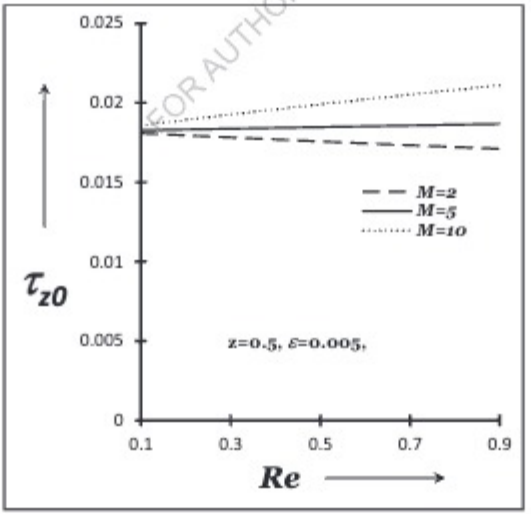

Fig. 5.10: Skin-friction profiles for M and Re

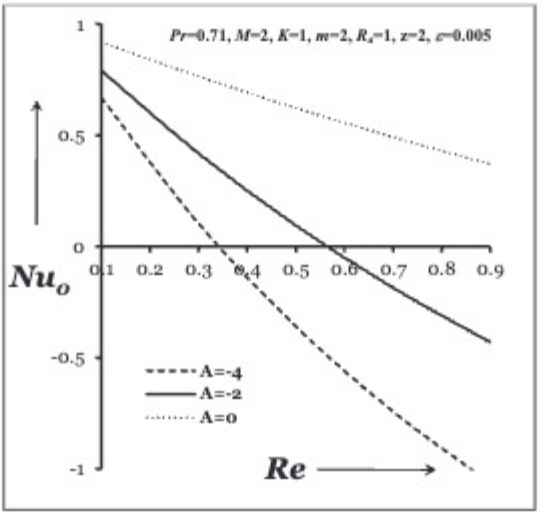

Fig. 5.11: Nusselt number for A and *Re*

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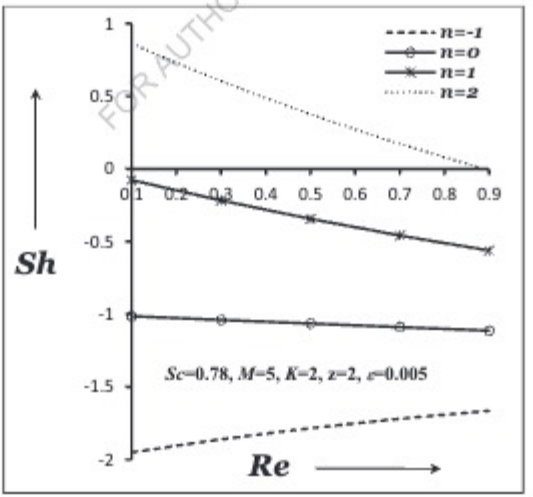

Fig. 5.12: Sherwood number for *n* and *Re*

5.11 Conclusion :

A Magnetohydrodynamic three-dimensional Couette flow of a viscous incompressible electrically conducting fluid and chemically radiating fluid in presence of transverse sinusoidal injection velocity has been analyzed. The governing non-leaner partial differential equations were solved analytically. The main results of the present study can be summarized as follows:

1. The overshoot flow has been occurred in both the main flow velocity and skin-friction distributions due to external magnetic field (M);
2. Chemical reaction parameter (K) has quite opposite effects on the velocity as well as molar species concentration;
3. Due to thermal radiation (R_a), a similar behaviour for the velocity and skin-friction distribution has been observed, while this behaviour is opposite to the fluid temperature;
4. The wall mass ratio (n) enhances the molar spices concentration and Sherwood number;
5. Similar behaviour is observed for the fluid temperature and the Sherwood number due to Reynolds number;
6. Nusselt number is an increasing function of suction parameter (A), while it is a decreasing function of Reynolds number.

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Chapter - VI

Rosseland Diffusion Flux Approximation along a Variable Temperature / Concentration Plate with Viscous Dissipative Heat: A Darcian Model

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6.1 Introduction :

The study of hydromagnetic flow and heat transfer of an electrically conducting fluid past a Darcian porous medium finds useful applications in many engineering problems such as MHD generator, plasma studies, nuclear reactors, geothermal extractions and the boundary layer control in the field of aeronautics and missile aerodynamics. As the structure of stars and planets are greatly influenced by thermal convection in their interiors, these studies are important in astrophysics also. The influence of magnetic field on viscous incompressible flow of electrically conducting fluid has its importance in many applications such as extrusion of plastics in the manufacture of rayon and nylon, purification of crude oil, pulp, paper industry, textile industry and in different geophysical cases etc. In many process of industries, the cooling of threads or sheets of some polymer materials is of importance in the production line. The rate of cooling can be controlled effectively to achieve final products of desired characteristics by drawing threads etc. in the presence of electrically conducting fluid subject to a magnetic field.

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Radiative heat transfer flow is very important in manufacturing industries for the design of reliable equipment, nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles. The study of radiative heat and mass transfer in convection flow found to be most important in industrial and technologies. The applications are often found in situation such as fiber and granules insulation, geothermal systems in the heating and cooling chamber, energy processes and Astor-physical flows. Chamkha (2000) studied thermal radiation and buoyancy effects on hydro-magnetic flow over an accelerating permeable surface with heat source and sink. Thermal radiation and buoyancy effects on MHD free convection heat generation flow over an accelerating permeable surface with temperature dependent viscosity was presented by Seddek (2001). Ganesan and Loganadan (2002) investigated radiation and mass transfer effects on flow of incompressible viscous fluid past a moving cylinder. Raptis and Perdikis (2006) studied the effects of radiation on two dimensional steady MHD optically thin gray gas flow along an infinite vertical plate taking into account the induced magnetic field. Seddek *et al*. (2007) studied the effects of chemical reaction, radiation and

variable viscosity on hydro-magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media. The effects of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction was studied by Ibrahim *et al.* (2008). Malapati and Polarapu (2015) investigate the thermal radiation and chemical reaction effects on unsteady MHD free convective heat and mass transfer flow past a vertical permeable plate. Ibrahim *et al*. (2015) considered the radiation and mass transfer effects on MHD oscillatory flow in a channel filled with porous medium in the presence of chemical reaction. Bakier and Gorla (1996) studied thermal radiation effects on mixed convection from horizontal surfaces in porous medium. The effect of radiation on the mixed convection flow on an isothermal vertical surface in a saturated porous medium and has obtained a self- similar solution reported by Bakier (2001). Kim and Fedorov (2003) analyzed transient mixed radiative convective flow of a micro polar fluid past a moving semi-infinite vertical porous plate. Radiation effects on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium was studied by Prasad and Reddy (2008).

The viscous dissipation effects are important in geophysical flows and also in certain industrial operations are usually characterized by the Eckert number. The viscous dissipation effect is expected to be relevant for fluids with high values of dynamic viscosity as for high velocity flows. The viscous dissipation heat is important in the natural convective flows, when the field is of extreme size or at extremely low temperature or in high gravitational field. Soundalgekar (1974) studied the viscous dissipation effect on unsteady free convection flow past an infinite, vertical porous plate with constant suction. Viscous dissipation effects on the unsteady free convection flow of an elastico-viscous fluid past an infinite vertical plate with constant suction have been studied by Soundalgekar and Desai (1979). Gebhart and Mollendorf (1969) considered the effects of viscous dissipation for external natural convection flow over a surface. Rao and Srinivasa (2010) have studied on applied magnetic field on transient free convection flow of an incompressible viscous dissipation fluid in a vertical channel. MHD free convection and mass transfer with Hall current, viscous

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dissipation, Joule heating and thermal diffusion was studied by Singh (2003). Pandya and Shukla (2014) presented Soret-Dufour and radiation effects on MHD flow over an inclined porous plate embedded in porous medium with viscous dissipation. Ahmed (2010) investigated the effect of viscous dissipative heat on three dimensional oscillatory flows with periodic suction velocity.

The study of convective fluid flow with mass transfer along a vertical porous plate in the presence of magnetic field and internal heat generation receiving considerable attention due to its useful applications in different branches of Science and Technology such as comical and geophysical science, fire engineering, combustion modeling etc. In certain porous media applications such as those involving heat removal from nuclear fuel debris, underground disposal of radioactive waste material, storage of food stuffs, exothermic and/or endothermic chemical reactions, dissociating fluids in packed-bed reactors, the working fluid heat generation (source) or absorption (sink) effects are important. Representative studies dealing with these effects have been reported by such authors as Achaya and Goldstein (1985), Vajravelu and Nayfeh (1992) and Chamkha (1996, 1997). Natural convection flows along a heated semi-infinite vertical plate with internal heat generation studied by Vajravelu (1979). Chamkha (2004) investigated the problem of unsteady two dimensional electrically conducting MHD convective heats and mass transfer flow with heat absorption. Sharma and Singh (2008) discussed unsteady MHD free convection flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. The heat and mass transfer effects on unsteady MHD free convective flow along a vertical porous plate with internal heat generation and variable suction analyzed by Sharma *et al.* (2012). Alam *et al*. (2006) studied the combined free-forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal diffusion. They also investigated MHD free convection heat and mass transfer flow past an inclined surface with heat generation. The effects of chemical reaction and thermophoresis on MHD mixed convective heat and mass transfer flow along an inclined plate in the presence of heat generation/absorption with viscous dissipation and Joule heating analyzed by Alam *et al.* (2008).

The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions and those concerned with dissociating fluids. Heat generation effects many alter the temperature distribution and this in turn can affect the particle deposition rate in nuclear reactors, electronic chips and semi-conductor wafers. Moalem (1976) studied the effect of temperature dependent heat sources taking place in electrically heating on the heat transfer within a porous medium. The effects of radiation, heat generation and viscous dissipation on MHD free convective flow along a stretching sheet have been investigated by Tania and Sarma (2010). Chamkha (1999) studied the effects of heat generation or absorption on hydromagnetic three-dimensional free convection flow over a vertical stretching surface. Effects of chemical reaction on two-dimensional MHD flow with viscous dissipation in the presence of heat sink investigated by Sekhar and Reddy (2012). Sharma and Choudhary (2015) have been presented the effect of radiation on MHD free convective flow of an electrically conducting incompressible viscous fluid in presence of heat source.

In the present analysis, we investigate theoretically the effects of dissipative heat and heat source/generation on unsteady, hydromagnetic flow of viscous incompressible electrically conducting fluid over a vertical surface immersed in a Darcian porous regime in presence of radiation. Such a study has does far not being communicated in the Engineering Science or Applied Mathematical literature and finds pertinent application in high temperature magneto-material processing.

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6.2 Mathematical Formulation :

We consider the unsteady two-dimensional nonlinear MHD free convective flows of a viscous incompressible and electrically conducting, radiating and viscous dissipative fluid past an infinite heated vertical porous plate embedded in a porous medium under the influence of thermal and concentration buoyancy effects. Let the $\overline{x}$ – axis be taken in vertically upward direction along the plate and $\overline{y}$ – axis is normal to the plate. It is assumed that there exists a homogeneous chemical reaction of first order with constant rate $\overline{K_r}$ between the diffusing species and the fluid. A uniform magnetic field is applied in the direction perpendicular to the plate. The

magnetic Reynolds number and transverse applied magnetic field are assumed to be very small, so that the produced magnetic field is insignificant. Also it is supposed that there is no applied voltage, so that the electric field is vanished. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species, which are present. Hence the Soret and Dufour effects are negligible and the temperature in the fluid flow is governed by the energy concentration equation involving radiative heat temperature. Under the above hypothesis as well as Boussinesq's approximation, the equations of conversation of mass, momentum, energy and concentration governing the free convective nonlinear boundary layer flow over a vertical porous plate in porous channel can be expressed as:

$$\frac{\partial \overline{v}}{\partial \overline{y}} = 0 \tag{6.2.1}$$

$$\frac{\partial \overline{u}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{u}}{\partial \overline{y}} = \left\{ \begin{array}{c} \nu \dfrac{\partial^2 \overline{u}}{\partial \overline{y}^2} + g\beta\left(\overline{T} - \overline{T}_\infty\right) + g\overline{\beta}\left(\overline{C} - \overline{C}_\infty\right) \\ -\dfrac{\sigma B_0^2 \overline{u}}{\rho} - \dfrac{\nu}{\overline{k}}\overline{u} \end{array} \right\} \tag{6.2.2}$$

$$\frac{\partial \overline{T}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} = \alpha \frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{1}{\rho C_p}\frac{\partial \overline{q}_r}{\partial \overline{y}} + \frac{\nu}{C_p}\left(\frac{\partial \overline{u}}{\partial \overline{y}}\right)^2 - Q_0\left(\overline{T} - \overline{T}_\infty\right) \tag{6.2.3}$$

$$\frac{\partial \overline{C}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{C}}{\partial \overline{y}} = D\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} - \overline{K}_r\left(\overline{C} - \overline{C}_\infty\right) \tag{6.2.4}$$

The corresponding boundary conditions for the velocity, temperature and concentration fields are given as follows:

$$\left[\begin{array}{l} \left\{ \begin{array}{c} \overline{u} = \overline{L}\left(\dfrac{\partial \overline{u}}{\partial \overline{y}}\right), \quad \overline{T} = \overline{T}_w + \varepsilon\left(\overline{T}_w - \overline{T}_\infty\right)e^{i\overline{\omega}\overline{t}}, \\ \overline{C} = \overline{C}_w + \varepsilon\left(\overline{C}_w - \overline{C}_\infty\right)e^{i\overline{\omega}\overline{t}} \ \ at \ \ \overline{y} = 0 \end{array} \right\} \\ \\ \overline{u} \to 0, \quad \overline{T} \to \overline{T}_\infty, \quad \overline{C} \to \overline{C}_\infty \quad as \quad \overline{y} \to \infty \end{array} \right] \tag{6.2.5}$$

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By using the Rosseland approximation, the radioactive flux vector $\overline{q}_r$ can be written as:

$$\overline{q}_r = -\frac{4\overline{\sigma}}{3\overline{a}}\frac{\partial \overline{T}^4}{\partial \overline{y}} \tag{6.2.6}$$

where $\overline{\sigma}$ and $\overline{a}$ are the Stefan-Boltzmann constant and the mean absorption coefficient respectively. We assume that the temperature difference within the flow is sufficiently small such that $\overline{T}^4$ may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about the free stream temperature $\overline{T}_\infty$ and neglecting higher order terms, thus

$$\overline{T}^4 \cong 4\overline{T}_\infty^3\overline{T} - 3\overline{T}_\infty^4 \tag{6.2.7}$$

From Eq. (6.2.1) it is clear that suction velocity at the plate is either a constant or function of time only. Hence the suction velocity normal to the plate is assumed to be the form

$$\overline{v} = -V_0\left(1 + \varepsilon A e^{i\overline{\omega}\overline{t}}\right) \tag{6.2.8}$$

where A is a real constant and ε is small such that $\varepsilon << 1$, $\varepsilon A << 1$ and V_0 is a non-zero positive constant, the negative sign indicates that the suction is towards the plate.

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Now we introduce the following non-dimensional quantities.

$$\left.\begin{array}{l} u = \dfrac{\overline{u}}{V_0}, v = \dfrac{\overline{v}}{V_0}, y = \dfrac{V_0\overline{y}}{\nu}, t = \dfrac{\overline{t}V_0^2}{4\nu}, \omega = \dfrac{4\overline{\omega}\nu}{V_0^2}, R = \dfrac{\overline{a}k}{4\overline{\sigma}\overline{T}_\infty^3}, \\ \theta = \dfrac{\overline{T}-\overline{T}_\infty}{\overline{T}_w-\overline{T}_\infty}, C = \dfrac{\overline{C}-\overline{C}_\infty}{\overline{C}_w-\overline{C}_\infty}, K = \dfrac{\overline{k}V_0^2}{\nu^2}, Pr = \dfrac{\nu\rho C_p}{k}, h = \dfrac{V_0\overline{L}}{\nu} \\ K_r = \dfrac{\overline{K_r}\nu}{V_0^2},\ Sc = \dfrac{\nu}{D},\ M = \dfrac{\sigma B_0^2\nu}{\rho V_0^2},\ Gr = \dfrac{\nu\beta g\left(\overline{T}_w-\overline{T}_\infty\right)}{V_0^3}, \\ Gm = \dfrac{\nu\overline{\beta}g\left(\overline{C}_w-\overline{C}_\infty\right)}{V_0^3},\ Ec = \dfrac{4V_0^2}{C_p\left(\overline{T}_w-\overline{T}_\infty\right)},\ \phi = \dfrac{4\nu Q_0}{V_0^2} \end{array}\right\} \tag{6.2.9}$$

According to the Eqs (6.2.6), (6.2.7), (6.2.8) and (6.2.9), the Eqs (6.2.2), (6.2.3) and (6.2.4) can be reducing to the following non-dimensional form:

$$\frac{1}{4}\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + GmC - \left(M + \frac{1}{K}\right)u \quad (6.2.10)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial \theta}{\partial y} = \left\{\begin{matrix} \frac{1}{Pr}\left(1 + \frac{4}{3R}\right)\frac{\partial^2 \theta}{\partial y^2} + \\ \frac{1}{4}Ec\left(\frac{\partial u}{\partial y}\right)^2 - \frac{1}{4}\phi\theta \end{matrix}\right\} \quad (6.2.11)$$

$$\frac{1}{4}\frac{\partial C}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - K_r C \quad (6.2.12)$$

The corresponding non-dimensional boundary conditions are:

$$\left\{\begin{matrix} u = h\frac{\partial u}{\partial y}, & \theta = 1 + \varepsilon e^{i\omega t}, & C = 1 + \varepsilon e^{i\omega t} & \text{at} & y = 0 \\ u \to 0, & \theta \to 0, & C \to 0 & \text{as} & y \to \infty \end{matrix}\right\} \quad (6.2.13)$$

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6.3 Solution of the Problem :

In order to reduce the above system of partial differential equations to a system of ordinary equations into non-dimensional form, we may represent the velocity, temperature and concentration as:

$$f(y,t) = f_0(y) + \varepsilon e^{i\omega t} f_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \quad (6.3.14)$$

where f stands for u, θ or C

Substituting Eq. (6.3.14) into Eqs (6.2.10 – 6.2.12) and equating harmonic and non-harmonic terms, and neglecting the higher order terms of $O(\varepsilon^2)$, we obtain:

$$u_0'' + u_0' - \left(M + \frac{1}{K}\right)u_0 = -[Gr\theta_0 + GmC_0] \quad (6.3.15)$$

$$u_1'' + u_1' - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)u_1 = -[Gr\theta_1 + GmC_1 + Au_0'] \quad (6.3.16)$$

$$\theta_0'' + \left(\frac{3PrR}{3R+4}\right)\theta_0' - \frac{1}{4}\left(\frac{3PrR}{3R+4}\right)\phi\theta_0 = -\frac{1}{4}\left(\frac{3PrR}{3R+4}\right)Ec[u_0']^2 \quad (6.3.17)$$

$$\left\{\begin{array}{c} \theta_1'' + \left(\frac{3PrR}{3R+4}\right)\theta_1' - \\ -\frac{1}{4}\left(\frac{3PrR}{3R+4}\right)(\phi + i\omega)\theta_1 \end{array}\right\} = \left\{\begin{array}{c} -\left(\frac{3PrR}{3R+4}\right)A\theta_0' \\ -\frac{1}{2}\left(\frac{3PrR}{3R+4}\right)Ecu_0'u_1' \end{array}\right\} \quad (6.3.18)$$

$$C_0'' + ScC_0' - ScK_rC_0 = 0 \quad (6.3.19)$$

$$C_1'' + ScC_1' - Sc\left(K_r + \frac{i\omega}{4}\right)C_1 = -AScC_0' \quad (6.3.20)$$

where the primes denote the differentiation with respect to y.

The corresponding boundary conditions can be written as:

$$\left\{\begin{array}{c} u_0 = h\left(\frac{\partial u_0}{\partial y}\right), \quad u_1 = h\left(\frac{\partial u_1}{\partial y}\right), \quad \theta_0 = 1, \\ \\ u_0 \to 0, \quad u_1 \to 0, \quad \theta_0 \to 0, \quad \theta_1 \to 0, \\ C_0 \to 0, \quad C_1 \to 0 \quad \text{as} \quad y \to \infty \end{array}\right\} \quad (6.3.21)$$

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The Eqs (6.3.15 – 6.3.20) are still coupled and non-linear, whose exact solutions are not possible. In order to obtain the solutions of above coupled differential Eqs, we expand f_0 , f_1 in powers of number $Ec \ll 1$, for all incompressible fluid

$$f_j(y) = f_{j1}(y) + Ecf_{j2}(y) \quad for\ j = 0, 1 \quad (6.3.22)$$

Substituting Eq. (6.3.22) into the Eqs (6.3.15 – 6.3.20), equating the coefficients of Ec^0 and Ec^1, we get the following Eqs:

The zeroth-order Eqs are:

$$u''_{0j} + u'_{0j} - \left(M + \frac{1}{K}\right) u_{0j} = -\left[Gr\theta_{0j} + GmC_{0j}\right] for\ j = 1,2 \quad (6.3.23)$$

$$\begin{Bmatrix} \theta''_{0j} + \left(\frac{3PrR}{3R+4}\right)\theta'_{0j} \\ -\frac{1}{4}\left(\frac{3PrR}{3R+4}\right)\phi\theta_{0j} \end{Bmatrix} = \begin{Bmatrix} 0 \qquad\qquad for \quad j = 1 \\ -\frac{1}{4}\left(\frac{3PrR}{3R+4}\right)[u'_{01}]^2 \ for\ j = 2 \end{Bmatrix} \quad (6.3.24)$$

$$C''_{0j} + ScC'_{0j} - ScK_rC_{0j} = 0 \qquad for \quad j = 1,2 \quad (6.3.25)$$

and the respective boundary conditions are:

$$\left[\begin{Bmatrix} u_{01} = h\left(\frac{\partial u_{01}}{\partial y}\right), \quad u_{02} = h\left(\frac{\partial u_{02}}{\partial y}\right), \quad \theta_{01} = 1, \\ \theta_{02} = 0, \quad C_{01} = 1, \ C_{02} = 0 \ \ at \ \ y = 0 \end{Bmatrix}\right] \quad (6.3.26)$$

$$\left[\begin{matrix} u_{01} \to 0, \ u_{02} \to 0, \ \theta_{01} \to 0, \ \theta_{02} \to 0, \\ C_{01} \to 0, \ C_{02} \to 0 \ as\ y \to \infty \end{matrix}\right]$$

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The first order Eqs are:

$$\begin{Bmatrix} u''_{1j} + u'_{1j} - \\ \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)u_{1j} \end{Bmatrix} = -\begin{bmatrix} Gr\theta_{1j} + GmC_{1j} \\ +Au'_{0j} \end{bmatrix} for\ j = 1,2 \quad (6.3.27)$$

$$\begin{Bmatrix} \theta''_{1j} + \left(\frac{3PrR}{3R+4}\right)\theta'_{1j} \\ -\frac{1}{4}\left(\frac{3PrR}{3R+4}\right) \\ (\phi + i\omega)\theta_{1j} \end{Bmatrix} = \begin{Bmatrix} -\left(\frac{3PrR}{3R+4}\right)A\theta'_{0j} \ for\ j = 1,2 \\ -\frac{1}{2}\left(\frac{3PrR}{3R+4}\right)u'_{01}u'_{11} \ for\ j = 2 \end{Bmatrix} \quad (6.3.28)$$

$$C''_{1j} + ScC'_{1j} - Sc\left(K_r + \frac{i\omega}{4}\right)C_{1j} = -AScC'_{0j} \quad for \ \ j = 1,2 \quad (6.3.29)$$

and the respective boundary conditions are:

$$\left.\begin{array}{c} u_{11} = h\left(\dfrac{\partial u_{11}}{\partial y}\right),\ \ u_{12} = h\left(\dfrac{\partial u_{12}}{\partial y}\right),\ \ \theta_{11} = 1,\ \ \theta_{12} = 0\ , \\ C_{11} = 1,\ \ C_{12} = 0 \quad at \quad y = 0 \\ \\ u_{11} \to 0,\ \ u_{12} \to 0,\ \ \theta_{11} \to 0,\ \ \theta_{12} \to 0, \\ C_{11} \to 0,\ \ C_{12} \to 0\ \ as\ \ y \to \infty \end{array}\right\} \quad (6.3.30)$$

Solving Eqs (6.3.23–6.3.25) under the boundary conditions (6.3.26) and Eqs (6.3.27–6.3.29) under the boundary conditions (6.3.30) we get,

$$u_{01}(y) = P_3 e^{-m_3 y} + P_2 e^{-m_2 y} + P_1 e^{-m_1 y}$$

$$u_{02}(y) = \left\{\begin{array}{c} P_{11} e^{-m_3 y} + P_4 e^{-m_2 y} + P_5 e^{-2m_3 y} + P_6 e^{-2m_2 y} + P_7 e^{-2m_1 y} \\ +P_8 e^{-(m_2+m_3)y} + P_9 e^{-(m_1+m_2)y} + P_{10} e^{-(m_1+m_3)y} \end{array}\right\}$$

$$u_{11}(y) = \left\{\begin{array}{c} P_{17} e^{-m_6 y} + P_{12} e^{-m_5 y} + P_{13} e^{-m_2 y} + P_{14} e^{-m_4 y} \\ +P_{15} e^{-m_1 y} + P_{16} e^{-m_3 y} \end{array}\right\}$$

$$u_{12}(y) = \left\{\begin{array}{c} P_{36} e^{-m_6 y} + P_{18} e^{-m_5 y} + P_{19} e^{-m_2 y} + P_{20} e^{-2m_3 y} \\ +P_{21} e^{-2m_2 y} + P_{22} e^{-2m_1 y} + P_{23} e^{-(m_2+m_3)y} \\ +P_{24} e^{-(m_1+m_2)y} + P_{25} e^{-(m_1+m_3)y} + P_{26} e^{-(m_3+m_6)y} \\ +P_{27} e^{-(m_3+m_5)y} + P_{28} e^{-(m_3+m_4)y} + P_{29} e^{-(m_2+m_6)y} \\ +P_{30} e^{-(m_2+m_5)y} + P_{31} e^{-(m_2+m_4)y} + P_{32} e^{-(m_1+m_6)y} \\ +P_{33} e^{-(m_1+m_5)y} + P_{34} e^{-(m_1+m_4)y} + P_{35} e^{-m_3 y} \end{array}\right\}$$

$$\theta_{01}(y) = e^{-m_2 y}$$

$$\theta_{02}(y) = \left\{\begin{array}{c} S_7 e^{-m_2 y} + S_1 e^{-2m_3 y} + S_2 e^{-2m_2 y} + S_3 e^{-2m_1 y} + \\ S_4 e^{-(m_2+m_3)y} + S_5 e^{-(m_1+m_2)y} + S_6 e^{-(m_1+m_3)y} \end{array}\right\}$$

$$\theta_{11}(y) = S_9 e^{-m_5 y} + S_8 e^{-m_2 y}$$

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$$\theta_{12}(y) = \left\{ \begin{array}{c} S_{26}e^{-m_5 y} + S_{10}e^{-m_2 y} + S_{11}e^{-2m_3 y} + \\ S_{12}e^{-2m_2 y} + S_{13}e^{-2m_1 y} \\ +S_{14}e^{-(m_2+m_3)y} + S_{15}e^{-(m_1+m_2)y} + S_{16}e^{-(m_1+m_3)y} \\ +S_{17}e^{-(m_3+m_6)y} + S_{18}e^{-(m_3+m_5)y} + S_{19}e^{-(m_3+m_4)y} \\ +S_{20}e^{-(m_2+m_6)y} + S_{21}e^{-(m_2+m_5)y} + S_{22}e^{-(m_2+m_4)y} \\ +S_{23}e^{-(m_1+m_6)y} + S_{24}e^{-(m_1+m_5)y} + S_{25}e^{-(m_1+m_4)y} \end{array} \right\}$$

$$C_{01}(y) = e^{-m_1 y}$$

$$C_{02}(y) = 0$$

$$C_{11}(y) = J_2 e^{-m_4 y} + J_1 e^{-m_1 y}$$

$$C_{12}(y) = 0$$

In view of the above solutions, using the Eq. (6.3.14) and Eq. (6.3.22), we obtain the velocity, temperature and concentrations in the boundary layer as:

$$u(y,t) = \left[\begin{array}{c} P_3 e^{-m_3 y} + P_2 e^{-m_2 y} + P_1 e^{-m_1 y} + \\ Ec \left\{ \begin{array}{c} P_{11}e^{-m_3 y} + P_4 e^{-m_2 y} + P_5 e^{-2m_3 y} + \\ P_6 e^{-2m_2 y} + P_7 e^{-2m_1 y} + P_8 e^{-(m_2+m_3)y} \\ +P_9 e^{-(m_1+m_2)y} + P_{10} e^{-(m_1+m_3)y} \end{array} \right\} \\ +\varepsilon e^{i\omega t} \left[\begin{array}{c} \left\{ \begin{array}{c} P_{17}e^{-m_6 y} + P_{12}e^{-m_5 y} + P_{13}e^{-m_2 y} + \\ P_{14}e^{-m_4 y} + P_{15}e^{-m_1 y} + P_{16}e^{-m_3 y} \end{array} \right\} \\ +Ec \left\{ \begin{array}{c} P_{36}e^{-m_6 y} + P_{18}e^{-m_5 y} + P_{19}e^{-m_2 y} + \\ P_{20}e^{-2m_3 y} + P_{21}e^{-2m_2 y} \\ +P_{22}e^{-2m_1 y} + P_{23}e^{-(m_2+m_3)y} \\ +P_{24}e^{-(m_1+m_2)y} + P_{25}e^{-(m_1+m_3)y} \\ +P_{26}e^{-(m_3+m_6)y} + P_{27}e^{-(m_3+m_5)y} \\ +P_{28}e^{-(m_3+m_4)y} + P_{29}e^{-(m_2+m_6)y} \\ +P_{30}e^{-(m_2+m_5)y} + P_{31}e^{-(m_2+m_4)y} \\ +P_{32}e^{-(m_1+m_6)y} + P_{33}e^{-(m_1+m_5)y} \\ +P_{34}e^{-(m_1+m_4)y} + P_{35}e^{-m_3 y} \end{array} \right\} \end{array} \right] \end{array} \right]$$

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$$\theta(y,t)=\begin{bmatrix} e^{-m_2y} \\ Ec\begin{Bmatrix} S_7e^{-m_2y}+S_1e^{-2m_3y}+S_2e^{-2m_2y}+S_3e^{-2m_1y}+ \\ S_4e^{-(m_2+m_3)y}+S_5e^{-(m_1+m_2)y}+S_6e^{-(m_1+m_3)y} \end{Bmatrix} \\ S_9e^{-m_5y}+S_8e^{-m_2y} \\ +\varepsilon e^{i\omega t}\begin{bmatrix} +Ec\begin{Bmatrix} S_{26}e^{-m_5y}+S_{10}e^{-m_2y}+S_{11}e^{-2m_3y} \\ +S_{12}e^{-2m_2y}+S_{13}e^{-2m_1y}+S_{14}e^{-(m_2+m_3)y} \\ +S_{15}e^{-(m_1+m_2)y}+S_{16}e^{-(m_1+m_3)y}+ \\ S_{17}e^{-(m_3+m_6)y}+S_{18}e^{-(m_3+m_5)y} \\ +S_{19}e^{-(m_3+m_4)y}+S_{20}e^{-(m_2+m_6)y} \\ +S_{21}e^{-(m_2+m_5)y}+S_{22}e^{-(m_2+m_4)y} \\ +S_{23}e^{-(m_1+m_6)y}+S_{24}e^{-(m_1+m_5)y} \\ +S_{25}e^{-(m_1+m_4)y} \end{Bmatrix} \end{bmatrix} \end{bmatrix}$$

$$C(y,t)=e^{-m_1y}+\varepsilon e^{i\omega t}[J_2e^{-m_4y}+J_1e^{-m_1y}]$$

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6.3.1 Skin-Friction :

Knowing the velocity field, the skin-friction at the plate can be obtained

$$C_f=\left[\frac{\tau_w}{\rho U_0V_0}\right]=\left(\frac{\partial u}{\partial y}\right)_{y=0}=\left(\frac{\partial u_0}{\partial y}+\varepsilon e^{i\omega t}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$=\begin{bmatrix} -m_3P_3-m_2P_2-m_1P_1 \\ +Ec\begin{Bmatrix} -m_3P_{11}-m_2P_4-2m_3P_5 \\ -2m_2P_6-2m_1P_7-(m_2+m_3)P_8 \\ -(m_1+m_2)P_9-(m_1+m_3)P_{10} \end{Bmatrix} \\ -m_6P_{17}-m_5P_{12}-m_2P_{13}-m_4P_{14}-m_1P_{15}-m_3P_{16} \\ +\varepsilon e^{i\omega t}\begin{bmatrix} +Ec\begin{Bmatrix} -m_6P_{36}-m_5P_{18}-m_2P_{19}-2m_3P_{20}-2m_2P_{21} \\ -2m_1P_{22}-(m_2+m_3)P_{23}-(m_1+m_2)P_{24} \\ -(m_1+m_3)P_{25}-(m_3+m_6)P_{26}-(m_3+m_5)P_{27} \\ -(m_3+m_4)P_{28}-(m_2+m_6)P_{29}-(m_2+m_5)P_{30} \\ -(m_2+m_4)P_{31}-(m_1+m_6)P_{32}-(m_1+m_5)P_{33} \\ -(m_1+m_4)P_{34}-m_3P_{35} \end{Bmatrix} \end{bmatrix} \end{bmatrix}$$

6.3.2 Nusselt Number :

From temperature field, the rate of heat transfer co-efficient can be obtained, which in the non-dimensional form, in terms of the Nusselt number is given by:

$$Nu Re_x^{-1} = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -\left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{i\omega t}\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$= \left[\begin{array}{c} m_2 + \\ Ec\left\{\begin{array}{c} m_2 S_7 + 2m_3 S_1 + 2m_2 S_2 + 2m_1 S_3 \\ +(m_2 + m_3)S_4 + (m_1 + m_2)S_5 \\ +(m_1 + m_3)S_6 \end{array}\right\} \\ +\varepsilon e^{i\omega t}\left[\begin{array}{c} m_5 S_9 + m_2 S_8 \\ +Ec\left\{\begin{array}{c} m_5 S_{26} + m_2 S_{10} + 2m_3 S_{11} + 2m_2 S_{12} \\ +2m_1 S_{13} + (m_2 + m_3)S_{14} \\ +(m_1 + m_2)S_{15} + (m_1 + m_3)S_{16} \\ +(m_3 + m_6)S_{17} + (m_3 + m_5)S_{18} \\ +(m_3 + m_4)S_{19} + (m_2 + m_6)S_{20} \\ +(m_2 + m_5)S_{21} + (m_2 + m_4)S_{22} \\ +(m_1 + m_6)S_{23} + (m_1 + m_5)S_{24} \\ +(m_1 + m_4)S_{25} \end{array}\right\} \end{array}\right] \end{array}\right]$$

where $Re_x = \frac{V_0 x}{\nu}$ is the local Reynolds number.

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6.3.3 Sherwood Number :

From concentration field, the rate of mass transfer co-efficient can be obtained, which in the non-dimensional form, in terms of Sherwood number is given by:

$$Sh Re_x^{-1} = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = -\left(\frac{\partial C_0}{\partial y} + \varepsilon e^{i\omega t}\frac{\partial C_1}{\partial y}\right)_{y=0}$$

$$= \left[m_1 + \varepsilon e^{i\omega t}(m_4 J_2 + m_1 J_1)\right]$$

6.4 Accuracy :

In order to check the accuracy of the employed perturbation method, comparisons with the previously published work Malapati and Polarapu (2015) are performed.

Table - 6.1: Comparison of the present results with the results of Malapati and Polarapu (2015) with the effects of Gr on velocity (u) when $Pr = 0.71$, $Sc = 0.60$, $\omega = 0.1$, $R = 1$, $M = 1$, $K = 1$, $Gm = 5$, $h = 0.1$, A = 0.5, $K_r = 0.2$, $t = 1$, $\varepsilon = 0.001$

	Present work			**Malapati and Polarapu (2015)**		
y	Gr=0	Gr=5	Gr=10	Gr=0	Gr=5	Gr=10
0	0.423708	0.911083	1.39856	0.423708	0.91145	1.39838
2	0.528717	1.36105	2.19394	0.528717	1.36085	2.19299
4	0.14364	0.486311	0.829304	0.14364	0.4862	0.82876
6	0.0364923	0.171377	0.306403	0.0364923	0.171328	0.306164
8	0.0092287	0.062215	0.11526	0.0092287	0.062195	0.115162
10	0.0023332	0.0231456	0.0439812	0.00233316	0.0231378	0.043942

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Table - 6.2: Comparison of the present results with the results of Malapati and Polarapu (2015) with the effects of R on Temperature (θ) when Pr = 0.71, Sc = 0.60, ω = 0.1, M = 1, K = 1, Gr = 5, Gm = 5, h = 0.1, A = 0.5, K_r = 0.2, t = 1, ε = 0.001

y	Present work			Malapati and Polarapu (2015)		
	R=1	R=2	R=3	R=1	R=2	R=3
0	1.001	1.001	1.001	1.001	1.001	1.001
2	0.393264	0.299862	0.260067	0.393177	0.29977	0.259975
4	0.154482	0.0898122	0.0675547	0.154435	0.0897727	0.067519
6	0.0606799	0.0268971	0.0175458	0.060659	0.0268844	0.017536
8	0.0238344	0.0080549	0.0045569	0.023826	0.0080511	0.004554
10	0.0093618	0.00241224	0.00118352	0.0093586	0.00241107	0.011828

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6.5 Results and Discussion :

Comprehensive solutions have been obtained and are presented in figures 6.1(a) to 6.14. Throughout the numerical calculations, the following default parameters are presented (unless otherwise stated); Pr = 0.71, Sc = 0.60, ω = 0.1, R = 1, M = 1, K = 1, Ec = 0.001, Gr = 5, Gm = 5, h = 0.1, A = 0.5, K_r = 0.2, ϕ = 1, t = 1, ε = 0.001. All the results of Thermo physical parameters have been presented through graph.

Figures 6.1(a) and **6.1(b)** illustrate the influence of heat source/generation on the boundary layer variables u and θ. Increasing ϕ clearly serves to decelerate the flow velocity (Fig. 6.1(a)). This effect is accentuated close to the plate surface where a pick in velocity arises. With further distant transverse to the surface, velocity profile is found to decay into free stream. With increasing ϕ, the temperature (Fig 6.1(b)) in the region is found to be decreases i.e. the boundary layer is cooled.

Figures 6.2(a) and **6.2(b)** present the response of velocity (u) and temperature (θ) to Eckert number (Ec). Ec represent the relationship of kinetic energy in the flow to the boundary layer enthalpy difference. It embodies conservation of kinetic energy into the internal energy by work done against the viscous fluid stresses. Although this parameter often uses in high speed compressible flow, for example in Rocket aerodynamics in very high altitude, it has significance in high temperature in compressible flows, which are encounter in chemical engineering system, magnetic materials processing, Nuclear engineering system etc. $Ec > 0$ implies cooling of the wall and therefore a transfer of heat to the fluid. $Ec < 0$ would correspond to heating of the wall and transfer of heat from the fluid. Clearly increasingly positive Eckert number i.e. wall cooling be beneficial to the flow velocity. Again the plate is cooled and the temperature boosted in boundary layer region.

In **Figure 6.3** the variation of velocity with transverse co-ordinate (y) over a wide range of Grashof Number (Gr). For $Gr > 0$, the thermal Grashof simulates the relative influence of thermal buoyancy force to viscous hydrodynamic force in the region i.e. buoyancy force dominates the flow. An increasing in Gr from 0 (pure convection) through 5 to the maximum value of 10, clearly elevated the fluid velocity (u).

Figure 6.4 presences the influence of Magnetic body force (M) on the fluid velocity versus distant transverse to the plate. The magnetic body force $M = \frac{\sigma B_0^2 \nu}{\rho V_0^2}$ significances the ratio of Lorentz hydromagnetic body force to viscous hydrodynamic force. Increasing M from 0 (Non-conducting case), through 1 (Magnetic body force and viscous force equal), 2, 4 (very strong Magnetic body force) induces distinct reduction in velocities. With higher M variables change the Magnetic body force $-Mu$ in momentum Eq. (6.2.10) is amplified, this serves to increasingly return to the flow. The imposition of a transverse magnetic field is therefore a powerful mechanism for inhabiting flow in the region. Maximum velocities as before arise closed to the surface and velocity vanishes in consistently with the no slip condition i.e. $u = 0$.

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Figure 6.5 shows the influence of Porosity (K) on the flow velocity. Increasing Porosity clearly serves to enhance the flow velocity i.e. accelerate the flow. Enhance Porosity clearly corresponds to a reduce presence the matrix fibers in the region which therefore provides a lower resistance to the flow and in turn boosts the momentum.

Figures 6.6(a) and **6.6(b)** illustrate the effect of radiation on the flow velocity (u) and temperature (θ) respectively. The radiation parameter $R = \frac{\bar{a}k}{4\bar{\sigma}T_{\infty}^{3}}$ defines the ratio of thermal conduction contribution relative to thermal radiation. For radiative transfer dominates in the boundary layer region $R \to 0$. For finite values of R there will be a simultaneous presence of thermal conduction and radiation transfer contribution. An increasing R from 1 through 2 to 4 causes a significant decrease in velocity with distant into the boundary layer i.e. decelerate the flow.

The **Figures 6.7(a)** and **6.7(b)** shows the spatial response of velocity (u) and concentration (C) profiles to thermal diffusivity. An increase in K_r from 0 through 0.5 to 2 clearly decreases significantly the velocity (u) (Fig. 6.7(a)) for some considerable distant into the boundary layer. Flow is therefore decelerated with an increase in K_r. Moreover, similar effect has been observed for chemical reaction on the concentration profiles.

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The variation of slip parameter (h) on the flow velocity (u) is presented in **Figure 6.8**. Increasing slip parameter enhances the flow velocity in the boundary layer. However significant effects of h have been observed near the plate i.e. within the region $0 \leq y \leq 2$, but $y > 2$ significant effects is not occurred.

Figure 6.9 depicts the variation of temperature with y co-ordinate, for various Prandtl number (Pr). Pr defines the ratio of momentum diffusivity (ν) to thermal diffusivity. It also expresses the ratio of the product of dynamic viscosity and specific heat capacity to the thermal conductivity of the principal fluid. $Pr < 1$ physically implies that heat will diffuse faster than momentum in the fluid. For $Pr = 1$ the diffusion rate will be the same for heat and momentum i.e. thermal and velocity boundary layer thickness will be equal. For $Pr > 1$ momentum will diffuse faster than heat. The temperatures are considerably lowered with an increased Pr. Higher Pr

fluids (e.g. $Pr = 7.00$) for electrically conducting / water we will therefore possess a much lower thermal conductivity. This will result in a significant decrease in temperatures in the boundary layer. Conversely lower Pr fluids will possess a much greater thermal conductivity (e.g. $Pr = 0.71$ for conducting air) and will generate much higher temperatures. All temperatures are observed to decay smoothly from a maximum at the wall to zero in the free stream of the boundary layer.

Figure 6.10 illustrates the influence of Schmidt number (Sc) on species concentration (C). Sc represents the ratio of the mass (spices) and viscous diffusion. It is also the ratio of momentum diffusivity to species diffusivity. For $Sc < 1$ the momentum diffusivity is lower than the species diffusivity and the spices diffusion rates exceed the momentum diffusion rate and this accounts for the greater concentration values for $Sc = 0.22, 0.3, 0.6, 0.78$. The concentration profiles are, as expected, found to be much more markedly effected by a rising Sc values. C values strongly reduce with increasing Sc values. With thinner concentration boundary layer, the concentration gradient will be enhance causing a decrease in concentration of spices in the boundary layer.

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Figure 6.11 depicts the variation of surface shear stress for various Eckert number (Ec) and Magnetic body force (M). Increasing Ec clearly boosts the wall skin-friction (τ) which grows strongly from the leading edge along the surface and it is significant near the surface. Conversely, with increasing M, the surface shear stress is consistently reduced.

The effects of heat source / generation on surface shear stress (τ) variation against the free convection (Gr) is presented in **Figure 6.12**. With an Increasing ϕ, corresponding to progressively lower contribution of heat source / generation, wall shear stress is consistently reducing, i.e. the flow is decelerated along surface. However, for each profile there is a growth in τ with free convection parameter from the leading edge i.e. increasing Gr values the surface shear stress is markedly increased.

In **Figure 6.13** we have plotted the influence of Eckert number (Ec) on the Nusselt number (Nu) against the heat source / generation. In this figure a strong decrease in surface heat transfer rate (Nu) is associated with

an increase in *Ec* from 0 through 0.5, 1, 1.5 to 2. With increasing *Ec* more and more thermal energy is transferred from the surface to the fluid so that simultaneously less and less heat is transferred to the surface from the external boundary layer region. This results in a depression in surface heat transfer gradient (*Nu*). Conversely, with an increase in ϕ, the surface heat transfer is strongly becoming an increasing function. Significantly within the region $0 \leq \phi \leq 2$ the surface heat transfer is negative for $Ec = 1, 1.5, 2$ and it means that the heat is defused from fluid medium to the surface.

Figure 6.14 presence the effects of chemical reaction (K_r) on the Sherwood number (*Sh*) profiles against the Schmidt number (*Sc*). A much more dramatic response in *Sh* to an increase in *Sc* is observed in this figure. As expected surface species gradient i.e. mass transfer rate at the surface is strongly elevated with a rise in *Sc* and the profiles becomes increasingly divergent. Further enhance mass transfer rates are maximized from the surface. Similar effect has been observed for K_r i.e. the surface mass transfer rate becomes a monotonic increasing function.

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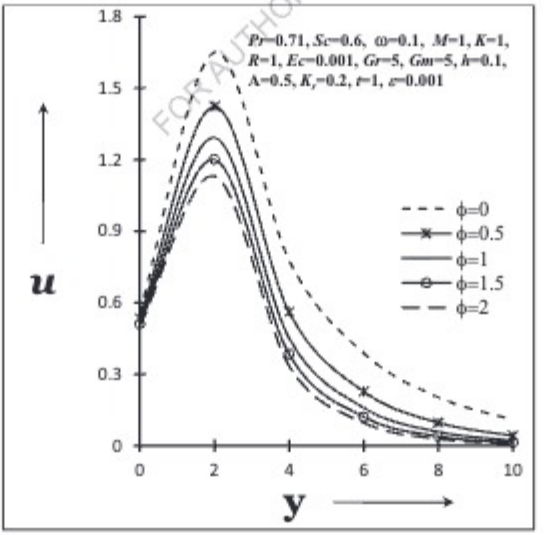

Fig. 6.1(a): Velocity profile for ϕ

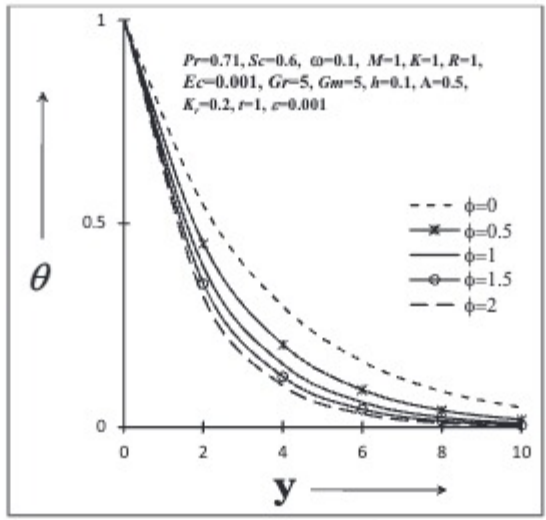

Fig. 6.1(b): Temperature profile for ϕ

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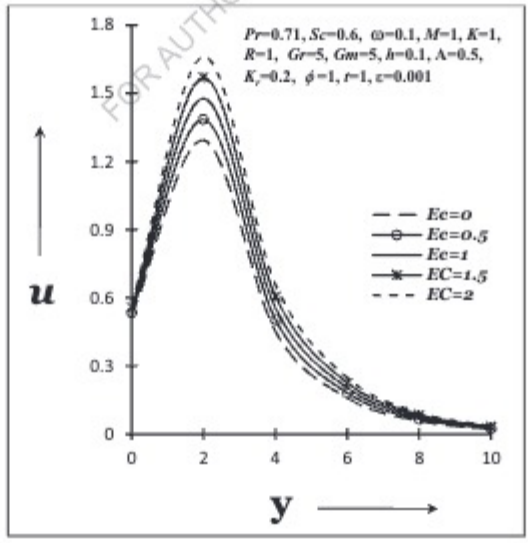

Fig. 6.2(a): Velocity profile for *Ec*

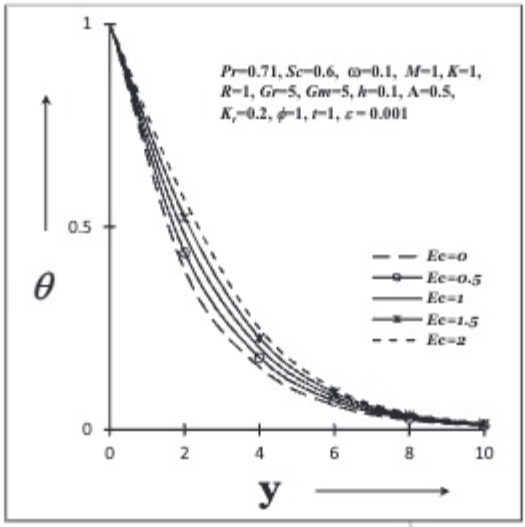

Fig. 6.2(b): Temperature profile for *Ec*

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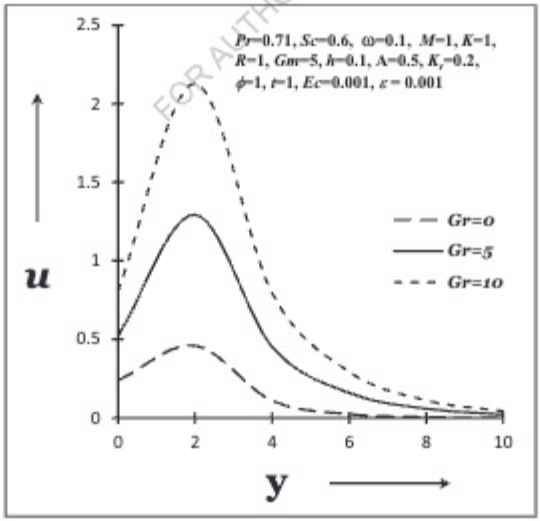

Fig. 6.3: Velocity profile for *Gr*

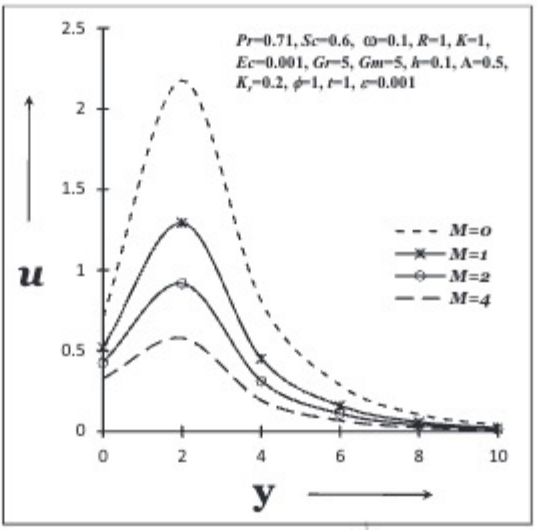

Fig. 6.4: Velocity profile for *M*

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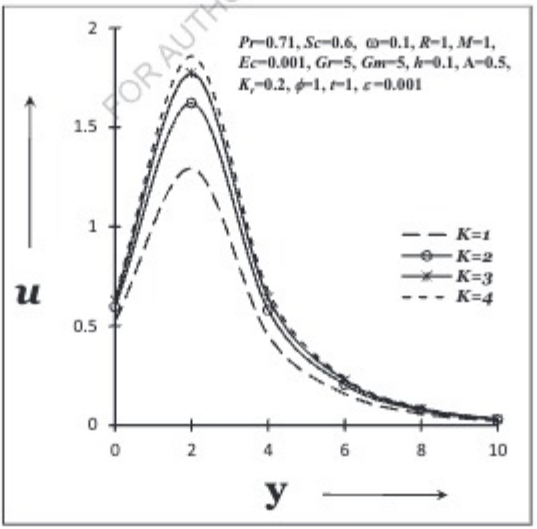

Fig. 6.5: Velocity profile for *K*

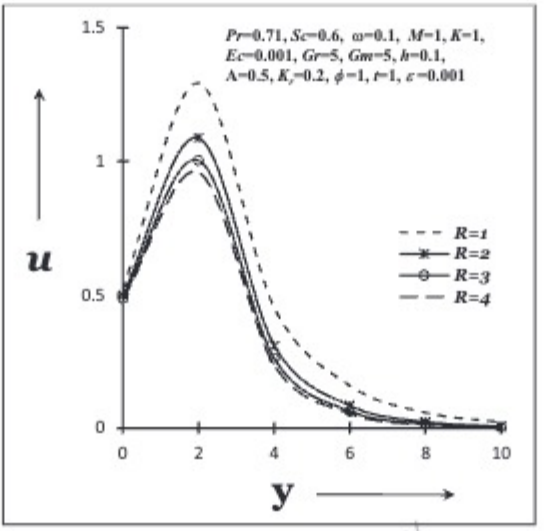

Fig. 6.6(a): Velocity profile for *R*

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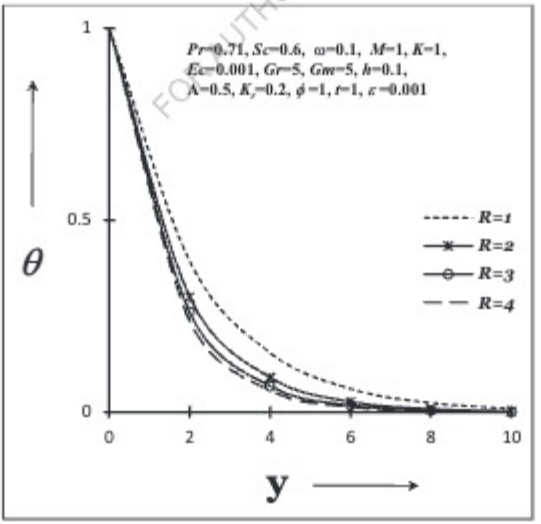

Fig 6.6(b): Temperature profile for *R*

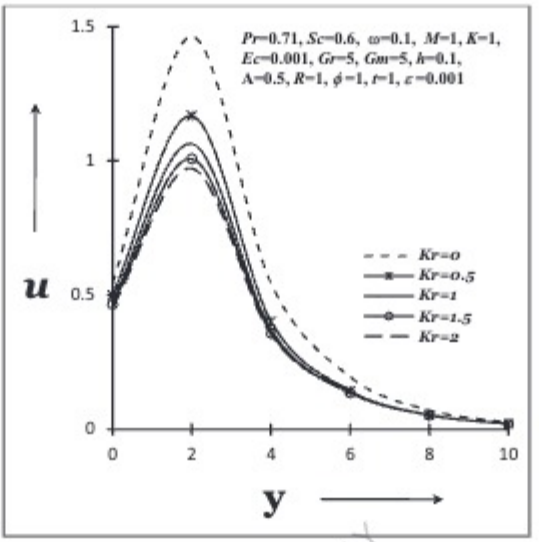

Fig. 6.7(a): Velocity profile for *Kr*

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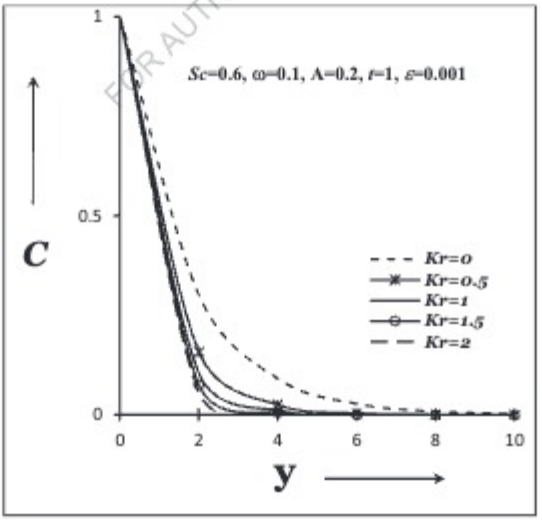

Fig. 6.7(b): Concentration profile for K_r

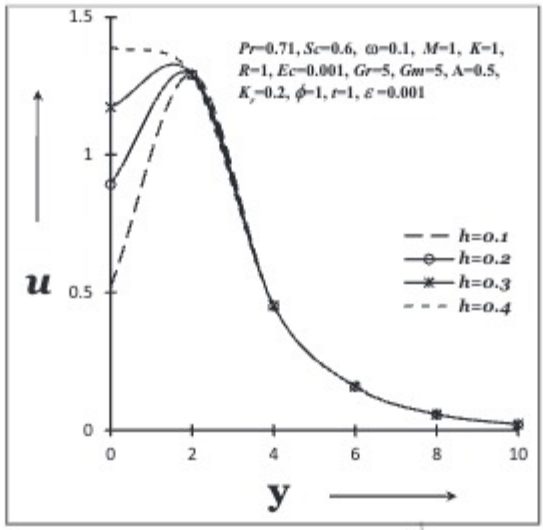

Fig. 6.8: Velocity profile for *h*

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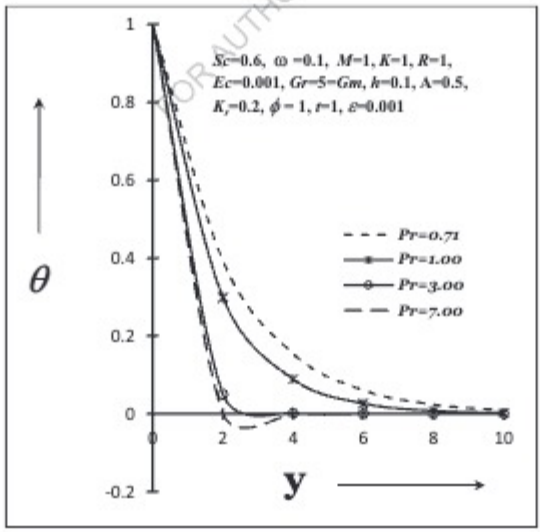

Fig. 6.9: Temperature profile for *Pr*

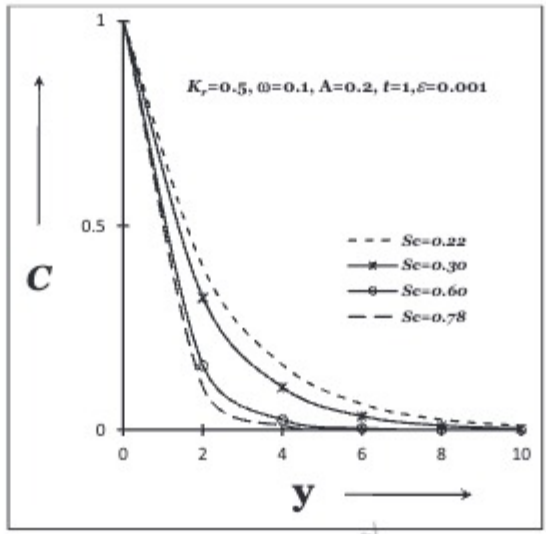

Fig. 6.10: Concentration profile for *Sc*

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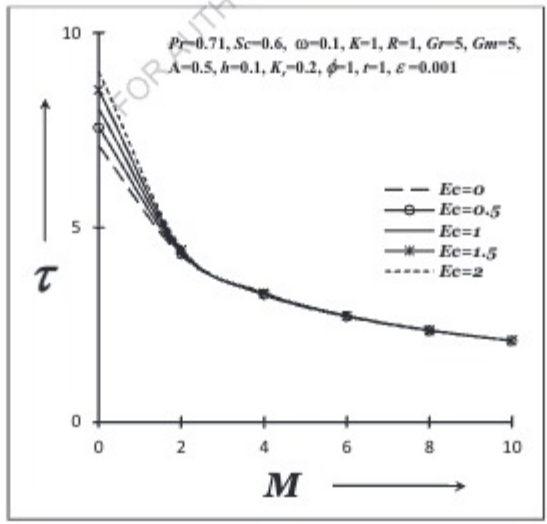

Fig. 6.11: Skin-friction for *Ec* and *M*

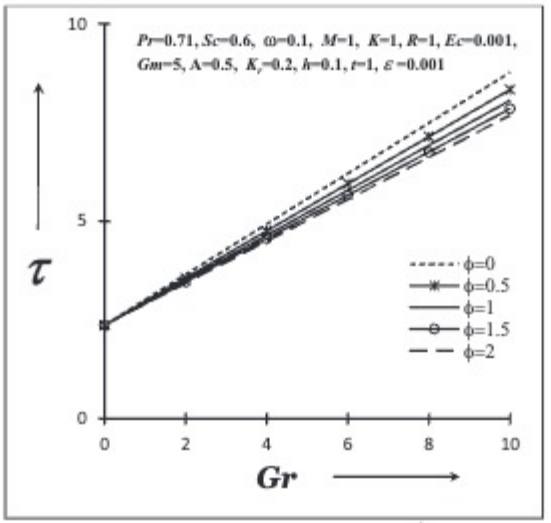

Fig. 6.12: Skin-friction for ϕ and *Gr*

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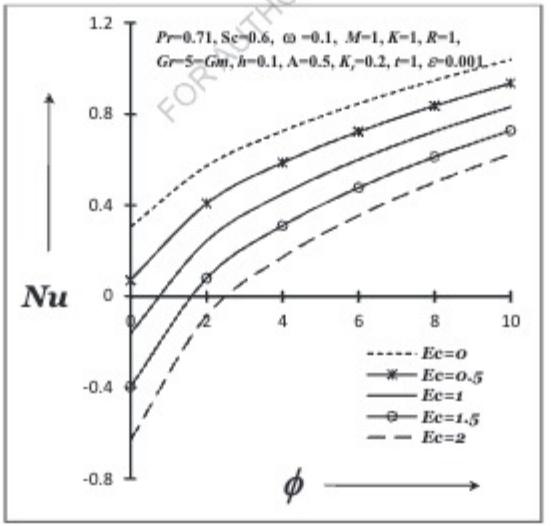

Fig. 6.13: Nusselt Number for *Ec* and ϕ

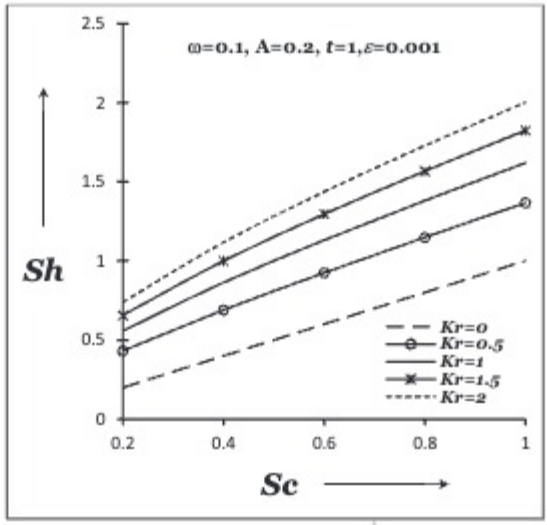

Fig. 6.14: Sherwood Number for K_r and Sc

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6.6 Conclusion :

A detailed mathematical study of the unsteady, laminar, incompressible hydromagnetic convective boundary layer heat and mass transfer from a vertical surface immersed in a Darcian porosity medium with heat generation and viscous dissipation has been conducted. Analytical solutions have been obtained for the normalized conservations Eqs. The main results of the present study can be summarized as follows:

1. It has been shown that increasing magnetic field generally decelerates the flow and also decrease surface shear stress values in the regime;
2. Increasing Eckert number serves to accelerate the flow velocity and the temperature, but reduce surface shear stress values;
3. Increasing heat generation / source decrease the velocity, temperature and surface shear stress;
4. The Grashof number for heat transfer and porosity leads to accelerate the flow velocity. As well as an increasing radiation parameter leads to faster reduction in velocity and enhance the flow;

5. With increasing values of chemical reaction, the flow velocity and Sherwood number have been increased and opposite tend are seen in the concentration boundary layer;
6. For increasing values of various Prandtl number and Schmidt number the temperature and concentration profiles are decreased correspondingly. While the flow velocity in the boundary layer is enhancing with the increasing of slip parameter.

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Chapter - VII

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Thermo-Diffusive flow of Chemically Reacting fluid in a Saturated Porous Medium for Radiative Heat Flux

7.1 Introduction :

Convection flows in porous media have gained significant attention in the recent years because of their importance in engineering applications such as geothermal systems, solid matrix heat exchangers, thermal insulations, oil extraction and store of nuclear waste materials. These can also be applied to underground coal gasification, ground water hydrology, wall cooled catalytic reactors, energy efficient drying processes and natural convection in earth's crust. Hiremath and Patil (1993) studied the effect on free convection currents on the oscillatory flow through a porous medium, which is bounded by vertical plate surface of constant temperature. A comprehensive account of available information in this field is provided in books by Pop and Ingham (2001), Ingham and Pop (2005), Vafai (2005), Vadasz (2008) etc. Mythreye *et al.* (2015) experimented on Unsteady MHD convective Heat and Mass transfer flow past a semi-infinite vertical permeable moving plate with heat absorption and first order chemical reaction.

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Many processes in new engineering areas take place at high temperatures and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Recent developments in hypersonic flights, nuclear power plant, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles have focused attention of researchers on thermal radiation as a mode of energy transfer and emphasized the need for inclusion of radiative heat transfer in these processes. The interaction of radiation with mixed convection flow past a vertical plate was investigated by Hossain and Takhar (1996). El-Hakiem (2000) studied the unsteady MHD oscillatory flow on the free convection-radiation through a porous medium with a vertical infinite surface that absorbs the fluid with constant velocity. Abo-Eldahab and Elgendy (2000) presented radiation effect on convective heat transfer in an electrically conducting fluid at a stretching surface with variable viscosity and uniform free stream velocity. The effect of radiation on 2D steady MHD optically thin gray gas flow along an infinite vertical plates taking into account the magnetic field presented by Raptis and Perdikis (2006). Pal (2009) studied heat and mass transfer in stagnation-point flow toward a stretching sheet in the presence of buoyancy force and thermal radiation.

Abd El-Naby *et al*. (2004) examined the effect of radiation on MHD unsteady free convection flow over a vertical porous plate by using implicit finite difference method. The effects of chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical moving plate immersed in a porous medium was investigated Seethamahalakshmi *et al*. (2011). Sugunamma *et al*. (2011) presented the radiation effects on natural convection with magnetic field between heated inclined plates. Uwanta (2012) studied the effects of chemical reaction and radiation on heat and mass transfer past a semi-infinite vertical porous plate in the presence of mass flux and dissipation. Vidyasagar *et al*. (2013) consider the effects of heat and mass transfer over a moving vertical porous plate. Radiation effect on free convective flow along a uniform moving porous vertical plate in the presence of heat source / sink and transverse magnetic field was discussed Sharma *et al*. (2008).

However, in the above mentioned works, the thermal diffusion (Soret) effect was not taken into account. This assumption is justified when the concentration level is very low. The flux of mass caused due to temperature gradient is known as Soret effect or thermal diffusion effect. On the other hand, the energy flux caused by concentration gradient is called Dufour effect. Soret and Dufour effects are important phenomena in areas such as hydrology, petrology and geosciences. The experimental investigation of the thermal-diffusion effect on mass transfer related problems was first done by Charles Soret in 1879. There after this thermal diffusion is termed as the Soret effect in honour of Charles Soret. In general, the Soret effect is of a smaller order of magnitude than the effect described in Fick's law and very often it is neglected in mass transfer process. Though this effect is quite small, but the devices can be arranged to produce very steep temperature gradient so that the separation of components in mixtures is affected. Eckert and Drake (1972) have emphasized that in the cases concerning isotope separation and in mixtures between gases with very light molecular weight (H_2, He) and for medium molecular weight (N_2, air), Soret effect is found to be considerable magnitude such that it cannot be ignored. Hurle and Jakeman (1974) have analyzed theoretically the Soret effect on the Rayleigh-Jeffrey problem neglecting the Dufour coefficient. Platten and Chavepeyer (1973) have analyzed oscillatory motion in Bernard

cells due to the Soret effect theoretically and experimentally. Delahaye *et al.* (2002) studied the influence of Soret effect on convection in a binary liquid layer with a free upper surface whereas Ouriemi *et al.* (2005) analyzed the natural convection of a binary mixture confined in a slightly inclined tall enclosure considering the Soret effect. The influence of fluctuating thermal and mass diffusion on unsteady MHD flow with chemical reaction and Soret effects investigated Pal and Talukdar (2012). Ahmed and Kalita (2009) discussed the effect of the thermal diffusion (Soret) as well as magnetic field on free convection and mass transfer flow through porous medium, taking into account the effect of heat source. Oscillatory MHD free convective flow through a porous medium with mass transfer, Soret effect and chemical reaction was analyzed Ahmed and Kalita (2012). Bhavana *et al.* (2013) proposed the Soret effect on unsteady MHD free convective flow over a vertical plate in presence of heat source. The Soret and Radiation effects on unsteady MHD free convective flow past a vertical porous plate was explained Rao *et al.* (2012). Soret effect on MHD flow of heat and mass transfer over a vertical stretching plate in a porous medium in presences of heat source was proposed by Ali and Alam (2014). Chamkha and Nakhi (2008) have been studied MHD mixed convection-radiation interaction along a permeable surface immersed in a porous medium in the presence of Soret and Dufour effects. Chemically reacting mixed convective heat and mass transfer along inclined and vertical plates with Soret and Dufour effects and was presented the numerical solutions by Bég *et al.* (2009). Cheng (2012) studied Soret and Dufour effects on mixed convection heat and mass transfer from a vertical wedge in a porous medium with constant wall temperature and concentration. Sharma *et al.* (2014) investigated Soret and Dufour effects on an unsteady MHD mixed convective flow past an infinite vertical plate with ohmic dissipation and heat source. Kalyani *et al.* (2015) has been investigated the effects of MHD boundary layer flow over a vertical porous plate embedded in a porous medium with the effects of heat source / sink, suction / injection and Soret.

The objective of this chapter is to analyze the effects of Soret number and thermal Radiation on free convective periodic heat and mass transport of a viscous incompressible chemically reacting fluid over an infinite porous

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vertical plate subject to a time dependent suction velocity in presence of a uniform transverse magnetic field and heat generation / absorption.

7.2 Problem Formulation :

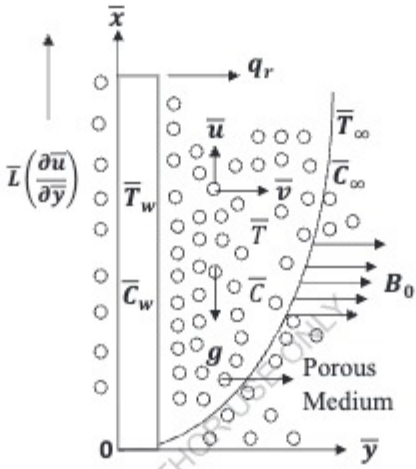

Figure 7.1: Physical configuration and coordinate system

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We consider unsteady two-dimensional flow of a laminar, incompressible, viscous, electrically conducting, heat absorbing and chemically reacting fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of Soret and thermal Radiation effects. In rectangular Cartesian co-ordinate system, we take $\overline{x}$-axis along the plate in the direction of flow and $\overline{y}$-axis normal to it as shown in the flow Fig. 7.1. In the analysis magnetic Reynolds number is taken to be small so that the induced magnetic field is neglected. The flow in the medium is entirely due to buoyancy force cause by temperature difference between the porous plate and the fluid. The governing equations for this investigation are based on the balances of mass, linear momentum, energy and concentration species.

Taking into consideration the assumption made above, these equations can be written in Cartesian frame of reference, as follows

$$\frac{\partial \overline{v}}{\partial \overline{y}} = 0 \tag{7.2.1}$$

$$\frac{\partial \overline{u}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{u}}{\partial \overline{y}} = \left\{ \begin{array}{l} -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{x}} + \nu\frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + g\beta_T\left(\overline{T} - \overline{T}_\infty\right) \\ +g\beta_C\left(\overline{C} - \overline{C}_\infty\right) - \frac{\sigma B_0^2 \overline{u}}{\rho} - \frac{\nu}{\overline{K}}\overline{u} \end{array} \right\} \tag{7.2.2}$$

$$\frac{\partial \overline{T}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} = \alpha\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{1}{\rho C_p}\frac{\partial \overline{q}_r}{\partial \overline{y}} - \frac{Q_0}{\rho C_p}\left(\overline{T} - \overline{T}_\infty\right) \tag{7.2.3}$$

$$\frac{\partial \overline{C}}{\partial \overline{t}} + \overline{v}\frac{\partial \overline{C}}{\partial \overline{y}} = D_m\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} + D_T\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \overline{K_r}\left(\overline{C} - \overline{C}_\infty\right) \tag{7.2.4}$$

Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration fields are:

$$\left\{ \begin{array}{c} \overline{u} = \overline{u}_p,\ \overline{T} = \overline{T}_w + \varepsilon\left(\overline{T}_w - \overline{T}_\infty\right)e^{\overline{nt}}, \\ \overline{C} = \overline{C}_w + \varepsilon\left(\overline{C}_w - \overline{C}_\infty\right)e^{\overline{nt}} \ \text{ at } \ \overline{y} = 0 \\ \\ \overline{u} \to \overline{U}_\infty = U_0\left(1 + \varepsilon e^{\overline{nt}}\right),\ \overline{T} \to \overline{T}_\infty,\ \overline{C} \to \overline{C}_\infty \ \text{as} \ \overline{y} \to \infty \end{array} \right\} \tag{7.2.5}$$

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It is clear from Eq. (7.2.1) that the suction velocity at the plate surface is a function of time only. Assuming that it takes the following exponential form:

$$\overline{v} = -V_0\left(1 + \varepsilon A e^{\overline{nt}}\right) \tag{7.2.6}$$

Outside the boundary layer, Eq. (7.1.2) gives

$$-\frac{1}{\rho}\frac{d\overline{p}}{d\overline{x}} = \frac{d\overline{U}_\infty}{d\overline{t}} + \frac{\nu}{\overline{K}}\overline{U}_\infty + \frac{\sigma}{\rho}B_0^2\overline{U}_\infty \tag{7.2.7}$$

By using the Rosseland approximation, the Radiative heat flux can be written as,

$$\overline{q}_r = -\frac{4\overline{\sigma}}{3\overline{a}}\frac{\partial \overline{T}^4}{\partial \overline{y}}\ , \tag{7.2.8}$$

where $\overline{\sigma}$ and $\overline{a}$ are respectively the Stefan-Boltzmann constant and the mean absorption co-efficient. We assume that the temperature difference within the flow is sufficiently small such that $\overline{T}^4$ may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about the free stream temperature $\overline{T}_\infty$ and neglecting higher order terms, thus

$$\overline{T}^4 \cong 4\overline{T}_\infty^3\overline{T} - 3\overline{T}_\infty^4 \tag{7.2.9}$$

It is convenient to employ the following dimensionless variables:

$$\left\{\begin{array}{c} u = \dfrac{\overline{u}}{U_0},\ v = \dfrac{\overline{v}}{V_0},\ y = \dfrac{V_0\overline{y}}{\nu},\ U_\infty = \dfrac{\overline{U}_\infty}{U_0},\ U_p = \dfrac{\overline{u}_p}{U_0},\ t = \dfrac{\overline{t}V_0^2}{\nu}, \\ \theta = \dfrac{\overline{T} - \overline{T}_\infty}{\overline{T}_w - \overline{T}_\infty},\ \phi = \dfrac{\overline{C} - \overline{C}_\infty}{\overline{C}_w - \overline{C}_\infty},\ n = \dfrac{\overline{n}\nu}{V_0^2},\ K = \dfrac{\overline{K}V_0^2}{\nu^2}, \\ Pr = \dfrac{\nu\rho C_p}{k} = \dfrac{\nu}{\alpha},\ Sc = \dfrac{\nu}{D_m},\ M = \dfrac{\sigma B_0^2\nu}{\rho V_0^2},\ R = \dfrac{4\overline{\sigma}\overline{T}_\infty^3}{k\overline{a}}, \\ Gr = \dfrac{g\beta_T\nu(\overline{T}_w - \overline{T}_\infty)}{U_0V_0^2},\ Gm = \dfrac{g\beta_C\nu(\overline{C}_w - \overline{C}_\infty)}{U_0V_0^2},\ K_r = \dfrac{\overline{K_r}\nu}{V_0^2}, \\ S_0 = \dfrac{D_T(\overline{T}_w - \overline{T}_\infty)}{\nu(\overline{C}_w - \overline{C}_\infty)},\ Q = \dfrac{\nu Q_0}{\rho C_p V_0^2} \end{array}\right\} \tag{7.2.10}$$

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In view of Eqs (7.2.6) – (7.2.10), Eqs (7.2.2) – (7.2.4) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial u}{\partial y} = \left\{ \begin{array}{l} \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + Gr\theta \\ +Gm\phi + N(U_\infty - u) \end{array} \right\} \tag{7.2.11}$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\left[1 + \frac{4R}{3}\right]\frac{\partial^2 \theta}{\partial y^2} - Q\theta \tag{7.2.12}$$

$$\frac{\partial \phi}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial \phi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} + S_0\frac{\partial^2 \theta}{\partial y^2} - K_r\phi \tag{7.2.13}$$

where

$$N = M + \frac{1}{K}$$

The dimensionless form of the boundary condition becomes

$$\left\{ \begin{array}{l} u = U_p\,,\ \theta = 1 + \varepsilon e^{nt}\,,\ \phi = 1 + \varepsilon e^{nt} \quad \text{at} \quad y = 0 \\ u \longrightarrow U_\infty = 1 + \varepsilon e^{nt}\,,\ \theta \longrightarrow 0\,,\ \phi \longrightarrow 0 \quad \text{as} \quad y \longrightarrow \infty \end{array} \right\} \tag{7.2.14}$$

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7.3 Solution of the Problem :

Eqs (7.2.11) – (7.2.13) represents a set of partial differential equations that cannot be solved in closed form. However, it can be reduced to a set of ordinary differential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as,

$$\left\{ \begin{array}{l} u = u_0(y) + \varepsilon e^{nt} u_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \\ \theta = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \\ \phi = \phi_0(y) + \varepsilon e^{nt} \phi_1(y) + O(\varepsilon^2) + \cdots\cdots\cdots\cdots \end{array} \right\} \tag{7.3.15}$$

Substituting Eq. (7.3.15) into Eqs (7.2.11) – (7.2.13), equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $O(\varepsilon^2)$, we obtain

$$u_0'' + u_0' - Nu_0 = -N - Gr\theta_0 - Gm\phi_0 \tag{7.3.16}$$

$$u_1'' + u_1' - (N+n)u_1 = -Au_0' - Gr\theta_1 - Gm\phi_1 - (N+n) \tag{7.3.17}$$

$$(3+4R)\theta_0'' + 3Pr\theta_0' - 3PrQ\theta_0 = 0 \tag{7.3.18}$$

$$(3+4R)\theta_1'' + 3Pr\theta_1' - 3Pr(n+Q)\theta_1 = -3APr\theta_0' \tag{7.3.19}$$

$$\phi_0'' + Sc\phi_0' - ScK_r\phi_0 = -S_0Sc\theta_0'' \tag{7.3.20}$$

$$\phi_1'' + Sc\phi_1' - Sc(n+K_r)\phi_1 = -ASc\phi_0' - S_0Sc\theta_1'' \tag{7.3.21}$$

The corresponding boundary conditions can be written as

$$\left\{\begin{matrix} u_0 = U_p,\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 1, \\ \phi_0 = 1,\quad \phi_1 = 1 \quad at \quad y = 0 \\ \\ u_0 = 1,\ u_1 = 1,\ \theta_0 \longrightarrow 0,\ \theta_1 \longrightarrow 0, \\ \phi_0 \longrightarrow 0,\quad \phi_1 \longrightarrow 0 \ \ as \ \ y \longrightarrow \infty \end{matrix}\right\} \tag{7.3.22}$$

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Without going into details, the solutions of Eqs (7.3.16) – (7.3.21) under boundary conditions (7.3.22) can be shown as

$$u_0(y) = 1 + A_9e^{-m_5y} - A_7e^{-m_1y} - A_8e^{-m_3y}$$

$$u_1(y) = \left\{\begin{matrix} 1 + A_{15}e^{-m_6y} + A_{10}e^{-m_5y} - A_{11}e^{-m_1y} \\ -A_{12}e^{-m_3y} + A_{13}e^{-m_2y} - A_{14}e^{-m_4y} \end{matrix}\right\}$$

$$\theta_0(y) = e^{-m_1y}$$

$$\theta_1(y) = e^{-m_2y} + A_1(e^{-m_1y} - e^{-m_2y})$$

$$\phi_0(y) = e^{-m_3y} + A_2(e^{-m_3y} - e^{-m_1y})$$

$$\phi_1(y) = A_6e^{-m_4y} + A_3e^{-m_3y} - A_4e^{-m_1y} - A_5e^{-m_2y}$$

In view of the above solutions, the velocity, temperature and concentrations in the boundary layer become,

$$u(y,t) = \left[\begin{matrix} 1 + A_9e^{-m_5y} - A_7e^{-m_1y} - A_8e^{-m_3y} \\ +\varepsilon e^{nt}\begin{pmatrix} 1 + A_{15}e^{-m_6y} + A_{10}e^{-m_5y} - A_{11}e^{-m_1y} \\ -A_{12}e^{-m_3y} + A_{13}e^{-m_2y} - A_{14}e^{-m_4y} \end{pmatrix} \end{matrix}\right]$$

$$\theta(y,t) = e^{-m_1y} + \varepsilon e^{nt}[e^{-m_2y} + A_1(e^{-m_1y} - e^{-m_2y})]$$

$$\phi(y,t) = \left[\begin{matrix} e^{-m_3 y} + \\ A_2(e^{-m_3 y} - e^{-m_1 y}) + \varepsilon e^{nt} \begin{pmatrix} A_6 e^{-m_4 y} + A_3 e^{-m_3 y} \\ -A_4 e^{-m_1 y} - A_5 e^{-m_2 y} \end{pmatrix} \end{matrix} \right]$$

7.3.1 Skin-friction

Knowing the velocity field, the Skin-friction at the plate can be obtained, which in non-dimensional form is given by

$$C_f = \left[\frac{\tau_w}{\rho U_0 V_0}\right] = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$= \left[-m_5 A_9 + m_1 A_7 + m_3 A_8 + \varepsilon e^{nt} \begin{pmatrix} -m_6 A_{15} - m_5 A_{10} + m_1 A_{11} \\ +m_3 A_{12} - m_2 A_{13} + m_4 A_{14} \end{pmatrix} \right]$$

7.3.2 Nusselt Number

From temperature field, the rate of heat transfer co-efficient can be obtained, which in the non-dimensional form, in terms of Nusselt number is given by,

$$Nu Re_x^{-1} = -\left(1 + \frac{4R}{3}\right)\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -\left(1 + \frac{4R}{3}\right)\left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$= \left(1 + \frac{4R}{3}\right)[m_1 + \varepsilon e^{nt}\{m_1 A_1 + m_2(1 - A_1)\}]$$

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7.3.3 Sherwood Number

From concentration field, the rate of mass transfer co-efficient can be obtained, which in the non-dimensional form, in terms of Sherwood number is given by,

$$Sh Re_x^{-1} = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = -\left(\frac{\partial \phi_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \phi_1}{\partial y}\right)_{y=0}$$

$$= [m_3(1 + A_2) - m_1 A_2 + \varepsilon e^{nt}(m_4 A_6 + m_3 A_3 - m_1 A_4 - m_2 A_5)]$$

where $Re_x = \frac{V_0 x}{\nu}$ is the local Reynolds number.

7.4 Accuracy :

In order to check the accuracy of the employed perturbation method, comparisons with the previously published work of Mythreye *et al*. (2015) have been done. In this present flow model when Soret effect ($S_o = 0$) and thermal Radiation ($R = 0$), the work reduced to the flow model done by Mythreye *et al*. (2015).

Table – 1: Comparison of the present results with the results done by Mythreye *et al*. (2015) with the effects of heat absorption (Q) on flow velocity (u) when $Pr = 0.71$, $Sc = 0.6$, $Gr = 2$, $Gm = 1$, $M = 1$, $K = 0.5$, $U_p = 0.5$, A = 0.5, $t = 0.5$, $n = 0.1$, $\varepsilon = 0.2$.

	Present work			**Mythreye *et al*. (2015)**		
y	$Q = 0$	$Q = 2$	$Q = 4$	$Q = 0$	$Q = 2$	$Q = 4$
0	0.5	0.5	0.5	0.5	0.5	0.5
2	1.80585	1.42948	1.36691	1.7996	1.41769	1.35472
4	1.50549	1.24897	1.23248	1.50134	1.24524	1.22942
6	1.3587	1.21623	1.2131	1.35644	1.21539	1.21256
8	1.28668	1.21116	1.21036	1.2855	1.211	1.21055
10	1.25003	1.21039	1.21031	1.24942	1.21036	1.21029

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Table – 2: Comparison of the present results with the results done by Mythreye *et al.* (2015) with the effects of various thermal Grashof number (Gr) and Magnetic body force (M) on skin-friction (τ) when $Pr = 0.71$, $Sc = 0.6$, $Gm = 1$, $K = 0.5$, $U_p = 0.5$, A = 0.5, t = 0.5, $n = 0.1$, $\varepsilon = 0.2$.

	Present work			**Mythreye *et al.* (2015)**		
M	$Gr = 0$	$Gr = 2$	$Gr = 4$	$Gr = 0$	$Gr = 2$	$Gr = 4$
0	2.01812	4.66395	7.30978	1.94506	4.59089	7.23672
2	2.11437	3.46314	4.81192	2.09339	3.44216	4.79093
4	2.35857	3.39417	4.42977	2.34587	3.38147	4.41707
6	2.58818	3.4628	4.33741	2.579	3.45361	4.32823
8	2.79935	3.57138	4.34342	2.79213	3.56416	4.3362
10	2.99475	3.69397	4.3932	2.98879	3.68801	4.38724

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7.5 Results and Discussion :

In this work, we have investigated the two-dimensional flow model of free convective unsteady flow with periodic heat and mass transfer over a flat porous plate in a Darcian porous regime under oscillatory suction and free stream velocities in presence of Soret and Radiation effects. The solutions for various physical parameters have been obtained using perturbation technique. Throughout the discussion all the numerical calculations have been done for the real constants $Pr = 0.71$, $Sc = 0.6$, $Gr = 10$, $Gm = 5$, $R = 1$, $M = 1$, $K = 5$, $Q = 1$, $K_r = 0.5$, $S_0 = 0.2$, $n = 0.2$, A = 0.5, $Up = 0.5$, $t = 1$ and $\varepsilon = 0.002$.

The effects of Radiation parameter (R) on the flow velocity (u) is presented in **Figure** 7.**2**. An increase in R from 0 through 1, 2 to 4, the velocity profiles are elevated near the plate and diminishing in the free

stream velocity. Significantly, the greater value of u has attained for $R = 4$ rather than $R = 0$.

Figure 7.3 is a plot of velocity profiles for different values of Soret number (S_0). The Soret number signifies the ratio of temperature difference to the concentration. Hence, the bigger Soret number ($S_0 = 5$) stands for a large temperature difference and precipitous gradient. In this figure it is clear that the velocity profiles increase with the increasing the values of Soret number (S_0). Thus the fluid velocity rises due to greater thermal diffusion factor.

The effects of heat source /generation (Q) on the velocity distribution are shown in **Figure 7.4**. The term $Q_0(\overline{T} - \overline{T}_\infty)$ is assumed to be the amount of heat generated or absorbed per unit volume. Q_0 is a constant, which may take on either positive or negative values when $\overline{T} > \overline{T}_\infty$, the source term $Q_0 > 0$ and heat sink when $Q_0 < 0$. From this figure, it is seen that the heat is absorbed due to the buoyancy forces which induces the flow rate to decrease giving reduction to the decrease in the velocity profiles.

The variation of velocity distribution of the flow field with the generative Chemical Reaction (K_r) is shown in **Figure 7.5**. It is observed from this figure that the velocity distribution decreases at all points of the flow field with increasing in the Chemical Reaction parameter. This shows that the generative chemical reaction with higher values of K_r have the retarding effect on the velocity distribution of the flow field.

Figure 7.6 show the variation of dimensionless temperature profiles with y for different values of Radiation parameter (R). It shows that the temperature increases with increasing Radiation parameter. This is due to the fact that the increase in the values of thermal radiation parameter increases the flux of energy transport to the fluid and accordingly increases the fluid temperature in the thermal boundary layer. Thus it is found that the effect of thermal radiation is to enhance heat transfer and due to which there is an increase in the thermal boundary layer thickness.

Figure 7.7 depicts the variation of dimensionless temperature profiles for different values of heat generation / absorption rate (Q). The positive sign indicates the heat absorption whereas negative means heat generation.

In this figure we may realize that the temperature profiles decrease with increasing the parameter (Q), which results in decreasing the thermal boundary layer thickness with stronger Q.

The variation of Concentration distribution of the flow field with the diffusion of the foreign mass (S_o) is presented in **Figure 7.8** in absence of K_r, R and Q. It is observed that the concentration distribution strongly elevated at all points of the flow field with increasing in the Soret number (S_o). This shows that the diffusive spices with higher value of Soret number have an enhancing effect on the concentration distribution of the flow field. It is interesting to note that the higher values of Soret number ($S_o > 1$) have the tendency in formation of pick concentration profiles near the plate.

The variation of velocity gradient distribution at the plate $y = 0$ for different values of S_o and M are shown in **Figure 7.9**. It is seen that there is substantial increase in (τ) at the plate $y = 0$ for the increasing effects of S_o, whereas no significance effects have been observed in τ when $M > 2$. However, the skin-friction enhanced for the region $0 \leq M \leq 2$, but for $M >$ 2 the skin-friction has no effects in the boundary layer.

Figure 7.10 depicts the rate of heat transfer responses for various Radiation parameter (R) and heat absorption parameter (Q). When Q increases, it is observed that the rate of heat transfer gradually increases. However, there is a substantial increase in the rate of heat transfer due to the effects of thermal Radiation (R). For higher Radiation ($R = 5$) the thermal energy is boosted rather than the no thermal Radiation ($R = 0$).

In **Figure 7.11** the evolution of Sherwood number distribution (Sh) with the effects of Soret number (S_o) and thermal Radiation (R) is shown. With an increasing in (S_o) the magnitude of mass transfer gradient at the plate is reduces due to the temperature difference to the concentration. However, there is a progressive increasing in mass transfer gradient indicating that thermal Radiation exerts a stronger effect than the Soret effect. Significantly, the negative values of Sherwood number (Sh) have been observed at $S_o = 3$ and $S_o = 5$ for $R < 2$.

The influence of Magnetic body force (M) and Soret number (S_o) on the velocity distributions with distant normal to the plate (transverse co-

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ordinate y) is presented in **Figure 7.12**. The hydromagnetic term in the dimensionless Eq. (7.2.11), $-Mu$ is a linear drag force term. With increasing magnetic field strength B_0, M is increased and this serves to decelerate the flow along the plate. The strong inhabiting effect of magnetic field is therefore evident. Moreover, the velocity profiles are elevated due to the effects of Soret number for both the cases of $M = 0$ and $M = 10$. Significantly velocity overshoot near the plate have been observed for the pure hydrodynamic fluid ($M = 0$).

The variations of Radiation and heat generation / absorption on the temperature distributions against the transverse distance y are plotted in the **Figure 7.13**. When $Q = 0.5$ i.e. for heat generation, the temperature distribution is enhanced, therefore the thermal boundary layer thickness gradually increased. On the other hand, the temperature distributions are diminished from heat absorption to heat generation near the plate ($0 \leq y \leq 4$) but away the plate $y > 4$ the reverse effect has been observed.

The effects of Soret number (S_o) and Chemical reaction (K_r) on the concentration distribution are presented in **Figure 7.14**. Due to generative Chemical reaction ($K_r = 0.5$), the concentration distribution enhances by the increasing effect of Soret number (S_o). Moreover, an increasing Soret number the concentration distribution has negative increasing values for destructive chemical reaction when y > 2. Interestingly, for destructive Chemical reaction ($K_r = -0.5$), the Soret number enhance the concentration distribution near the plate. However, the concentration distribution changes from destructive to generative Chemical reaction regions.

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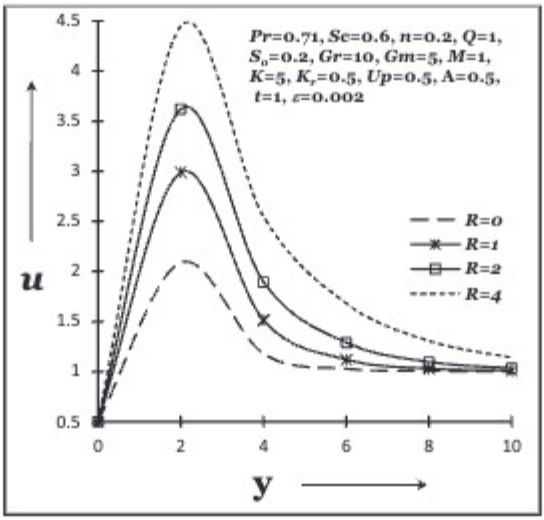

Fig.7.2: Velocity profiles for *R*

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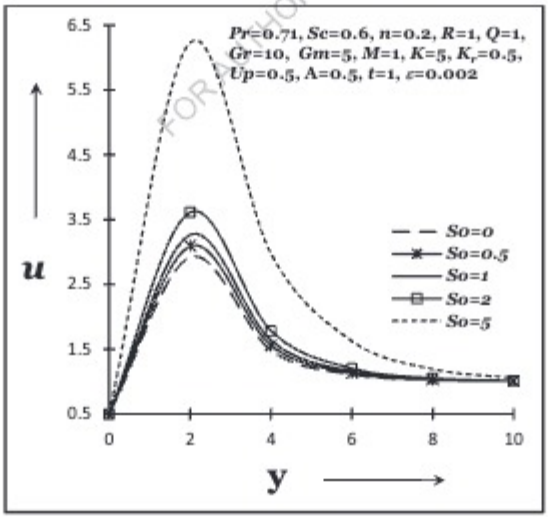

Fig. 7.3: Velocity profiles for S_o

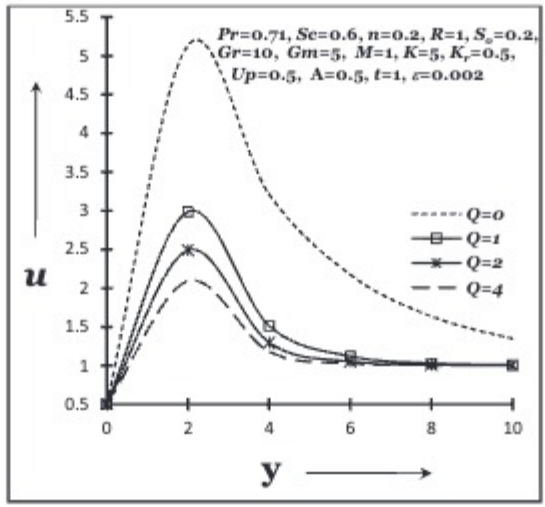

Fig. 7.4: Velocity profiles for Q

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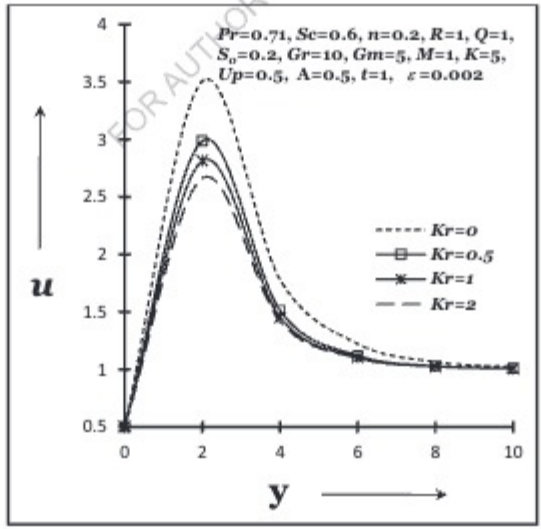

Fig. 7.5: Velocity profiles for K_r

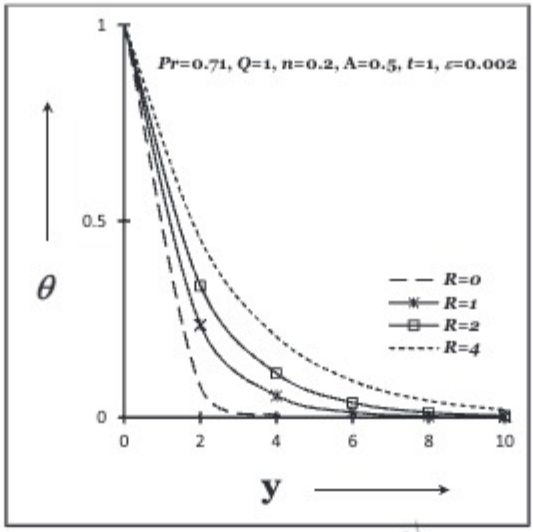

Fig. 7.6: Temperature profiles for *R*

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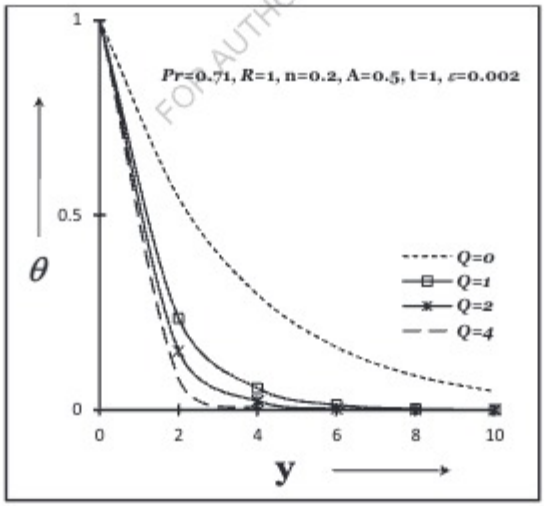

Fig. 7.7: Temperature profiles for *Q*

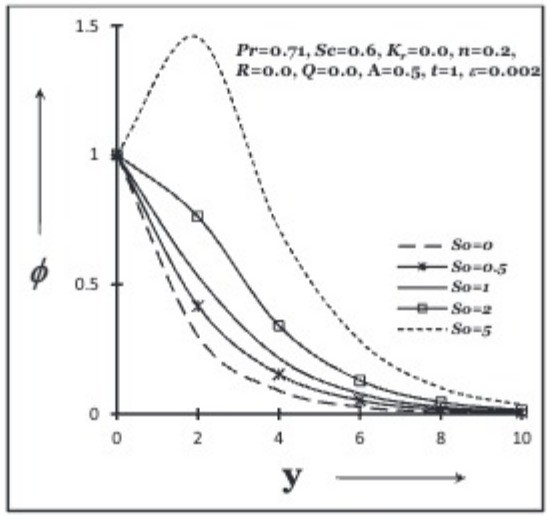

Fig. 7.8: Concentration profiles for S_o

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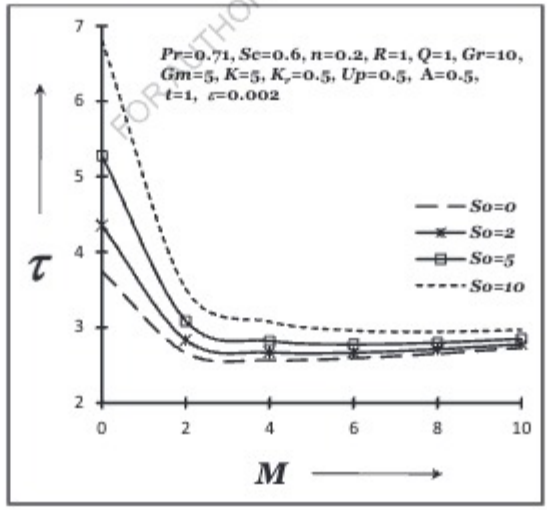

Fig. 7.9: Skin-friction for S_o and M

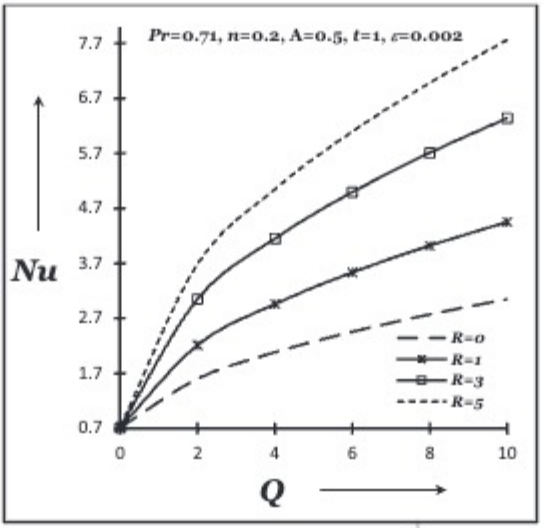

Fig. 7.10: Nusselt number for R and Q

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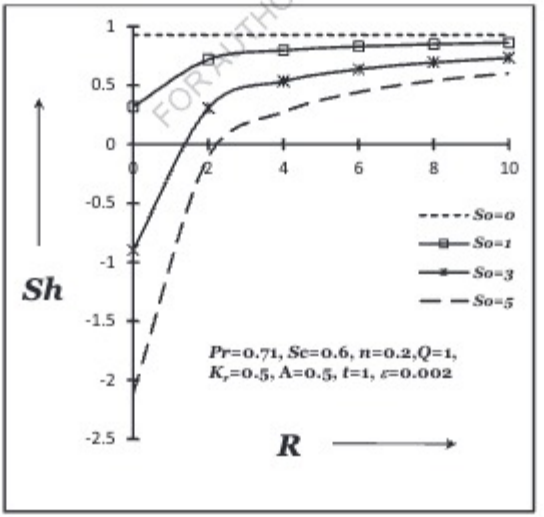

Fig. 7.11: Sherwood number for S_o and R

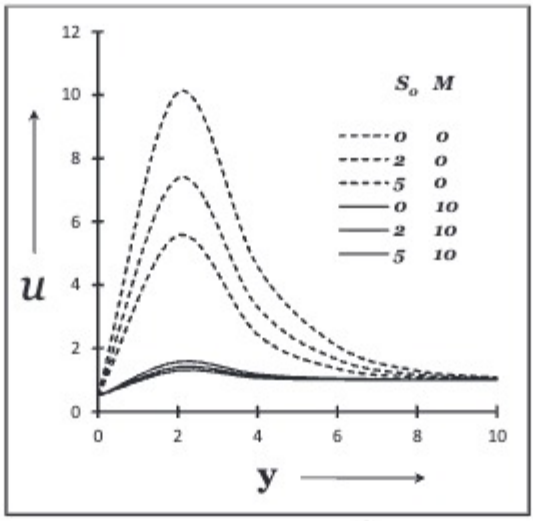

Fig. 7.12: Velocity profiles for S_o and M

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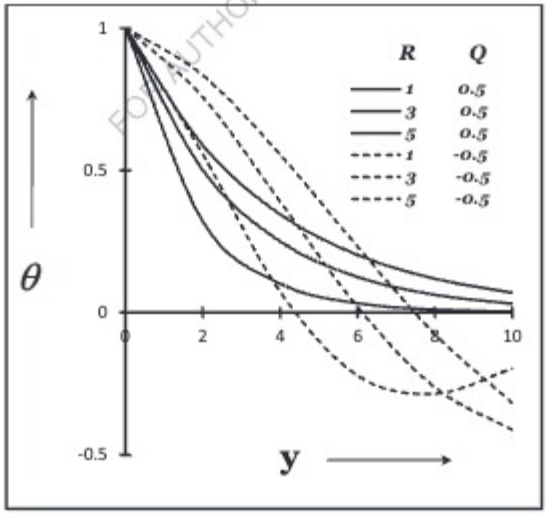

Fig. 7.13: Temperature profiles for R and Q

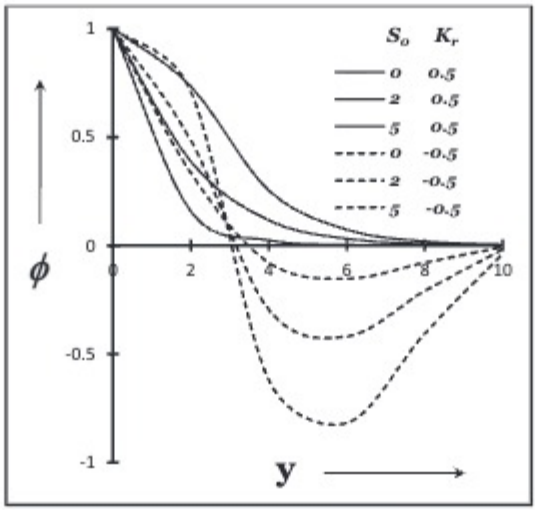

Fig. 7.14: Concentration profiles for S_o and K_r

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7.6 Conclusion:

The problem of unsteady boundary layer, heat and mass transfer flow of a viscous incompressible electrically-conducting fluid through porous medium over an infinite vertical plate immersed in a Darcian porous plate with thermal Radiation and Soret effects has been considered in presence of heat source / sink and first order Chemical reaction. The resulting partial differential equations were transformed into a set of ordinary differential equations using two-term series and solved in closed form. Analytical solutions of the closed form results were performed and some graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some of the physical parameters. The main results of the present study can be concluding as follows:

- The effect of increasing values of Radiation is to accelerate the flow velocity as well as same behaviour has been observed in the thermal boundary layer and in the rate of heat transfer;
- The velocity profiles and concentration boundary layer have been increased in the increasing effects of Soret number and opposite trends have been shown in the skin-friction and Sherwood number;
- Due to heat absorption the flow velocity as well as the temperature profiles has been decelerates;
- With increasing values of chemical reaction, the flow velocity enhanced.
- The flow velocity is accelerated with the increasing values of Soret number for both the cases when $M = 0$ and $M = 10$;
- Due to generative chemical reaction the concentration boundary layer enhanced by the increasing effects of Soret number. For destructive chemical reaction the Soret number enhanced the concentration profiles near the plate.

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Chapter - VIII

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Free Convection past a Vertical Porous Plate in a Rotating Fluid with Ramped Wall Temperature: A Laplace Technique

8.1 Introduction :

The rotating fluid is receiving the attention of many workers and because of their applications in geophysical and cosmical sciences. It is very well known that in a rotating fluid near a plate Ekman layer exists wherein the viscous and Coriolis forces are of the same order of magnitude. A number of mathematical and numerical studies of transient and rotating hydromagnetic flows have also appeared, employing a wide spectrum of analytical and computational methods. For example, oscillatory hydromagnetic flow in a continuous electrode Faraday generator was studied by Ibáñez *et al.* (2002), who also considered optimization aspects and derived generator efficiencies. Takhar *et al.* (1993) studied unsteady hydromagnetic flow of a dusty viscous liquid in a rotating channel with Hall currents and heat transfer, obtaining exact solutions and studying in detail the effect of Hartmann number and Strouhal number on the velocity evolution in the channel. Hayat *et al.* (2007) investigated Hall current magneto-hydrodynamics in rotating oscillating flows of a non-Newtonian fluid in a porous medium.

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In recent years a number of studies have also appeared in the literature on the fluid phenomena on earth involving rotation to a greater or lesser extent viz. Vidyanidhuand and Nigam (1967), Gupta (1972), Jana and Datta (1977). Mazumder (1991) obtained an exact solution of an oscillatory Couette flow in a rotating system. Singh (2000) analyzed the oscillatory magnetohydrodynamic (MHD) Couette flow in a rotating system in the presence of transverse magnetic field.

When the strength of the magnetic field is strong enough then one cannot neglect the effects of Hall currents. Even though it is of considerable importance to study how the results of the hydrodynamical problems get modified by the effects of Hall currents. A comprehensive discussion of Hall currents is given by Cowling (1957). Soundalgekar (1979) studied the Hall and Ion-slip effects in MHD Couette flow with heat transfer. Soundalgekar and Uplekar (1986) also analyzed Hall effects in MHD Couette flow with heat transfer. Hossain and Rashid (1987) investigate Hall effects on hydromagnetic free convection flow along a porous flat plate with mass

transfer. Attia (1998) studied Hall current effects on the velocity and temperature fields on an unsteady Hartmann flow.

Literatures on rotating unsteady MHD convection heat transfer with or without Hall currents are very extensive due to its technical importance in geophysics and astrophysics. In the recent years still a lot has been done in this area. Narahari (2012) discussed unsteady free convection flow between two vertical plates with ramped temperature within one of the plates in the presence of thermal radiation and mass diffusion. Seth *et al*. (2011) studied unsteady MHD natural convection flow with radiative heat transfer past an impulsively moving vertical plate with ramped temperature embedded in a fluid saturated porous medium with thermal diffusion.

In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid. Chemical reactions can be classified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. These processes take place in numerous industrial applications viz. polymer production, manufacturing of ceramics or glassware, food processing, etc. Afify (2004) studied the effect of radiation on free convective flow and mass transfer past a vertical isothermal cone surface with chemical reaction in the presence of a transverse magnetic field. Bakr (2011) discussed the effects of chemical reaction on MHD free convection and mass transfer flow of a micro-polar fluid with oscillatory plate velocity and constant heat source in a rotating frame of reference. Chamkha *et al*. (2011) discussed the effects of Joule heating, chemical reaction and thermal radiation on unsteady hydromagnetic natural convection boundary layer flow with heat and mass transfer of a micropolar fluid from a semi-infinite heated vertical porous plate in the presence of a uniform transverse magnetic field

Moreover, both Hall current and rotation induce secondary flow in the flow-field. Therefore, it is appropriate to study the combined effects of Hall current and rotation on MHD fluid flow problems. Keeping in view this fact, Farhad *et al*. (2012) investigated unsteady hydromagnetic rotating flow of a viscous incompressible fluid past a moving infinite porous plate in a porous medium with slip condition and Hall current whereas Takhar and

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Ram (1991) considered the effects of Hall current on hydromagnetic free convection boundary layer flow of heat generating fluid past an infinite plate in a porous medium using harmonic analysis. Unsteady MHD natural convection flow past an impulsively moving vertical plate with ramped temperature in a porous medium in the presence of thermal diffusion is investigated by Seth *et al*. (2013). The problem of heat and mass transfer in a rotating vertical porous channel taking into account the effects of Hall current are presented by Ahmed and Zueco (2011).

The purpose of this investigation is to study the effects of chemical reaction and Hall current on the combined effects of thermal and mass diffusion of an electrically conducting and optically thick radiating fluid past an impulsively moving vertical plate embedded in a fluid saturated porous medium taking into account the effects of thermal and mass diffusions when temperature of the plate has a temporarily ramped profile. The present flow model has several engineering applications viz. in designing of electromagnetic devices, in high temperature aerodynamics, plasma physics, cosmical flight, nuclear power reactors, etc. where initial temperature profiles are of much significance and thermal radiation is highly prevalent.

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8.2 Formulation of the Problem :

We consider a Cartesian co-ordinate system rotating uniformly with a conducting fluid in a rigid state of rotation with angular velocity Ω about $\overline{y}$ - axis taken positive in the direction normal to the vertical plate which is assumed to be electrically non-conducting. The plate is further assumed to coincide with $\overline{y} = 0$ plane where $\overline{x}$ - axis is along the plate in upward direction $\overline{z}$ - axis is perpendicular to $\overline{xy}$ - plane. The applied magnetic field is in the $\overline{y}$ - direction which is transverse to the flow with a strength B_0. The fluid is incompressible viscous and conducting fluid. Initially (i.e. when time $t' \leq 0$) both the fluid and plate are at rest and at a uniform temperature T_∞'. At time $t'>0$, plate starts moving in x'- direction with uniform velocity U_0 and the temperature of plate is raised or lowered to $T_\infty' + (T_w' - T_\infty')t'/t_0$ when $t' \leq t_0$, and thereafter, it is maintained at uniform temperature T_w' (t_0 being the characteristic time).

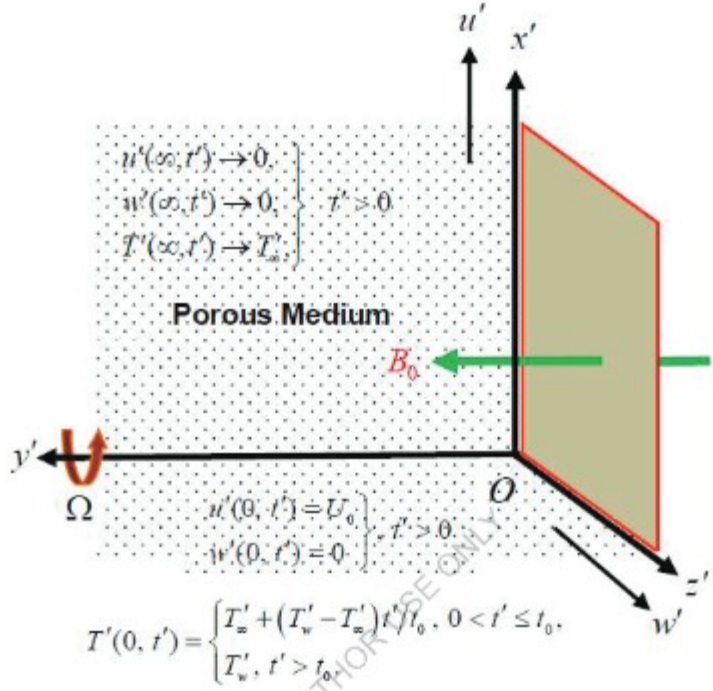

Fig. 8.1: Flow configuration

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Geometry of the problem is presented in Fig. 8.1. Since plate is of infinite extent along $\overline{x}$ and $\overline{z}$ - directions and electrically non-conducting, all physical quantities, except pressure, depend on $\overline{y}$ and $\overline{t}$ only. It is assumed that no applied or polarization voltages exist so induced electric field $\vec{E} = (0, 0, 0)$. This is due to the reason that no energy is being added or extracted from fluid by electrical means, Cramer and Pai (1973). It may be noted that magnetic Reynolds number is very small for liquid metals and partially ionized fluids so induced magnetic field produced by fluid motion is negligible in comparison to applied one, Cramer and Pai (1973) i.e. magnetic field $\vec{B} = (0, B_0, 0)$.

Under the assumptions made above, the governing equations of boundary layer flow with heat and mass transport in a uniform porous

medium in presence of Hall and chemical reaction, in a rotating frame of reference are given by

$$\frac{\partial \overline{u}}{\partial \overline{t}} + 2\Omega \overline{w} = \left\{ \begin{array}{l} \nu \dfrac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \dfrac{\sigma B_0^2}{\rho(1+m^2)}(\overline{u} + m\overline{w}) + \\ g\beta(\overline{T} - \overline{T}_\infty) + g\overline{\beta}(\overline{C} - \overline{C}_\infty) - \dfrac{\nu}{\overline{K}_r}\overline{u} \end{array} \right\} \tag{8.2.1}$$

$$\frac{\partial \overline{w}}{\partial \overline{t}} - 2\Omega \overline{u} = \nu \frac{\partial^2 \overline{w}}{\partial \overline{y}^2} + \frac{\sigma B_0^2}{\rho(1+m^2)}(m\overline{u} - \overline{w}) - \frac{\nu}{\overline{K}_r}\overline{w} \tag{8.2.2}$$

$$\frac{\partial \overline{T}}{\partial \overline{t}} = \frac{\kappa}{\rho C_P}\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{Q_0}{\rho C_P}(\overline{T} - \overline{T}_\infty) \tag{8.2.3}$$

$$\frac{\partial \overline{C}}{\partial \overline{t}} = D\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} - \overline{C}_r \overline{C} \tag{8.2.4}$$

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Initial and boundary conditions for the fluid-flow problem are

$$\overline{u} = \overline{w} = 0\,,\ \overline{T} = \overline{T}_\infty\,,\ \overline{C} = \overline{C}_\infty \text{ at } \overline{y} \geq 0 \text{ for } \overline{t} \leq 0 \tag{8.2.5a}$$

$$\overline{u} = U_0\,,\ \overline{w} = 0 \text{ at } \overline{y} = 0 \text{ for } \overline{t} > 0 \tag{8.2.5b}$$

$$\left\{ \begin{array}{l} \overline{T} = \overline{T}_\infty + (\overline{T}_w - \overline{T}_\infty)\,\overline{t}/t_0\,, \\ \overline{C} = \overline{C}_\infty + (\overline{C}_w - \overline{C}_\infty)\,\overline{t}/t_0 \end{array} \right\} \overline{y} = 0 \; for \; 0 < \overline{t} \leq t_0 \tag{8.2.5c}$$

$$\overline{T} = \overline{T}_w\,,\ \overline{C} = \overline{C}_w \quad at \quad \overline{y} = 0 \quad for \quad \overline{t} > t_0 \tag{8.2.5d}$$

$$\overline{u} \to 0\,,\ \overline{w} \to 0\,,\ \overline{T} \to \overline{T}_\infty\,,\ \overline{C} \to \overline{C}_\infty \; as \; \overline{y} \to \infty \text{ for } \overline{t} > 0 \tag{8.2.5e}$$

Introducing the following non-dimensional parameter:

$$\left.\begin{array}{c} y=\dfrac{\bar{y}}{U_0 t_0},\ u=\dfrac{\bar{u}}{U_0},\ w=\dfrac{\bar{w}}{U_0},\ T=\dfrac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty}, \\ C=\dfrac{\bar{C}-\bar{C}_\infty}{\bar{C}_w-\bar{C}_\infty},\ M^2=\dfrac{\sigma\upsilon B_0^2}{\rho U_0^2},\ K^2=\dfrac{\upsilon\Omega}{U_0^2},\ K_r=\dfrac{\bar{K}_r U_0^2}{\upsilon^2}, \\ Gr=\dfrac{g\beta(\bar{T}_w-\bar{T}_\infty)}{U_0^3},\ Gm=\dfrac{g\bar{\beta}(\bar{C}_w-\bar{C}_\infty)}{U_0^3},\ Pr=\dfrac{\upsilon\rho C_p}{\kappa}, \\ t=\dfrac{\bar{t}}{t_0},\ \phi=\dfrac{\upsilon Q_0}{\rho C_p U_0^2},\ Sc=\dfrac{\upsilon}{D},\ C_r=\dfrac{\bar{C}_r\upsilon}{U_0^2} \end{array}\right\} \quad (8.2.6)$$

The characteristic time t_0 may be defined as

$$t_0=\frac{\upsilon}{U_0^2}$$

Eqs (8.2.1) to (8.2.4) in non-dimensional form are as follows:

$$\frac{\partial u}{\partial t}+2K^2 w=\frac{\partial^2 u}{\partial y^2}-\frac{M^2}{(1+m^2)}(u+mw)-\frac{u}{K_r}+GrT+GmC \quad (8.2.7)$$

$$\frac{\partial w}{\partial t}-2K^2 u=\upsilon\frac{\partial^2 w}{\partial y^2}+\frac{M^2}{(1+m^2)}(mu-w)-\frac{\upsilon}{K_r}w \quad (8.2.8)$$

$$\frac{\partial T}{\partial t}=\frac{1}{Pr}\frac{\partial^2 T}{\partial y^2}-\phi T \quad (8.2.9)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-C_r C \quad (8.2.10)$$

Initial and boundary conditions (8.2.5a) – (8.2.5e) in non-dimensional form are given by

$$u=w=0,\ T=0,\ C=0\ for\ y\geq 0\ \text{and}\ t\leq 0 \quad (8.2.11a)$$

$$u=1,\quad w=0\quad at\quad y=0\quad for\quad t>0 \quad (8.2.11b)$$

$$T=t,\ C=t\quad at\quad y=0\quad for\quad 0<t\leq 1 \quad (8.2.11c)$$

$$T=1,\ C=1\quad at\quad y=0\quad \text{for}\quad t>1 \quad (8.2.11d)$$

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$$u \to 0\,,\ w \to 0\,,\ T \to 0\,,\ C \to 0\ as\ y \to \infty\ for\ t > 0 \qquad (8.2.11e)$$

Combining Eqs (8.2.7) and (8.2.8) we obtain

$$\frac{\partial F}{\partial t} - 2i\mathrm{K}^2 F = \frac{\partial^2 F}{\partial y^2} - NF + GrT + GmC\,, \qquad (8.2.12)$$

where $F = u + iw$ and $N = \frac{M^2(1-im)}{1+m^2} + \frac{1}{K_r}$

Initial and boundary conditions (8.2.11a) – (8.2.11e) in compact form, are given by

$$F = 0\,,\ T = 0\,,\ C = 0\ \ for\ y \geq 0\ \ and\ \ t \leq 0\,, \qquad (8.2.13a)$$

$$F = 1 \quad at \quad y = 0 \quad for \quad t > 0 \qquad (8.2.13b)$$

$$T = t\,,\ C = t \quad at \quad y = 0 \quad for \quad 0 < t \leq 1 \qquad (8.2.13c)$$

$$T = 1\,,\ C = 1 \quad at \quad y = 0 \quad \text{for} \quad t > 1 \qquad (8.2.13d)$$

$$F \to 0\,,\ \mathrm{T} \to 0\,,\ C \to 0 \quad as \quad y \to \infty \quad for \quad t > 0 \qquad (8.2.13e)$$

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8.3 Solution Methodology :

The Eqs (8.2.9), (8.2.10) and (8.2.12) are to solved by using Laplace Transform Technique under the boundary conditions (8.2.13a) – (8.2.13e).

Taking Laplace transforms of Eqs (8.2.9), (8.2.10) and (8.2.12) using initial conditions (8.2.13a) we obtain

$$\frac{d^2T'}{dy^2} - Pr(s + \phi)T' = 0 \qquad (8.3.14)$$

$$\frac{d^2C'}{dy^2} - Sc(s + C_r)C' = 0 \qquad (8.3.15)$$

$$\frac{d^2F'}{dy^2} - (s + N - 2iK^2)F' = -GrT' - GmC' \qquad (8.3.16)$$

where

$$T'(y,s) = L\{T(y,t)\} = \int_0^\infty e^{-st}\, T(y,t)dt$$

$$C'(y,s) = L\{C(y,t)\} = \int_0^\infty e^{-st}\, C(y,t)dt$$

$$F'(y,s) = L\{F(y,t)\} = \int_0^\infty e^{-st}\, F(y,t)dt$$

(s being the Laplace Transform Parameter)

After taking Laplace transform the boundary conditions (8.2.13b) – (8.2.13e) reduce to

$$F' = \frac{1}{s},\quad T' = \frac{1-e^{-s}}{s^2},\quad C' = \frac{1-e^{-s}}{s^2} \quad at \quad y = 0 \qquad (8.3.17a)$$

$$F' \to 0,\quad T' \to 0,\quad C' \to 0 \quad at \quad y \to \infty \qquad (8.3.17b)$$

Solving Eqs (8.3.14) – (8.3.16) subject to the boundary conditions (8.3.17a) and (8.3.17b) we obtain

$$C'(y,s) = \frac{1-e^{-s}}{s^2} e^{-y\sqrt{Pr(s+\phi)}} \qquad (8.3.18)$$

$$T'(y,s) = \frac{1-e^{-s}}{s^2} e^{-y\sqrt{Sc(s+C_r)}} \qquad (8.3.19)$$

$$F'(y,s) = \left[\begin{array}{c} \frac{1}{s} e^{-y\sqrt{s+a}} + \frac{b(1-e^{-s})}{s^2(s-c)}\left\{e^{-y\sqrt{Pr(s+\phi)}} - e^{-y\sqrt{s+a}}\right\} \\ + \frac{p(1-e^{-s})}{s^2(s-q)}\left\{e^{-y\sqrt{Sc(s+C_r)}} - e^{-y\sqrt{s+a}}\right\} \end{array}\right] \qquad (8.3.20)$$

(a, b, c, p, q are given in the appendix)

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After taking inverse Laplace Transform of Eqs (8.3.18), (8.3.19) and (8.3.20) the exact solutions for $C(y,t), T(y,t)$ *and* $F(y,t)$ are obtained as follows:

$$C(y,t) = G_1(y,t) - H(t-1)G_1(y,t-1)\,,$$

$$T(y,t) = G_2(y,t) - H(t-1)G_2(y,t-1)\,,$$

$$F(y,t) = \begin{bmatrix} \frac{1}{2}\left\{e^{y\sqrt{a}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{at}\right) + e^{-y\sqrt{a}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{at}\right)\right\} \\ +b\{G_3(y,t) - H(t-1)G_3(y,t-1)\} \\ +p\{G_4(y,t) - H(t-1)G_4(y,t-1)\} \end{bmatrix},$$

where $G_1(y,t)$, $G_2(y,t)$, $G_3(y,t)$ and $G_4(y,t)$ are given in the appendix.

8.3.1 Skin-Friction

$$\tau = \tau_x + i\tau_z = \begin{Bmatrix} \sqrt{a}\left\{erfc\left(\sqrt{at}\right) - 1\right\} - \frac{1}{\sqrt{\pi t}}e^{-at} \\ +b[F_1(t) - H(t-1)F_1(t)] \\ +p[F_2(t) - H(t-1)F_2(t)] \end{Bmatrix}$$

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8.3.2 Nusselt Number

$$Nu = F_3(t) - H(t-1)F_3(t)$$

8.3.3 Sherwood Number

$$Sh = F_4(t) - H(t-1)F_4(t)$$

8.4 Validity :

In order to validate the accuracy of the calculated present numerical values, the present numerical results are compared with the available exact solution in the literature. The effects of m *and* K^2 on primary and secondary skin-frictions for $Pr = 0.71$, $Sc = 0.60$, $K_r = 0.2$, $M = 2$, $t = 0.5$, $Gr = Gm = 5$ are compared at ramped wall temperature with the available solution of Seth *et*

al. (2013) in Table – 1 and Table – 2 respectively and they are found to be in excellent agreement.

Table – 1: Comparison of the present results with the results of Seth *et al.* (2013) with the effects of m *and* K^2 on the skin-fiction of primary velocity (τ_u) at ramped temperature plate when $Pr = 0.71$, $Sc = 0.60$, $K_r = 0.2$, $M = 2$, $t = 0.5$, $Gr = Gm = 5$:

	Seth *et al.* (2013)			**Present work**		
m	$K^2 = 2$	$K^2 = 4$	$K^2 = 6$	$K^2 = 2$	$K^2 = 4$	$K^2 = 6$
0.2	3.1027	3.4105	3.6814	3.1057	3.4205	3.6904
0.4	2.7103	3.0273	3.4217	2.7092	3.0310	3.4315
0.6	1.5122	2.7152	3.1075	1.5148	2.7174	3.1083

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Table – 2: Comparison of the present results with the results of Seth *et al.* (2013) with the effects of m *and* K^2 on the skin-fiction of transverse velocity (τ_v) at ramped temperature plate when $Pr = 0.71$, $Sc = 0.60$, $K_r = 0.2$, $M = 2$, $t = 0.5$, $Gr = Gm = 5$:

	Seth *et al.* (2013)			**Present work**		
m	$K^2 = 2$	$K^2 = 4$	$K^2 = 6$	$K^2 = 2$	$K^2 = 4$	$K^2 = 6$
0.2	2.6194	3.0753	3.4175	2.6208	3.0767	3.4169
0.4	2.9210	3.4712	3.7918	2.9221	3.4683	3.7907
0.6	3.3054	3.7209	4.1023	3.3047	3.7213	4.1052

Table – 1 shows that the primary skin friction at ramped temperature plate is reduced when the Hall current (m) increases, this behaviour of primary skin-friction is opposite for rotation parameter (K^2). In Table – 2, an increase in Hall current (m)/rotation parameter (K^2) leads to enhanced the secondary skin-friction at ramped temperature plate.

8.5 Results and Discussion :

Throughout the numerical computations, the default numerical values of the physical parameters are considered as $Gr = Gm = 5$, $M = 5$, $m = 0.5$, $t = 0.2$, $\phi = 5$, $K_r = 0.2$, $K^2 = 2$.

The variation of time parameter on the distribution of velocity, temperature and concentration are presented respectively in Figs. 8.2(a) – 8.2(c). An increase in time parameter (t) enhanced all the profiles of flow velocity, temperature and concentration. Therefore, the boundary layer thickness of momentum, thermal and concentration are increased.

The Primary and transverse velocity distributions for Hall parameter (m) have been displayed in Figs. 8.3(a) and 8.3(b) respectively. On increasing Hall current for ramped temperature, the primary velocity (u) accelerated near the plate, but the transverse velocity (v) accelerated throughout the boundary layer regime.

Figs. 8.4(a) and 8.4(b) illustrate the effects of Ekman number (K) on Primary and transverse velocity distributions for ramped wall temperature. Increasing Ekman number decelerated the primary velocity and a reversed effect has been observed for the transverse velocity i.e. the transverse velocity accelerated in the boundary layer regime.

Figs. 8.5(a) and 8.5(b) demonstrate the behaviour of mass Grashof number (Gm) on primary and transverse velocities for ramped temperature. Both the velocities are accelerated throughout the boundary layer on increasing mass Grashof number.

Primary (τ_u) and secondary (τ_v) Skin-frictions for different values of Hall current (m) and magnetic field (M) at the ramped wall temperature are respectively shown in Figs. 8.6(a) and 8.6(b). Due to magnetic field effect, a substantial negative increasing has been observed for the primary skin-friction and it is effective for higher magnetic field ($M = 10, 15$). However, the primary skin-friction is reduced for the Hall current effect and it is significant for $m \geq 0.6$. An increase in magnetic field/Hall current leads to enhanced the secondary skin-friction in the boundary layer regime. Both the skin-frictions become a linear function of Hall current for non-conducting

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fluid ($M = 0$). Due to negative values of primary skin-friction there may exists back flow in the regime.

In Fig. 8.7(a) and 8.7(b), the Primary (τ_u) and secondary (τ_v) Skin-frictions for the variations of free convection parameter (Gr) and time (t) have been presented. As free convection parameter increases the primary skin-friction is reduced and negative values are seen and it leads to back flow within the regime. Primary skin-friction has attained its maximum values near the ramped temperature wall and at $t = 1$. Reversed effect has been observed for secondary skin-friction on account of increasing Gr. As time progresses, there is an enhancement in secondary skin-friction and maximum value is observed at $t = 0.6$.

The Rate of heat transfer (Nu) distribution for the variations of ϕ and t is shown in Fig. 8.8. Increasing heat generation/time elevated the rate of heat transfer and higher elevation has attained for $\phi = 20$ at $t = 0.8$. The negative values of Nusselt number (Nu) means that the heat is diffused from fluid region to the surface of the wall. All the profiles of rate of heat transfer approaches zero towards $t = 1$.

The variations of chemical reaction and time parameter for Sherwood number (Sh) have been presented in Fig. 8.9. Enhanced Sherwood number has been marked for generative chemical reactions and time, whereas a reversed trend has been seen when $t > 0.8$. The elevation of Sherwood number has attained at $t = 0.8$.

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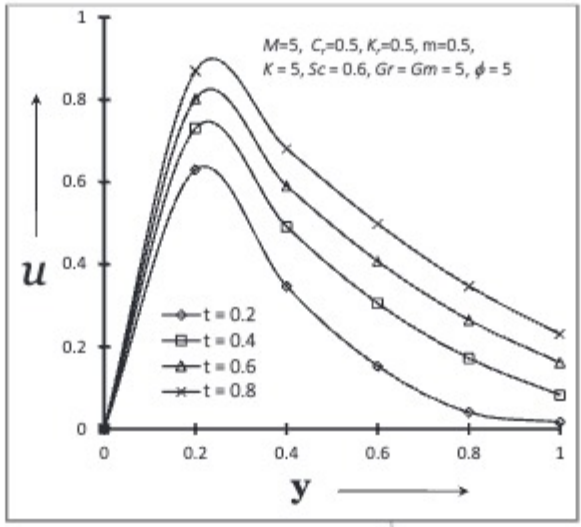

Fig. 8.2(*a*): Velocity distribution for time *t*

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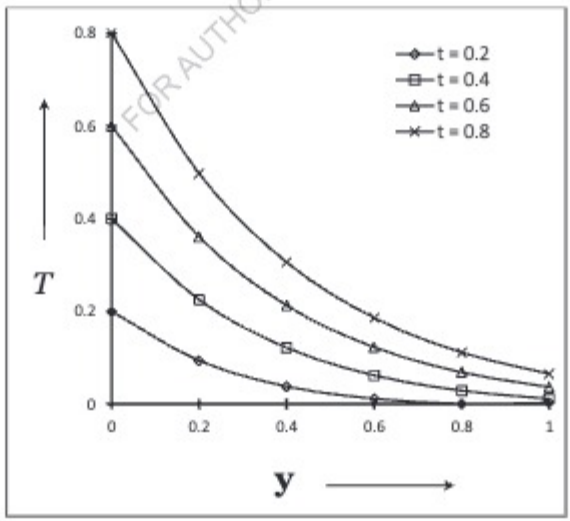

Fig. 8.2(*b*): Temperature distribution for time *t*

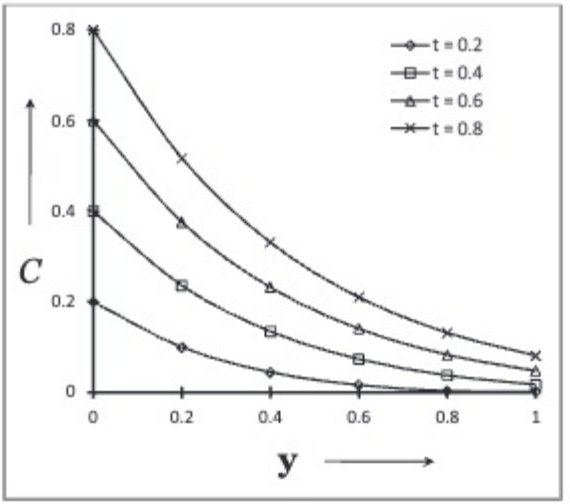

Fig. 8.2(*c*): Concentration distribution for time *t*

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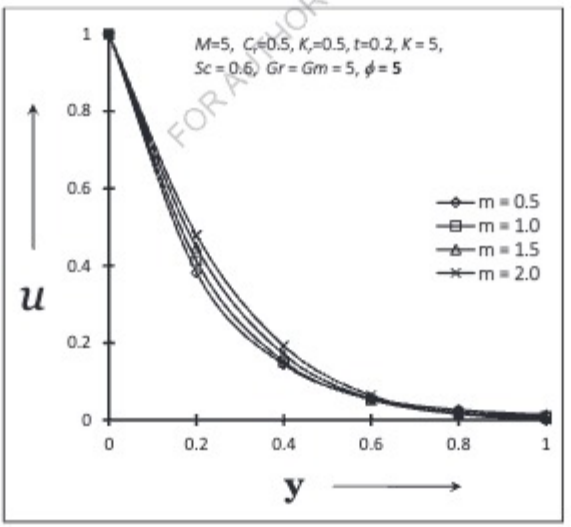

Fig. 8.3(*a*): Primary Velocity distribution for Hall parameter *m*

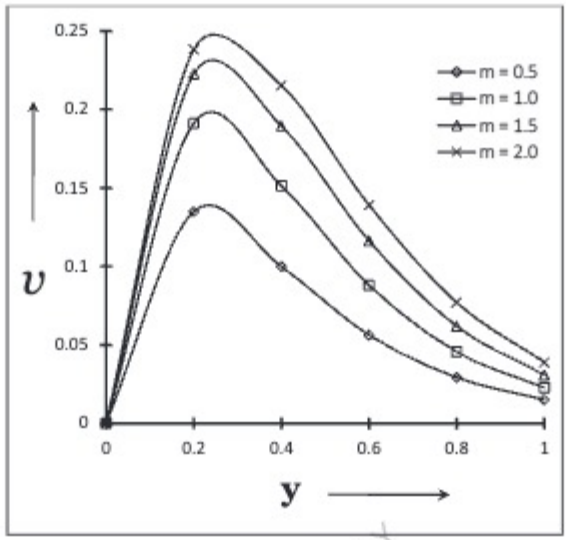

Fig. 8.3(*b*): Transverse Velocity distribution for Hall parameter *m*

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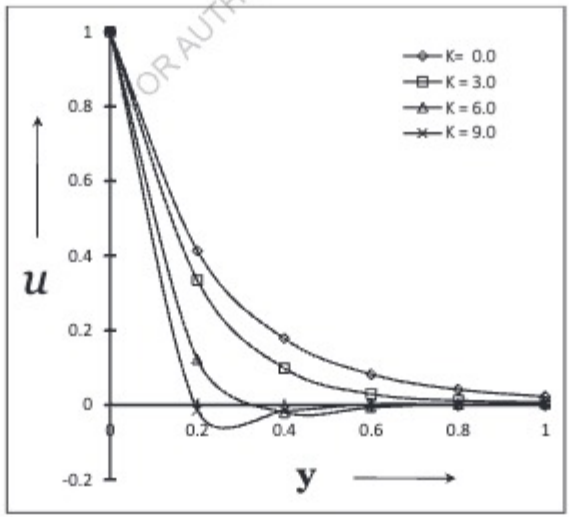

Fig. 8.4(*a*): Primary Velocity distribution for Ekman number *K*

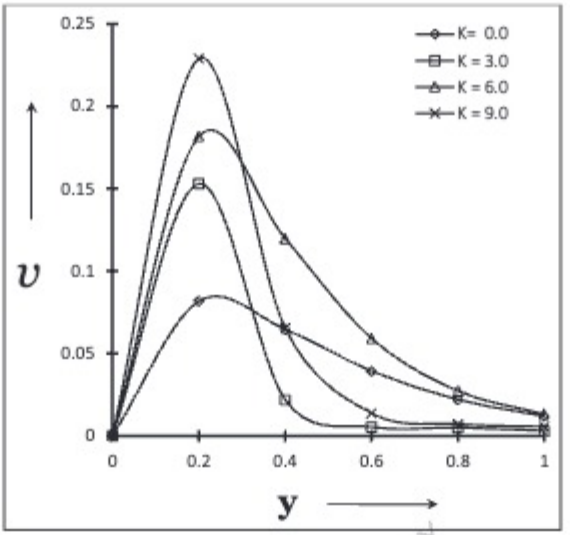

Fig. 8.4(*b*): Transverse Velocity distribution for Ekman number *K*

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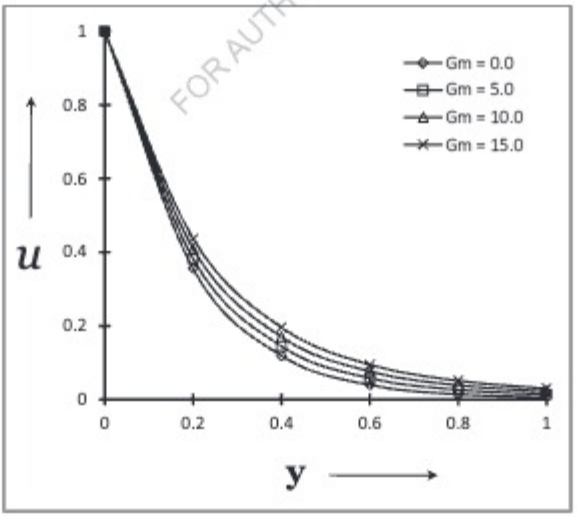

Fig. 8.5(*a*): Primary Velocity distribution for *Gm*

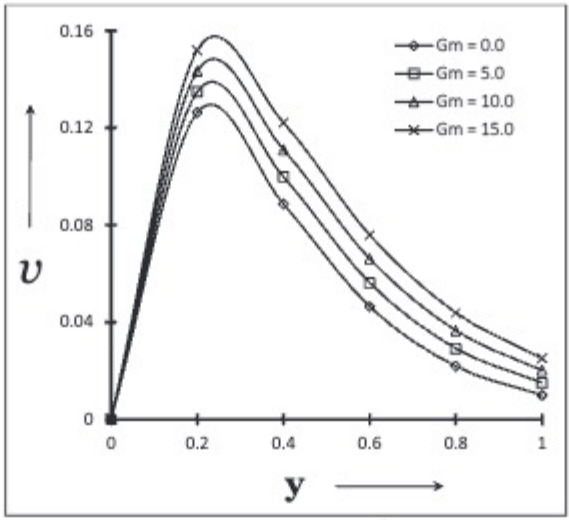

Fig. 8.5(*b*): Transverse Velocity distribution for *Gm*

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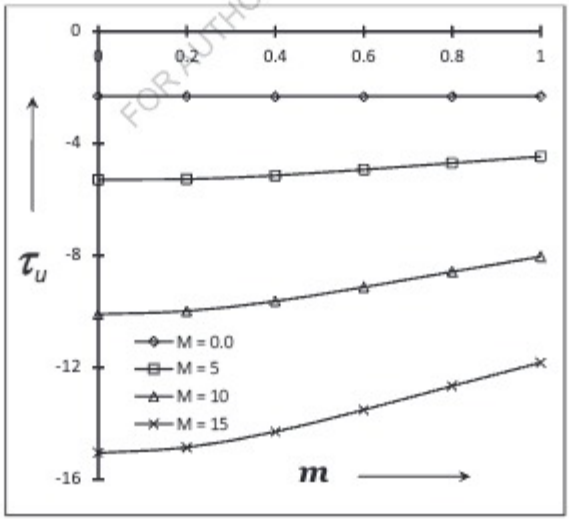

Fig. 8.6(*a*): Skin-friction for Primary Velocity for *m* and *M*

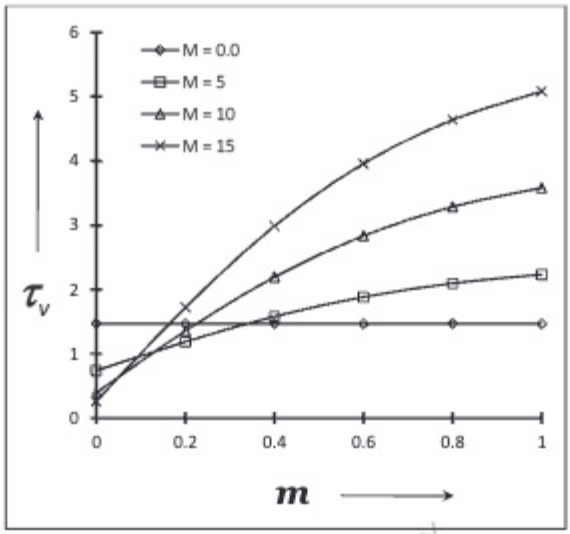

Fig. 8.6(*b*): Skin-friction for Transverse Velocity for *m* and *M*

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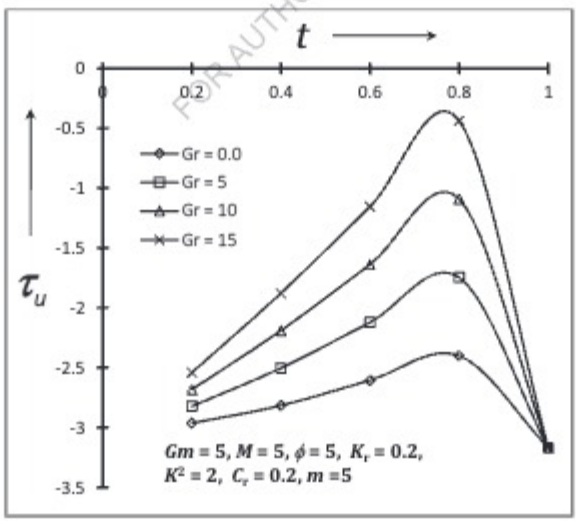

Fig. 8.7(*a*): Skin-friction for Primary Velocity for *Gr* and *t*

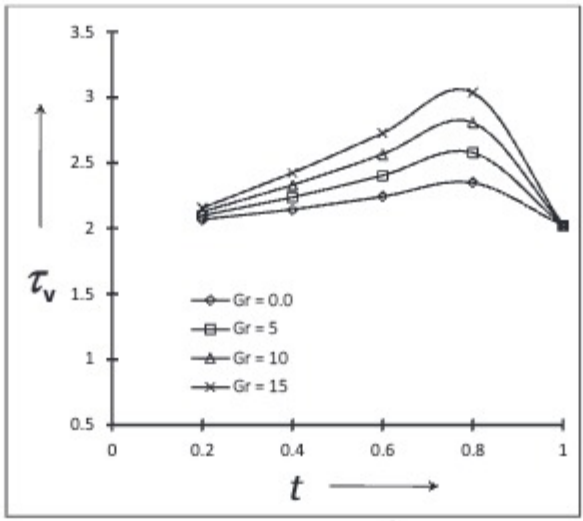

Fig. 8.7(*b*): Skin-friction for Transverse Velocity for *Gr* and *t*

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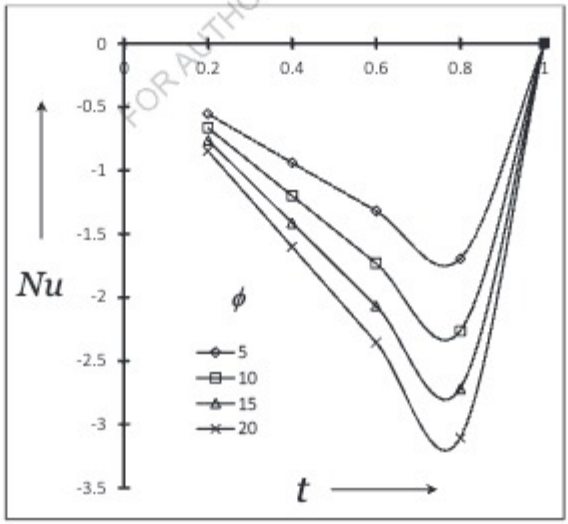

Fig. 8.8: Rate of heat transfer distribution for ϕ and *t*

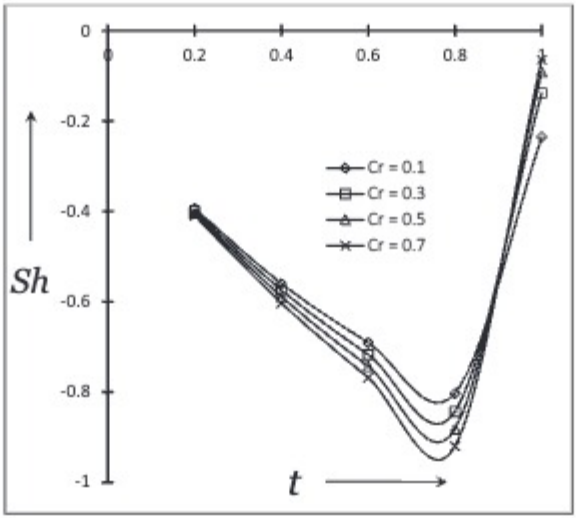

Fig. 8.9: Rate of mass transfer distribution C_r for and t

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8.6 Conclusion :

A theoretical analysis for a rotating model is developed for the ramped wall temperature on transient convective chemically reacting flow past an impulsively started vertical infinite porous plate in a saturated porous medium with Hall currents and heat generation/absorption. Laplace transform Technique has been applied for analytical solutions. Significant results due to ramped wall temperature are mentioned herewith:

- Increasing Hall currents accelerate the primary velocity, whereas it reflects a opposite behaviour in primary skin friction;
- An increase in Hall currents leads to decelerate the secondary velocity, but it enhanced the secondary skin friction;
- All the distributions of primary velocity, temperature and concentration have been raised by enhancing the time parameter;
- Increasing free convection currents boost the secondary skin-friction at the plate, but a significant reduction is observed in primary skin-friction;
- Rate of heat transfer at the ramped wall temperature is increased for the heat generation effect;

- Peak values of concentration gradients at the plate are attained at $t = 0.8$ due to generative chemical reaction in the regime;
- Significantly both the primary and secondary skin-frictions become linear due to Hall currents without magnetic field;
- Ekman number accelerates the primary velocity, but a reverse trend has seen in secondary velocity.

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Chapter – IX

Indirect Natural Convection for Transient Hydromagnetic Gas Flow along an Inclined Plane in a Porous Media: Laplace Technique

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9.1 Introduction :

Radiative convective flows are encountered in countless industrial and environment processes e.g. heating and cooling chambers, fossil fuel combustion energy processes, evaporation from large open water reservoirs, solar power technology and space vehicle re-entry. Radiative heat transfer plays an important role in manufacturing industries for the design of reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. If the temperature of the surrounding fluid is rather high, radiation effects play an important role and this situation does exist in space technology. In such cases, one has to take into account the effect of thermal radiation. The hydrodynamic rotating flow of an electrically conducting viscous incompressible fluid has gained considerable attention because of its numerous applications in physics and engineering. The free convective flow in channels formed by vertical plates has received attention among the researchers in last few decades due to its widespread importance in engineering applications like cooling of electronic equipments, design of passive solar systems for energy conversion, design of heat exchangers, human comfort in buildings, thermal regulation processes and many more. Many researchers have worked in this field such as:

Helliwell (1973) used a flux model to analyzed radiation magnetohydrodynamic channel flow. Gupta and Gupta (1974) studied hydromagnetic thermal convection in a vertical conduit with significant thermal radiation effects. Helliwell (1979) investigated the steady radiative magnetogasdynamic Couette flow using temperature dependent coefficients of viscosity and electrical conductivity, together with a density-dependent absorption coefficient. He numerically computed velocity, induced magnetic field, radiative flux and temperature profiles, showing that wall electrical conductivity and emissivity exert a major effect on the velocity and magnetic field distributions but minor influence on temperatures. Mandal *et al.* (1983) considered combined radiative-hydromagnetic flow,

heat and mass transfer in a vertical channel. Raptis and Masslas (1998) studied unsteady magnetohydrodynamic convection in a gray, absorbing-emitting but non-scattering fluid regime using the Rosseland radiation model. They presented analytical solutions for the mean temperature, velocity and the induced magnetic field.

Thermal radiation flux influence on hydromagnetic mixed free-forced convective steady optically-thick laminar boundary layer flow also using the Rosseland approximation is considered by Azzam (2002). Gbadeyan and Idowu (2006) studied the magnetohydrodynamic heat transfer between two concentric rotating spheres employing the optically thin limit case for thermal radiation. Ogulu and Prakash (2006) studied analytically free convection magneto-heat transfer using the differential approximation for optically-thin radiative flux in the energy equation and incorporating viscous dissipation effects. Mahmoud (2009) considered temperature-dependent viscosity effects in transient dissipative radiation-hydromagnetic convection, showing that an increase in Eckert number and decrease in air viscosity accelerate the flow, whereas increasing magnetic field or thermal radiation flux decelerates the flow. Jang and Hsu (2009) considered numerically the vortex instability of a horizontal MHD natural convection boundary layer flow in a saturated porous medium including thermal radiation. They found that as magnetic parameter increases or radiation parameter decreases, the heat transfer rate is reduced, and that magnetic effect destabilizes the flow to the vortex mode of disturbance, while thermal radiation stabilizes the flow.

The above studies did not assess however the flow from an inclined surface, a regime of considerable importance in glass manufacturing (Obidina and Kiseleva, 1980; Pankova 1989), solar energy collectors, film cooling chemical engineering systems, and electronic circuit cooling mechanisms. Ghosh *et al*. (2010) investigated the transient convection flow past an inclined plane in presence of magnetic field with thermal radiation.

The aim of this investigation is to consider a Darcian flow model for the unsteady convection flow of an electrically-conducting, absorbing-emitting, optically-thick gray gas along an inclined plane in a saturated porous medium in the presence of a transverse magnetic field with thermal

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radiation flux. Analytical solutions are developed through Laplace Transform and the effects of the significant physical parameters on the flow regime are discussed in detail. Such a study has to the authors' knowledge not appeared in the scientific literature.

9.2 Mathematical Formulation :

We consider the transient hydromagnetic flow of a viscous, incompressible, electrically-conducting, absorbing-emitting, non-scattering, optically-thick gas along an infinite plate inclined at α to the horizontal immersed in a saturated porous medium, the plate is moving with constant velocity, u_0 as shown below in Figure - 9.1. Refractive index of the gas medium is constant.

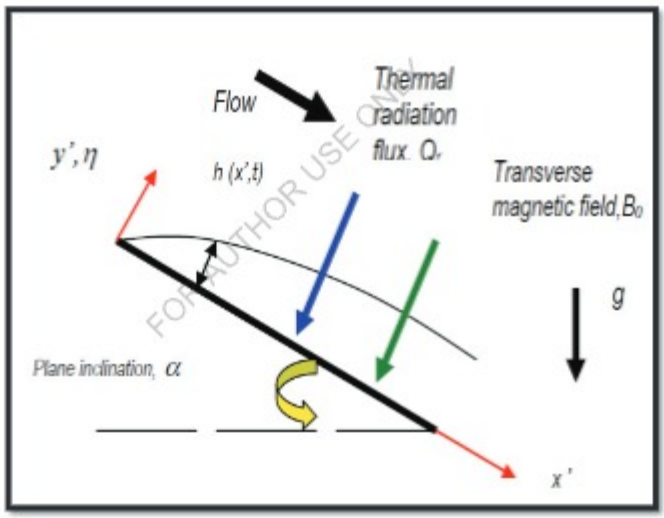

Fig. 9.1: Flow configuration

A uniform magnetic field, B_0, is applied perpendicular to the plate. The $\bar{x}$-axis is orientated along the plate and the $\bar{y}$- axis perpendicular to the plate. The Maxwell field equations, as described by Sutton and Sherman (1965) comprise five vector equations-the Ampere law, magnetic field continuity, Faraday's law, Kirchoff's law and finally Ohm's law. The generalized

equations in vectorial form, for flow of an electrically-conducting gas are the Maxwell equations:

$$curl\left(\vec{B}\right) = \mu\vec{J} \quad Ampere's\ Law \tag{9.2.1}$$

$$div\left(\vec{B}\right) = 0 \quad Magnetic\ field\ continuity \tag{9.2.2}$$

$$curl\left(\vec{E}\right) = -\frac{\partial\vec{B}}{\partial t} \quad Faraday's\ Law \tag{9.2.3}$$

$$div\left(\vec{J}\right) = -\frac{\partial\vec{B}}{\partial t} \quad Kirchoff's\ Law \tag{9.2.4}$$

$$\vec{J} = \sigma\left[\vec{E} + \vec{v} \times \vec{B}\right] \quad Ohm's\ Law \tag{9.2.5}$$

where $\vec{J}$ is the current density, $\vec{B}$ is the magnetic field vector, σ is the electrical conductivity, $\vec{E}$ is the electrical field intensity vector, ρ is density, v is the velocity vector, μ is co-efficient of viscosity, t is time.

From an order of magnitude analysis, it can be shown, Sutton and Sherman (1965) that for two-dimensional (x-y) magneto-hydrodynamic gas dynamic flows, the hydromagnetic retarding force (Lorentz body force) acts only parallel to the flow and has the form:

$$F_{magnetic} \approx -\sigma B_{\bar{y}}^2 u\,, \tag{9.2.6}$$

where B_y is the component of magnetic field in the $\bar{y}$- direction.

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We consider an aerodynamic viscous flow where the magnetic field is sufficiently weak to sustain a small magnetic Reynolds number such that induced magnetic field effects can be neglected. Joule electro-heating and Hall current/ion-slip effects are also neglected. The temperature of the gas in the regime is $\bar{T}$ and an induced pressure gradient generated by indirect natural convection acts along the $\bar{x}$ - direction. All fluid properties are constant. The plate temperature is prescribed $\bar{T}_w$ and is of sufficiently high magnitude that thermal radiation effects are significant. In accordance with the Boussinesq approximation, all fluid properties are constant with the exception of the density variation in the buoyancy term. Unidirectional radiation flux, Q_r, is considered and it is assumed that $\frac{\partial Q_r}{\partial\bar{y}} >> \frac{\partial Q_r}{\partial\bar{x}}$.

Under these simplification, the mass, momentum and energy conservation equations for the regime with regard to indirect natural convection, may be presented as follows:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0 \tag{9.2.7}$$

$$\frac{\partial \bar{u}}{\partial \bar{t}} + u\frac{\partial \bar{u}}{\partial \bar{x}} + v\frac{\partial \bar{v}}{\partial \bar{y}} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} + g\beta(\bar{T} - \bar{T}_\infty)\sin\alpha + \nu\frac{\partial^2 \bar{u}}{\partial^2 \bar{y}} - \frac{\sigma B_0^2}{\rho}\bar{u} - \frac{\nu}{\bar{K}}\bar{u} \tag{9.2.8}$$

$$0 = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{y}} - g\beta(\bar{T} - \bar{T}_\infty)\cos\alpha \tag{9.2.9}$$

$$\rho C_p \frac{\partial \bar{T}}{\partial \bar{t}} = \kappa\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - \frac{\partial q_r}{\partial \bar{y}} \quad . \tag{9.2.10}$$

The initial and boundary conditions are

$$\left.\begin{array}{l} \bar{u} = 0, \bar{T} = \bar{T}_\infty, \forall \bar{y}, \bar{t} \le 0 \\ \bar{u} = u_0, \bar{T} = \bar{T}_w \quad at \quad \bar{y} = 0\ ,\ \bar{t} > 0 \\ \bar{u} \to 0,\ \bar{T} \to \bar{T}_\infty \quad as \quad \bar{y} \to \infty\ ,\ \bar{t} > 0 \end{array}\right\} \tag{9.2.11}$$

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where $\bar{u}$ is the velocity in the $\bar{x}$- direction, $\bar{v}$ is velocity in the $\bar{y}$- direction, $\bar{t}$ denotes time, g the acceleration due to gravity, ν is the kinematic viscosity of the optically-dense gas, β is volumetric coefficient of thermal expansion, $\bar{T}$ the temperature of the fluid, $\bar{T}_\infty$ is free stream temperature of the fluid, $\bar{T}_w$ is the plate surface temperature, ρ the density, C_p is the specific heat at constant pressure, κ is thermal conductivity of the optically-dense fluid, σ is electrical conductivity of the gas and B_0 is magnetic field and Q_r is the radiative heat flux.

In transient flow, the frictional (viscous) and gravitational forces do not balance exactly and the discrepancy is proportional to the acceleration of the fluid. The deviation between the free surface of the gas and the plate

inclination also contributes to this and an instability mechanism arises in the inclined plane flow.

There is a pressure distribution in the flow with a gradient defined as:

$$\frac{\partial p}{\partial \bar{y}} = \rho g \tag{9.2.12}$$

After integration, Eq. (9.2.9) becomes:

$$p = \rho g y (h - \bar{y})(\bar{T} - \bar{T}_\infty)\cos\alpha \tag{9.2.13}$$

where h denotes free surface elevation.

Differentiating (9.2.13) with respect to $\bar{x}$, yields:

$$\frac{\partial p}{\partial \bar{x}} = \rho g y (\bar{T} - \bar{T}_\infty)\frac{\partial h}{\partial \bar{x}}\cos\alpha \tag{9.2.14}$$

Above the leading edge of the plate ($\bar{x} = 0$), the density variation with depth is constant i.e. will remain unchanged for all $\frac{\partial h}{\partial \bar{x}}$. We therefore prescribe the following condition:

$$\frac{\partial h}{\partial \bar{x}} = \cos\alpha \tan t = F_1 \tag{9.2.15}$$

Introducing the following non-dimensional quantities for the solution of the two-point boundary value problem defined by Eqs (9.2.7) to (9.2.10) under the boundary conditions (9.2.11):

$$\left\{\begin{array}{l} y = \dfrac{\bar{y}u_0^2}{\nu},\ u = \dfrac{\bar{u}}{u_0},\ M = \dfrac{\sigma B_0^2 \nu}{\rho u_0^2},\ K = \dfrac{u_0^2 \bar{K}}{\nu^2},\ Gr = \dfrac{g\beta\nu\left(\bar{T}_w - \bar{T}_\infty\right)}{u_0^3}, \\ \theta = \dfrac{\bar{T} - \bar{T}_\infty}{\bar{T}_w - \bar{T}_\infty},\ Pr = \dfrac{\mu C_p}{\kappa},\ t = \dfrac{\bar{t}u_0^2}{\nu},\ R_a = \dfrac{16\bar{\sigma}\nu^2\bar{T}_\infty^3}{\kappa^*\kappa},\ \nu = \dfrac{\mu}{\rho} \end{array}\right\} \tag{9.2.16}$$

where u denotes dimensionless $\bar{x}$- direction velocity, t is non-dimensional time, y is dimensionless transverse coordinate, θ is the dimensionless

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temperature function, Gr is the Grashof (free convection) number, Pr is the Prandtl number and M denotes the square root of the Hartmann hydromagnetic number.

On using Eq. (9.2.15) in Eqs (9.2.8) and (9.2.9), and neglecting convective acceleration terms, the dimensionless form of the momentum equation is:

$$\frac{\partial u}{\partial t} = Gr(\sin\alpha - F_1\cos\alpha)\theta + \frac{\partial^2 u}{\partial y^2} - (M + K^{-1})u \tag{9.2.17}$$

The radiation heat flux vector is addressed using the approach outlined by Isachenko *et al.* (1980). The Rosseland diffusion flux approximation is therefore used leading to a Fourier-type gradient function, viz:

$$Q_r = -\frac{4\bar{\sigma}}{3\kappa^*}\frac{\partial \bar{T}^4}{\partial \bar{y}}, \tag{9.2.18}$$

where $\bar{\sigma}$ is the Stefan-Boltzmann constant and κ^* is the spectral mean absorption coefficient of the medium.

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This model is valid for optically-thick media in which thermal radiation propagates only a limited distance prior to experiencing scattering or absorption. The local thermal radiation intensity is due to radiation emanating from proximate locations in the vicinity of which emission and scattering are comparable to the location of interest. For zones where conditions are appreciably different thermal radiation has been shown to be greatly attenuated before arriving at the location under consideration. The energy transfer depends on conditions only in the area adjacent to the plate regime i.e. the boundary layer regime. Rosseland's model yields accurate results for intensive absorption i.e. optically-thick flows which are optically far from the bounding surface. Implicit in this approximation is also the existence of wavelength regions where the optical thickness may exceed a value of five. As such the Rosseland model, while limited compared with other flux models, can simulate to a reasonable degree of accuracy thermal radiation effects in engineering flow problems, as elaborated upon by Modest (1993). We further assume that the temperature differences within the flow are sufficiently small such that $\bar{T}^4$ can be expressed as a linear

function of the temperature, $\overline{T}$. Expansion of $\overline{T}^4$ as a Taylor series about the free stream temperature, $\overline{T}_\infty$, neglecting higher order terms, generates a result of the form:

$$\overline{T}^4 \cong 4\overline{T}_\infty^3 \overline{T} - 3\overline{T}_\infty^4 \tag{9.2.19}$$

Proceeding with the analysis, the energy Eq. (9.2.10) may be orchestrated in dimensionless form subject to Eq. (9.2.16) as follows:

$$(1+R_a)\frac{\partial^2 \theta}{\partial y^2} - Pr\frac{\partial \theta}{\partial t} = 0, \tag{9.2.20}$$

where R_a denotes the Boltzmann-Rosseland radiation-conduction number.

The first term in Eq. (9.2.20) is an augmented diffusion term i.e. with $R_a = 0$, thermal radiation vanishes and Eq. (9.2.20) reduces to the familiar unsteady one-dimensional conduction-convection equation.

The boundary conditions (9.2.11) are transformed to:

$$\left\{\begin{array}{l} u = 0, \theta = 0, \forall y, t \leq 0 \\ \\ u = 1, \theta = 1 \quad for \ y = 0, \ t > 0 \\ \\ u \to 0, \theta \to 0 \quad for \ y \to \infty, \ t > 0 \end{array}\right\} \tag{9.2.21}$$

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9.3 Analytical Solutions :

The two-point boundary value problem defined by Eqs (9.2.17) and (9.2.20) along with their boundary conditions (9.2.21) have been solved analytically using Laplace transforms technique and their exact solutions are as follows:

$$u(y,t)=\left[\begin{array}{l}\dfrac{1}{2}\left\{1-\dfrac{Gr}{N}\left(\sin\alpha-F_1\cos\alpha\right)\right\}\left\{\begin{array}{l}e^{-Ny}\,erfc\left(\dfrac{y-2Nt}{\sqrt{t}}\right)+\\ e^{Ny}\,erfc\left(\dfrac{y+2Nt}{\sqrt{t}}\right)\end{array}\right\}\\ +\dfrac{Gr}{N}\left(\sin\alpha-F_1\cos\alpha\right)erfc\left(\dfrac{y}{2}\sqrt{\dfrac{Pr}{(1+R_a)t}}\right)\\ +\left(\sin\alpha-F_1\cos\alpha\right)\dfrac{y}{\sqrt{4\pi}}\dfrac{Gr}{N}\dfrac{\sqrt{2}-1}{\sqrt{t}}\\ \left[\left[exp\left\{-\left(\dfrac{y^2}{4}+Nt\right)\right\}-\sqrt{\dfrac{Pr}{1+R_a}}\,exp\left\{-\left(\dfrac{y^2Pr}{4(1+R_a)t}\right)\right\}\right]\right]\end{array}\right] \tag{9.3.22}$$

$$\theta(y,t)=erfc\left\{\left(\frac{y}{2}\sqrt{\frac{Pr}{(1+R_a)t}}\right)\right\} \tag{9.3.23}$$

where

$$N=M^2+K^{-1}$$

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In order to interest in engineering design, the frictional shear stress at the plate surface (y = 0) and the surface temperature gradient, are defined respectively as:

$$\tau = -\left[\frac{\partial u(y,t)}{\partial y}\right]_{y=0}$$

$$= \left[\begin{array}{l} \frac{1}{2}\left\{1-\frac{Gr}{N}\left(\sin\alpha - F_1\cos\alpha\right)\right\}\left\{N\,erfc\left(N\sqrt{t}\right) - N\,erfc\left(-N\sqrt{t}\right) - e^{-Nt}\right\} \\ \quad -\frac{Gr}{N}\left(\sin\alpha - F_1\cos\alpha\right)\frac{1}{\sqrt{\pi}}erfc\left(\sqrt{\frac{Pr}{(1+R_a)t}}\right) \\ \quad +\left(\sin\alpha - F_1\cos\alpha\right)\frac{1}{\sqrt{4\pi}}\frac{Gr}{N}\frac{\sqrt{2}-1}{\sqrt{t}}\left[exp\left\{-\left(Nt\right)\right\} - \sqrt{\frac{Pr}{1+R_a}}\right] \end{array}\right] \quad (9.3.24)$$

$$Nu = -\left[\frac{\partial\theta(y,t)}{\partial y}\right]_{y=0} = -\frac{1}{\sqrt{\pi}}\left\{\sqrt{\frac{1}{(1+R_a)t}}\right\} \quad (9.3.25)$$

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Some special cases have studied during the investigation:

Case I: Non-Radiative Hydromagnetic Inclined Plate Flow

In the absence of thermal radiation effects, $R_a \to 0$ and the velocity and temperature solutions (9.3.22) and (9.3.23) reduce to the case for hydromagnetic free convection flow from an inclined plane:

$$u(y,t)=\left[\begin{array}{l}\dfrac{1}{2}\left\{1-\dfrac{Gr}{N}(\sin\alpha-F_1\cos\alpha)\right\}\left\{\begin{array}{l}e^{-Ny}\,erfc\left(\dfrac{y-2Nt}{\sqrt{t}}\right)+\\ e^{Ny}\,erfc\left(\dfrac{y+2Nt}{\sqrt{t}}\right)\end{array}\right\}\\ +\dfrac{Gr}{N}(\sin\alpha-F_1\cos\alpha)\,erfc\left(\dfrac{y}{2}\sqrt{\dfrac{Pr}{t}}\right)\\ +(\sin\alpha-F_1\cos\alpha)\dfrac{y}{\sqrt{4\pi}}\dfrac{Gr}{N}\dfrac{\sqrt{2}-1}{\sqrt{t}}\left[\begin{array}{l}exp\left\{-\left(\dfrac{y^2}{4}+Nt\right)\right\}\\ -\sqrt{Pr}\,exp\left\{-\left(\dfrac{y^2Pr}{4t}\right)\right\}\end{array}\right]\end{array}\right] \tag{9.3.26}$$

$$\theta(y,t)=erfc\left\{\left(\frac{y}{2}\sqrt{\frac{Pr}{t}}\right)\right\} \tag{9.3.27}$$

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Case II: Magnetohydrodynamic Radiative-Convection from a Horizontal Plane

With $\alpha\to 0$, $\sin\alpha\to 0$ and $\cos\alpha\to 1$, the plate becomes horizontal and the velocity solution (9.3.22) reduces to:

$$u(y,t)=\begin{bmatrix}\frac{1}{2}\left\{1-\frac{Gr}{N}(-F_1)\right\}\left\{e^{-Ny}erfc\left(\frac{y-2Nt}{\sqrt{t}}\right)+e^{Ny}erfc\left(\frac{y+2Nt}{\sqrt{t}}\right)\right\}\\ +\frac{Gr}{N}(-F_1)erfc\left(\frac{y}{2\sqrt{\frac{Pr}{(1+R_a)t}}}\right)\\ -F_1\frac{y}{\sqrt{4\pi}}\frac{Gr}{N}\frac{\sqrt{2}-1}{\sqrt{t}}\left[\begin{array}{l}exp\left\{-\left(\frac{y^2}{4}+Nt\right)\right\}-\\ \sqrt{\frac{Pr}{1+R_a}}exp\left\{-\left(\frac{y^2Pr}{4(1+R_a)t}\right)\right\}\end{array}\right]\end{bmatrix} \quad (9.3.28)$$

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Case III: Magnetohydrodynamic Radiative-Convection from a Vertical Plane

With $\alpha \to \pi/2$, $\sin\alpha \to 1$ and $\cos\alpha \to 0$, the plate becomes vertical and the velocity solution (9.3.22) will reduce to:

$$u(y,t)=\begin{bmatrix}\frac{1}{2}\left\{1-\frac{Gr}{N}\right\}\left\{e^{-Ny}erfc\left(\frac{y-2Nt}{\sqrt{t}}\right)+e^{Ny}erfc\left(\frac{y+2Nt}{\sqrt{t}}\right)\right\}\\ +\frac{Gr}{N}erfc\left(\frac{y}{2\sqrt{\frac{Pr}{(1+R_a)t}}}\right)\\ +\frac{y}{\sqrt{4\pi}}\frac{Gr}{N}\frac{\sqrt{2}-1}{\sqrt{t}}\left[\begin{array}{l}exp\left\{-\left(\frac{y^2}{4}+Nt\right)\right\}-\\ \sqrt{\frac{Pr}{1+R_a}}exp\left\{-\left(\frac{y^2Pr}{4(1+R_a)t}\right)\right\}\end{array}\right]\end{bmatrix} \quad (9.3.29)$$

9.4 Validity :

The effects of α *and* R_a on skin-friction distributions at the wall ($y = 0$) are compared with the available solution of Ghosh *et al*. (2010) for accuracy has been presented in Table – 1 and it is found to be in excellent agreement and hence the proposed flow model is validated and stable for investigation.

Table – 1: Skin friction, $\left(\frac{\partial u}{\partial y}\right)_{y=0}$, at $y = 0$ for $F_1 = 2.0$, $Pr = 0.71$, $Gr = 5.0$, $t = 2$ with various plate inclinations (α) and Boltzmann-Rosseland numbers (R_a) without porosity.

	Present work			**Ghosh *et al.* (2010)**		
α	$R_a = 0.0$	$R_a = 2.0$	$R_a = 5.0$	$R_a = 0.0$	$R_a = 2.0$	$R_a = 5.0$
0	–6.53617	–6.91585	–7.26052	–6.53614	–6.91580	–7.26051
π/6	–6.35161	–6.39627	–6.47289	–6.35159	–6.39626	–6.47284
π/4	–6.09274	–5.97856	–5.99731	–6.09271	–5.97852	–5.99728
π/3	–5.65850	–5.64379	–5.63778	–5.65842	–5.64372	–5.63775
π/2	–5.36129	–5.29911	–5.25813	–5.36127	–5.29837	–5.25807

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The results through the Table – 1 shows that the velocity gradients, $\left(\frac{\partial u}{\partial y}\right)_{y=0}$, at the wall $y = 0$ enhanced by the influence of various plate inclinations (α) and Boltzmann-Rosseland numbers (R_a). Back flow may also observed due to negativity of the values of $\left(\frac{\partial u}{\partial y}\right)_{y=0}$.

9.5 Results and Discussion :

All the numerical computations have been done from the analytical solutions given in Eqs (9.3.22) and (9.3.23) with respect to air ($Pr = 0.71$) and the arbitrary constant, $F_1 = 1$. The entire boundary layer regime has controlled by five thermo physical parameters, R_a, Pr, Gr, M, K, a single geometric parameter α and time t.

The influence of magnetic parameter (M) and plane inclinations (α) on the flow velocity distributions with transverse distance (y) normal to the cooled plate ($Gr > 0$) for conduction air ($Pr = 0.71$) have been presented in Figure - 9. 2. The hydromagnetic term in the dimensionless Eq. (9.2.17), is a linear drag force term. With increasing magnetic field strength, B_0, M is increased and this serves to decelerate the flow along the inclined plate and therefore all the velocity profiles are strongly reduced with increasing M. It is seen that the velocity profiles are elevated near the surface and decay to zero progressively for all values of M, α and y. Moreover, an increase in the plane inclination, the flow velocity is significantly increased. When plane inclination is zero i.e. for the horizontal plane, velocity is minimized since gravitational acceleration effects are neglected. Also the flow is strongly accelerated for maximum plane inclination ($\alpha = \pi/3$) and these profiles correspond to strong buoyancy (free convection) force.

Figure - 9.3 depicts the temperature response for different thermal radiations (R_a) and time parameter (t) with distance transverse to the surface (i.e. with y-coordinate). The parameter R_a defines the ratio of thermal conduction contribution relative to thermal radiation. For $R_a = 1$, the thermal radiation and the thermal conduction contributions are equivalent. For $R_a > 1$, the thermal radiation effect is dominant over the thermal conduction effect and vice versa for $R_a < 1$. An increase in the value of R_a from 0 (non-radiating) through 2.0, to 4.0 (radiation is dominant over thermal conduction), causes a significant increase in the velocity with distance into the boundary layer i.e. accelerates the flow. The velocities in all cases ascend from the surface, peak close to the wall and then decay smoothly to zero in the free stream. As expected, the temperature values are also significantly enhanced with an increase in the value of t as there is a progressive increase in the time parameter contribution accompanying this. Rosseland's radiation diffusion model effectively enhances the thermal diffusivity, as described by Siegel and Howell (1972). In Eq. (9.2.20) this is apparent in the coefficient of the spatial temperature gradient i.e. diffusion term, $(1+R_a)\frac{\partial^2\theta}{\partial y^2}$. The temperature profiles all decay monotonically from the maximum at the plate surface to the free stream.

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Figure - 9.4 illustrates the behaviour of the porosity (K) and free convection parameter i.e. Grashof number (Gr) on the boundary layer variable u. Increasing the porosity of the porous medium clearly serves to enhance the flow velocity i.e. accelerates the flow. This effect is accentuated close to the surface where a peak in the velocity profile arises. With further distance transverse to the surface, the velocity profiles are all found to decay into the free stream. An increased porosity clearly corresponds to a reduced presence of matrix fibers in the flow regime which, therefore, provides a lower resistance to the flow and in turn, boosts the momentum. However, the free convection currents as simulated with the buoyancy term, $Gr(\sin\alpha - F_1\cos\alpha)\theta$, in Eq. (9.2.17), clearly serves to accelerate the flow along the inclined plate and maximum peaks have been attained at higher free convection ($Gr = 10$).

The rate of heat transfers in terms of Nusselt number (Nu) at the plate $y = 0$ for various effects of Boltzmann-Rosseland number (R_a) and time parameter (t) is shown in Figure - 9.5. An increase in R_a serves to reduction in rate of heat transfer throughout the regime, but maximum effect has observed at the plate. Also a substantial decrease has seen in the rate of heat transfer for increasing time parameter. The negative values of Nu assert that the heat is diffused through fluid region to the plate.

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In Figure - 9.6 we have plotted the behaviour of velocity gradients at the plate $y = 0$ for the variance of porosity of the porous medium (K) and inclinations of the plate (α) against time (t). With increasing porosity and inclination values, the velocity gradients in the regime are found to increases. Also the velocity gradients have a reverse behaviour for the time parameter i.e. substantial decrease is observed in velocity gradients. Insignificant effect has occurred in the velocity gradients when the plane becomes vertical ($\alpha = \pi/2$).

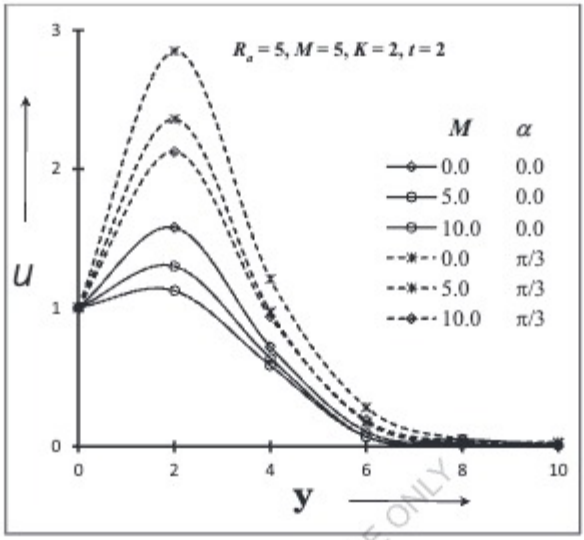

Fig. 9.2: Velocity distribution for magnetic number (M) and inclinations of the plate (α)

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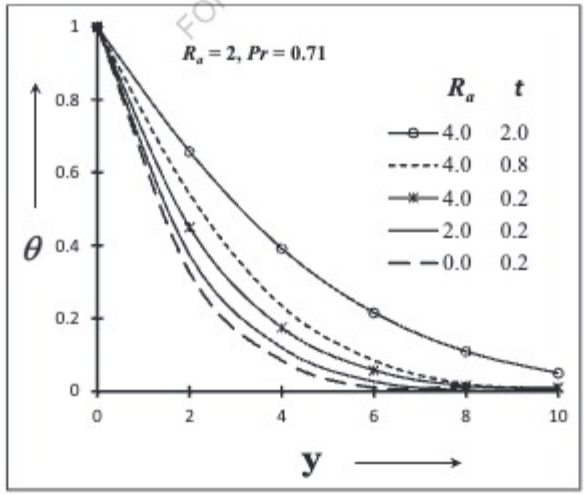

Fig. 9.3: Temperature distribution for Boltzmann-Rosseland radiation-convection parameter (R_a) and time (t)

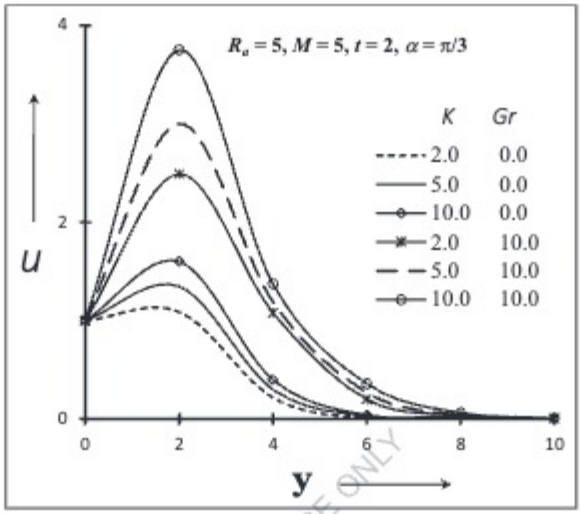

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Fig. 9.4: Velocity distribution for porosity parameter (K) and Grashof number (Gr)

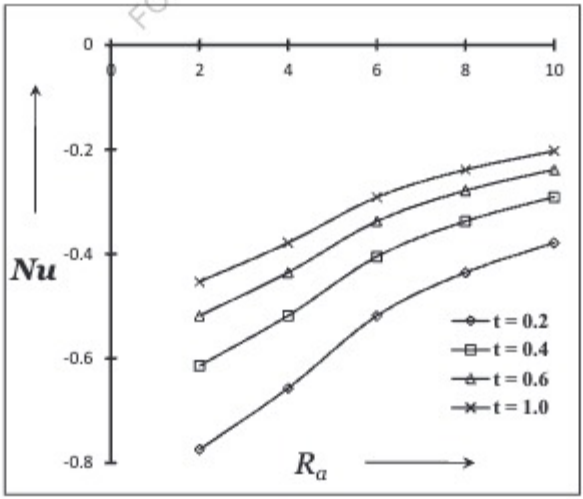

Fig. 9.5: Rate of heat transfer distribution for Boltzmann-Rosseland radiation-convection parameter (R_a) and time (t)

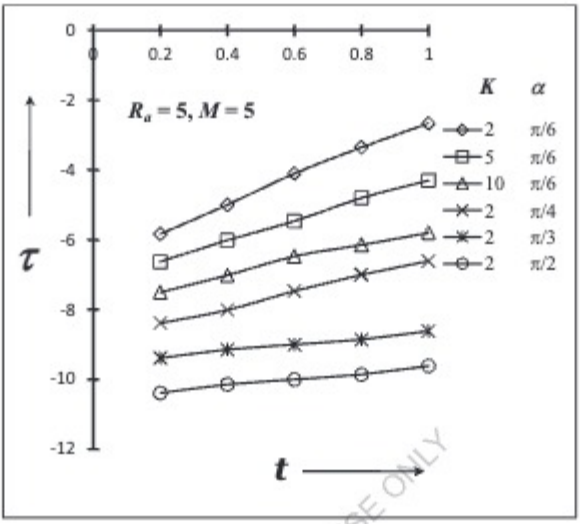

Fig. 9.6: Skin-friction distribution for porosity (K) and inclinations of the plate (α) against time (t)

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9.6 Conclusions :

A Darcian flow model is developed for the transient hydromagnetic free convection-radiation flow of an incompressible viscous fluid along an inclined plane in a saturated porous medium under a transverse magnetic field. The Rosseland diffusion approximation, valid for optically-thick gases has been utilized. The governing partial differential equations are transformed into a system of ordinary differential equations using similarity transformations. The transformed ordinary differential equations are then solved analytically by Laplace transform Technique. Few significant results are summarized:

- Enhancement of the magnetic parameter (M) and inclination of the plane (α) accelerated the flow velocity;

- Increasing the porosity (K) and free convection parameter (G) serves to boosts the flow velocity and velocity gradients at the plate in the boundary layer regime;
- Increasing Boltzmann- Rosseland number (R_a) i.e. greater thermal radiation heat transfer contribution serves to enhanced the fluid temperature, but a converse behaviour has occurred in the rate of heat transfer at the plate;
- Increasing time parameter escalated the fluid temperature and the rate of heat transfer, whereas an opposite character is sustained for the velocity gradients.

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Chapter – X

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Viscous Dissipative Heat with Chemically Reacting/Radiating fluid past an infinite Vertical Porous Plate: Finite Difference Scheme

10.1. Introduction :

The phenomenon of viscous dissipation heat in the natural convective flow is important when the flow field is of extreme size or at low temperature or in high gravitational field. Such effects are also important in geophysical flows and also in certain industrial operations and are usually characterized by the Eckert number. A number of authors have considered viscous heating effects on Newtonian flows. The influence of viscous heating dissipation effects in natural convective flows was reported by Mahajan and Gebhart (1989), showing that the heat transfer rates are reduced by an increase in the dissipation parameter. Merkin (1994) was the first to consider a somewhat different but practically relevant driving mechanism for the natural convection boundary layer flow near a vertical surface in which it was assumed that the flow was set up by Newtonian heating from the bounding surface, i.e., the heat transfer from the surface was taken to be proportional to the local surface temperature. An analysis of transient free convection flow of a dissipative fluid past an infinite vertical porous plate is presented by Soundalgekar *et al*. (2004) and they were adopted a finite difference scheme. Joaquin (2006) presented a new method to solve the transient free convection MHD flow of a dissipative fluid along a semi-infinite vertical plate with mass transfer, the surface of which is exposed to a constant heat flux. Salleh *et al*. (2010) presented the steady laminar boundary layer flow and heat transfer over a stretching sheet with Newtonian heating. The forced convection boundary layer flow over a circular cylinder with Newtonian heating in a uniform stream is investigated by Salleh *et al*. (2011). Unsteady free convection flow over a moving vertical plate with thermal radiation and Newtonian heating was studied by Narahari and Ishak (2011), however Rajesh (2012) analyzed the mass transfer on flow past an impulsively started infinite vertical plate with Newtonian heating and chemical reaction. The model of unsteady natural convection flow of an optically dense viscous incompressible fluid near a vertical plate with Newtonian heating was studied by Narahari and Dutta (2012). Dada (2012) studied numerical solution for the combined effects of dissipation, thermal radiation and MHD on the viscous incompressible unsteady fluid flow past an impulsively started infinite vertical plate with Newtonian heating for optically thin radiation limit case. The study of the effects of radiation and chemical

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reaction on unsteady magnetohydrodynamic free convection flow of a dissipative fluid past an impulsively started infinite vertical plate in the presence of Newtonian heating and uniform mass diffusion has been invested by Rajesh *at el*. (2013). Very recently, Palani *et al*. (2017) studied the flow model for unsteady MHD laminar viscous dissipative fluid flow past a semi-infinite vertical plate with variable surface temperature in the presence of heat source. Hazarika and Ahmed (2017) have been investigated an unsteady MHD flow of two-dimensional radiating fluid along a semi-infinite vertical permeable moving plate with periodic heat and mass transfer by taking into account the effect of viscous dissipation in presence of chemical reaction.

Many processes in new engineering areas occur at high temperatures and knowledge of radiation heat transfer beside the convective heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. England and Emery (1969) have studied the radiation effects of an optically thin gray gas bounded by a stationary plate. Takhar *et al*. (1996) who reported on the radiation effects on MHD free convention flow of a radiating fluid past a semi-infinite vertical plate. Again the effects of thermal radiation on moving vertical plate in the presence of mass diffusion studied Raptis and Perdikis (2003). The governing equations were solved by the Laplace transform technique. Raptis (1998) considered the thermal radiation effects in a steady free convective flow through a porous medium bounded by a vertical infinite porous plate. Jaiswal and Soundalgekar (2001) obtained an approximate solution to the problem of an unsteady flow past an infinite vertical plate with constant suction and embedded in a porous medium with oscillating plate temperature. An analysis of the thermal radiation effects on stationary mixed convection from vertical surfaces in saturated porous media for both a hot and a cold surface has been presented by Bakier (2001). Zueco (2007) studied Network simulation method applied to radiation and dissipation effects on MHD unsteady free convection over vertical porous plate. The effects of radiation and chemical reaction on natural convection flows of a Newtonian fluid along a vertical surface embedded in a porous medium presented by Mahmud and Chamkha (2010). Recently, Hazarika

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and Ahmed (2017) has been investigated the two-dimensional unsteady, hydromagnetic flow immersed in a Darcian porous regime with the effects of viscous dissipation and heat source/generation in presence of thermal radiation and first order chemical reaction. The Rosseland diffusion flux approximation is employed to simulate radiative heat transfer contribution.

In natural process and industrial applications many transport processes exist where transfer of heat and mass takes place simultaneously as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. The process of heat and mass transfer is encountered in fluid fuel nuclear reactor, chemical process industries and many engineering applications in which fluid is considered to be the working medium. Chamkha (2003) investigated the chemical reaction effects on heat and mass transfer laminar boundary layer flow in the presence of heat generation/absorption effects. Ahmed and Kalita (2013) analyzed the effects of chemical reaction as well as magnetic field on the heat and mass transfer of Newtonian fluids over an infinite vertical oscillating plate with variable mass diffusion. Makinde (2005) used a superposition technique and a Rosseland diffusion flux model to study the natural convection heat and mass transfer in a gray, absorbing-emitting fluid along a porous vertical translating plate. Loganathan *et al.* (2008) investigated first order chemical reaction on flow past an impulsively started semi-infinite vertical plate in the presence of thermal radiation by an implicit finite-difference scheme of the Crank-Nicolson type. Bég *et al.* (2003) presented a non-Darcy model for mixed convection flow of an optically dense viscous fluid along a vertical surface in a porous regime with the effects of thermal radiation. The combined effects of Joule heating and chemical reaction on unsteady magnetohydrodynamic mixed convection of a viscous dissipating fluid over a vertical plate in porous media with thermal radiation was analyzed by Pal and Talukdar (2011).

In this investigation, the effects of viscous dissipative heat, conduction-radiation and chemical reaction on unsteady hydromagnetic free convection flow past an impulsively-started semi-infinite vertical plate in a porous medium is studied. The dimensionless governing equations are solved by an efficient, accurate, extensively validated and unconditionally

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stable finite difference scheme of the *Crank-Nicolson* type. The study finds applications in high-temperature materials processing.

10.2 Mathematical Analysis :

Viscous dissipative heat on transient convective hydromagnetic flow of a viscous incompressible fluid through a porous medium bounded by an impulsively-started semi-infinite vertical plate taking into account of first order chemical reaction and conduction-radiation has been considered and shown in Fig. 10.1. It is assumed that a first-order chemical reaction between the diffusing species and the fluid exists. Magnetic Reynolds number is small enough to neglect induced hydro magnetic effects.

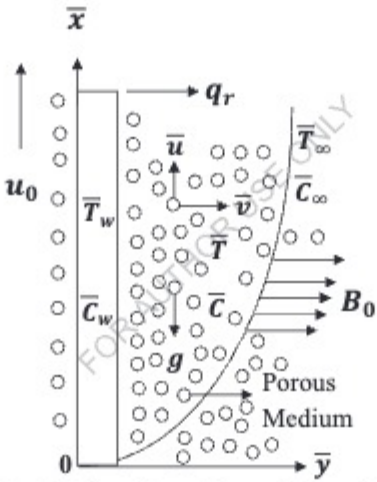

Fig. 10.1: Physical configuration and coordinate system

Here, the $\overline{x}$ - axis is taken along the plate in the vertically upward direction and the $\overline{y}$ -axis is taken normal to the plate. Initially, it is assumed that the plate and the fluid are of the same temperature. The temperature of the plate and the concentration level are also raised to $\overline{T}_w = \overline{T}_\infty + ax^n$ and $\overline{C}_w = \overline{C}_\infty + bx^m$. They are maintained at the same level for all time $\overline{t} > 0$.

Then under the above assumptions, the governing boundary layer equations with usual Boussinesq's approximation are as follows:

Equation of Continuity:

$$\frac{\partial \overline{u}}{\partial \overline{x}} + \frac{\partial \overline{v}}{\partial \overline{y}} = 0 \tag{10.2.1}$$

Equation of Momentum:

$$\frac{\partial \overline{u}}{\partial \overline{t}} + \overline{u}\frac{\partial \overline{u}}{\partial \overline{x}} + \overline{v}\frac{\partial \overline{u}}{\partial \overline{y}} = \begin{Bmatrix} g\beta(\overline{T} - \overline{T}_\infty) + g\overline{\beta}(\overline{C} - \overline{C}_\infty) + \\ \nu\dfrac{\partial^2 \overline{u}}{\partial \overline{y}^2} - \left(\dfrac{\sigma B_0^2}{\rho} + \dfrac{\nu}{\overline{K}}\right)\overline{u} \end{Bmatrix} \tag{10.2.2}$$

Equation of Energy:

$$\frac{\partial \overline{T}}{\partial \overline{t}} + \overline{u}\frac{\partial \overline{T}}{\partial \overline{x}} + \overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} = \frac{1}{\rho C_P}\left(\kappa\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{\partial q_r}{\partial \overline{y}}\right) + \frac{\nu}{C_P}\left(\frac{\partial \overline{u}}{\partial \overline{y}}\right)^2 \tag{10.2.3}$$

Equation of mass diffusion:

$$\frac{\partial \overline{C}}{\partial \overline{t}} + \overline{u}\frac{\partial \overline{C}}{\partial \overline{x}} + \overline{v}\frac{\partial \overline{C}}{\partial \overline{y}} = D\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} - \overline{C}_r\overline{C} \tag{10.2.4}$$

The initial and boundary conditions are

$$\overline{t} \le 0 : \ \overline{u} = 0, \ \overline{v} = 0, \ \overline{T} = \overline{T}_\infty, \ \overline{C} = \overline{C}_\infty$$

$$\overline{t} > 0 : \overline{u} = u_0, \ \overline{v} = 0, \ \overline{T} = \overline{T}_\infty + a\overline{x}^n, \ \overline{C} = \overline{C}_\infty + b\overline{x}^m \text{ at } \overline{y} = 0$$

$$\overline{u} = 0, \ \overline{T} = \overline{T}_\infty, \ \overline{C} = \overline{C}_\infty \text{ at } \overline{x} = 0 \tag{10.2.5}$$

$$\overline{u} \to 0, \ \overline{T} \to \overline{T}_\infty, \ \overline{C} \to \overline{C}_\infty \text{ as } \overline{y} \to \infty$$

For the case of an optically thin gray gas, the local radiant absorption is expressed by

$$\frac{\partial q_r}{\partial \overline{y}} = -4\overline{a}\,\overline{\sigma}\left(\overline{T}_\infty^4 - \overline{T}^4\right) \tag{10.2.6}$$

We assume that the temperature differences within the flow are sufficiently small such that $\overline{T}^4$ may be expressed as a linear function of the temperature.

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This is accomplished by expanding $\overline{T}^4$ in a Taylor series about $\overline{T}_\infty$ and neglecting higher-order terms, thus

$$\overline{T}^4 \cong 4\overline{T}_\infty^3 \overline{T} - 3\overline{T}_\infty^4 \tag{10.2.7}$$

By using Eqs (10.2.6) and (10.2.7), Eq. (10.2.3) reduces to

$$\frac{\partial \overline{T}}{\partial \overline{t}} + \overline{u}\frac{\partial \overline{T}}{\partial \overline{x}} + \overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} = \left\{ \begin{array}{c} \dfrac{1}{\rho C_P}\left[\kappa \dfrac{\partial^2 \overline{T}}{\partial \overline{y}^2} - 16\overline{a}\sigma \overline{T}_\infty^3 (\overline{T} - \overline{T}_\infty)\right] \\ + \dfrac{\nu}{C_P}\left(\dfrac{\partial \overline{u}}{\partial \overline{y}}\right)^2 \end{array} \right\} \tag{10.2.8}$$

On introducing the following non-dimensional quantities:

$$\left\{ \begin{array}{l} x = \dfrac{u_0 \overline{x}}{\nu}\ ,\ y = \dfrac{u_0 \overline{y}}{\nu}\ ,\ u = \dfrac{\overline{u}}{u_0}\ ,\ v = \dfrac{\overline{v}}{u_0}\ ,\ t = \dfrac{\overline{t} u_0^2}{\nu}\ ,\ Sc = \dfrac{\nu}{D} \\ \theta = \dfrac{\overline{T} - \overline{T}_\infty}{\overline{T}_w - \overline{T}_\infty},\ \phi = \dfrac{\overline{C} - \overline{C}_\infty}{\overline{C}_w - \overline{C}_\infty},\ Gr = \dfrac{\nu g \overline{\beta}(\overline{T}_w - \overline{T}_\infty)}{u_0^3}, \\ Gr_m = \dfrac{\nu g \overline{\beta}(\overline{C}_w - \overline{C}_\infty)}{u_0^3}\ ,\ K = \dfrac{u_0^2 \overline{K}}{\nu^2}\ ,\ R_a = \dfrac{64\,\overline{a}\,\nu^2\,\overline{\sigma}\,\overline{T}_\infty^3}{\kappa u_0^2}, \\ M = \dfrac{\sigma B_0^2 \nu}{\rho u_0^2}\ , Pr = \dfrac{\rho \nu C_P}{\kappa}\ , C_r = \dfrac{\nu\,\overline{C}_r}{u_0^2}\ , Ec = \dfrac{u_0^2}{C_P(\overline{T}_w - \overline{T}_\infty)} \end{array} \right\} \tag{10.2.9}$$

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Equations (10.2.1) to (10.2.4) are reduced to the following non-dimensional form:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{10.2.10}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = Gr\theta + Gr_m\phi + \frac{\partial^2 u}{\partial y^2} - (M + K^{-1})u \tag{10.2.11}$$

$$\frac{\partial \theta}{\partial t} + u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta}{\partial y^2} - R_a\theta\right) + Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{10.2.12}$$

$$\frac{\partial \phi}{\partial t} + u\frac{\partial \phi}{\partial x} + v\frac{\partial \phi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - C_r\,\phi \tag{10.2.13}$$

The corresponding initial and boundary conditions in non-dimensional form are

$$\left.\begin{array}{c} t \le 0 : u = 0,\ v = 0,\ \theta = 0,\ \phi = 0 \\ t > 0 : u = 1,\ v = 0,\ \theta = x^n,\ \phi = x^m \quad \text{at } y = 0 \\ u = 0,\ \theta = 0,\ \phi = 0 \quad \text{at } x = 0 \\ u \to 0,\ \theta \to 0,\ \phi \to 0 \quad \text{as } y \to \infty \end{array}\right\} \quad (10.2.14)$$

The local skin friction (wall shear stress), local Nusselt number (surface heat transfer gradient) and the local Sherwood number (surface species transfer gradient) are given respectively by

$$\tau_x = -\mu\left(\frac{\partial \overline{u}}{\partial \overline{y}}\right)_{\overline{y}=0} = -\left(\frac{\partial u}{\partial y}\right)_{y=0} \quad (10.2.15)$$

$$Nu_x = -\frac{\overline{x}}{\overline{T}_w - \overline{T}_\infty}\left(\frac{\partial \overline{T}}{\partial \overline{y}}\right)_{\overline{y}=0} = -x\left(\frac{\partial \theta}{\partial y}\right)_{y=0} \quad (10.2.16)$$

$$Sh_x = -\frac{\overline{x}}{\overline{C}_w - \overline{C}_\infty}\left(\frac{\partial \overline{C}}{\partial \overline{y}}\right)_{\overline{y}=0} = -x\left(\frac{\partial \phi}{\partial y}\right)_{y=0} \quad (10.2.17)$$

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10.3. Numerical Techniques :

The set of differential Eqs (10.2.10) – (10.2.13) are coupled nonlinear partial differential equations and are solved by using the initial and boundary conditions (10.2.14). However, exact or approximate solutions are not possible for this set of equations. Therefore, we solve these equations by an implicit finite difference scheme of the Crank-Nicolson type for a numerical solution.

$$\frac{\left[u_{i,j}^{n+1} - u_{i-1,j}^{n+1} + u_{i,j}^{n} - u_{i-1,j}^{n} - u_{i-1,j-1}^{n+1} + u_{i,j-1}^{n} - u_{i-1,j-1}^{n}\right]}{4\Delta x} + \frac{\left[v_{i,j}^{n+1} - v_{i-1,j}^{n+1} + v_{i,j}^{n} - u_{i,j-1}^{n}\right]}{2\Delta y} = 0 \quad (10.3.18)$$

$$\left\{\begin{array}{l}\dfrac{\left[u_{i,j}^{n+1}-u_{i,j}^{n}\right]}{\Delta t}+u_{i,j}^{n}\dfrac{\left[u_{i,j}^{n+1}-u_{i-1,j}^{n+1}+u_{i,j}^{n}-u_{i-1,j}^{n}\right]}{2\Delta x}\\ \quad+v_{i,j}^{n}\dfrac{\left[u_{i,j+1}^{n+1}-u_{i,j-1}^{n+1}+u_{i,j+1}^{n}-u_{i,j-1}^{n}\right]}{4\Delta y}\end{array}\right\}$$

$$=\frac{Gr\left[\theta_{i,j}^{n+1}+\theta_{i,j}^{n}\right]}{2}+\frac{Gr_{m}\left[\phi_{i,j}^{n+1}+\phi_{i,j}^{n}\right]}{2}$$

$$+\frac{1}{2(\Delta y)^{2}}\left[u_{i,j-1}^{n+1}-2u_{i,j}^{n+1}+u_{i,j+1}^{n+1}\right.$$

$$\left.+u_{i,j-1}^{n}-2u_{i,j}^{n}+u_{i,j+1}^{n}\right]-\frac{\left[u_{i,j}^{n+1}+u_{i,j}^{n}\right]}{2}(M+K^{-1}) \qquad (10.3.19)$$

$$\left\{\begin{array}{l}\dfrac{\left[\theta_{i,j}^{n+1}-\theta_{i,j}^{n}\right]}{\Delta t}+u_{i,j}^{n}\dfrac{\left[\theta_{i,j}^{n+1}-\theta_{i-1,j}^{n+1}+\theta_{i,j}^{n}-\theta_{i-1,j}^{n}\right]}{2\Delta x}\\ \quad+v_{i,j}^{n}\dfrac{\left[\theta_{i,j+1}^{n+1}-\theta_{i,j-1}^{n+1}+\theta_{i,j+1}^{n}-\theta_{i,j-1}^{n}\right]}{4\Delta y}\end{array}\right\}$$

$$=\frac{\left[\theta_{i,j-1}^{n+1}-2\theta_{i,j}^{n+1}+\theta_{i,j+1}^{n+1}+\theta_{i,j-1}^{n}-2\theta_{i,j}^{n}+\theta_{i,j+1}^{n}\right]}{2\,Pr\,(\Delta y)^{2}}$$

$$-\frac{R_{a}\left[\theta_{i,j}^{n+1}+\theta_{i,j}^{n}\right]}{2\,Pr}+Ec\left|\frac{u_{i,j+1}^{n}-u_{i,j}^{n}}{\Delta y}\right|^{2} \qquad (10.3.20)$$

$$\frac{\left[\phi_{i,j}^{n+1}-\phi_{i,j}^{n}\right]}{\Delta t}+u_{i,j}^{n}\frac{\left[\phi_{i,j}^{n+1}-\phi_{i-1,j}^{n+1}+\phi_{i,j}^{n}-\phi_{i-1,j}^{n}\right]}{2\Delta x}$$

$$+v_{i,j}^{n}\frac{\left[\phi_{i,j+1}^{n+1}-\phi_{i,j-1}^{n+1}+\phi_{i,j+1}^{n}-\phi_{i,j-1}^{n}\right]}{4\Delta y}$$

$$=\frac{\left[\phi_{i,j-1}^{n+1}-2\phi_{i,j}^{n+1}+\phi_{i,j+1}^{n+1}+\phi_{i,j-1}^{n}-2\phi_{i,j}^{n}+\phi_{i,j+1}^{n}\right]}{2\,Sc\,(\Delta y)^{2}}$$

$$-\frac{C_{r}\left[\phi_{i,j}^{n+1}+\phi_{i,j}^{n}\right]}{2\,Sc} \qquad (10.3.21)$$

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The region of integration is considered as a rectangle with sides $x_{max}(=1)$ and $y_{max}(=10)$, where y_{max} corresponds to $y = \infty$ which lies very well outside both the momentum and energy boundary layers. The maximum of y was chosen as 10 after some preliminary investigations so that the last two of the boundary conditions (10.2.14) are satisfied with in the tolerance limit 10^{-5}. After experimenting with a few set of mesh sizes, the mesh sizes have been fixed at the level $\Delta x = 0.02,\ \Delta y = 0.20$ with time step $\Delta t = 0.02$. In this case, the spatial mesh sizes are reduced by 50% in one direction, and later in both directions, the results are compared. It is observed that, when the mesh size is reduced by 50% in the $y-$direction, the results differ in the fifth decimal place while the mesh sizes are reduced by 50% in $x-$direction or in both directions; the results are comparable to three decimal places.

Hence, the above mesh sizes have been considered as appropriate for calculation. The coefficients $u_{i,j}^n$ and $v_{i,j}^n$ appearing in the finite-difference equations are treated as constants in any one time step. Here $i-$designates the grid point along the $x-$direction, j along the $y-$direction. The values of u, v and θ are known at all grid points at $t = 0$ from the initial conditions.

The computations of u, v, θ and ϕ at time level $(n+1)$ using the values at previous time level (n) are carried out as follows: The finite difference Eq. (10.3.21) at every internal nodal point on a particular $i-$level constitutes a tridiagonal system of equations. Such systems of equations are solved by using Thomas algorithm as discussed in Carnahan *et al.* (2008). Thus, the values of ϕ are found at every nodal point for a particular i at $(n+1)$th time level. Similarly, the values of θ are calculated from Eq. (10.3.20). Using the values of ϕ and θ at $(n+1)$th time level in the Eq. (10.3.19), the values of u at $(n+1)$th time level are found in a similar manner. Thus, the values of ϕ, θ and u are known on a particular $i-$level. Finally, the values of v are calculated explicitly using the Eq. (10.3.18) at every nodal point on a particular $i-$level at $(n+1)$th time level. This process is repeated for various $i-$level. Thus the values of ϕ, θ , u and v are known, at all grid points in the rectangular region at $(n+1)$th time level.

In a similar manner, computations are carried out by moving along the i −direction. After computing values corresponding to each i at a time level, the values at the next time level are determined in a similar manner. Computations are repeated until the steady-state is reached. The steady state solution is assumed to have been reached, when the absolute difference between the values of u, as well as temperature θ and concentration ϕ at two consecutive time steps are less than 10^{-5} at all grid points.

10.4 Stability analysis :

The stability criterion of the finite difference scheme for constant mesh sizes is examined using Von-Neumann technique as explained by Carnahan *et al.* (2008). The general term of the *Fourier expansion* for u, θ and ϕ at a time arbitrarily called $t = 0$, is assumed to be of the form $exp(i\alpha x)\ exp(i\beta y)$ (here $i = \sqrt{-1}$). At a later time t, these terms will become,

$$\left.\begin{array}{l} u = F(t) exp(i\alpha x)\ \exp(i\beta y) \\ \theta = G(t) exp(i\alpha x)\ exp(i\beta y) \\ \phi = H(t) exp(i\alpha x)\ exp(i\beta y) \end{array}\right\} \qquad (10.4.22)$$

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Substituting Eq. (10.4.22) in Eqs (10.3.19) – (10.3.21) under the assumption that the coefficients u, θ and ϕ are constants over any one time step and denoting the values after one time step by F', G' *and* H'. After simplification, we get

$$\frac{F'-F}{\Delta t} + \frac{u(F'-F)[1-exp(-i\alpha\Delta x)]}{2\,\Delta x} + \frac{v(F'+F)\,i\sin(\beta\Delta y)}{2\,\Delta y}$$

$$= \frac{(G'+G)Gr + (H'+H)Gr_m}{2}$$

$$+ (F'+F)\left[\frac{\{\cos(\beta\Delta y)-1\}}{(\Delta y)^2} - \frac{(M+K^{-1})}{2}\right] \qquad (10.4.23)$$

$$\frac{G'-G}{\Delta t}+\frac{u(G'-G)[1-exp(-i\alpha\Delta x)]}{2\,\Delta x}+\frac{v(G'+G)\,i\sin(\beta\Delta y)}{2\,\Delta y}$$

$$=\frac{(G'+G)\,[\cos(\beta\Delta y)-1]}{\mathrm{Pr}(\Delta y)^2}-\frac{R_a\,(G'+G)}{2\,Pr}$$

$$+Ec\left|\frac{u^n_{i,j+1}-u^n_{i,j}}{\Delta y}\right|\frac{F[\exp(i\beta\Delta y)-1]}{\Delta y} \qquad (10.4.24)$$

$$\frac{H'-H}{\Delta t}+\frac{u(H'-H)[1-exp(-i\alpha\Delta x)]}{2\,\Delta x}+\frac{v(H'+H)\,i\sin(\beta\Delta y)}{2\,\Delta y}$$

$$=\frac{(H'+H)\,[\cos(\beta\Delta y)-1]}{Sc\,(\Delta y)^2}-\frac{C_r\,(H'+H)}{2} \qquad (10.4.25)$$

Equations (10.4.23) – (10.4.25) can be rewritten as,

$$(1+A)F'=(1-A)F+\frac{\Delta t}{2}[Gr(G'+G)+Gr_m(H'+H)] \qquad (10.4.26)$$

$$(1+B)G'=(1-B)G\ +CF \qquad (10.4.27)$$

$$(1+E)H'=(1-E)H \qquad (10.4.28)$$

where

$$A=\left\{\begin{matrix}\frac{u}{2}\frac{\Delta t}{\Delta x}[1-\exp(-i\alpha\Delta x)]+\frac{v}{2}\frac{\Delta t}{\Delta y}i\sin(\beta\Delta y)\\ -[\cos(\beta\Delta y)-1]\frac{\Delta t}{(\Delta y)^2}+\frac{(M+K^{-1})\Delta t}{2}\end{matrix}\right\}$$

$$B=\left\{\begin{matrix}\frac{u}{2}\frac{\Delta t}{\Delta x}[1-\exp(-i\alpha\Delta x)]+\frac{v}{2}\frac{\Delta t}{\Delta y}i\sin(\beta\Delta y)\\ -[\cos(\beta\Delta y)-1]\frac{\Delta t}{Pr\,(\Delta y)^2}+\frac{R_a\Delta t}{2Pr}\end{matrix}\right\}$$

$$E=\left\{\begin{matrix}\frac{u}{2}\frac{\Delta t}{\Delta x}[1-\exp(-i\alpha\Delta x)]+\frac{v}{2}\frac{\Delta t}{\Delta y}i\sin(\beta\Delta y)\\ -[\cos(\beta\Delta y)-1]\frac{\Delta t}{Sc\,(\Delta y)^2}+\frac{C_r\Delta t}{2Sc}\end{matrix}\right\}$$

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$$C = Ec\left|\frac{u^n_{i,j+1} - u^n_{i,j}}{\Delta y}\right|\frac{\Delta t}{\Delta y}[\exp(i\beta\Delta y) - 1]\,.$$

After eliminating G' and H' in Eq. (10.4.26) using Eqs (10.4.27) and (10.4.28), the resultant equation is given by,

$$(1+A)F' = \left(1 - A + \frac{C}{1+B}\right)F + \frac{Gr\Delta t}{(1+B)}G + \frac{Gr_m\Delta t}{(1+E)}H \quad (10.4.29)$$

Eqs (10.4.27) – (10.4.29) can be written in matrix form as follows:

$$\begin{pmatrix} F' \\ G' \\ H' \end{pmatrix} = \begin{pmatrix} D_1 & D_2 & D_3 \\ C & \dfrac{1-B}{1+B} & 0 \\ 0 & 0 & \dfrac{1-E}{1+E} \end{pmatrix}\begin{pmatrix} F \\ G \\ H \end{pmatrix}, \quad (10.4.30)$$

where

$$D_1 = \frac{1-A}{1+A} + \frac{C}{(1+A)(1+B)},$$

$$D_2 = \frac{Gr\,\Delta t}{(1+A)(1+B)} \text{ and } D_3 = \frac{Gr_m\,\Delta t}{(1+A)(1+E)}$$

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Now, for stability of the finite difference scheme, the modulus of each *Eigen* value of the amplification matrix does not exceed unity. Since the matrix Equation (10.4.30) is triangular, the *Eigen* values are its diagonal elements. The *Eigen* values of the amplification matrix are $(1-A)/(1+A)$, $(1-B)/(1+B)$ and $(1-E)/(1+E)$.

Assuming that, u is everywhere non-negative and v is everywhere non-positive, we get

$$A = 2a_1\,sin^2\left(\frac{\alpha\Delta x}{2}\right) + 2c_1\,sin^2\left(\frac{\beta\Delta y}{2}\right) + i\,[a_1\sin(\alpha\Delta x) - b_1\sin(\beta\Delta y)] + \frac{(M + K^{-1})\Delta t}{2}$$

where

$$a_1 = \frac{u}{2}\frac{\Delta t}{\Delta x},\quad b_1 = \frac{v}{2}\frac{\Delta t}{\Delta y},\quad c_1 = \frac{\Delta t}{(\Delta y)^2}$$

Since the real part of A is greater than or equal to zero, $|(1-A)/(1+A)| \leq 1$ always. Similarly, $|(1-B)/(1+B)| \leq 1$ and $|(1-E)/(1+E)| \leq 1$. Hence, the finite difference scheme is unconditionally stable. The local truncation error is $O(\Delta t^2 + \Delta y^2 + \Delta x)$ and it tends to zero as Δt , Δx and Δy tend to zero. Hence, the scheme is compatible. Stability and compatibility ensures convergence.

10.5 Accuracy :

Table –1: Comparison of values of the flow velocity (u) for chemical reaction (C_r) with those obtained by Loganathan *et al.* (2008) at $R_a = 0.2, Sc = 0.60, m = n = 1, t = 0.25$ and $Pr = 0.71$:

	Loganathan *et al.* (2008)			**Present work**		
	C_r			C_r		
y	2.0	4.0	6.0	2.0	4.0	6.0
0.0	1	1	1	1	1	1
2.0	2.415201	1.327120	1.279035	2.415762	1.327251	1.279152
4.0	0.723107	0.637083	0.580531	0.723210	0.637130	0.580605
6.0	0.057653	0.042308	0.037402	0.057682	0.042375	0.037473
8.0	0.016208	0.015303	0.010420	0.016267	0.015408	0.010434
10.0	0.003571	0.003475	0.001252	0.003617	0.003499	0.001275

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Table – 2: Comparison of values of the flow velocity (u) for porosity (K) with those obtained by Ahmed *et al.* (2014) at $R_a = 1.5, C_r = 2, Sc = 0.60, m = n = 0.2, t = 1.5, M = 2$ and $Pr = 0.71$:

	Ahmed *et al.* (2014)			**Present work**		
	K			K		
y	0.0	5.0	10.0	0.0	5.0	10.0
0.0	1	1	1	1	1	1
2.0	3.248351	3.514718	3.859281	3.248412	3.514752	3.859291
4.0	0.718014	0.835205	1.073710	0.718130	0.835249	1.073752
6.0	0.105520	0.109153	0.182382	0.105615	0.109153	0.182410
8.0	0.053172	0.053210	0.053410	0.053231	0.053237	0.053473
10.0	0.015371	0.015812	0.030520	0.015388	0.015851	0.030620

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In order to ascertain the accuracy of the numerical results, the results for the present study are compared with the available exact solution in the literature. It is clearly observed from the Table – 1 and Table – 2 that the present results are in good agreement with the available theoretical solution at lower time level. This favorable comparison lends confidence in the numerical results reported subsequently.

The analysis showed that in Table – 1 increasing the chemical reaction effects decelerated the flow velocity. In Table – 2 it is seen that increasing porosity serves to accelerate the flow velocity.

10.6 Results and Discussion :

Selected computations have been depicted graphically in all the Figures. All parametric values corresponding to each figure are included therein. It should be noted that $Gm = Gr = 5$ imply strong species and thermal buoyancy forces; $Sc = 0.60$ approximately simulates lower molecular weight gases diffusing in air, $Pr = 0.71$ which represents air unless otherwise stated.

The velocity (u) and temperature (θ) distribution profiles with the variation of Eckert number (Ec) and time (t) have been shown in **Figs. 10.2(a)** and **10.2(b)**, respectively. It is seen from Figs. 10.2(a) and 10.2(b) that the fluid velocity and temperature increases with an increase in Eckert number Ec. The Eckert number is the ratio of the kinetic energy of the flow to the boundary layer enthalpy difference. The effect of viscous dissipation on the flow field is to increase the energy, yielding a greater fluid temperature and as a consequence greater buoyancy force. The increase in the buoyancy force due to an increase in the dissipation parameter enhances both the fluid velocity and temperature in the boundary layer. The velocity near the wall rises rapidly and descends gradually to zero as its distance from the plate increases. Moreover, it is seen that the fluid velocity of air accelerates in the upward direction with increasing time in the case of cooling of the surface. This is due to the increasing buoyancy effects in the vertical direction as time progresses. It is observed that the fluid temperature increases as time increases.

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Fig. 10.3 shows that the fluid velocity (u) increases with an increase in Grashof number (Gr). Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force. As expected, it is observed that there is a rise in the fluid velocity due to the enhancement of thermal buoyancy force. It is due to the fact that an increase of Grashof number has a tendency to increase the thermal effect. This gives rise to an increase in the induced flow. However, the fluid velocity (u) decreases with an increase in magnetic body force (M) for air ($Pr = 0.71$) in the cases of cooling of the surface. This is because the application of a transverse magnetic field will result in a resistive type of force (Lorentz force) similar to drag force, which tends to resist the flow, thus reducing its velocity.

Therefore, an increase in M leads to a decrease in the momentum boundary layer thickness for air.

The temperature profiles are plotted in **Fig. 10.4** for different values of R_a and Pr. It is observed that an increase in the radiation parameter decreases the temperature for both air (Pr = 0.71) and water (Pr = 7). Therefore, increases in the value of R_a lead to a decrease in the thermal boundary layer thicknesses. The reason for this is that radiation provides an additional means to diffuse energy. An increase in the Prandtl number results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of Pr are equivalent to increase in the thermal conductivity of the fluid and therefore, heat is able to diffuse away from the heated surface more rapidly for higher values of Pr. Hence in the case of smaller Prandtl number as the thermal boundary later is thicker and the rate of heat transfer is reduced.

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The concentration profiles for different values of C_r and Sc are illustrated in **Fig. 10.5**. It is observed that the concentration decreases with an increase in C_r for both hydrogen (Sc = 0.22) and water vapor (Sc = 0.6). Therefore, an increase in the value of C_r from 0 to 3 and 5 leads to a decrease in the concentration boundary layer thicknesses. It should be mentioned that the studied case is for a destructive chemical reaction C_r. As Sc increases the concentration decreases. The cause is that concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reduction in the velocity and concentration profiles is accompanied by simultaneous reductions in velocity and concentration boundary layer.

In **Fig. 10.6**, the effects of viscous dissipative heat (Ec) and magnetic body force (M) on skin-friction distribution (τ) at the plate $y = 0$ is presented. We observe from this figure that greater viscous dissipative heat causes a rise in the skin-friction of air (Pr = 0.71) but there is a reduction in the skin-friction owing to an increase in the magnetic body force (M). The skin-friction increases with increasing time t, but at large values of time t, it is more significantly affected. However, we observe that, as compared to Ec = 0, the skin-friction is greater when viscous dissipative heat is present for least magnetic body force (M = 2.0). The converse response is seen for M,

wherein a decrease in skin-friction is induced by increasing the magnetic parameter, M from 2.0 through 4.0 to 6.0. Therefore greater retarding effect is generated in the flow with greater M values (i.e. stronger magnetic field strengths) which causes the prominent depression in skin-friction.

Fig. 10.7 depicts the rate of heat transfer (Nusselt number, Nu) against time t for different values of Eckert number and magnetic body force. The Nusselt number is observed to decrease owing to greater viscous dissipative heat. The Nusselt number is found to sharp decrease with time, but maximum values of Nu are attained near the plat when $t = 0.2$ and gradually diminishing by increasing time t when $t \geq 0.2$. A similar response is computed for the effect of magnetic parameter, M, on the Nusselt number function $(-\theta')$ distributions in same figure. Increasing magnetic field enhances the *Lorentzian hydromagnetic drag* which serves to decelerate the flow and warm the fluid. Therefore, heat will be transferred at progressively lower rates from the fluid to the surface.

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Finally the response of surface mass transfer rate i.e. Sherwood number function $(Sh = -\phi')$ to a change in viscous dissipative heat (Ec) and magnetic parameter (M) has been presented in **Fig. 10.8**. As with the Sherwood number distributions, $(-\phi')$ is found to be strongly enhanced with increasing viscous dissipative heat for ammonia gas ($Sc = 0.78$), but reduced with an increase in magnetic parameter. Again, maximum numerical values of mass transfer rates arise at the surface of the wall for smaller time and decrease continuously towards zero for $t > 0.2$. On the other hand, it is observed that the Sherwood number decreases as time increases.

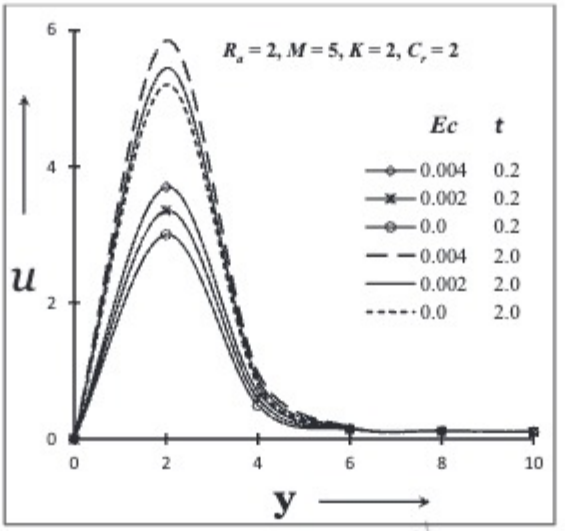

Fig. 10.2(a): Velocity distribution for Eckert number and time

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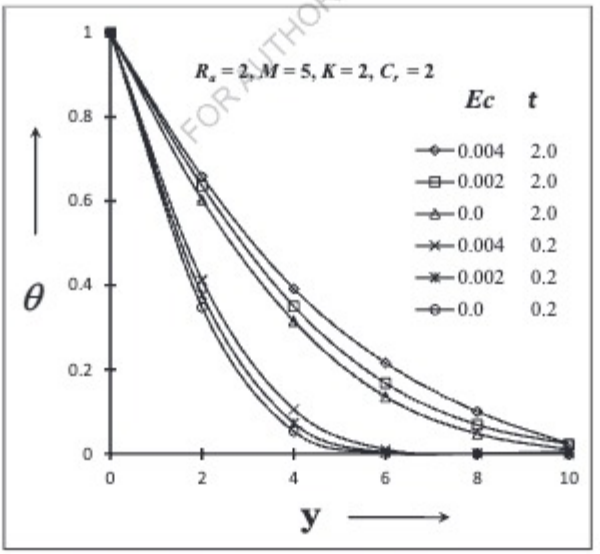

Fig. 10.2(b): Temperature distribution for Eckert number and time

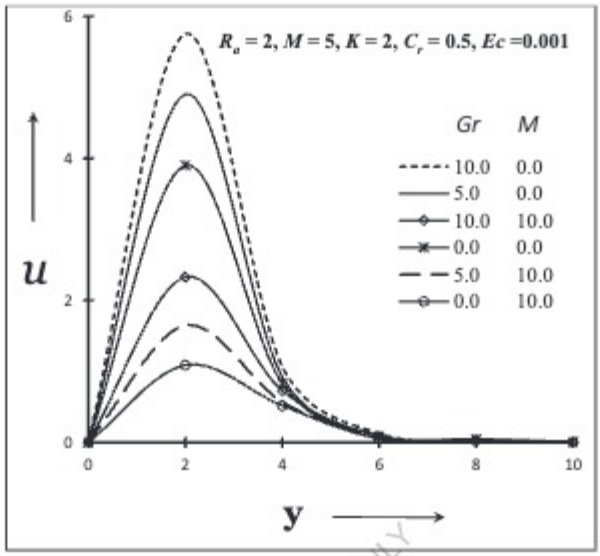

Fig.10.3: Velocity distribution for *Gr* and *M*

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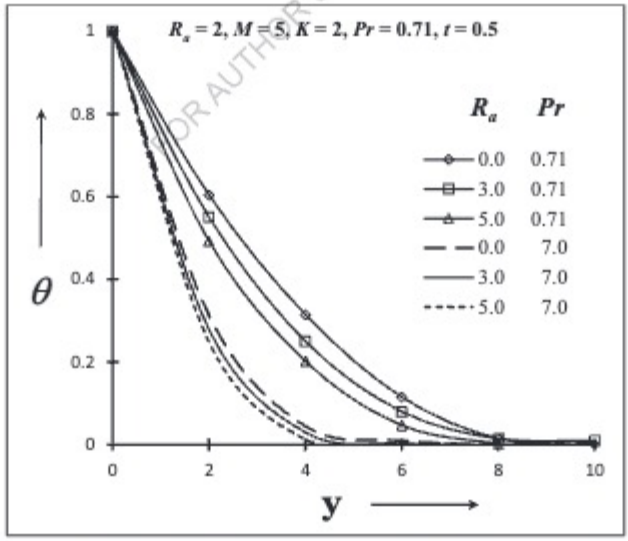

Fig. 10.4: Temperature distribution for Radiation and Prandtl number

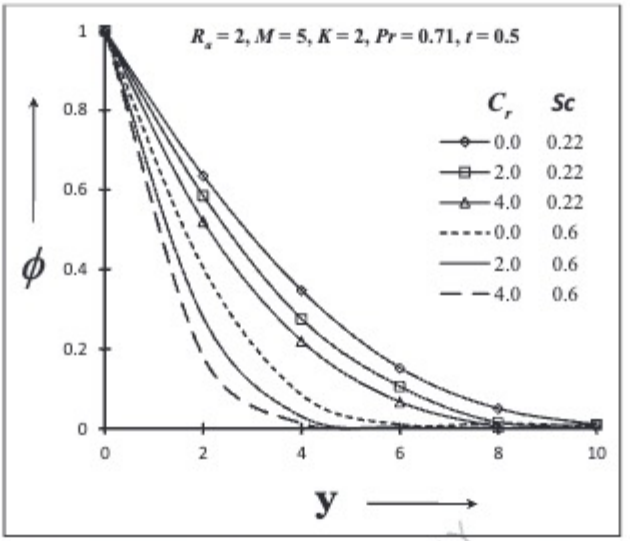

Fig. 10.5: Concentration distribution for Chemical reaction and Schmidt number

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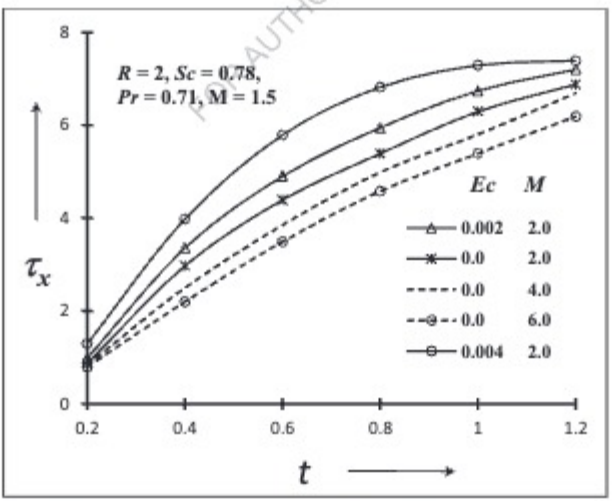

Fig. 10.6: Skin friction distribution for Eckert number and magnetic number against time

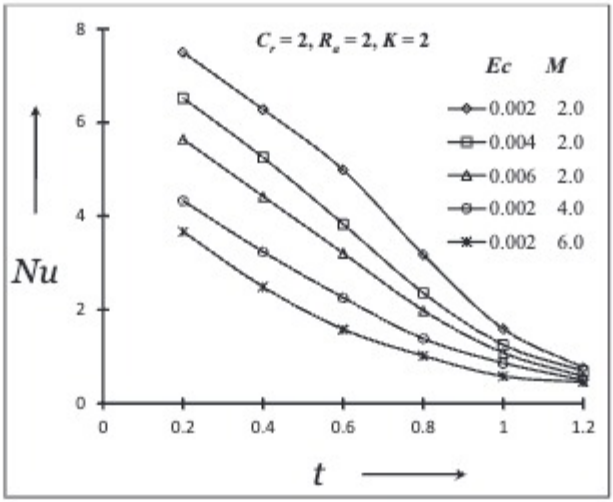

Fig. 10.7: Rate of heat transfer for Eckert number and magnetic number against time

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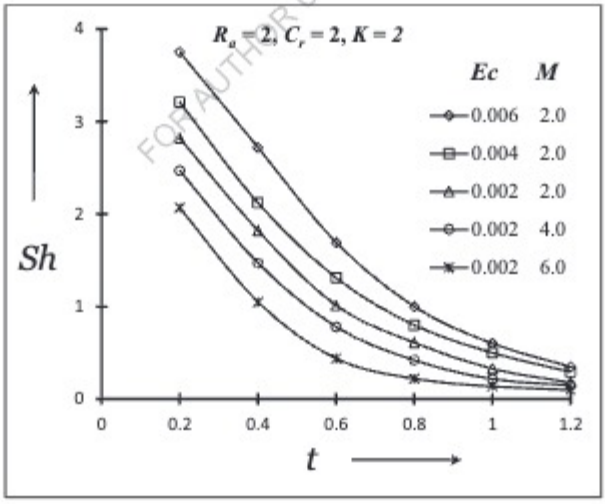

Fig. 10.8: Rate of mass transfer for Eckert number and magnetic number against time

10.7 Conclusions :

A mathematical model has been presented for the unsteady dissipative MHD convective flow past an impulsively started plane in a porous medium with Newtonian heating in the presence of thermal radiation and homogeneous chemical reaction of first order. The governing boundary layer equations have been transformed into non-dimensional forms and solved by an efficient, accurate, and extensively validated and unconditionally stable *finite-difference scheme* of the *Crank-Nicolson* type. A flux model was employed to simulate thermal radiation effects. Few outputs are summarized as:

- Increasing viscous dissipative heat serves to accelerate the flow velocity as well as flow temperature values;
- Increasing radiation enhanced the flow temperature for both air and water;
- Increasing the viscous dissipative heat boosted the wall shear stress as well as rate of mass transfer, but significantly depressed the rate of heat transfer at the wall;
- Increasing the magnetic parameter effectively reduced the shear stress as well as the Nusselt and Sherwood numbers at the wall;
- It has been shown that increasing magnetic field generally decelerates the flow, but velocity overshoot has observed for the higher free convection parameter (Gr) in the regime.

It is hoped that the present results be used as a vehicle for understanding more complex problems dealing with viscoelastic and power-law rheological fluid models.

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APPENDIX

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Chapter – II

$$\xi = \frac{Pr + \sqrt{Pr^2 + 4i\omega Pr}}{2}, \quad \eta_1 = \frac{Sc + \sqrt{Sc^2 + 4ScCr}}{2},$$

$$\eta_2 = \frac{Sc + \sqrt{Sc^2 + 4(i\omega + Cr)Sc}}{2}, \quad \lambda_1 = \frac{1 + \sqrt{1 + 4(2iR + K_0^{-1} + M^2)}}{2}$$

$$\lambda_2 = \frac{1 + \sqrt{1 + 4\left(K_0^{-1} + M^2 + i(\omega + 2R)\right)}}{2},$$

$$L_1 = \frac{Gr}{Pr^2 - Pr - (2iR + K_0^{-1} + M^2)}$$

$$L_2 = \frac{Gm}{\eta_1^2 - \eta_1 - (2iR + K_0^{-1} + M^2)}, \quad L_3 = L_1 + L_2,$$

$$L_4 = \frac{Gr}{\xi^2 - \xi - \left(\frac{1}{K_0} + M^2 + i(\omega + 2R)\right)}$$

$$L_5 = \frac{Gm}{\eta_2^2 - \eta_2 - \left(\frac{1}{K_0} + M^2 + i(\omega + 2R)\right)}, \quad L_6 = L_4 + L_5$$

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Chapter – III

$$\xi_1 = \frac{1+\sqrt{1+4n}}{2}, \quad \xi_2 = \frac{1+\sqrt{1+4(N+n)}}{2}$$

$$m_1 = \frac{Pr+\sqrt{Pr^2+4Pr\phi}}{2}, m_2 = \frac{Pr+\sqrt{Pr^2+4\Pr(\phi+n)}}{2},$$

$$\lambda_1 = \frac{Sc+\sqrt{Sc^2+4ScCr}}{2}, \lambda_2 = \frac{Sc+\sqrt{Sc^2+4nSc}}{2}$$

$$C_3 = U_p - 1 - B_2 - B_3, \quad B_2 = \frac{G_r}{-m_1^2+m_1+N}, \quad B_3 = \frac{G_c}{-\lambda_1^2+\lambda_1+N},$$

$$B = \frac{ASc\lambda_1}{\lambda_1^2 - Sc\lambda_1 - nSc}, B_1 = \frac{APrm_1}{m_1^2 - Prm_1 - \Pr(\phi+n)},$$

$$C_4 = -(1+B_4+B_5+B_6+B_7+B_8), \quad B_4 = \frac{A\xi_1 C_3}{\xi_1^2 - \xi_1 - (N+n)},$$

$$B_5 = \frac{AB_2m_1 - G_rB_1}{m_1^2 - m_1 - (N+n)},$$

$$B_6 = \frac{AB_2\lambda_1 - G_cB}{\lambda_1^2 - \lambda_1 - (N+n)}, \qquad B_7 = \frac{G_r(1-B_1)}{-m_2^2+m_2+(N+n)},$$

$$B_8 = \frac{G_c(1-B)}{-\lambda_2^2+\lambda_2+(N+n)}.$$

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Chapter – IV

$$m_1 = \frac{Sc + \sqrt{Sc^2 + 4ScCr}}{2},\ m_2 = \frac{Pr + \sqrt{Pr^2 + 4R^2}}{2},$$

$$m_3 = \frac{1 + \sqrt{1 + 4N}}{2},$$

$$m_4 = \frac{Sc + \sqrt{Sc^2 + 4Sc(n + Cr)}}{2},\ m_5 = \frac{Pr + \sqrt{Pr^2 + 4N_1}}{2},$$

$$m_6 = \frac{1 + \sqrt{1 + 4(N + n)}}{2},\ P_1 = \frac{-Gr}{m_2^2 - m_2 - N},\ P_2 = \frac{-Gm}{m_1^2 - m_1 - N},$$

$$P_1 = \frac{-Gr}{m_2^2 - m_2 - N},\ P_2 = \frac{-Gm}{m_1^2 - m_1 - N},\ P_3 = U_p - 1 - P_1 - P_2$$

$$J_1 = \frac{-GrS_7}{m_2^2 - m_2 - N},\ J_2 = \frac{-GrS_1}{4m_3^2 - 2m_3 - N},\ J_3 = \frac{-GrS_2}{4m_2^2 - 2m_2 - N}$$

$$J_4 = \frac{-GrS_3}{4m_1^2 - 2m_1 - N},\ J_5 = \frac{-GrS_4}{(m_2 + m_3)^2 - (m_2 + m_3) - N}$$

$$J_6 = \frac{-GrS_5}{(m_1 + m_2)^2 - (m_1 + m_2) - N},$$

$$J_7 = \frac{-GrS_6}{(m_1 + m_3)^2 - (m_1 + m_3) - N}$$

$$J_8 = -(J_1 + J_2 + J_3 + J_4 + J_5 + J_6 + J_7)$$

$$G_1 = \frac{-GrD_2}{m_5^2 - m_5 - (N + n)},\ G_2 = \frac{Am_2P_1 - GrD_1}{m_2^2 - m_2 - (N + n)},$$

$$G_3 = \frac{-GmZ_2}{m_4^2 - m_4 - (N + n)}$$

$$G_4 = \frac{Am_1P_2 - GmZ_1}{m_1^2 - m_1 - (N + n)},\ G_5 = \frac{Am_3P_3}{m_3^2 - m_3 - (N + n)},$$

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$$G_6 = -(1 + G_1 + G_2 + G_3 + G_4 + G_5),$$

$$L_1 = \frac{-GrR_{17}}{m_5^2 - m_5 - (N+n)}, L_2 = \frac{Am_2J_1 - GrR_1}{m_2^2 - m_2 - (N+n)},$$

$$L_3 = \frac{2Am_3J_2 - GrR_2}{4m_3^2 - 2m_3 - (N+n)},$$

$$L_4 = \frac{2Am_2J_3 - GrR_3}{4m_2^2 - 2m_2 - (N+n)}, \quad L_5 = \frac{2Am_1J_4 - GrR_4}{4m_1^2 - 2m_1 - (N+n)},$$

$$L_6 = \frac{A(m_2 + m_3)J_5 - GrR_5}{(m_2 + m_3)^2 - (m_2 + m_3) - (N+n)},$$

$$L_7 = \frac{A(m_1 + m_2)J_6 - GrR_6}{(m_1 + m_2)^2 - (m_1 + m_2) - (N+n)},$$

$$L_8 = \frac{A(m_1 + m_3)J_7 - GrR_7}{(m_1 + m_3)^2 - (m_1 + m_3) - (N+n)},$$

$$L_9 = \frac{-GrR_8}{(m_3 + m_6)^2 - (m_3 + m_6) - (N+n)},$$

$$L_{10} = \frac{-GrR_9}{(m_3 + m_5)^2 - (m_3 + m_5) - (N+n)},$$

$$L_{11} = \frac{-GrR_{10}}{(m_3 + m_4)^2 - (m_3 + m_4) - (N+n)},$$

$$L_{12} = \frac{-GrR_{11}}{(m_2 + m_6)^2 - (m_2 + m_6) - (N+n)},$$

$$L_{13} = \frac{-GrR_{12}}{(m_2 + m_5)^2 - (m_2 + m_5) - (N+n)},$$

$$L_{14} = \frac{-GrR_{13}}{(m_2 + m_4)^2 - (m_2 + m_4) - (N+n)},$$

$$L_{15} = \frac{-GrR_{14}}{(m_1 + m_6)^2 - (m_1 + m_6) - (N+n)},$$

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$$L_{16} = \frac{-GrR_{15}}{(m_1+m_5)^2-(m_1+m_5)-(N+n)},$$

$$L_{17} = \frac{-GrR_{16}}{(m_1+m_4)^2-(m_1+m_4)-(N+n)},$$

$$L_{18} = \frac{Am_3J_8}{m_3^2-m_3-(N+n)},$$

$$L_{19} = -\begin{pmatrix}1+L_1+L_2+L_3+L_4+L_5+L_6+L_7+L_8+L_9+L_{10}\\ +L_{11}+L_{12}+L_{13}+L_{14}\ +L_{15}+L_{16}+L_{17}+L_{18}\end{pmatrix},$$

$$S_1 = \frac{-Prm_3^2P_3^2}{4m_3^2-2Prm_3-R^2},\ S_2 = \frac{-Prm_2^2P_1^2}{4m_2^2-2Prm_2-R^2},$$

$$S_3 = \frac{-Prm_1^2P_2^2}{4m_1^2-2Prm_1-R^2},$$

$$S_4 = \frac{-2Prm_2m_3P_3P_1}{(m_2+m_3)^2-Pr(m_2+m_3)-R^2},$$

$$S_5 = \frac{-2Prm_1m_2P_1P_2}{(m_1+m_2)^2-Pr(m_1+m_2)-R^2},$$

$$S_6 = \frac{-2Prm_3m_1P_2P_3}{(m_1+m_3)^2-Pr(m_1+m_3)-R^2},$$

$$S_7 = -(S_1+S_2+S_3+S_4+S_5+S_6)$$

$$D_1 = \frac{PrAm_2}{m_2^2-Prm_2-N_1},\ D_2 = 1-D_1,\ R_1 = \frac{PrAm_2S_7}{m_2^2-Prm_2-N_1},$$

$$R_2 = \frac{2PrAm_3S_1-2Prm_3^2G_5P_3}{4m_3^2-2Prm_3-N_1},\ R_3 = \frac{2PrAm_2S_2-2Prm_2^2G_2P_1}{4m_2^2-2Prm_2-N_1},$$

$$R_4 = \frac{2PrAm_1S_3-2Prm_1^2G_4P_2}{4m_1^2-2Prm_1-N_1},$$

$$R_5 = \frac{PrA(m_2+m_3)S_4-2Prm_2m_3(G_2P_3+G_5P_1)}{(m_2+m_3)^2-Pr(m_2+m_3)-N_1},$$

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$$R_6 = \frac{PrA(m_1+m_2)S_5 - 2Prm_1m_2(G_4P_1+G_2P_2)}{(m_1+m_2)^2 - Pr(m_1+m_2) - N_1},$$

$$R_7 = \frac{PrA(m_1+m_3)S_6 - 2Prm_3m_1(G_4P_3+G_5P_2)}{(m_1+m_3)^2 - Pr(m_1+m_3) - N_1},$$

$$R_8 = \frac{2Prm_3m_6G_6P_3}{(m_3+m_6)^2 - Pr(m_3+m_6) - N_1},$$

$$R_9 = \frac{2Prm_3m_5G_1P_3}{(m_3+m_5)^2 - Pr(m_3+m_5) - N_1},$$

$$R_{10} = \frac{2Prm_3m_4G_3P_3}{(m_3+m_4)^2 - Pr(m_3+m_4) - N_1},$$

$$R_{11} = \frac{2Prm_2m_6G_6P_1}{(m_2+m_6)^2 - Pr(m_2+m_6) - N_1},$$

$$R_{12} = \frac{2Prm_2m_5G_1P_1}{(m_2+m_5)^2 - Pr(m_2+m_5) - N_1},$$

$$R_{13} = \frac{2Prm_2m_4G_3P_1}{(m_2+m_4)^2 - Pr(m_2+m_4) - N_1},$$

$$R_{14} = \frac{2Prm_1m_6G_6P_2}{(m_1+m_6)^2 - Pr(m_1+m_6) - N_1},$$

$$R_{15} = \frac{2Prm_1m_5G_1P_2}{(m_1+m_5)^2 - Pr(m_1+m_5) - N_1},$$

$$R_{16} = \frac{2Prm_1m_4G_3P_2}{(m_1+m_4)^2 - Pr(m_1+m_4) - N_1},$$

$$R_{17} = -\begin{pmatrix} R_1+R_2+R_3+R_4+R_5+R_6+R_7+R_8+R_9 \\ +R_{10}+R_{11}+R_{12}+R_{13}+R_{14}+R_{15} \end{pmatrix},$$

$$Z_1 = \frac{Am_1Sc}{m_1^2 - Sc\,m_1 - Sc(n+Cr)}, \quad Z_2 = 1 - Z_1.$$

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Chapter – V

$$J_1 = \frac{1}{2}\left[PrRe + \sqrt{Pr^2Re^2 - 4(ReA - PrReR_a)}\right],$$

$$J_2 = \frac{1}{2}\left[PrRe - \sqrt{Pr^2Re^2 - 4(ReA - PrReR_a)}\right],$$

$$J_3 = \frac{1}{2}\left[ScRe + \sqrt{Sc^2Re^2 + 4ScReK}\right],$$

$$J_4 = \frac{1}{2}\left[ScRe - \sqrt{Sc^2Re^2 + 4ScReK}\right],$$

$$J_5 = \frac{1}{2}\left[Re + \sqrt{Re^2 + 4ReM}\right], \; J_6 = \frac{1}{2}\left[Re - \sqrt{Re^2 + 4ReM}\right],$$

$$C_1 = \frac{m - e^{J_2}}{e^{J_1} - e^{J_2}}, C_2 = \frac{e^{J_1} - m}{e^{J_1} - e^{J_2}}, C_3 = \frac{n - e^{J_4}}{e^{J_3} - e^{J_4}}, C_4 = \frac{e^{J_3} - n}{e^{J_3} - e^{J_4}},$$

$$C_5 = \frac{N - L(hJ_6 - 1)e^{J_6}}{(hJ_5 - 1)e^{J_5} - (hJ_6 - 1)e^{J_6}}, C_6 = \frac{L(hJ_5 - 1)e^{J_5} - N}{(hJ_5 - 1)e^{J_5} - (hJ_6 - 1)e^{J_6}},$$

$$C_7 = \frac{-ReGrC_1}{J_1^2 - ReJ_1 - ReM}, C_8 = \frac{-ReGrC_2}{J_2^2 - ReJ_2 - ReM},$$

$$C_9 = \frac{-ReGmC_3}{J_3^2 - ReJ_3 - ReM},$$

$$C_{10} = \frac{-ReGmC_4}{J_4^2 - ReJ_4 - ReM}, \quad L = -(C_7 + C_8 + C_9 + C_{10}),$$

$$N = \left\{\begin{matrix} -1 + C_7(1 - hJ_1)e^{J_1} + C_8(1 - hJ_2)e^{J_2} + C_9(1 - hJ_3)e^{J_3} \\ +C_{10}(1 - hJ_4)e^{J_4}, \end{matrix}\right\}$$

$$\lambda_1 = \frac{1}{2}\left[Re + \sqrt{Re^2 + 4(\pi^2 + ReM)}\right],$$

$$\lambda_2 = \frac{1}{2}\left[Re - \sqrt{Re^2 + 4(\pi^2 + ReM)}\right],$$

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$$\lambda_3 = \frac{1}{2}\left[ScRe + \sqrt{Sc^2Re^2 + 4(\pi^2 + ScReK)}\right],$$

$$\lambda_4 = \frac{1}{2}\left[ScRe - \sqrt{Sc^2Re^2 + 4(\pi^2 + ScReK)}\right],$$

$$\lambda_5 = \frac{1}{2}\left[PrRe + \sqrt{Pr^2Re^2 - 4(ARe - \pi^2 - PrReR_a)}\right],$$

$$\lambda_6 = \frac{1}{2}\left[PrRe - \sqrt{Pr^2Re^2 - 4(ARe - \pi^2 - PrReR_a)}\right],$$

$$D = \begin{Bmatrix} (\pi - \lambda_1)(\pi + \lambda_2)\left(e^{\pi+\lambda_1} + e^{\lambda_2-\pi}\right) - (\pi + \lambda_1)(\pi - \lambda_2) \\ \left(e^{\pi+\lambda_2} + e^{\lambda_1-\pi}\right) - 2\pi(\lambda_2 - \lambda_1)\left(e^{\lambda_1+\lambda_2} + 1\right) \end{Bmatrix},$$

$$D_1 = -2\pi\lambda_2 + \pi(\pi + \lambda_2)e^{\lambda_2-\pi} - \pi(\pi - \lambda_2)e^{\lambda_2+\pi},$$

$$D_2 = 2\pi\lambda_1 - \pi(\pi + \lambda_1)e^{\lambda_1-\pi} - \pi(\lambda_1 - \pi)e^{\lambda_1+\pi},$$

$$D_3 = -\lambda_1(\lambda_2 + \pi)e^{\lambda_2-\pi} + \lambda_2(\lambda_1 + \pi)e^{\lambda_1-\pi} - \pi(\lambda_2 - \lambda_1)e^{\lambda_1+\lambda_2},$$

$$D_4 = \lambda_1(\lambda_2 - \pi)e^{\lambda_2+\pi} + \lambda_2(\pi - \lambda_1)e^{\pi+\lambda_1} + \pi(\lambda_1 - \lambda_2)e^{\lambda_1+\lambda_2},$$

$$D_5 = D_3(\pi Re + ReM), \quad D_6 = D_4(\pi Re - ReM),$$

$$D_7 = \frac{N_1 - L_1e^{\lambda_4}}{e^{\lambda_3} - e^{\lambda_4}}, \quad D_8 = \frac{L_1e^{\lambda_3} - N_1}{e^{\lambda_3} - e^{\lambda_4}},$$

$$D_9 = \frac{C_3J_3D_1}{(J_3 + \lambda_1)^2 - ScRe(J_3 + \lambda_1) - (\pi^2 + ScReK)},$$

$$D_{10} = \frac{C_3J_3D_2}{(J_3 + \lambda_2)^2 - ScRe(J_3 + \lambda_2) - (\pi^2 + ScReK)},$$

$$D_{11} = \frac{C_3J_3D_3}{(J_3 + \pi)^2 - ScRe(J_3 + \pi) - (\pi^2 + ScReK)},$$

$$D_{12} = \frac{C_3J_3D_4}{(J_3 - \pi)^2 - ScRe(J_3 - \pi) - (\pi^2 + ScReK)},$$

$$D_{13} = \frac{C_4J_4D_1}{(J_4 + \lambda_1)^2 - ScRe(J_4 + \lambda_1) - (\pi^2 + ScReK)},$$

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$$D_{14} = \frac{C_4 J_4 D_2}{(J_4+\lambda_2)^2 - ScRe(J_4+\lambda_2) - (\pi^2 + ScReK)},$$

$$D_{15} = \frac{C_4 J_4 D_3}{(J_4+\pi)^2 - ScRe(J_4+\pi) - (\pi^2 + ScReK)},$$

$$D_{16} = \frac{C_4 J_4 D_4}{(J_4-\pi)^2 - ScRe(J_4-\pi) - (\pi^2 + ScReK)},$$

$$L_1 = -\frac{ScRe}{D}(D_9 + D_{10} + D_{11} + D_{12} + D_{13} + D_{14} + D_{15} + D_{16}),$$

$$N_1 = -\frac{ScRe}{D}\begin{Bmatrix} D_9 e^{J_3+\lambda_1} + D_{10} e^{J_3+\lambda_2} + D_{11} e^{J_3+\pi} + D_{12} e^{J_3-\pi} \\ +D_{13} e^{J_4+\lambda_1} + D_{14} e^{J_4+\lambda_2} + D_{15} e^{J_4+\pi} + D_{16} e^{J_4-\pi} \end{Bmatrix},$$

$$D_{17} = \frac{N_2 - L_2 e^{\lambda_6}}{e^{\lambda_5} - e^{\lambda_6}}, \quad D_{18} = \frac{L_2 e^{\lambda_5} - N_2}{e^{\lambda_5} - e^{\lambda_6}},$$

$$D_{19} = \frac{C_1 J_1 D_1}{(J_1+\lambda_1)^2 - PrRe(J_1+\lambda_1) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{20} = \frac{C_1 J_1 D_2}{(J_1+\lambda_2)^2 - PrRe(J_1+\lambda_2) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{21} = \frac{C_1 J_1 D_3}{(J_1+\pi)^2 - PrRe(J_1+\pi) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{22} = \frac{C_1 J_1 D_4}{(J_1-\pi)^2 - PrRe(J_1-\pi) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{23} = \frac{C_2 J_2 D_1}{(J_2+\lambda_1)^2 - PrRe(J_2+\lambda_1) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{24} = \frac{C_2 J_2 D_2}{(J_2+\lambda_2)^2 - PrRe(J_2+\lambda_2) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{25} = \frac{C_2 J_2 D_3}{(J_2+\pi)^2 - PrRe(J_2+\pi) + (ARe - \pi^2 - PrReR_a)},$$

$$D_{26} = \frac{C_2 J_2 D_4}{(J_2-\pi)^2 - PrRe(J_2-\pi) + (ARe - \pi^2 - PrReR_a)},$$

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$$L_2 = -\frac{PrRe}{D}(D_{19} + D_{20} + D_{21} + D_{22} + D_{23} + D_{24} + D_{25} + D_{26}),$$

$$N_2 = -\frac{PrRe}{D}\begin{Bmatrix} D_{19}e^{J_1+\lambda_1} + D_{20}e^{J_1+\lambda_2} + D_{21}e^{J_1+\pi} + D_{22}e^{J_1-\pi} \\ +D_{23}e^{J_2+\lambda_1} + D_{24}e^{J_2+\lambda_2} + D_{25}e^{J_2+\pi} + D_{26}e^{J_2-\pi} \end{Bmatrix},$$

$$D_{27} = \frac{N_3 - L_3(h\lambda_2 - 1)e^{\lambda_2}}{(h\lambda_1 - 1)e^{\lambda_1} - (h\lambda_2 - 1)e^{\lambda_2}},$$

$$D_{27} = \frac{L_3(h\lambda_1 - 1)e^{\lambda_1} - N_3}{(h\lambda_1 - 1)e^{\lambda_1} - (h\lambda_2 - 1)e^{\lambda_2}},$$

$$D_{29} = \frac{C_5J_5D_1}{(J_5 + \lambda_1)^2 - Re(J_5 + \lambda_1) - (\pi^2 + ReM)},$$

$$D_{30} = \frac{C_5J_5D_2}{(J_5 + \lambda_2)^2 - Re(J_5 + \lambda_2) - (\pi^2 + ReM)},$$

$$D_{31} = \frac{C_5J_5D_3}{(J_5 + \pi)^2 - Re(J_5 + \pi) - (\pi^2 + ReM)},$$

$$D_{32} = \frac{C_5J_5D_4}{(J_5 - \pi)^2 - Re(J_5 - \pi) - (\pi^2 + ReM)},$$

$$D_{33} = \frac{C_6J_6D_1}{(J_6 + \lambda_1)^2 - Re(J_6 + \lambda_1) - (\pi^2 + ReM)},$$

$$D_{34} = \frac{C_6J_6D_2}{(J_6 + \lambda_2)^2 - Re(J_6 + \lambda_2) - (\pi^2 + ReM)},$$

$$D_{35} = \frac{C_6J_6D_3}{(J_6 + \pi)^2 - Re(J_6 + \pi) - (\pi^2 + ReM)},$$

$$D_{36} = \frac{C_6J_6D_4}{(J_6 - \pi)^2 - Re(J_6 - \pi) - (\pi^2 + ReM)},$$

$$D_{37} = \frac{C_7J_1D_1}{(J_1 + \lambda_1)^2 - Re(J_1 + \lambda_1) - (\pi^2 + ReM)},$$

$$D_{38} = \frac{C_7J_1D_2}{(J_1 + \lambda_2)^2 - Re(J_1 + \lambda_2) - (\pi^2 + ReM)},$$

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$$D_{39} = \frac{C_7 J_1 D_3}{(J_1+\pi)^2 - Re(J_1+\pi) - (\pi^2 + ReM)},$$

$$D_{40} = \frac{C_7 J_1 D_4}{(J_1-\pi)^2 - Re(J_1-\pi) - (\pi^2 + ReM)},$$

$$D_{41} = \frac{C_8 J_2 D_1}{(J_2+\lambda_1)^2 - Re(J_2+\lambda_1) - (\pi^2 + ReM)},$$

$$D_{42} = \frac{C_8 J_2 D_2}{(J_2+\lambda_2)^2 - Re(J_2+\lambda_2) - (\pi^2 + ReM)},$$

$$D_{43} = \frac{C_8 J_2 D_3}{(J_2+\pi)^2 - Re(J_2+\pi) - (\pi^2 + ReM)},$$

$$D_{44} = \frac{C_8 J_2 D_4}{(J_2-\pi)^2 - Re(J_2-\pi) - (\pi^2 + ReM)},$$

$$D_{45} = \frac{C_9 J_3 D_1}{(J_3+\lambda_1)^2 - Re(J_3+\lambda_1) - (\pi^2 + ReM)},$$

$$D_{46} = \frac{C_9 J_3 D_2}{(J_3+\lambda_2)^2 - Re(J_3+\lambda_2) - (\pi^2 + ReM)},$$

$$D_{47} = \frac{C_9 J_3 D_3}{(J_3+\pi)^2 - Re(J_3+\pi) - (\pi^2 + ReM)},$$

$$D_{48} = \frac{C_9 J_3 D_4}{(J_3-\pi)^2 - Re(J_3-\pi) - (\pi^2 + ReM)},$$

$$D_{49} = \frac{C_{10} J_4 D_1}{(J_4+\lambda_1)^2 - Re(J_4+\lambda_1) - (\pi^2 + ReM)},$$

$$D_{50} = \frac{C_{10} J_4 D_2}{(J_4+\lambda_2)^2 - Re(J_4+\lambda_2) - (\pi^2 + ReM)},$$

$$D_{51} = \frac{C_{10} J_4 D_3}{(J_4+\pi)^2 - Re(J_4+\pi) - (\pi^2 + ReM)},$$

$$D_{52} = \frac{C_{10} J_4 D_4}{(J_4-\pi)^2 - Re(J_4-\pi) - (\pi^2 + ReM)},$$

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$$D_{53} = \frac{D_{17}}{\lambda_5^2 - Re\lambda_5 - (\pi^2 + ReM)}, \quad D_{54} = \frac{D_{18}}{\lambda_6^2 - Re\lambda_6 - (\pi^2 + ReM)},$$

$$D_{55} = \frac{D_{19}}{(J_1 + \lambda_1)^2 - Re(J_1 + \lambda_1) - (\pi^2 + ReM)},$$

$$D_{56} = \frac{D_{20}}{(J_1 + \lambda_2)^2 - Re(J_1 + \lambda_2) - (\pi^2 + ReM)},$$

$$D_{57} = \frac{D_{21}}{(J_1 + \pi)^2 - Re(J_1 + \pi) - (\pi^2 + ReM)},$$

$$D_{58} = \frac{D_{22}}{(J_1 - \pi)^2 - Re(J_1 - \pi) - (\pi^2 + ReM)},$$

$$D_{59} = \frac{D_{23}}{(J_2 + \lambda_1)^2 - Re(J_2 + \lambda_1) - (\pi^2 + ReM)},$$

$$D_{60} = \frac{D_{24}}{(J_2 + \lambda_2)^2 - Re(J_2 + \lambda_2) - (\pi^2 + ReM)},$$

$$D_{61} = \frac{D_{25}}{(J_2 + \pi)^2 - Re(J_2 + \pi) - (\pi^2 + ReM)},$$

$$D_{62} = \frac{D_{26}}{(J_2 - \pi)^2 - Re(J_2 - \pi) - (\pi^2 + ReM)},$$

$$D_{63} = \frac{D_7}{\lambda_3^2 - Re\lambda_3 - (\pi^2 + ReM)}, \quad D_{64} = \frac{D_8}{\lambda_4^2 - Re\lambda_4 - (\pi^2 + ReM)},$$

$$D_{65} = \frac{D_9}{(J_3 + \lambda_1)^2 - Re(J_3 + \lambda_1) - (\pi^2 + ReM)},$$

$$D_{66} = \frac{D_{10}}{(J_3 + \lambda_2)^2 - Re(J_3 + \lambda_2) - (\pi^2 + ReM)},$$

$$D_{67} = \frac{D_{11}}{(J_3 + \pi)^2 - Re(J_3 + \pi) - (\pi^2 + ReM)},$$

$$D_{68} = \frac{D_{12}}{(J_3 - \pi)^2 - Re(J_3 - \pi) - (\pi^2 + ReM)},$$

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$$D_{69} = \frac{D_{13}}{(J_4+\lambda_1)^2 - Re(J_4+\lambda_1) - (\pi^2+ReM)},$$

$$D_{70} = \frac{D_{14}}{(J_4+\lambda_2)^2 - Re(J_4+\lambda_2) - (\pi^2+ReM)},$$

$$D_{71} = \frac{D_{15}}{(J_4+\pi)^2 - Re(J_4+\pi) - (\pi^2+ReM)},$$

$$D_{72} = \frac{D_{16}}{(J_4-\pi)^2 - Re(J_4-\pi) - (\pi^2+ReM)},$$

$$L_3 = \left\{ \begin{array}{l} -\frac{Re}{D}\left(\begin{array}{l} D_{29}+D_{30}+D_{31}+D_{32}+D_{33}+D_{34}+D_{35}+D_{36} \\ +D_{37}+D_{38}+D_{39}+D_{40}+D_{41}+D_{42}+D_{43}+D_{44} \\ +D_{45}+D_{46}+D_{47}+D_{48}+D_{49}+D_{50}+D_{51}+D_{52} \end{array} \right) \\ +ReGr\left[D_{53}+D_{54}+\frac{PrRe}{D}\left(\begin{array}{l} D_{55}+D_{56}+D_{57}+D_{58} \\ +D_{59}+D_{60}+D_{61}+D_{62} \end{array} \right) \right] \\ +ReGm\left[D_{63}+D_{64}+\frac{ScRe}{D}\left(\begin{array}{l} D_{65}+D_{66}+D_{67}+D_{68} \\ +D_{69}+D_{70}+D_{71}+D_{72} \end{array} \right) \right] \end{array} \right\},$$

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$$N_3 = \left\{ \begin{array}{c} \dfrac{Re}{D} \\ \left[\begin{array}{c} \{1-h(J_5+\lambda_1)\}D_{29}e^{J_5+\lambda_1} + \{1-h(J_5+\lambda_2)\}D_{30}e^{J_5+\lambda_2} \\ +\{1-h(J_5+\pi)\}D_{31}e^{J_5+\pi} + \{1-h(J_5-\pi)\}D_{32}e^{J_5-\pi} \\ +\{1-h(J_6+\lambda_1)\}D_{33}e^{J_6+\lambda_1} + \{1-h(J_6+\lambda_2)\}D_{34}e^{J_5+\lambda_2} \\ +\{1-h(J_6+\pi)\}D_{35}e^{J_6+\pi} + \{1-h(J_6-\pi)\}D_{36}e^{J_6-\pi} \\ +\{1-h(J_1+\lambda_1)\}D_{37}e^{J_1+\lambda_1} + \{1-h(J_1+\lambda_2)\}D_{38}e^{J_1+\lambda_2} \\ +\{1-h(J_1+\pi)\}D_{39}e^{J_1+\pi} + \{1-h(J_1-\pi)\}D_{40}e^{J_1-\pi} \\ +\{1-h(J_2+\lambda_1)\}D_{41}e^{J_2+\lambda_1} + \{1-h(J_2+\lambda_2)\}D_{42}e^{J_2+\lambda_2} \\ +\{1-h(J_2+\pi)\}D_{43}e^{J_2+\pi} + \{1-h(J_2-\pi)\}D_{44}e^{J_2-\pi} \\ +\{1-h(J_3+\lambda_1)\}D_{45}e^{J_3+\lambda_1} + \{1-h(J_3+\lambda_2)\}D_{46}e^{J_3+\lambda_2} \\ +\{1-h(J_3+\pi)\}D_{47}e^{J_3+\pi} + \{1-h(J_3-\pi)\}D_{48}e^{J_3-\pi} \\ +\{1-h(J_4+\lambda_1)\}D_{49}e^{J_4+\lambda_1} + \{1-h(J_4+\lambda_2)\}D_{50}e^{J_4+\lambda_2} \\ +\{1-h(J_4+\pi)\}D_{51}e^{J_4+\pi} + \{1-h(J_4-\pi)\}D_{52}e^{J_4-\pi} \end{array} \right] \\ ReGr \\ \left[\begin{array}{c} (1-h\lambda_5)D_{53}e^{\lambda_5} + (1-h\lambda_6)D_{54}e^{\lambda_6} + \dfrac{PrRe}{D} \\ \left\{ \begin{array}{c} \{1-h(J_1+\lambda_1)\}D_{55}e^{J_1+\lambda_1} + \{1-h(J_1+\lambda_2)\}D_{56}e^{J_1+\lambda_2} \\ +\{1-h(J_1+\pi)\}D_{57}e^{J_1+\pi} + \{1-h(J_1-\pi)\}D_{58}e^{J_1-\pi} \\ +\{1-h(J_2+\lambda_1)\}D_{59}e^{J_2+\lambda_1} + \{1-h(J_2+\lambda_2)\}D_{60}e^{J_2+\lambda_2} \\ +\{1-h(J_2+\pi)\}D_{61}e^{J_2+\pi} + \{1-h(J_2-\pi)\}D_{62}e^{J_2-\pi} \end{array} \right] \end{array} \right] \\ ReGm \\ \left[\begin{array}{c} (1-h\lambda_3)D_{63}e^{\lambda_3} + (1-h\lambda_4)D_{64}e^{\lambda_4} + \dfrac{ScRe}{D} \\ \left\{ \begin{array}{c} \{1-h(J_3+\lambda_1)\}D_{65}e^{J_3+\lambda_1} + \{1-h(J_3+\lambda_2)\}D_{66}e^{J_3+\lambda_2} \\ +\{1-h(J_3+\pi)\}D_{67}e^{J_3+\pi} + \{1-h(J_3-\pi)\}D_{68}e^{J_3-\pi} \\ +\{1-h(J_4+\lambda_1)\}D_{69}e^{J_4+\lambda_1} + \{1-h(J_4+\lambda_2)\}D_{70}e^{J_4+\lambda_2} \\ +\{1-h(J_4+\pi)\}D_{71}e^{J_4+\pi} + \{1-h(J_4-\pi)\}D_{72}e^{J_4-\pi} \end{array} \right] \end{array} \right] \end{array} \right\}.$$

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Chapter – VI

$$m_1 = \frac{1}{2}\left[Sc + \sqrt{Sc^2 + 4ScKr}\right] ,$$

$$m_2 = \frac{1}{2(3R+4)}\left[3PrR + \sqrt{9Pr^2R^2 + 3PrR(3R+4)\phi}\right],$$

$$m_3 = \frac{1}{2}\left[1 + \sqrt{1 + 4\left(M + \frac{1}{K}\right)}\right],$$

$$m_4 = \frac{1}{2}\left[Sc + \sqrt{Sc^2 + 4Sc\left(Kr + \frac{i\omega}{4}\right)}\right],$$

$$m_5 = \frac{1}{2(3R+4)}\left[3PrR + \sqrt{9Pr^2R^2 + 3PrR(3R+4)(\phi + i\omega)}\right] ,$$

$$m_6 = \frac{1}{2}\left[1 + \sqrt{1 + 4\left(M + \frac{i\omega}{4} + \frac{1}{K}\right)}\right],$$

$$P_1 = \frac{-Gm}{m_1^2 - m_1 - \left(M + \frac{1}{K}\right)} \quad , \quad P_2 = \frac{-Gr}{m_2^2 - m_2 - \left(M + \frac{1}{K}\right)} \quad ,$$

$$P_3 = h\left(\frac{\partial u_{01}}{\partial y}\right) - P_1 - P_2 \, , \quad P_4 = \frac{-GrS_7}{m_2^2 - m_2 - \left(M + \frac{1}{K}\right)} \, ,$$

$$P_5 = \frac{-GrS_1}{4m_3^2 - 2m_3 - \left(M + \frac{1}{K}\right)} \quad , \quad P_6 = \frac{-GrS_2}{4m_2^2 - 2m_2 - \left(M + \frac{1}{K}\right)} \, ,$$

$$P_7 = \frac{-GrS_3}{4m_1^2 - 2m_1 - \left(M + \frac{1}{K}\right)},$$

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$$P_8 = \frac{-GrS_4}{(m_2+m_3)^2-(m_2+m_3)-\left(M+\frac{1}{K}\right)},$$

$$P_9 = \frac{-GrS_5}{(m_1+m_2)^2-(m_1+m_2)-\left(M+\frac{1}{K}\right)},$$

$$P_{10} = \frac{-GrS_6}{(m_1+m_3)^2-(m_1+m_3)-\left(M+\frac{1}{K}\right)},$$

$$P_{11} = h\left(\frac{\partial u_{02}}{\partial y}\right)-(P_4+P_5+P_6+P_7+P_8+P_9+P_{10}),$$

$$P_{12} = \frac{-GrS_9}{m_5^2-m_5-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)}, \quad P_{13} = \frac{Am_2P_2-GrS_8}{m_2^2-m_2-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{14} = \frac{-GmJ_2}{m_4^2-m_4-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)}, \quad P_{15} = \frac{Am_1P_1-GmJ_1}{m_1^2-m_1-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{16} = \frac{Am_3P_3}{m_3^2-m_3-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{17} = h\left(\frac{\partial u_{11}}{\partial y}\right)-(P_{12}+P_{13}+P_{14}+P_{15}+P_{16}),$$

$$P_{18} = \frac{-GrS_{26}}{m_5^2-m_5-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)}, \quad P_{19} = \frac{Am_2P_4-GrS_{10}}{m_2^2-m_2-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{20} = \frac{2Am_3P_5-GrS_{11}}{4m_3^2-2m_3-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{21} = \frac{2Am_2P_6-GrS_{12}}{4m_2^2-2m_2-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{22} = \frac{2Am_1P_7-GrS_{13}}{4m_1^2-2m_1-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

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$$P_{23} = \frac{A(m_2+m_3)P_8 - GrS_{14}}{(m_2+m_3)^2 - (m_2+m_3) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{24} = \frac{A(m_1+m_2)P_9 - GrS_{15}}{(m_1+m_2)^2 - (m_1+m_2) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{25} = \frac{A(m_1+m_3)P_{10} - GrS_{16}}{(m_1+m_3)^2 - (m_1+m_3) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{26} = \frac{-GrS_{17}}{(m_3+m_6)^2 - (m_3+m_6) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{27} = \frac{-GrS_{18}}{(m_3+m_5)^2 - (m_3+m_5) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{28} = \frac{-GrS_{19}}{(m_3+m_4)^2 - (m_3+m_4) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{29} = \frac{-GrS_{20}}{(m_2+m_6)^2 - (m_2+m_6) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{30} = \frac{-GrS_{21}}{(m_2+m_5)^2 - (m_2+m_5) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{31} = \frac{-GrS_{22}}{(m_2+m_4)^2 - (m_2+m_4) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{32} = \frac{-GrS_{23}}{(m_1+m_6)^2 - (m_1+m_6) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

$$P_{33} = \frac{-GrS_{24}}{(m_1+m_5)^2 - (m_1+m_5) - \left(M + \frac{i\omega}{4} + \frac{1}{K}\right)},$$

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$$P_{34} = \frac{-GrS_{25}}{(m_1+m_4)^2-(m_1+m_4)-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{35} = \frac{Am_3P_{11}}{m_3^2-m_3-\left(M+\frac{i\omega}{4}+\frac{1}{K}\right)},$$

$$P_{36} = h\left(\frac{\partial u_{12}}{\partial y}\right)-\begin{Bmatrix} P_{18}+P_{19}+P_{20}+P_{21}+P_{22}+ \\ P_{23}+P_{24}+P_{25}+P_{26}+ \\ P_{27}+P_{28}+P_{29}+P_{30}+P_{31}+ \\ P_{32}+P_{33}+P_{34}+P_{35} \end{Bmatrix},$$

$$S_1 = \frac{-\frac{3}{4}PrRm_3^2P_3^2}{4(3R+4)m_3^2-6PrRm_3-\frac{3}{4}PrR\phi},$$

$$S_1 = \frac{-\frac{3}{4}PrRm_2^2P_2^2}{4(3R+4)m_2^2-6PrRm_2-\frac{3}{4}PrR\phi},$$

$$S_3 = \frac{-\frac{3}{4}PrRm_1^2P_1^2}{4(3R+4)m_1^2-6PrRm_1-\frac{3}{4}PrR\phi},$$

$$S_4 = \frac{-\frac{3}{2}PrRm_2m_3P_2P_3}{(3R+4)(m_2+m_3)^2-3PrR(m_2+m_3)-\frac{3}{4}PrR\phi},$$

$$S_5 = \frac{-\frac{3}{2}PrRm_1m_2P_1P_2}{(3R+4)(m_1+m_2)^2-3PrR(m_1+m_2)-\frac{3}{4}PrR\phi},$$

$$S_6 = \frac{-\frac{3}{2}PrRm_1m_3P_1P_3}{(3R+4)(m_1+m_3)^2-3PrR(m_1+m_3)-\frac{3}{4}PrR\phi},$$

$$S_7 = -(S_1+S_2+S_3+S_4+S_5+S_6),$$

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$$S_8 = \frac{3PrRAm_2}{(3R+4)m_2^2 - 3PrRm_2 - \frac{3}{4}PrR(\phi + i\omega)} \quad , \quad S_9 = 1 - S_8 \ ,$$

$$S_{10} = \frac{3PrRAm_2S_7}{(3R+4)m_2^2 - 3PrRm_2 - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{11} = \frac{6PrRAm_3S_1 - \frac{3}{2}PrRm_3^2P_3P_{16}}{4(3R+4)m_3^2 - 6PrRm_3 - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{12} = \frac{6PrRAm_2S_2 - \frac{3}{2}PrRm_2^2P_2P_{13}}{4(3R+4)m_2^2 - 6PrRm_2 - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{13} = \frac{6PrRAm_1S_3 - \frac{3}{2}PrRm_1^2P_1P_{15}}{4(3R+4)m_1^2 - 6PrRm_1 - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{14} = \frac{3PrRA(m_2+m_3)S_4 - \frac{3}{2}PrRm_2m_3(P_3P_{13} + P_2P_{16})}{(3R+4)(m_2+m_3)^2 - 3PrR(m_2+m_3) - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{15} = \frac{3PrRA(m_1+m_2)S_5 - \frac{3}{2}PrRm_1m_2(P_2P_{15} + P_1P_{13})}{(3R+4)(m_1+m_2)^2 - 3PrR(m_1+m_2) - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{16} = \frac{3PrRA(m_1+m_3)S_6 - \frac{3}{2}PrRm_1m_3(P_3P_{15} + P_1P_{16})}{(3R+4)(m_1+m_3)^2 - 3PrR(m_1+m_3) - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{17} = \frac{-\frac{3}{2}PrRm_3m_6P_3P_{17}}{(3R+4)(m_3+m_6)^2 - 3PrR(m_3+m_6) - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

$$S_{18} = \frac{-\frac{3}{2}PrRm_3m_5P_3P_{12}}{(3R+4)(m_3+m_5)^2 - 3PrR(m_3+m_5) - \frac{3}{4}PrR(\phi + i\omega)} \ ,$$

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$$S_{19} = \frac{-\frac{3}{2}PrRm_3m_4P_3P_{14}}{(3R+4)(m_3+m_4)^2 - 3PrR(m_3+m_4) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{20} = \frac{-\frac{3}{2}PrRm_2m_6P_2P_{17}}{(3R+4)(m_2+m_6)^2 - 3PrR(m_2+m_6) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{21} = \frac{-\frac{3}{2}PrRm_2m_5P_2P_{12}}{(3R+4)(m_2+m_5)^2 - 3PrR(m_2+m_5) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{22} = \frac{-\frac{3}{2}PrRm_2m_4P_2P_{14}}{(3R+4)(m_2+m_4)^2 - 3PrR(m_2+m_4) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{23} = \frac{-\frac{3}{2}PrRm_1m_6P_1P_{17}}{(3R+4)(m_1+m_6)^2 - 3PrR(m_1+m_6) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{24} = \frac{-\frac{3}{2}PrRm_1m_5P_1P_{12}}{(3R+4)(m_1+m_5)^2 - 3PrR(m_1+m_5) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{25} = \frac{-\frac{3}{2}PrRm_1m_4P_1P_{14}}{(3R+4)(m_1+m_4)^2 - 3PrR(m_1+m_4) - \frac{3}{4}PrR(\phi+i\omega)},$$

$$S_{26} = -\begin{Bmatrix} S_{10}+S_{11}+S_{12}+S_{13}+S_{14}+S_{15}+S_{16}+S_{17} \\ +S_{18}+S_{19}+S_{20}S_{21}+S_{22}+S_{23}+S_{24}+S_{25} \end{Bmatrix},$$

$$J_1 = \frac{Am_1Sc}{m_1^2 - Scm_1 - Sc\left(Kr + \frac{i\omega}{4}\right)}, \quad J_2 = 1 - J_1.$$

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Chapter – VII

$$m_1 = \frac{1}{2(3+4R)}\left[3Pr + \sqrt{9Pr^2 + 12PrQ(3+4R)}\right],$$

$$m_2 = \frac{1}{2(3+4R)}\left[3Pr + \sqrt{9Pr^2 + 12Pr(3+4R)(n+Q)}\right],$$

$$m_3 = \frac{1}{2}\left[Sc + \sqrt{Sc^2 + 4ScK_r}\right], \quad m_4 = \frac{1}{2}\left[Sc + \sqrt{Sc^2 + 4Sc(n+K_r)}\right],$$

$$m_5 = \frac{1}{2}\left[1 + \sqrt{1+4N}\right], \quad m_6 = \frac{1}{2}\left[1 + \sqrt{1+4(N+n)}\right],$$

$$A_1 = \frac{3m_1PrA}{(3+4R)m_1^2 - 3m_1Pr - 3Pr(n+Q)},$$

$$A_2 = \frac{m_1^2S_0Sc}{m_1^2 - m_1Sc - ScK_r},$$

$$A_3 = \frac{m_3ASc(1+A_2)}{m_3^2 - m_3Sc - Sc(n+K_r)}, \quad A_4 = \frac{m_1Sc(AA_2 + m_1A_1S_0)}{m_1^2 - m_1Sc - Sc(n+K_r)},$$

$$A_5 = \frac{m_2^2S_0Sc(1-A_1)}{m_2^2 - m_2Sc - Sc(n+K_r)}, \quad A_6 = 1 - A_3 + A_4 + A_5,$$

$$A_7 = \frac{Gr - A_2Gm}{m_1^2 - m_1 - N}, \quad A_8 = \frac{Gm(1+A_2)}{m_3^2 - m_3 - N}, \quad A_9 = U_p - 1 + A_7 + A_8,$$

$$A_{10} = \frac{m_5A_9A}{m_5^2 - m_5 - (N+n)}, \quad A_{11} = \frac{m_1A_7A + GrA_1 - GmA_4}{m_1^2 - m_1 - (N+n)},$$

$$A_{12} = \frac{m_3A_8A + GmA_3}{m_3^2 - m_3 - (N+n)}, \quad A_{13} = \frac{GmA_5 - Gr(1-A_1)}{m_2^2 - m_2 - (N+n)},$$

$$A_{14} = \frac{GmA_6}{m_4^2 - m_4 - (N+n)}, A_{15} = -1 - A_{10} + A_{11} + A_{12} - A_{13} + A_{14}.$$

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Chapter – VIII

$$a = N - 2iK^2, b = \frac{Gr}{1-Pr}, c = \frac{Pr\phi - a}{1-Pr}, p = \frac{Gm}{1-Sc}, q = \frac{ScC_r - a}{1-Sc},$$

$$G_1(y,t) = \frac{1}{2}\left[\begin{array}{l}\left(t + \frac{y}{2}\sqrt{\frac{Sc}{C_r}}\right)e^{y\sqrt{ScC_r}}erfc\left(\frac{y}{2}\sqrt{\frac{Sc}{t}} + \sqrt{C_r t}\right) \\ + \left(t - \frac{y}{2}\sqrt{\frac{Sc}{C_r}}\right)e^{-y\sqrt{ScC_r}}erfc\left(\frac{y}{2}\sqrt{\frac{Sc}{t}} - \sqrt{C_r t}\right)\end{array}\right],$$

$$G_2(y,t) = \frac{1}{2}\left[\begin{array}{l}\left(t + \frac{y}{2}\sqrt{\frac{Pr}{\phi}}\right)e^{y\sqrt{Pr\phi}}erfc\left(\frac{y}{2}\sqrt{\frac{Pr}{t}} + \sqrt{\phi t}\right) \\ + \left(t - \frac{y}{2}\sqrt{\frac{Pr}{\phi}}\right)e^{-y\sqrt{Pr\phi}}erfc\left(\frac{y}{2}\sqrt{\frac{Pr}{t}} - \sqrt{\phi t}\right)\end{array}\right],$$

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$$G_3(y,t)=\frac{1}{2}\left[\begin{array}{c}\dfrac{e^{ct}}{c^2}\left\{\begin{array}{c}e^{y\sqrt{Pr(\phi+c)}}erfc\left(\dfrac{y}{2}\sqrt{\dfrac{Pr}{t}}+\sqrt{(\phi+c)t}\right)+\\ e^{-y\sqrt{Pr(\phi+c)}}\\ erfc\left(\dfrac{y}{2}\sqrt{\dfrac{Pr}{t}}-\sqrt{(\phi+c)t}\right)-\\ e^{y\sqrt{a+c}}erfc\left(\dfrac{y}{2\sqrt{t}}+\sqrt{(a+c)t}\right)\\ -e^{-y\sqrt{a+c}}erfc\left(\dfrac{y}{2\sqrt{t}}-\sqrt{(a+c)t}\right)\end{array}\right\}\\ -\dfrac{1}{c}\left\{\begin{array}{c}\left(t+\dfrac{1}{c}+\dfrac{y}{2}\sqrt{\dfrac{Pr}{\phi}}\right)e^{y\sqrt{Pr\phi}}erfc\left(\dfrac{y}{2}\sqrt{\dfrac{Pr}{t}}+\sqrt{\phi t}\right)\\ +\left(t+\dfrac{1}{c}-\dfrac{y}{2}\sqrt{\dfrac{Pr}{\phi}}\right)e^{-y\sqrt{Pr\phi}}erfc\left(\dfrac{y}{2}\sqrt{\dfrac{Pr}{t}}-\sqrt{\phi t}\right)\\ -\left(t+\dfrac{1}{c}+\dfrac{y}{2\sqrt{a}}\right)e^{y\sqrt{a}}erfc\left(\dfrac{y}{2\sqrt{t}}+\sqrt{at}\right)\\ -\left(t+\dfrac{1}{c}-\dfrac{y}{2\sqrt{a}}\right)e^{-y\sqrt{a}}erfc\left(\dfrac{y}{2\sqrt{t}}-\sqrt{at}\right)\end{array}\right\}\end{array}\right]$$

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$$G_4(y,t)=\frac{1}{2}\begin{bmatrix}\frac{e^{qt}}{q^2}\begin{Bmatrix}e^{y\sqrt{Sc(C_r+q)}}erfc\left(\frac{y}{2}\sqrt{\frac{Sc}{t}}+\sqrt{(C_r+q)t}\right)\\+e^{-y\sqrt{Sc(C_r+q)}}\\erfc\left(\frac{y}{2}\sqrt{\frac{Sc}{t}}-\sqrt{(C_r+q)t}\right)\\-e^{y\sqrt{a+q}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(a+q)t}\right)\\-e^{-y\sqrt{a+q}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(a+q)t}\right)\end{Bmatrix}\\-\frac{1}{q}\begin{Bmatrix}\left(t+\frac{1}{q}+\frac{y}{2}\sqrt{\frac{Sc}{C_r}}\right)e^{y\sqrt{ScC_r}}erfc\left(\frac{y}{2}\sqrt{\frac{Sc}{t}}+\sqrt{C_rt}\right)\\+\left(t+\frac{1}{q}-\frac{y}{2}\sqrt{\frac{Sc}{C_r}}\right)e^{-y\sqrt{ScC_r}}erfc\left(\frac{y}{2}\sqrt{\frac{Sc}{t}}-\sqrt{C_rt}\right)\\-\left(t+\frac{1}{q}+\frac{y}{2\sqrt{at}}\right)e^{y\sqrt{a}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{at}\right)\\-\left(t+\frac{1}{q}-\frac{y}{2\sqrt{a}}\right)e^{-y\sqrt{a}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{at}\right)\end{Bmatrix}\end{bmatrix},$$

$$F_1(t)=\begin{bmatrix}\frac{e^{ct}}{c^2}\begin{bmatrix}\sqrt{Pr(\phi+c)}\left\{erfc\left(\sqrt{(\phi+c)t}\right)-1\right\}-\\\sqrt{a+c}\left\{erfc\left(\sqrt{(a+c)t}\right)-1\right\}\end{bmatrix}\\-\frac{1}{c}\left(t+\frac{1}{c}\right)\left[\sqrt{Pr\phi}\left\{erfc\left(\sqrt{\phi t}\right)-1\right\}-\sqrt{a}\left\{erfc\left(\sqrt{at}\right)-1\right\}\right]\\-\frac{1}{2c}\left[\sqrt{\frac{Pr}{\phi}}\left\{erfc\left(\sqrt{\phi t}\right)-1\right\}-\frac{1}{\sqrt{a}}\left\{erfc\left(\sqrt{at}\right)-1\right\}\right]\\+\frac{1}{c}\sqrt{\frac{t}{\pi}}\left[\sqrt{Pr}e^{-\phi t}-e^{-at}\right]\end{bmatrix},$$

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$$F_2(t)=\begin{bmatrix} \frac{e^{qt}}{q^2}\begin{bmatrix}\sqrt{Sc(C_r+q)}\left\{erfc\left(\sqrt{(C_r+q)t}\right)-1\right\}\\ -\sqrt{a+q}\left\{erfc\left(\sqrt{(a+q)t}\right)-1\right\}\end{bmatrix} \\ -\frac{1}{q}\left(t+\frac{1}{q}\right)\left[\sqrt{ScC_r}\{erfc(\sqrt{C_r t})-1\}-\sqrt{a}\{erfc(\sqrt{at})-1\}\right] \\ -\frac{1}{2q}\left[\sqrt{\frac{Sc}{C_r}}\{erfc(\sqrt{C_r t})-1\}-\frac{1}{\sqrt{a}}\{erfc(\sqrt{at})-1\}\right] \\ +\frac{1}{q}\sqrt{\frac{t}{\pi}}\left[\sqrt{Sc}e^{-C_r t}-e^{-at}\right] \end{bmatrix},$$

$$F_3(t)=\begin{bmatrix} \frac{1}{2}\sqrt{\frac{Pr}{\phi}}\{erfc(\sqrt{\phi t})-1\}-t\sqrt{Pr\phi} \\ +t\left\{\sqrt{Pr\phi}erfc(\sqrt{\phi t})-\sqrt{\frac{Pr}{\pi t}}e^{-\phi t}\right\} \end{bmatrix},$$

$$F_4(t)=\begin{bmatrix} \frac{1}{2}\sqrt{\frac{Sc}{C_r}}\{erfc(\sqrt{C_r t})-1\}-t\sqrt{ScC_r} \\ +t\left\{\sqrt{ScC_r}erfc(\sqrt{C_r t})-\sqrt{\frac{Sc}{\pi t}}e^{-C_r t}\right\} \end{bmatrix}.$$

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Revitalizing MSMEs' Performance with Transparency: Monitoring, Mentoring and Malwaring Through IoT Intervention

Tenzing Norbu[1], Manmohan Mall[1], Bikramjit Sarkar[2], Souvik Pal[2], and Arindam Chakrabarty[3(✉)]

[1] North Eastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh, India
tenzingnorbu.management@gmail.com, mallmanmohan79@gmail.com
[2] Department of Computer Science and Engineering, JIS College of Engineering, Kalyani, India
sarkar.bikramjit@gmail.com, souvikpal22@gmail.com
[3] Department of Management, Rajiv Gandhi University, Arunachal Pradesh, India
arindam.management@gmail.com

Abstract. The Micro, Small and Medium Enterprises (MSMEs) have been fueling the engine of growth worldwide. The relevance of MSMEs in India is enormous since the economy of the country is expanding and a large number of people directly or indirectly are associated with this sector. The government's ambitious projects like Start-up India, Stand-up India, MUDRA Yojana etc. are the testimony of such relentless efforts. The progression and maturation from first generation entrepreneurship and micro enterprises towards Small, Medium and even Large firms is the essence of the compounding growth vector for the nation. The micro firms suffer from the problems manifold which includes resource constraints, lack of vision and regular monitoring and consultancy. In fact, all these are either beyond their reach or too costly to afford. These results literally zero impact on the ground of the excellent and landmark policies of the government. The Indian MSMEs particularly Micro Enterprises essentially requires serious attention of the government not to be limited up to policy formulation rather it must go beyond to its successful implementation, monitoring, mentoring and review. This paper has attempted to develop conceptual framework using Internet of Things (IoT) interventions in administering MSME policies and providing guidance, consultancy and advocacy particularly to Micro Firms. This model is perceived to enhance performance and transparency in this segment.

Keywords: MSME · Transparency · IoT intervention

A. Chakrabarty—Mentor Author

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1 Introduction

1.1 Introduction to MSMEs in the World with Special Emphasis to India

MSMEs have gained enormous importance worldwide over a period of time. It is deemed as the engine of growth for many economies in the world. Realizing its importance, World Bank has helped millions of MSMEs worldwide to gain access to financial services with a view to make them proficient in dealing with constraints relating to risks, growth, cash flows etc., thereby creating employment and enhancing income. Despite such huge contribution, they are encountered with many issues like lack of access to finance, savings, insurance, credit, equity and payment services, to mention a few, which substantially hampers the growth of MSMEs.

1.2 Status of MSME in Indian Perspective

For last few decades, MSME sector in India has been playing pivotal role in economic development of the nation by virtue of generating employment lower cost and encouraging entrepreneurship. As per the National Sample Survey (NSS) 73rd Round (2015–16) Report, there were 633.88 lakh unincorporated non-agriculture MSMEs in the country engaged in different economic activities (196.64 lakh in Manufacturing, 230.35 lakh in Trade and 206.84 lakh in Other Services and 0.03 lakh in Non-captive Electricity Generation and Transmission). Of these, 31% MSMEs were found to have engaged in manufacturing activities, while 36% were in Trade and 33% in Other Services. Again, out of 633.88 estimated number of MSMEs, 324.88 lakh MSMEs (51.25%) were in rural and 309 lakhs MSMEs (48.75%) were in the urban areas.

1.3 Employment Generation Through MSMEs in India

As per the National Sample Survey (NSS) 73rd Round (2015–16) Report, MSME sector has been creating 11.10 crore jobs (360.41 lakh in Manufacturing, 387.18 lakh in Trade and 362.82 lakh in Other Services and 0.07 lakh in Non-captive Electricity Generation and Transmission) in the rural and the urban areas across the country. Micro sector with 630.52 lakh estimated enterprises provide employment to 1076.19 lakh people which accounts for around 97% of total employment in the sector whereas Small sector with 3.31 lakh and Medium sector with 0.05 lakh estimated MSMEs provide employment to 31.95 lakh (2.88%) and 1.75 lakh (0.16%) people out of total employment in MSME sector respectively.

1.4 The Issues of Transparency and Disclosure in Indian MSME

Revisiting the relevant literature, it is found that there is positive relationship between Corporate Disclosure and Profitability (Nandi and Ghosh 2013; Mangala and Isha 2016). Higher Corporate Disclosure leads to greater transparency. Greater transparency helps interested parties to know more about the company's present status, core competency and the challenges ahead (Sengupta 1998) and the higher transparency instills increasing trust and confidence among the stakeholders (Norbu et al. 2018). This is

evidenced as around 99% of Indian MSMEs are dominated by Micro organizations (MSME Report 2017–18). This is high time to adopt 'Turnaround Strategy' by virtue of which there is a serious need to design and develop a comprehensive framework which would be of least costly, real-time and full of transformational leadership. Based on these inputs, insights and reality, a dedicated strategy framework needs to be devised with the support of all the stakeholders and government or concerned ministry using advanced information technology gateway.

2 Review of Literature

2.1 Literary Inputs on Glimpse of Indian MSMEs

MSME is the engine of growth for many economies in the world especially for developing countries like India (Khaksar 2011; Syal 2015; Manna and Mistri 2017; Hamid 2017). Yadav and Tripathi (2018) mentioned that the role of MSMEs become very crucial as public and private firms are not able to provide employment as per the required rate in India. They state that the contribution of Indian MSMEs to country's GDP is around 8% and provide employment to approximately 595 lakhs people, nevertheless. MSMEs face different hurdles like poor infrastructure, shortage of electricity, political instability and financial problems which hamper overall growth and development (Hamid 2017). Therefore, the government should restructure and strengthen MSME sector of the country (Yadav and Tripathi 2018).

2.2 Transparency and Disclosure in Indian MSMEs

Revisiting the relevant literature, it is found that there is positive relationship between Corporate Disclosure and Profitability (Nandi and Ghosh 2013; Mangala and Isha 2016). Higher Corporate Disclosure leads to greater transparency. Greater transparency enables stakeholders to know well about the company's present status, core competency and the challenges ahead (Sengupta 1998) and the higher transparency instil increasing trust and confidence among the stakeholders (Norbu et al. 2018). However, Corporate Disclosure has been a mammoth exercise which essentially needs deployment of resources that include huge financial resources, competent workforce and infrastructural support. Thus, larger the size of the firm, better the transparency and disclosure pattern (Arsov and Bucevska 2017; Ullmann 1985; Aksu 2006) as large scale corporations are engaged in large volume of business which enables them to afford and absorb such cost.

3 Objectives of the Study

i. To study the rationale behind adopting IoT intervention strategy in MSME sector.
ii. To propose a conceptual model for Indian MSMEs to achieve growth and transparency of the sector through IoT intervention.

4 Research Methodology

The study is exploratory in nature which predominantly depends on secondary information from the domain sector. Barring a few firms, MSMEs suffer from adequate investment, deployment of resources and consultancy support as the perennial issues since its genesis. This can be evidenced with the fact that hardly a few firms could progress micro to small or small to medium. The study has attempted to understand variety of functions and forms of IoT through varied source of literature and report with the intention to develop a prototype model for the sector which would enable for bringing higher transparency, accountability and the most important aspect, that is, support of consultancy the domain expert. The model may require operational modifications and validity depending upon the complexity and unassumed/unanticipated attributes. The modified model if it is properly implemented could solve numerous issues. This study has attempted to understand and collate various attributes which needs to be incorporated to form a dedicated model for the sector.

5 Analysis and Interpretation

5.1 Analysis – I

Indian MSMEs are predominantly micro firms and they are not elevated up to Small and Medium enterprises. It may be interpreted as a lack of vision as well as resource crunch such as policy framework, functional competency (forward and backward integration), Value Chain Analysis (primary and secondary variables). The concept of development in India does not confine to listed large firms only. It must emphasize on MSMEs as well since large number of people are engaged directly or indirectly.

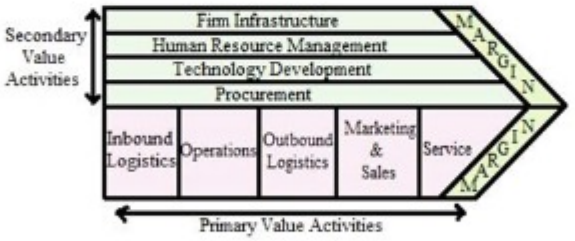

Fig. 1. Value chain model

In Fig. 1, The Value Chain model signifies that a firm needs to manage both primary and secondary activities effectively and efficiently. In fact, the primary activities are supported by secondary activities. In case of multiple SBUs, the secondary activities act as a resource center to extend adequate auxiliary support facilities so that the principal of shared value all the SBUs can be value added by the secondary services. In this research paper, IoT infrastructure coupled with Comprehensive Consultancy.

Mechanism (CCM) would act as secondary activities to all the SBUs in the light of Michael Porter's Value Chain Analysis.

5.2 Analysis – II

Modus-Operandi of IoT platform

IoT infrastructure is inevitable for phenomenal change in the sector. Mechanisms of IoT can be as follows-

Each Micro firm may ideally have few SBUs (Strategic Business Units) depending upon the product or service variety they offer or jurisdictional delimitation.
SBUs may work across the length and breadth of the geographical location.
The government should create a dedicated team of experts representing different domains of knowledge economy i.e., cross-functional experts like Marketing, Finance, HR, Operations, Research Academia and Researchers proven records in entrepreneurship.

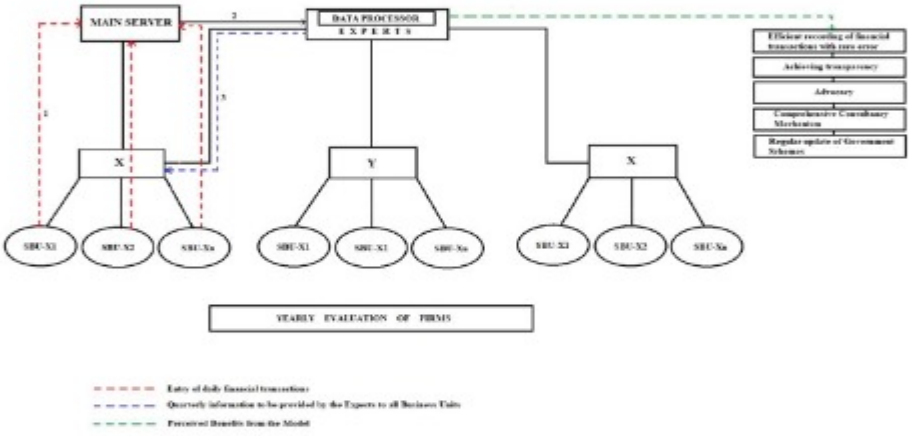

Fig. 2. Conceptual model of IoT intervention

In Fig. 2, we have discussed a conceptual model of IoT Intervention. A dedicated software package would be devised and offered to all the micro firms free of cost which would be deployed for regular transactional operations by each of the micro firms. Each and every transaction of SBUs would get transferred and transmitted into the dedicated server especially designed for the mission. Data/information would be transferred instantly on real time basis as and when it gets connected to desired network loop. Thus, all the transactions/daily activities of each SBU would be preserved in the main server which would be accessed by experts for data processing and analysis so that appropriate strategy or direction could be delivered to the extent of SBU level as a part of the commitment of government led expert agencies for monitoring and providing consultancy. Now, the guided instructions would be communicated for immediate attention and making possible reforms. Thus, the IoT intervention would play the role of mentoring the combination of real and artificial intelligence. The newly devised

system would monitor all the transactions of MSME firms which would help to maintain transparency and further the system itself would have adequate information for corporate disclosure. The devised virtual platform supported by the Consultancy/Experts team would study all the transactions in terms of multiple dimensions like growth, stability, business opportunity analysis etc. Based on the recommendations and regular feedback of the Experts team, each of the tiny firms would get adequate business direction and policy reforms. This set of services would be provided either free of cost service or least costly for the tiny firms (Fig. 3).

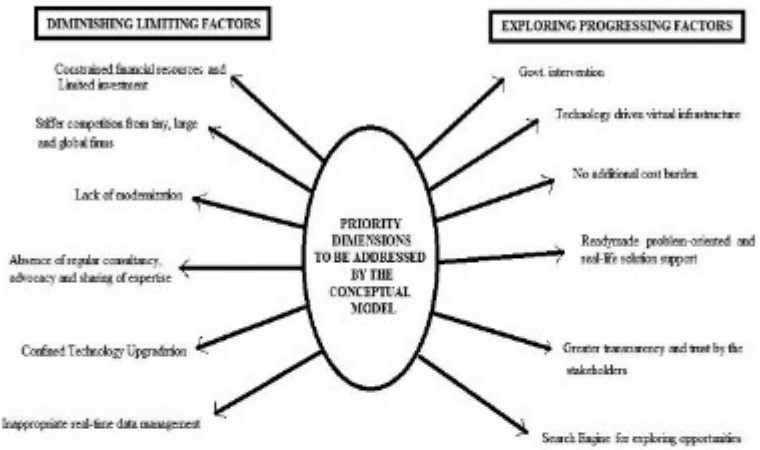

Fig. 3. Priority matrix of the conceptual model

The above Priority Matrix exhibits 'Diminishing Limiting factors' and 'Exploring Progressing factors'. The Diminishing Limiting factors include all sort of constraints and impediments as a part of Threat Matrix while the Progressing factors ideally explores Opportunity Matrix for the firms. The manifestation of this model would endeavor the firms to overcome its threat expedite its emerging opportunities so that the steady growth of Indian MSMEs could venture 'Inclusive Growth and Holistic Development' of society at large (Table 1).

Highlights of Perceived Benefits

A. **Short-term benefits**

Continuous improvement of firms following Deming Principle or PDCA (Plan-Do-Check-Act) through advocacy, consultancy, monitoring and mentoring of micro firms.

Knowledge society can do extensive research for improving ground level problems.

It would instil transparency of firms and in case of deviation, appropriate measures could be initiated.

B. **Long-term benefits**
It would bring forth culture of transparency and accountability among all the stakeholders of society if it could be tailor made and implemented in all the sectors. This would help to universal Corporate Data Management System which would be of immense use not only for transparency index but also for high-end researches.

Table 1. Analysis of potential benefit matrix of the model

Sl. no.	Nature of activities	Potential benefits	Financial indicators
1	Recording financial transactions	Day-to-day records of transactions	Favorable (cost reduction)
		Transparency	
		Generating monthly data for settlement	Favorable (profit oriented)
2	Transparency	Achieving transparency	Favorable (cost reduction)
3	Advocacy	Sectoral advice	Favorable (cost reduction)
4	Comprehensive Consultancy Mechanism (CCM)	Reduction of mistakes	Favorable (cost reduction)
		Improvement of performance	
		Reduction of errors	
		Increased efficiency	
5	Regular updates on Government Schemes	Useful information	Favorable (scheme/subsidy)
		Generation of new ideas	
		Training and development	Favorable (loans)
		Increased investment	

6 Conclusion

Indian MSMEs have been passing through series of challenges and lots of constraints despite best possible policies are formulated and implemented by the state from time to time. This paper has attempted to introduce IoT platform to energize the sector with definite objectives. The paper has suggested by developing a conceptual model with IoT intervention where the virtual infrastructure supported by the government agencies would facilitate to bring forth the threshold level of transparency and building of trust among all the stakeholders. The virtual ecosystem would also plan to provide regular consultancy support to the tiny firms particularly micro and small so that they could achieve competitive age over others. This process would enable the smaller firms for their successful progression and transformation into banyan organizations within a definite time period.

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Mapping Economic History of

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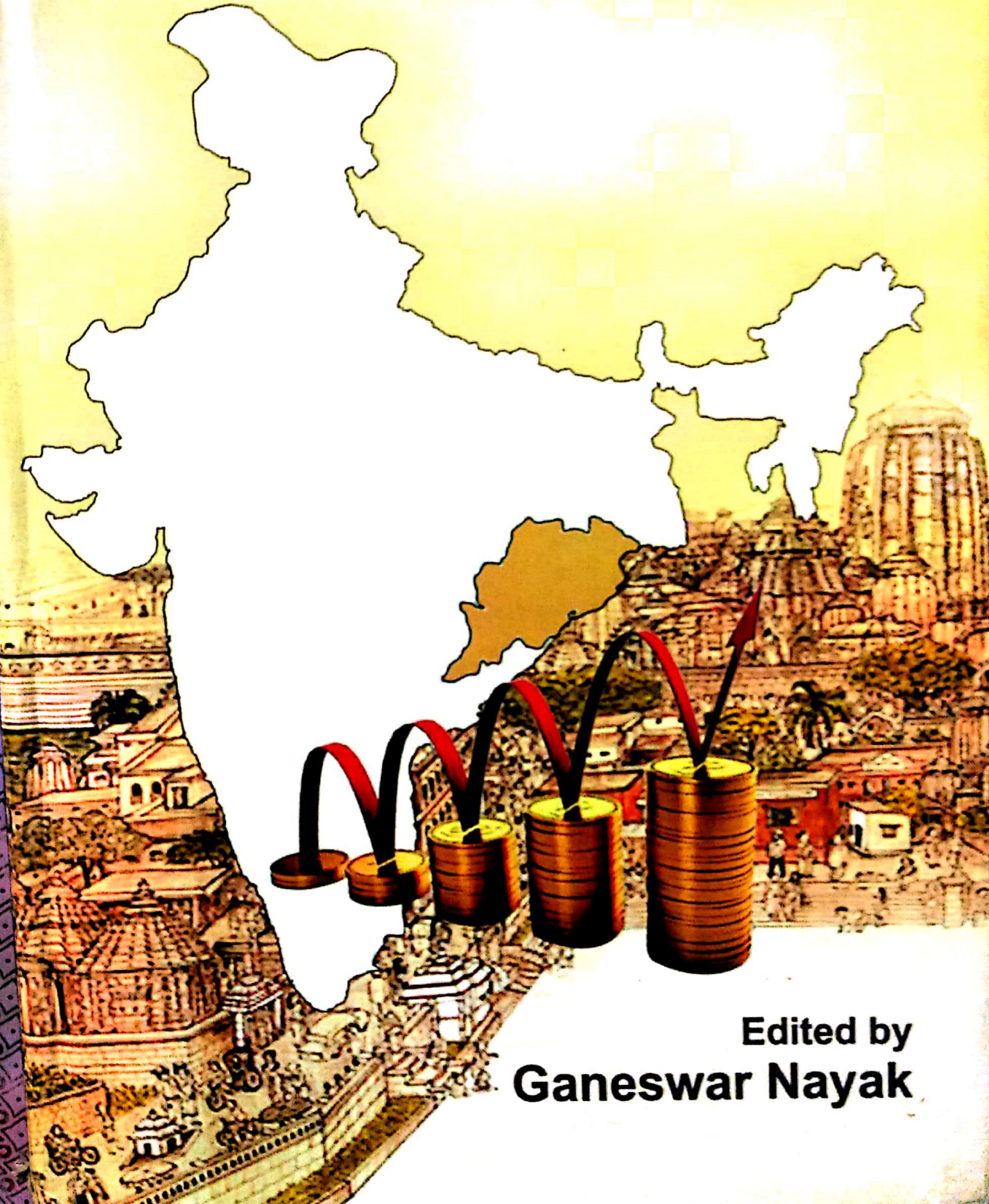

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CLAIMING THE DIFFERENCE

Identity in Literatures and Cultures

Claiming the Difference: Identity in Literatures and Cultures is an attempt to unfold representations of identity by a body of selected papers which critically engage the postcolonial world and its attendant issues. The authors appreciate and also evaluate the sense of difference as a key to understanding identities emerging through different literary traditions and cultural systems. Since identity in our times is increasingly believed to be a socio-psychological and culturo-political phenomenon, and likened to a constantly evolving and much-contested space, it appears nuanced with differentia; hence its representations in *literatures* instead of a universal literature, so also its cultures and peoples, are coefficients of each other. In other words, identity remains an embodied bloom of its culture as well as infolded in the literature that any culture nurtures. The book may be approached to view with a discernment of difference many identities, cultures and literary traditions in the world in which identity is formed and reclaimed.

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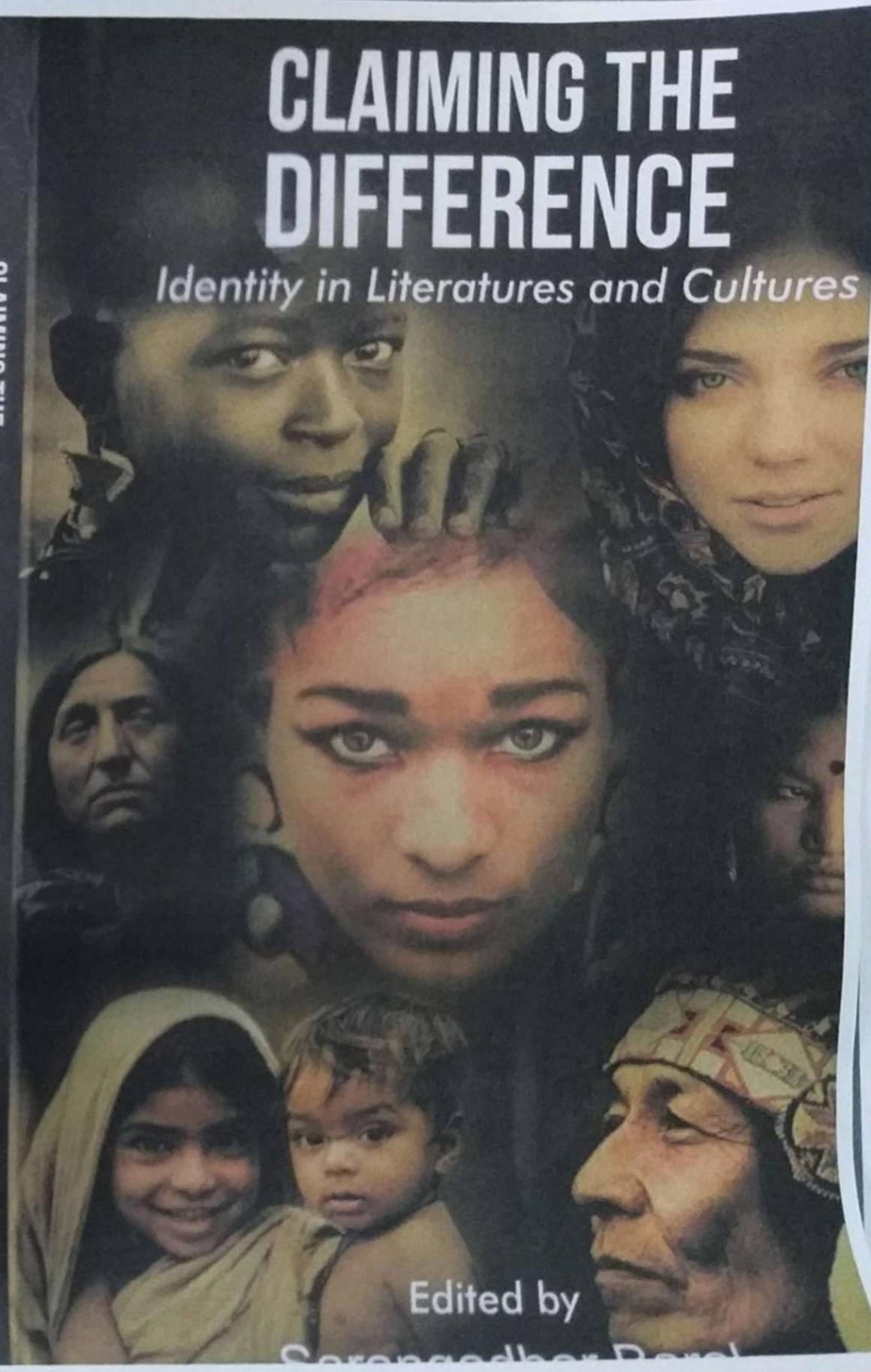

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10

Identifying Identity in Literature and Culture: Postcolonial Perspective

Bhagabat Nayak

The word 'literature' derives from the Latin word *Littera* which means *letter*. In French and English it means "book learning" or "acquaintance with books" which is "a historically variable and theoretically elastic term" (Pope 71). To take it with as light irony, in fact, all texts are not literary but "some texts are born literary, some achieve literariness, and some have literariness thrust upon them" (Eagleton 7). It expresses different kinds of creative, imaginative, aesthetic, factual and fictional narrations in different genres.

But 'culture' is derived from the Latin word *cultus* via French which means 'the nurturing of growth' in human life, human civilisation, artistic and aesthetic activity and universalist values. Culture study takes into its ambit disciplines like art, literature, sociology and anthropology, not of course in total disregard of historical events and scientific facts as irrelevant to its prime subjects.

The topic at hand is to reexamine how the interrelatedness between the individual and society forms the notion of identity, and how the question of identity formation is negotiated in literary and cultural domains in contemporary times. Identity based on the foundational self, stable and immutable, is now held to be a mystified notion of classical ages and turns out to be a misnomer in the postmodern era. The issue of identity in postcolonial literature

invariably relates the socio-political protest of the natives while recognising their evident self in struggles for freedom and survival. Their solidarity with their cultural heritage in contradistinction to their previous conditioning within imperial restrictions of a colonial history in terms of sordid human consequences is found to be libratory to forge a new identity for the decolonised. In postcolonial literature, the issue of identity has its epistemic significance produced eventually under the increased problematics of broken societies, immigrant numbers, hybrid nations, and constitution of countries with cultural diversities. The decolonised people with their retrieval of philosophical and political knowledge restlessly argue about their identity once determined by traditional matrices of sex, caste and customs as well as by the colonising culture's sedative injections and superiority complexes. People's fresh interest in their native (non-Western) life world is expressed in terms of opposition to the goals of conquest, and the people's subject position defies the West's 'extension of civilising mission 'that disguised the myriad motif and narrative of exploitation. Analysis of identity as a crucial human issue is now being exposed and expressed in terms of social and cultural perspectives in the domain of literature. Literature as cultural site since the late twentieth century is quite conscious of the colonial historicity that would essentially constitute postcolonial identity, mainly in its creative resistance to the culture of the coloniser. At the same time, the postmodern literature produced in the western world has continued questioning the conventional ideas of gender, class, race, morality, politics, and power regimes and civil rights, and that too sometimes militantly in literary productions and social movements, in order that social life is more wholesomely formed and thereby the concept of identity is better demystified and realised individually and culturally for a saner existence.

As regards the issue of identity, and the pleasure and pain of identifying it by uses of the postcolonial tools of philosophy and deconstruction, the elements of time and convention are not only important but make identity an issue of controversies and irresolution's. Various socio-political situations emerging in around the 1940-50s in the world had given rise to the decolonisation

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process, where by newly freed nations and races continue their search for the formation of identity. Although they are confused in many historical situations while on the road to achieving freedom from western colonisation, they are of course not happily clear about their culture and identity, as the authorised versions of history have played havoc with their racial memory, including loss of language and belief systems. Postcolonial societies acknowledge elemental losses of some kinds which it is difficult to retrieve fully and more difficult to forget. This awareness of loss and self-conscious attempt at recuperation are precariously set all the time to define the issue of identity formation, and make the meaning of identity not a fixed object to hold; thus to identify identity becomes more an emotionally involved, hence imaginatively creative, process for the people of a liberated nation. In the process they are to undergo many political vicissitudes and exigent adaptations in the face of consequent cultural and economic changes and crises. At least in case of the postcolonial community, it appears, resistance to cultural, political and economic colonialism is one obvious part of the problem of struggle; but seeking the power to establish their identity remains another part by its unobvious predicament, which their self-conscious and self-constraining negotiations alternately confirm despite after having their political independence somewhat won.

Postcolonial period provokes the individual's quest for identity. As the decolonisation process was politically difficult for them, for example in Asian and African countries, their postcolonial condition became more difficult and problematic with other economic and cultural colonialisms retained. Individual's attempt to establish or regain his identity at all levels is a rigor in the postcolonial condition. From the postcolonial perspective, identity is a complex concept that involves the individual's economic, political and cultural place, power and position; it unexceptionally involves the colonised people's struggle for independence, impact of colonising powers, decolonising process, 'contestation of forms of domination and the articulation of political and cultural identities, (Young 11, qtd in Habib 739).The postcolonial condition has

become a period of historic shift from one power centre to the other where the colonised people not only decolonise themselves socially, politically, economically and culturally in a form of 'revolutionary nationalism', they also write back to the 'centers' questioning their pastlegacies and countering their new dispensations if found illiberal and less liberating. Edward Said, Homi Bhabha and Gayatri Spivak Chakravarty in literary theory propelled basically by French theorists and deconstructionists, Tony Morrison, Chinua Achebe, Salman Rushdie and the like in creative writings have contributed enormously to the historic shifts not only in systemic and epistemic life but also more seriously in identity consciousness. With the political independence and restoration of love and loyalty to the native land, identifying identity for an individual or group or nation as 'I', 'us' and 'other' becomes a comfortable process to assert self-identity.

In the postcolonial situations, question of identity and culture to be understood not in terms of 'other hood' but of homogeneity alone would raise inherent problems. To admit with Stuart Hall, the importance of education, positive conceptualisation of postcolonial society, political changes, dilemmas and endurance in the past cannot be discounted as in definitive tools to define and redefine identity which appears "a kind of unsettled space or an unresolved question in that space, between a number of intersecting discourses" (Hall 10). The decolonised people who form three fourth of the world population living the status of 'other' raise many unsettling questions as to their collective and individual identities, as well as physical and psychological realities. Since the decolonising process is both physical and psychological in the struggle for political sovereignty, it brings multidimensional constraints for building identity. It converges, contests and interrelates many contexts of their colonisation, such as slavery, migration, exploitation and marginalisation. The Third World writers who write about their race, gender, process of decolonisation, forms of colonial domination indicating historic shifts focus on their identities as to be refurbished with the imagination of nation, cultural hybridisation and by embodying native ideas, thought and

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philosophy as retrieved. While writing on the issues and concerns of the Third World people, both the native and diasporic writers focus on construction of self and assertion of identity in their literary discourses and counter-discourses. The diasporic not only narrate the consequences and the changes formed in the experience of transition and immigration but also write on the themes of mimicry, difference, and discourse of their ambivalent position while being situated between two cultures. With "the ease of long acquaintance" with "the experience of having to wear 'white masks'" they try "to be free of all taint of primitive native traits" (Ryan 117-118). Writing with identity and for identity becomes one of the most important ways of expressing the perceptions of the decolonised people who have experienced the colonial realities. The much acclaimed book *The Empire Writes Back (1989)* has argued in support of a narrative shift in focus that the label 'postcolonial' demands, the shift away from British literature to the world literature in English.

Postcolonial literary genres have been greatly informed under the shaping influence of the Foucauldian idea of power with what crucial things are at stake in identity formation; in other words, his critical insights are being utilised in reconstructing identity of the colonised people by liberating their subject position from the repressive discourses of power. With education and educated self-awareness supplementing their sense of identity formation, they started using discourse analysis to deconstruct the general politics of constructed truths as grand narratives. They would turn to read how an "interstitial passage between fixed identifications opens up the possibility of a cultural hybridity that entertains the difference without an assumed or imposed hierarchy" (Bhabha 4). In postcolonial theory, the concept of hybridity and hybridised identity challenges the fixity of any essentialist cultural identity, which would echo similar philosophical nuances as developed by Deleuze and Guattari's rhizomatic theory questioning and upsetting established power structures and hierarchical social fixities, since as in plant nature subterranean shifts or dimensions get engendered by invisible and potential causes; and their concept of rhizome is also

useful to explain identity formation of the self which occurs along 'detachable, connectable, reversible, modifiable' modes and 'has multiple entranceways and exits…' (n. pag).Therefore, construction of identity is an ongoing process, as with rhizome, rife with unpredictable possibility. Thus in a faceoff with hegemonist colonial politics, what the postcolonial theorists and critics like Franz Fanon, Bill Ashcroft, and Salman Rushdie believe is that postcolonial literary genre is mostly "a reply on a minor scale to the dominating power, the literature produced by natives becomes differentiated and makes itself into a will to particularism" (Fanon 237). The once colonised countries and their people were always discussed with reference to universalist terms of civilisation, history, progress and reason, while the dynamics of power of ruling groups within a culture or nation colonised or otherwise was kept camouflaged seductively. Postcolonial writing keeps to central focus efforts to conceptualise national identity and negotiate between this and the other complex impingements from non-native worlds. Thus, the notion of identity, based on ideas of conflation, difference and multiplicity, has involved intellectual studies cutting across disciplinary categories and diverse theoretical standpoints, and as a result of which postcolonial thought has problematised traditional knowledge domains of humanities and sciences by stimulating rethinking and redefining of the same.

Identity formation of the native people through cultural practices, tradition, native heritage, history, dominant culture, flux of economy and existential confusions "tend to conceptualise memory as part of the development of the self or personality and to locate that process within an individual, with the aim of understanding human actions and their emotional basis" (Eyerman 64-65). For the affirmation of identity, cultural practices are "instigated as mobilised force and then advanced the struggle against western domination everywhere in non-European world" (Said 218). The themes of homelessness, migrant experience and psychological state of condition forms the essentials of the narratives produced by novelists of British ex-colonies after their migration to Britain or to the United States who expose the

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condition and crisis of identity of the diasporans by highlighting their immigrant struggle and sensibility.

Postcolonial writers are inclined to deconstruct identity as a construct of power, hybridity and ambivalence in the established tradition, values and struggle as carried in the life of immigrants or diasporans. Whether in Gilles Deleuzel's 'territorialisation', Felix Guattari's 'deterritorialisation', or in Rushdie's 'chutnification', Bhabha's 'hybridisation', 'contact zone' and continuous 'play' of history, culture and power – in all of these intellectually stimulating postmodern concepts, the insight beckons that "cultural identity is invariably hybrid, consistently incomplete and fluid, and is to be entertained within cultural, historical and political frames of reference" (Singh 101). The typical binarism of Western thought between enlightened/ignorant, civilised/savage or center/periphery facilitates, to certain extents, deconstruction of power, and "displays the necessary deformation and displacement of all sites of discrimination and domination" (Bhabha 112). In sociological theories cultural durability establishes identity as a "collective notion" and a system of knowledge and consciousness. While Lacan's view fundamentally justifies identity as inherently unstable and as a knowledge of consciousness; Edward Said demonstrates how the west's intellectual superiority is hypothetically unoriginal, for "European culture gained in strength and identity by setting itself off against the Orient as a sort of surrogated and even underground self". (Said 3)

Raymond Williams, one of the most influential Marxist and cultural critics of the twentieth century, holds that the notion of history including all events of the past is available through the text. Since text is the location, the postcolonial critic does the historian's interpretation and evaluation of existing material conditions of power, belief system, values and visions. Cultural relativism, cultural hybridity and cultural reductionism occupy important places in the formation of identity and psychic operation of the diasporas in the "affective experience of marginality" (Bhabha 438). Literature is one important cultural form that presents the social events, ethnographic contexts and individual human destiny,

feelings, social traditions and customs. It is agreeable what New Historicists like Catharine Gallagher and Stephen Greenblatt believe that a cultural formation or historical omission may be found as the "textual traces in a culture" (14). In the textual traces and arbitrariness of text, cultural artifacts like painting, music, film, television, and existing social formations, dominant ideologies, power structures and material products are accommodated and embroidered in cognitive, normative and aesthetic dimensions.

According to Ahmed, as a social and national document presenting the "language of national integration and bourgeois civility" (Ahmed 75), literature presents empirical reality, perspectival difficulties and political actualities of the Third World life in sociological, historical, psychological and intellectual awareness. In the postcolonial literary perspective, "culture and literature, in other words, are not necessarily coterminous with linguistic formation and state boundary, especially in historical epochs proceeding the emergence of the bourgeois nation – state and … rise of print capitalism is a variable but by no means an invariable determinant" (ibid 244). Both literature and culture in their relative autonomy have aesthetic forms, principles of pleasure and specialised knowledge which are available in the disciplines like ethnography, historiography and psychology.

Identifying identity in literature and culture is a moralist act and intellectual enquiry. Outside Theory, the analysis of 'real-world' issues are not over. Frequent intellectual enquiries continue through 'enhanced interrogation techniques' to study identity and cultural politics in literature. Identity in literature and culture is often considered as a hegemonic political expression in practice and analysis. When its politicality and 'political convictions' are fixed and consolidated in literature and culture studies, one wonders:

> If consolidated representations of identity and truth are the necessary premise of certain democratic political claims, they also necessarily destroy the openness which the intellectual life required by rich formulations of democracy depends (Brown 41).

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Postcolonial literature and culture are the sites relevant to study recent social, political and technological transformations, anti-capitalist movements, and transnational relationships.

Frantz Fanon, Edward Said, Gayatri Spivak, Dipesh Chakrabarty and Derek Gregory believe that quest for identity and identifying identity in the warzone of ideas is to de-essentialise the self.

Postcolonial theory deals with the discontinuous and divergent cultural phenomena in the world of genders, ethnicities, classes, languages, different ages, families, professions and nations, and at the same time deconstructs the identity in philosophic and power relations between East and West. Hence, the decolonised people off the erstwhile British, French, American and Dutch colonies nurture and nativize a pathological obsession with identity.

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Change and Continuity among Tribes

Edited by

TARUN MENE

SARIT K. CHAUDHURI

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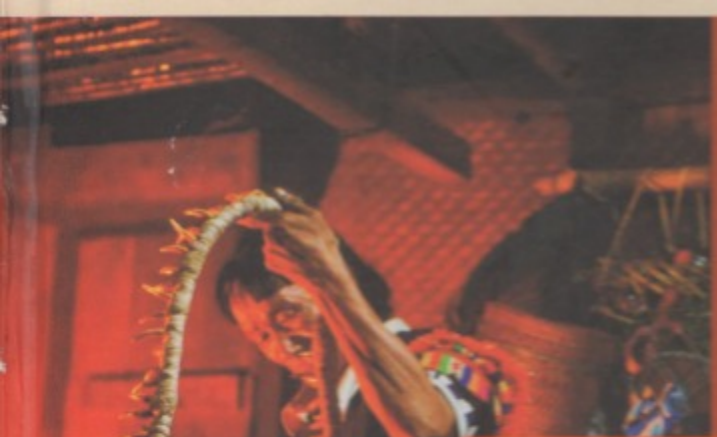
Change and Continuity among Tribes

Edited by
Tarun Mene
Sarit K. Chaudhuri



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Funeral Traditions of the Idu Mishmi Tribe of Arunachal Pradesh

S. SIMON JOHN AND MAYA PULU

Ritual practices, one of the important aspects of Intangible Cultural Heritage (ICH), have been a focus of study for long. Edmund Leach (1968) suggested that the term 'ritual' should be applied to all 'culturally defined sets of behaviour,' that is, to the symbolical dimension of human behaviour as such, regardless of its explicit religious, social, or other content. For Leach, such behaviour should be regarded as a form of social communication or code of information, and analysed in terms of its 'grammar'. Ritual is thus treated as a cognitive category. Eliade (1987) mentioned that 'rituals' are those conscious and voluntary, repetitious and stylized symbolic bodily actions that are centred on cosmic structures and/or sacred presences. Verbal behaviour such as chant, song and prayer are included in the category of bodily actions. Even more fundamentally, ritual is intentional body engagements in the paradigmatic forms and relationships of reality. As such, ritual brings not only the body but also that body's social and cultural identity to the encounter with the transcendental realm. By conforming to models or paradigms that refer to the primordial past and that can be shared by many people, ritual also enables each person to transcend the individual self, and thus it can link many people together into enduring and true forms of community. Ritual draws into itself every aspect of human life, and almost every discipline of the social sciences and humanities has something to say about it. The body is evidently more important in religious experience than is often thought of.

Rituals are orally transmitted from generation to generation and play a significant role in tribal culture. Generally, most of the rituals are associated

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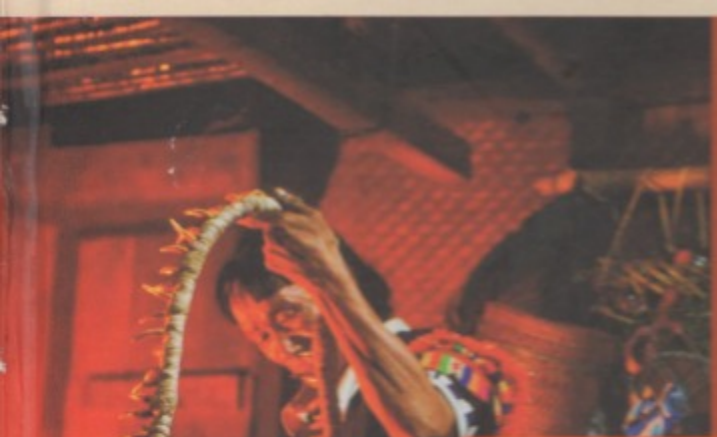

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The Great Fire and the Creation Myth

The Oral Tradition of the Idu Mishmis of Arunachal Pradesh

RUMO METO AND TARUN MENE

The Idu Mishmi tribe[1] is mainly concentrated in two districts viz. Lower Dibang Valley and Dibang Valley District of Arunachal Pradesh. Besides, they are also inhabited in small pockets in East Siang (Aohali village), Lohit (Tezu), Upper Siang (Singa) Districts of Arunachal Pradesh. They are included as a part of the larger constellation of the Mishmi group which includes Digaru and Miju Mishmis also.[2] Culturally, Idus are very much distinct from the rest of the two which are reflected in various aspects of their day-to-day life and social structure as well as value systems. Idu Mishmis are popularly known as the 'Chulikata Mishmis' because of their distinct hairstyle, perhaps this nomenclature is given by the people of the plains (Bhattacharjee, 1983: 13) with whom Idus had trade relations. Dalton (1872: 18) reported them as Midhi people and mentioned that they are greatly detested and mistrusted by their neighbours, the Abors and Tains and they are much dreaded by the Saudiya population in consequence of the prowling expeditions to kidnap women and children.

The migratory route is not clear; however, some light has been thrown on the topic by various researchers on the basis of oral history on the Idu tribe. For example, Bhattacharjee (1983: 13) believed that they must have come from the triangle of Burma where innumerable tribal groups of similar culture used to live in widely dispersed areas between Salween Mekong and Yangten. Baruah (1960: 7–13) in a similar fashion traces the original homeland of some clans such as *Inni-la Pon* of Mele clan, *Amriti* of the Taraon Polo and the Idu Pulu clan who migrated to the present place following the courses of Ilyu or Lohit rivers. He finally concluded that Idu's migrations took them through Tibet. Undeniable that the Idus have followed the various river courses such as Lohit or Illuh, Dri, Mathu, Ithun, Taloh, etc. from some ambiguous location and settled in various

Baseline correction of ECG using regression estimation method

Jagdeep Rahul[1*], Marpe Sora[2], LakhanDev Sharma[3]
[1]Department of Electronics and Communication Engineering, Rajiv Gandhi University,India.
[2]Department of Computer Science and Engineering, Rajiv Gandhi University ,India.
[3]Department of Electronics and Communication Engineering, MLV Textile & Engineering College, Bhilwara, India.
*Corresponding author
E-mail address: jagdeeprahul11@gmail.com

***Abstract*—The presence of baseline wander in ECG signal severely affects the quality of ECG signal. Baseline wander is generally eliminated at the initial stage of preprocessing of ECG signal. In this paper a method using regression estimation is applied to ECG signal to remove the baseline wander. This method uses two stage median filter and regression estimation for smoothing and correction of baseline. The cross correlation is performed between the baseline wander containing ECG signal with corrected ECG signal. Then cross-correlation coefficient is calculated. The method evolves with the lowess and loess of local regression estimation, rlowess and rloess of robust local regression estimation. We found highest coefficient of 0.9914 for the baseline wander amplitude of 0.5mV using local regression method (lowess) and lowest coefficient of 0.9688 for the amplitude of 0.8mV using robust local regression method (rlowess). Further this method is validated on MIT-BIH, Noise Stress Test Database (NSTD).**

Keywords—Baseline wander, ECG signal, local regression, noise.

I. INTRODUCTION

The heart diseases are the main cause of the sudden death in the world due to cardiac arrest. The electrocardiogram (ECG) is the electrical manifestation of the heart activity over the time shown in fig.1 [2]. It can be recorded for the purpose of detecting the various types of abnormalities in the heart [1]. The ECG is a non invasive and most widely used technique for the diagnosis of the heart diseases [10]. The ECG may be recorded in various conditions such as at rest, moving condition, or during stress situation. The recording of ECG at resting mode is performed, when subject is in supine condition for better ECG quality [1]. The moving condition ECG is recorded while patient carries out his daily activities for a period of twenty four hours or more. In this situation, the functioning capacity of heart is evaluated through the ECG recording and it is also capable to detect the arrhythmias such as arterial fibrillation, tachycardia, bradycardia and myocardial infarction [2]. The ECG contaminated with noises, when it is recorded in stress test during the time of acquisition[11,12]. The ECG is mainly affected by the main source of the noise in acquisition process is baseline wander. These are very low frequency noises ranging from 0.05 to 3Hz, inducted due to patient movement, breathing movement, poor body-electrode contact. The baseline wander (BW) noise almost affect the all ECG recording and degrade the accuracy of diagnosis. The presence BW noise in ECG also alters the ST segment characteristics, which play very important rolein determining the acute coronary syndrome. TheBW alsocreates the difficulty in real time monitoring of ECG and arrhythmia detection [3].

Several methods have been proposed by the many researchers to correct the baseline of ECG in order to remove the noise in ECG. In many methods, high pass filters using IIR or FIR have been used to remove the low frequency components by setting the cut off frequency but most of the time frequency spectrum of BW overlaps the ECG frequency spectrum [4]. Hence filtering of low frequency components may cause distortion in ECG. The moving average method is used to extract the BW from the original ECG. Then BW is subtracted from the contaminated ECG to obtain the clean ECG. However it may create distortion in ST segment. The cubic spline curve fitting method is also used to eliminate the BW by using fiducial points. Other methods such as wavelet filtering and empirical mode decomposition can be used to reduce the low frequency noises [13]. In BW removal, these methods give the excellent results but hardly implemented due to theirs cost in real time applications [5].

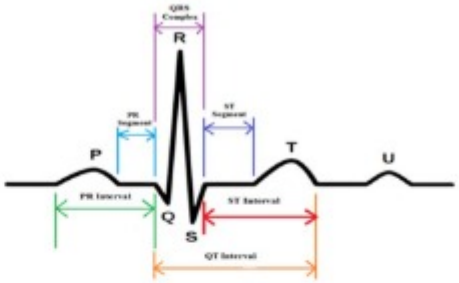

Fig.1 Representation of electrocardiogram (ECG) waveform [2]

In this work, we propose a method using regression estimation for baseline correction for accurate identification of arrhythmia. It accurately estimate the baseline and remove it, same time minimize the distortion and preserve the information of ECG signal. First of all ECG signal pass through the two stage median filter with different window size. Then regression method with and without weights and robustness (rlowess, rloess, lowess, and loess) is applied to estimate the BW. The lowess and loess are derived from the term 'locally weighted scatter plot smoothening', proposed by the Cleveland in 1979 [6]. Due to uncertainty in the variation of the BW, it is very hard to accurately estimate the BW by using a particular model. Lowess and loess both are locally weighted linear regression methods and used for smoothening the date. The rlowess and rloess are the robust local regression methods that can be utilized for smoothing the data, which are resistant to outliers. We have considered

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the standard ECG and baseline wander to verify the performance of lowess, loess, rlowess and rloess. Further it will be validated on MIH-BIH database.

II. METHODOLOGY

The basic preprocessing techniques and filters are mostly used in the ECG signal processing to suppress or remove the noises in ECG. This section is organized in four sub sections artificial ECG signal with baseline wander noise, local weighted linear regression estimation, robust local regression estimation and cross correlation coefficient.

A. ECG signal with Baseline wander noise.

An artificial ECG signal is generated using the ECGSYM software of Physionet, which allows user to configure the ECG parameters like heart rate, sampling rate, frequency and other morphology of ECG waves etc. A ten second duration segment of artificial ECG signal of 70 beats per minutes is chosen for this study, which is shown in fig.2. The baseline wander noise signal is generated and added with artificial signal. The considered BW for this study has assumed that these are generated during the time of breathing and movement of electrodes, which is shown in fig. 3.

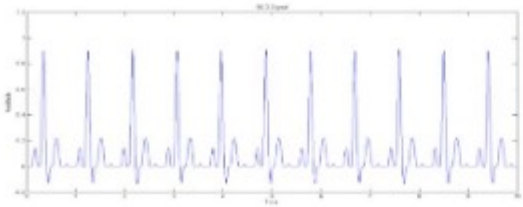

Fig.2. Generated artificial ECG signal

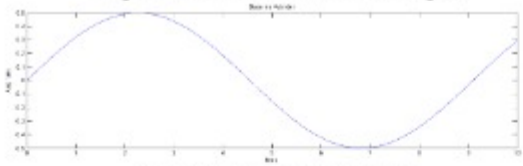

Fig.3. Baseline wander noise.

B. Local Regression Method

Local regression was initially developed for local scatter plot smoothening and also known as local polynomial regression. The lowess, and loess are non-parametric regression and built on classical methods like linear and non-linear least square regression. When each smooth value is generated by the weighted linear least square regression over a span is known as lowess plot. Other hand each smooth value given by weighted quadratic least square regression over a span is known as loess plot. The local polynomials can fit into each subset of the data that are always first or second degree. The higher degree polynomials generally work in theoryonly, numerically unstable and create difficulty in accurate computation [7]. The local regression methods go through the following steps

1. Computation of weights for each data points in a span. Weights are calculated by given below function

$$W_i = \left(1 - \left|\frac{x - x_i}{d(x)}\right|^3\right)^3$$

Where x is the predicted smooth value, xi is the nearest neighbor of x in a defined span and $d(x)$ is the distance from the x, most distant predicted value within the span. Weights should have the following characteristics

   (i) The largest weighted data point value to be smoothed within the span.
   (ii) The data point outside the span not to be considered and zero weight.

2. First degree polynomial is used in regression of lowess and second degree is used for loess.
3. The final smoothed value is estimated by the weighted linear regression at the predicted value of interest.

C. Local Robust Regression

The local robust regression method is used when data point contains outliers and smoothed value becomes distorted. Due to outlier, smoothed value does not reflect the behavior of bulk of neighboring data points. The small fraction of outlier does not affect the smooth value in robust regression method. The robust lowess and loess are used for smoothening the data. These robust methods use different methods for calculating the weights, which is resistant to outliers [8]. The weight calculating procedure follows these steps

1. Calculation of residuals from smoothening process
2. Computation of robust weights for each data point within the span. Weights are calculated by the equation given below

$$W_i = \begin{cases} (1 - (r_i/6MED)^2)^2 & |r_i| < 6MED, \\ 0 & |r_i| < 6MED \end{cases}$$

   Where r_i is the residual point, MED is the absolute deviation of the residuals $|r_i|$.
3. The data is smoothed again using robust weights. Final smooth data values are calculated using both robust weights and regression weights.
4. Last two steps will be repeated for five times.

D. Calculation of cross-correlation coefficient

The cross-correlation coefficient is calculated after removing the baseline wander from the raw ECG signal. The cross-correlation coefficient determines the similarity between the two series as a function of displacement one relative to other [9]. The coefficient (r) is calculated by given below equation.

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]}}$$

Where X is the artificial ECG signal, Y is the ECG signal after removal of baseline wander noise.The cross correlation coefficient value lies between the 0 and 1. The maximum correlation is represented by 1 and minimum correlation is represented by 0.

III. RESULTS AND DISCUSSION

The contaminated ECG signal pass through the two stage median filter to remove the varying baseline in the ECG signal. In the first stage median filter the size of window is equal to the sampling frequency and in second median filter the size window is equal to the half of the sampling frequency. Then regression estimation is performed to smooth the ECG wave for accurate identification and determination of the arrhythmia in the ECG recording. For validating this technique, the cross correlation coefficients are calculated with lowess and loess, using both weight and without weight local regression estimation. The cross correlation coefficient performed between the clean artificial ECG and corrected ECG signal after the subtraction of baseline wander (BW) noise. The fig.4 (a) shows the ECG signal with baseline wander noise or raw ECG signal. The fig.4 (b) shows the output of first median filter having the window size equal to the sampling frequency. The fig. 4(c) shows the output of second stage median filter having the window size equal to the half of the sampling frequency. Then the extracted baseline wander is subtracted from the contaminated ECG signal. After subtraction the regression estimation method is applied to the ECG signal for smoothing and correction of the ECG signal, which is shown in fig. 4(d).

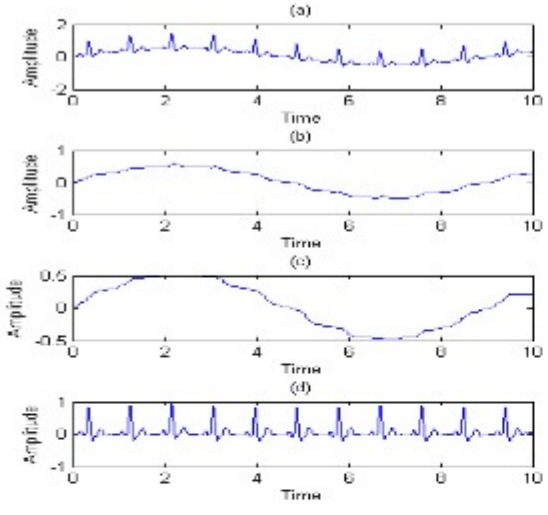

Fig.4. (a) ECG signal with Baseline wander noise. (b) Baseline wander noise after first median filter. (c) Baseline wander noise after second median filter (d) Clean ECG signal after subtraction and regression estimation.

In this study we have also considered six different amplitude baseline wander noises for validation of this technique through the calculation of cross correlation coefficients. The various types of BW are considered in this study, whose amplitude is ranging from 0.5 to 1 mV, are shown in fig.5. The cross correlation coefficients for different baseline wanders are shown in Table.1. All coefficients are found in the acceptable range from 0.9688 to 0.9914. We found highest coefficient for the BW amplitude of 0.5mV using local regression method (lowess) and lowest for the amplitude of 0.8mV using local robust regression method (rlowess).

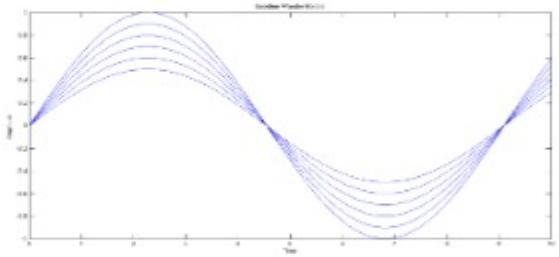

Fig.5. Different amplitude baseline wanders

Table1. Cross-correlation coefficient of baseline wanders with different amplitude.

Sl. No.	Amplitude(mV)	lowess	loess	rlowess	rloess
1	0.5	0.9914	0.9913	0.9841	0.9912
2	0.6	0.9895	0.9894	0.9817	0.9896
3	0.7	0.9874	0.9874	0.9779	0.9873
4	0.8	0.9851	0.9851	0.9688	0.9843
5	0.9	0.9828	0.9828	0.9750	0.9827
6	1.0	0.9802	0.9803	0.9818	0.9804

This method is applied to the MIT-BIH Noise Stress Test Database (NSTD) for further validation of this method using local regression (lowess).

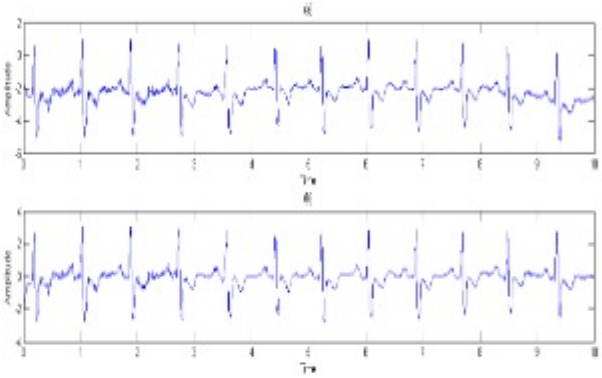

Fig.6. (a) MIT-BIH, ECG signal record 118e00m of NSTD (b) Baseline corrected ECG signal.

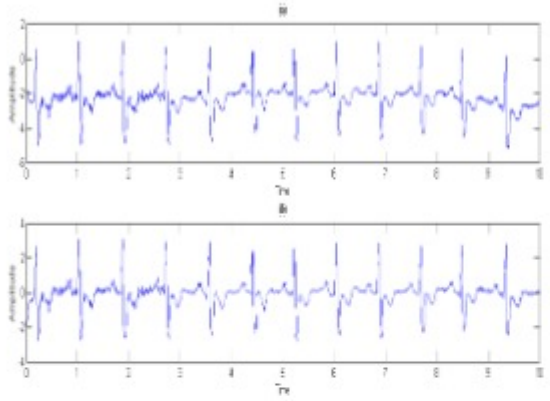

Fig.7. (a) MIT-BIH, ECG signal record 118e06m of NSTD (b) Baseline corrected ECG signal.

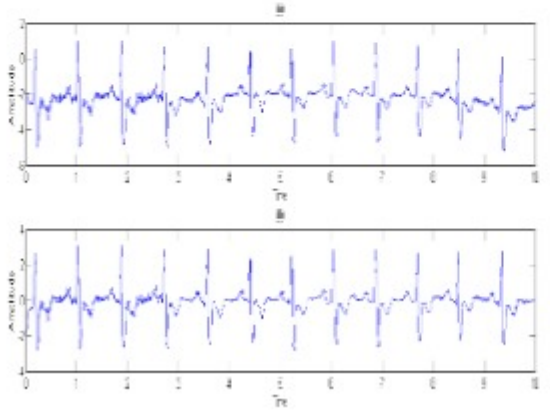

Fig.8. (a) MIT-BIH, ECG signal record 118e12m of NSTD (b) Baseline corrected ECG signal

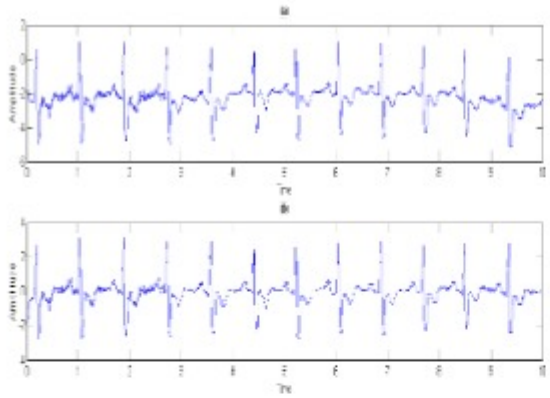

Fig.9. (a) MIT-BIH, ECG signal record 118e18m of NSTD (b) Baseline corrected ECG signal

The regression estimation method on MIT- BIH Noise Stress Test Database (NSTD) applied and gives the good results in acceptable range. The fig.6 (a) shows the 118e00m signal record from the database and fig. 6(b) shows the processed ECG signal after applying the regression method. This method is applied on ECG records 118e06m, 118e12m and 118e18m on MIT-BIH database respectively and results are found in acceptable range.

IV. CONCLUSION

The removal and correction of baseline wander (BW) in ECG is become very important step in ECG signal processing. In this work we proposed a method to remove the baseline wander using regression estimation. The clean ECG signal is obtained after the subtraction of BW from the raw ECG signal. This method is applied on variety of BW having different amplitude ranging from 0.5mV to 1mV. The simulated results shows that proposed method can effectively correct the baseline of ECG signal with minimum distortion. The performance of proposed method is depends on window size of median filters and also on type of local regression. We found that use of 'lowess' in local regression estimation methods gives the better results and suitable for ECG signal processing for devices.

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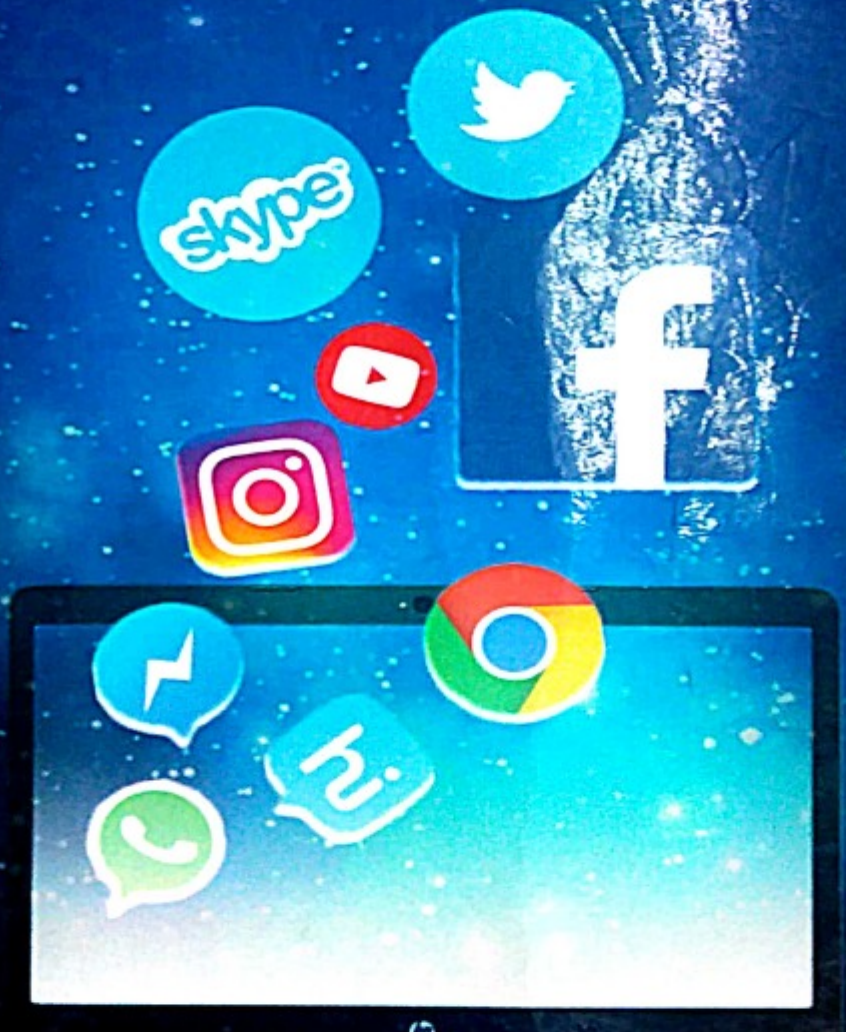

डॉ. सोनाली नरगुंदे | डॉ. नम्रता शर्मा

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मीडिया लेखन की नई जवाबदेहियाँ और चुनौतियाँ

डॉ. राजीव रंजन प्रसाद
सहायक प्रोफेसर, हिन्दी विभाग
राजीव गाँधी विश्वविद्यालय, रोनो हिल्स, दोईमुख, अरुणाचल प्रदेश-791112
मो. : 9436848281, ई-मेल : rrprgu@gmail.com

जन-समाज की एक बड़ी उपलब्धि भाषा का हमारे साथ होना है। सामाजिक-प्राणी के रूप में मनुष्य बोलने-सुनने-समझने योग्य तो है ही वह लेखन-कला में भी पारंगत है। बोलने वाला प्राणी होना एक जन्मजात नैसर्गिक गुण है जिसके माध्यम से वह बाद में भाषा अर्जित करता है और तदुपरांत लिखना। वास्तव में बोलना और सुनना अभिव्यक्ति-कुशल व्यक्ति का सशक्त औजार है, किन्तु लिखना एक विशेष विधा है। यह वह प्रभावशाली माध्यम है जिसमें रचित कालजयी रचनाओं यानी साहित्यिक कृतियों से हमारा भविष्य संस्कारित होता है, तो हमारा इतिहास-बोध सचेतन तथा जीवंत बनता है। इस बात से सभी पूर्णतया परिचित हैं कि भाषा किसी विचार या संकल्पना को साकार करने में अग्रणी भूमिका निभाती है। चिंतन-धारा को सहेजने तथा उसे जाहिर करने में उसका महत्त्व अनन्य है। कई मर्तबा भाषा स्वयं संशोधित-सम्पादित, परिष्कृत एवं परिवर्तित भी होती जाती है। विशेषतया लेखन में यह रचाव-बनाव या सौन्दर्य –सौष्ठव अधिक दिखलाई देता है।

लेखन का काम आसान नहीं है। चेतन-अचेतन के माध्यम से दिमाग में उपजे किसी विचार को आप वाक् में यकायक नहीं ढाल लेते हैं। दिलोंदिमाग में इसकी पूरी प्रक्रिया चलती है। भाषा में सम्बोधित होने से

पूर्व जो मानसिक-शारीरिक प्रक्रिया दिमाग में घटित होती है उसे मनोभाषिकी कहा जाता है अर्थात् मन के स्तर पर बोली जाने वाली वह भाषा जिसका अहसास तो होता है किन्तु उसमें वाक्-ध्वनि अनुपस्थित रहती है। यानी मन में किसी के बारे में भला-बुरा सोचिए, उसके बारे में अजीबोगरीब चित्रण कीजिए, उस पर आँखे टिकाए होने के बावजूद उसे नजरअंदाज कीजिए; यह सबकुछ होता आपके भीतर है लेकिन इस अनकहे की भाषा व्यक्त नहीं होती है। इसे मनोविज्ञान की भाषा में 'इन्टरनल स्पीच' या 'सेल्फ इमेजिनेशन' कहते हैं। अभ्यस्त होने के कारण मनुष्य इस रवैए का इस कदर आदी हो जाता है, मानो ये सबकुछ अपने आप घटित हो रहा हो, जबकि ऐसा बिल्कुल नहीं है। जिस तरह पढ़ने का इरादा न हो तो हम कतई पढ़ नहीं सकते हैं; उसी तरह लिखना भी प्रयत्नपूर्वक ही संभव है। इसकी पूर्व तैयारी अत्यावश्यक है। इसकी प्रक्रिया को अंजाम तक पहुँचाना पड़ता है। आपने किसी को 'टेक्सट मैसेज' भेजने को सोचा। क्या सोचने मात्र से वांछित संदेश अपने गंतव्य तक पहुँच जाएगा। नहीं न! उसके लिए संदेश लिखने होंगे या कंप्यूटर द्वारा टाइप करना होगा।

अब तो कंप्यूटर के आने से पारंपरिक तरह से लिखने और भेजने का झंझट नहीं रहा। अब हम बिना डाकघर गए, लिफाफ़े को चिपकाए बगैर अपना लिखा किसी को त्वरित ढंग से भेज सकते हैं। अपना मोबाइल फोन तो सबसे स्मार्ट है। सेल्फ़ी, वीडियो रिकार्डिंग, वायॅस चैट, वीडियो कॉलिंग इत्यादि तो आम बात है। लेखन-सामग्री हेतु अब धूल-धकड़ से सनी किताबों पर हाथ फेरने की आवश्यकता नहीं रही। क्योंकि कई सारे ऐप और सॉफ्टवेयर स्मार्टफोन में उपलब्ध हैं जिनके माध्यम से हम मनोवांछित सामग्री देख व पढ़ सकते हैं। कंप्यूटर ने इंटरनेट के साथ विशाल जालनुमा एक ऐसी आभासी जगह (वर्चुअल

स्पेस) बना दी है जिसमें दुनिया-ज़हान की सैर 'फ्रैक्शन आॅफ सेकण्ड' में संभव है। इस अन्तर्जाल को आजकल 'वर्चुअल वर्ल्ड' कहा जा रहा है तथा ये सब क्रियाकलाप जहाँ घटित होते हैं उसे 'वर्चुअल स्पेस' कहलाते हैं। यह माध्यम पुराने सभी माध्यमों से दिलचस्प है क्योंकि यह मल्टीमीडिया यानी बहुमाध्यम है। मल्टीमीडिया का कमाल यह है कि अब हम बोलते जाएँ और हमारा मोबाइल उसका लिप्यांकन भी करता जाएगा। हिंदी टाइपिंग और मनमाफ़िक टाइप-फेस सचाई है जिससे हिंदी भाषा में मुद्रित सामग्री का प्रस्तुतीकरण लाजवाब होता है। दरअसल, कंप्यूटर गुणों की खान है। जैसे-लेआउट, डिजाइन, ग्राफिक्स, एनिमेशन, कलर-कंट्रास्ट, साउंड इफेक्ट, पिक्चर एडिटिंग, वीडियो सर्फिंग, शेयर, अपडेट इत्यादि। आमजन से जुड़े सभी लेखन-माध्यम मिलकर जिस तौर-तरीके को जन्म देते हैं उसे जनसंचार माध्यम लेखन कहते हैं। विशाल भू-भाग में बसे लोगों तक अब संचार के पुराने 'एप्रोच' द्वारा पहुँच सकना संभव नहीं है। यथा: अन्तरवैयक्तिक संचार, समूह संचार आदि। लेकिन बीती सदी में समाचार-पत्र, रेडियो और टेलीविज़न के आगमन से यह काम आसान हो गया है। इस इक्कीसवीं सदी में कंप्यूटर और इंटरनेट ने 'सूचना', 'शिक्षा' एवं 'मनोरंजन' के क्षेत्र में 'आइस युग' का सूत्रपात कर डाला है। यह 'आइस युग' सूचना एवं संचार-प्रौद्योगिकी आधारित है जिसमें किताबों का महत्व घटा है जबकि तकनीकी-प्रौद्योगिकी आधारित पहुँच का दायरा अप्रत्याशित ढंग से बढ़ा है। सिनेमा और टेलीविजन से कंप्यूटर चार कदम आगे हैं क्योंकि उसके द्वारा कई और काम भी किये जा सकते हैं। कंप्यूटर अब एक प्राथमिक कौशल विकास का रूप ले चुका है। कंप्यूटर लिटरेसी पर बल ज्यादा है। इसी प्रकार इंटरनेट की विशेषताएँ बहुत सारी हैं। जैसे इंटरनेट से जुड़े कंप्यूटर गाने को सुन ही नहीं सकते हैं बल्कि उसे बाद के लिए सुरक्षित भी

रख सकते हैं। इसको कहते हैं-'डाउनलोड एण्ड सेव'। ये गाने जरूरी नहीं कि केवल सुनने वाले हों बल्कि वे आसानी से देखे और सुने भी जा सकते हैं। विडीयो की दृष्टि से यू-ट्यूब बड़ा ज़खीरा है।

कुछ समय पूर्व तक रेडियो की लोकप्रियता बहुत अधिक थी। उसे आकाशवाणी के रूप में जाना गया। बाद मे विविध भारती ने रेडियो कार्यक्रम में चार चाँद लगाए। इसके बाद रेडियो एफ.एम. का नया ज़माना आया जिसमें रेडियो जाॅकी की अदा और शोखी ने सुनने वालों का मन मोह लिया। शुरूआत में रेडियो पर कई मोहक शास्त्रीय और सुगम संगीत बजते थे। जरूरी एवं चर्चित विषयों पर परिचर्चा होती थी, तो कई बार गंभीर मुद्दों को लेकर विषय-विशेषज्ञ वार्ता प्रसारित करते थे। आज भी महात्मा गाँधी और सुभाष चन्द्र बोस के प्रसारण की खूब चर्चा होती है। रेडियो पर प्रसारित होने वाले नाटकों, प्रहसनों, झलकियों आदि की अपनी विशेष लोकप्रियता है। बहुचर्चित रेडियो की घोषणा थी-'बहुजन हिताय, बहुजन सुखाय'। लोग सुन-सुना रहे थे- देशहित में, लोगों को जागरूक कर रहे थे-राष्ट्रहित में। उनकी कामना में मंगल का उदय और संभावना के शुभ-चिह्न शामिल थे। राजनीति में हर तरह के लोग थे-किन्तु सबका मुख्य स्वर राष्ट्रीयता का था। साहित्यिक-पत्रकारिता का इतिहास देखें, तो लिखे-छपे अक्षरों की वास्तविकता समझ में आ जाती है। रेडियो ने भारतीय ज़मीं में रची-बसी सामूहिक रागात्मकता को जैसे सार्वजनिक कलरव में तब्दील कर दिया। उन दिनों टेलीविज़न की दुनिया एवं उनकी कहनशैली में वही सबकुछ शामिल था जो उनके आँखों के आगे रोज घटित और मंचित हो रहा था। सत्य की इस पक्षधरता का ध्येय वाक्य था-'सत्यम् शिवम् सुन्दरम्'। समाचार-पत्र, सिनेमा, रेडियो और आजादी के तुरंत बाद टेलीविज़न ने पूरा परिदृश्य ही बदल कर रख दिया था। स्वाधीनता प्राप्ति के बाद टेलीविज़न का घर-घर चलन बढ़ने लगा।

भारतीयता के मूल-भावना और पारिवारिक-संस्कार को रचने-बुनने में टेलीविज़न ने सबके बीच एक साझा मंच तैयार कर दिया। टेलीविज़न ने अपनी जगह ही नहीं बना ली, बल्कि कई महत्त्वपूर्ण सामाजिक बदलाव भी किए। 'हम लोग' और बुनियाद' धारावाहिक ने भारतीय समाज का घरेलू चेहरा सामने रखा, तो 'रामायण' एवं 'महाभारत' जैसे धारावाहिकों ने ऐतिहासिक मिथकों एवं पौराणिक गाथाओं को नई ऊँचाई प्रदान की। उन दिनों साहित्यसेवियों ने सिनेमा को नई धार दी। कई फ़िल्में ऐसी बनी जो मूलतया साहित्यिक कृतियों की भावभूमि यानी विचार एवं प्लॉट पर सीधे बनाए गए थे। सुजाता, शतरंज के खिलाड़ी, सारा आकाश, आँधी, हजार चौरासी की माँ आदि। इस तरह दृश्य-श्रव्य माध्यम ने तद्युगीन पीढ़ी को सांसारिकता से पिंड छुड़ाने की बजाए समकालीन परिस्थितियों से लड़ने-भिड़ने की चुनौती पेश की। इसी दौर में अमिताभ बच्चन के रूप में 'यंग्री यंगमैन' का जन्म हुआ। मिथुन चक्रवर्ती और अनिल कपूर भारतीय घरेलूपन का युवा चेहरा बनकर उभरे। इस प्रकार कई सारी विसंगतियों और आजादी के बाद की घटनाओं पर केन्द्रित ढेरों फिल्में बनी जिसके केन्द्र में स्वाधीन भारत का बनता-बिगड़ता हुआ समाज था। नए तरीके के कलात्मक-रचनात्मक-बौद्धिक लोग इन माध्यमों से जुड़े। उन्होंने इन माध्यमों के लिए लिखा भी खूब। प्रेमचन्द जैसे अग्रणी साहित्यकार भी पीछे नहीं रहे। यह और बात है, बाद के दिनों में प्रेमचन्द ने फ़िल्म इंडस्ट्री से दूरी बना ली। कमलेश्वर, राजेन्द्र यादव, मनोहर श्याम जोशी जैसे प्रख्यात साहित्यकारों का फ़िल्मी अवदान स्तुत्य है। उदाहरण के रूप में अच्छी फ़िल्मों की लम्बी फ़ेहरिस्त सामने रखी जा सकती है जिसने भारतीय जनसमाज के बदलते चेहरे का हू-ब-हू चित्रण किया।

समाचार-पत्र एवं पत्रिकाओं की बात करें, तो इसकी कहानी दिलचस्प है। 1780 के करीब भारत में प्रेस का आगमन हुआ जबकि गुटेनबर्ग ने 1455 ई. में ही मुद्रण-मशीन का आविष्कार कर दिया था। हिंदी में समाचार-पत्र की छपाई उन्नीसवीं सदी में शुरू हुई। पहला साप्ताहिक अख़बार पंडित युगल किशोर शुक्ल के सम्पादन में कलकत्ता से 30 मई, 1826 में प्रकाशित होना शुरू हुआ। इसके बाद तो हिंदी पट्टी के सोये मन में आग लग गई। गुलामी से बँधे-कसे भारतीयों में चेतना का संचार होने लगा। लोग आपस में संवाद करने का एक शक्तिशाली औजार पा गए। समाज में व्याप्त कुरीतियों-अंधविश्वासों पर प्रहार होने लगा। 1829 ई. में सती-प्रथा का उन्मूलन इसी जागृति या जन-जागरण का परिणाम कहा जाना चाहिए। जानकार और समझदार लोगों ने भारत की दुर्दशा के कारण के रूप में भारतीयों की यथास्थितिवाद और किं कर्तव्य विमूढ़ वाली धारणा को जवाबदेह ठहराया। यह कहा जाने लगा कि अंग्रेज हमारे भोलेपन का कम बल्कि हमारे भीतर बैठे आपसी भेदभाव की भावना के कारण अपना हुक्म हम सब पर चला रहे हैं। आपसी झगड़े, रंजिश, शत्रुता के कारण पूरे देश में एकजुटता का अभाव है। बाहरी विचारधारा और मानसिकता वाले लोग हमारी भलाई क्यों चाहेंगे जब हम खुद ही एक-दूसरे का अहित करने का सोचे बैठे हों। अंग्रेजी शिक्षा ने स्वतंत्रता यानी गुलामी से मुक्ति को मनुष्य की बेहतरी का प्रतीकचिह्न बतलाया। इसके अतिरिक्त उनका बल समानता और बंधुत्व पर अधिक था। भारतीयों में यह भावना बलवती होने लगी कि स्वाधीनता से बढ़कर कोई चीज नहीं है। इस बारे में खूब लिखा-पढ़ा गया। यह दौर ही नवजागरण का कहलाया। अख़बार और पत्र-पत्रिकाओं ने कड़े प्रेस कानून होने के बावजूद अपनी राष्ट्रीयता के लिए वे सब दुःख सहे, जिसकी कल्पना मात्र हमारी आत्मा को झकझोर देती है। समाचार पत्र संस्थान

हर राष्ट्र में 'वाचडॉग' की तरह होते हैं। जन-संवेदना एवं जन-सरोकार की सबसे अधिक पूछ एवं उनकी रक्षा प्रेस करता आया है।

आज प्रेस या समाचार-पत्र भले अपना महत्त्व खो चुके हों लेकिन एक समय था जिस समय अकबर इलाहाबादी का यह शेर बेहद मशहूर था-'खींचों न कमानो को और न तलवार निकालो, जब तोप मुकाबिल हो तो अख़बार निकालो।' वह समय कुछ और था। समाचार-पत्रों के पास स्वतंत्र विचार-दृष्टि हुआ करती थी। वे निष्पक्षता एवं पारदर्शिता के मिसाल थे। राजा राममोहन राय, पंडित युगल किशोर शुक्ल, भारतेन्दु हरिश्चन्द्र, पं. बालकृष्ण भट्ट, बालमुकुंद गुप्त, पं. मदन मोहन मालवीय, आचार्य महावीर प्रसाद द्विवेदी, बाल गंगाधर तिलक, गणेश शंकर विद्यार्थी, बाबूराव विष्णु पराड़कर, माखनलाल चतुर्वेदी इत्यादि का नाम गुणी और विवेकी सम्पादकों में अग्रगण्य है। महात्मा गाँधी और मुंशी प्रेमचंद की पत्रकारीय-चेतना और जन-जुड़ाव लोक-विदित है। गणेश शंकर विद्यार्थी की यह जनपक्षधरता ही थी जो युवाओं को आगाह करते हुए कहा था- ''गालियाँ देने, डींगे मारने, दूसरों पर धूल फेंकने से न कोई बड़ा होता है और न कोई बड़ा काम हुआ करता है। बहुधा तो जो गरजते हैं वे बरसते ही नहीं; जो बड़ी डींग मारा करते हैं वे बड़े कायर हुआ करते हैं। देश के नौजवान इस कुटेव से बचें। वे बढ़-बढ़कर बातें न मारें। बढ़-बढ़कर काम करें।''

बाद के दिनों में कई सारे सम्पादक हुए जो पत्रकारिता की मूल्य रक्षा हेतु अत्यंत सजग और प्रयासशील रहे। आज भी समाचार-पत्र टेलीविज़न से अधिक विश्वसनीय और आमजन के करीब हैं। अंध-व्यावसायिकता के इस दौर में भी गुणी तथा विवेकवान सम्पादक अपना पत्रकारीय-धर्म नहीं भूले हैं। वे बाज़ार के असंगत दबाव के बावजूद अपना

दायित्व-बोध अच्छे से निभाते हैं। उनकी दृष्टि में जनपक्षधरता का मूल्य सर्वोपरि है। इस नाते उनके चयन एवं प्रस्तुतीकरण अतिरंजता और सनसनीपन का शिकार नहीं हो पाते हैं। वे मुद्रित माध्यम की महत्ता और उसकी भूमिका से सुपरिचित हैं। ध्यातव्य है कि समाचार-पत्र का लेखन प्रायः सधा हुआ और विषय-सन्दर्भित होता है। सम्पादकीय-पृष्ठ वैचारिक आइने का सीधा गवाह होता है, इसलिए सम्पादक उसकी तैयारी अधिक सजगता एवं सावधानी के साथ करते हैं, ताकि जनसमाज को वास्तविकता बेलागलपेट मालूम हो सके। इधर हाल के दिनों में समाचार-पत्रों ने अपनी गरिमा को अवश्य गिराया है, लेकिन इसकी आलोचना-समालोचना भी इसी बिरादरी ने सबसे अधिक की है। बात चाहे पेड न्यूज़ की हो या गोदी मीडिया की या फिर इम्बेडेड जर्नलिज़्म एवं समाचार-मिलावट की; समाचार-पत्रों ने इस तरह के सार्वजनिक चलन को पत्रकारिता के स्वास्थ्य के लिए सबसे हानिकारक माना है।

दरअसल, किसी भी पत्र-पत्रिका का सम्पादक रचनाकार और पाठक के बीच मध्यस्थ होता है। प्रकाशन-पूर्व पत्रिका के सम्पादन की जवाबदेही उसी की होती है। उसका प्रयास होता है कि सम्पादित रचनाएँ भ्रामक एवं त्रुटिपूर्ण न हो। इसके लिए कॉपी-सम्पादक का विषय सम्बन्धी विशेषज्ञता अनिवार्य है। यदि सम्पादित सामग्री साहित्य और कला विषयक हो, तो वह विशेष सतर्कता बरतता है। सम्पादकीय अंतर्दृष्टि सम्पादन के अन्तर्गत उपयुक्त स्थान प्राप्त करती है। इसी कौशल के आधार पर वह परस्पर विरोधाभास व्यक्त करने वाले असंगत वाक्यांशों को अलग कर देता है, ताकि रचना का कोई भी अंश विरोधाभासी अथवा बेमेल नहीं लगे। सम्पादकीय-कार्य से जुड़े लोगों के भीतर कुछ खूबियों का होना आवश्यक है। यथा: विशेषज्ञता, इतिहास-बोध, अनुभव एवं अंतर्दृष्टि, कल्पनाशीलता, व्यापक दृष्टिकोण, सम्यक

विचारधारा और सचाई का आग्रह, कार्यशैली में एकरूपता, स्पष्ट वैचारिकी और भविष्य-योजना, परिवेश एवं देशकाल-बोध, तकनीकी सम्पादन-कौशल का ज्ञान, भाषा पर पकड़, चयनित पाठ का वस्तुपरक अन्तर्वस्तु विश्लेषण, सार्थक एवं प्रभावशाली प्रस्तुतीकरण का विवेक, नूतन-नवीन प्रयोगों का समर्थक, कलात्मक चित्रों का उपयुक्त चुनाव, पूर्वग्रहमुक्त, सम्पूर्णता की खोज, निर्णय की क्षमता, सामाजिक, सांस्कृतिक पक्ष और प्रभाव के प्रति सचेष्ट, पाठकीय मनोभाव और मनोगत संप्रत्ययों की समझ और पड़ताल, विश्व-मानव के निर्माण का लक्ष्य, सार्वदेशिक सांस्कृतिक आदान-प्रदान के लिए सुनियोजित प्रयास एवं प्रोत्साहन इत्यादि। जनहित और जन-सरोकार को प्राथमिकता देने वाले सम्पादकों ने अपने लिए सम्पादकीय मूल्य निर्धारित कर रखा है। जैसे-तथ्यपरकता, वस्तुनिष्ठता, निष्पक्षता, संतुलन, स्त्रोत का उल्लेख आदि। ऐसा नहीं है कि इन सब का अनुपालन करते हुए सम्पादक को किसी चुनौती अथवा संकट से जूझना न पड़ता हो; बल्कि वे बहुत सारे हैं। उदाहरणस्वरूप पूर्वग्रह, अतिरिक्त झुकाव, अवांछित दबाव, आवारा पूँजी से मुठभेड़, शासकीय या सरकारी-तंत्र द्वारा पिछलग्गू बनाए जाने का ख़तरा इत्यादि। अतः समाचार-पत्र लेखन में एक पत्रकार ख़तरों के खिलाड़ी की भूमिका में होता है। वह सदैव दोधारी तलवार पर चलता है।

अगर थोड़ी बात न्यूज़ चैनल की करें, तो समाचार का चैतरफा समय (24x7) और टेलीविजनों में महाएपिसोड का दौर बहुत बाद में शुरू हुए। बीसवीं सदी के एकदम आख़िर में। पहले तो रेडियो 'बीबीसी' और 'दूरदर्शन' विश्वसनीय जानकारी के पुख़्ता औज़ार थे। अख़बार कुछ जानने-समझने की पहली खुराक थी। वहीं अब समाचार-पत्रों और ख़बरिया-चैनलों के ई-पेपर/वेब-संस्करण मौजूद हैं। यानी अब का गतिशील समय 'डिजिटलाइजेशन' की बढ़ती माँग पर टिका हुआ है। अब

सबकुछ कंप्यूटरीकृत भाषा में दर्ज है। डिजिटल लाइब्रेरी के चलन ने हमें ज्ञान के अथाह स्रोत तक पहुँचा दिया है जिसमें अपनी अभिरुचि एवं आवश्यकता के अनुरूप कोई भी मुद्रित/श्रव्य/दृश्य-श्रव्य सामग्री 'एक्सेस' यानी प्राप्त की जा सकती है। अब ऐतिहासिक महत्त्व के पांडुलिपियों एवं हस्तलिखित सामग्रियों का दस्तावेजीकरण भी जोर-शोर से किया जा रहा है। यही नहीं कई लुप्तप्राय ऐसी भाषाएँ जिनका अस्तित्व ही खतरे में आ पड़ा है या कि उनका कोई लिपि-प्रतीक नहीं है; के संरक्षण-संवर्द्धन हेतु 'डिजिटल आर्काइव' बनाया जा रहा है। और यह सबकुछ माध्यम-लेखन की प्रक्रिया में कंप्यूटर द्वारा संभव हो पा रहा है। लेखन का महत्त्व है, क्योंकि भाषा को दीर्घायु बनाने में लिपि का महत्त्व अन्यत्म है। यूनीकोड की कंप्यूटरीकृत भाषा एक डिजिटल लिपि-प्रतीक है जिसमें सभी भाषिक-प्रतीक समाहित हैं। यथा: अक्षर, शब्द, पद, पदबंध, वाक्य आदि। हर किसी के लिए लिखना उसकी इच्छा पर निर्भर हैं किन्तु रचनात्मक एवं प्रभावी लिखने के लिए कठिन श्रम करना पड़ता है। बेहद अभ्यास से अपने लेखन को साधना होता है। सरल एवं आसान भाषा में लिखना तो और कठिन तप है। अतएव, समाचार लेखन हो या रेडियो लेखन या कि सिनेमा हेतु पटकथा लेखन; सबकुछ हमारे इस दिशा में किए जा रहे कार्य एवं सोचने के ढंग पर निर्भर है। वास्तव में, लेखन सम्बन्धी बारीकियों को समझे बिना लेखन-कार्य में दक्ष-प्रवीण होना संभव नहीं है। कुछ भी लिखना अथवा कैसे भी लिख लेने वाला रवैया हमें परीक्षा में पास तो येन-केन-प्रकारेण करा सकते हैं, किन्तु ज्ञान एवं अनुभूति के लिए, संवेदना और दृष्टि के लिए, विचार एवं प्रज्ञा हेतु यह तरीका बिल्कुल अपर्याप्त है। जिस तरह अच्छा वक्ता होने के लिए बेहतर श्रोता होना आवश्यक है; उसी तरह अच्छा लेखक बनने के लिए बेहतरीन और धैर्यशील पाठक/श्रोता/दर्शक बनना बेहद जरूरी है।

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देश के मुंडेर पर बसा प्रदेश अरुणाचल

□ डॉ. राजीव रंजन प्रसाद*

अरुणाचल प्रदेश बहुभाषिक और जनजातीयबहुल राज्य है। भारत के 29 राज्यों में से अरुणाचल प्रदेश एक है। अरुणाचल प्रदेश के विभिन्न जिलों में निवास करने वाले लोगों की कुल संख्या लगभग 13 लाख है, जबकि जनसंख्या घनत्व प्रति व्यक्ति वर्ग किलोमीटर पूरे देश में सबसे कम है। अरुणाचल प्रदेश में तकरीबन 26 तरह की मुख्य जनजातियाँ एवं सौ से अधिक उप-जनजातियाँ निवास करती हैं। इस प्रदेश में जनजातियों की सख्या सर्वाधिक होने के कारण यहाँ की लोक-संस्कृति, जीवन-शैली, बोली-वाणी, भाषा, रहन-सहन, खान-पान, कला, वेश-भूषा, रंग-ढंग आदि में विविधता का होना सामान्य-सी बात है। रागात्मक तादात्मय एवं अपनी जीवंत-प्रकृति इस प्रदेश की असल पहचान है। अरुणाचली लोक-साहित्य की चर्चा करें, तो यह रोचक और दिलचस्प बहुत है। प्राकृतिक ज्ञान एव विचारों से सम्पन्न लोकगाथाओं, लोक-गीतों, लोक-सुभाषितों, कथा-साहित्यों आदि की तो बात ही निराली है। देश के मुंडेर पर बसे इस प्रदेश के करीब पहुँचते ही या कि पहली नज़र में देखते ही अरुणाचली लोक-साहित्य में व्यक्त जीवन-दृष्टि तथा उनमें अनुस्यूत परम्परा-बोध का अभिज्ञान हो जाएगा, यह संभव नहीं है। इसके लिए जुड़ना होगा, जीना होगा। लोक जीवन-व्यवहार को शिद्दत से समझना होगा।

पहली बात जो हमारे लिए समझना आवश्यक है वह यह कि अरुणाचल का साहित्य समृद्ध और ऊर्जावान है। यह लोक-सम्पदा अपने जनजातीय समुदाय को सदैव लोक-जीवन, नैतिक-मूल्य तथा मूल अस्मिता से जोड़े रखता है। ईसाई मिशनरियों के प्रभाव ने यहाँ के वातावरण में अवश्य ही बड़ा हस्तक्षेप किया है और उनके आस्था के विषय को अपने धर्म-प्रचार की मूल नीति और ध्येय से जोड़ दिया

*सहायक प्रोफेसर, हिन्दी विभाग, राजीव गाँधी विश्वविद्यालय, रोनो हिल्स, दोईमुख, अरुणाचल प्रदेश-791112, ई-मेल : rrprgu@gmail.com

है, किन्तु यह बदलाव अथवा उलटफेर सर्वग्रासी नहीं है। ये आज भी दोन्यी-पोलो की उपासना करते हैं जिसमें सूर्य को माँ के रूप में और चन्द्रमा को पिता के रूप में स्मरण किया जाता है। अरुणाचल के पूर्व राज्यपाल एवं प्रबुद्ध लेखक माता प्रसाद ने अपनी पुस्तक 'मनोरम भूमि अरुणाचल' में कहा है - " 'दोन्यी' सूरज को कहें, 'पोलो' शशि को जान। दोन्यी पोलो देवता, मानि करें सम्मान।।"[1] आदिसंख्य अरुणाचलवासी आज भी स्वयं को आबोतानी का वंशज मानते हैं और उन्हीं पूजा-अराधना पूरी निष्ठा और श्रद्धा-भाव से करते हैं। सामान्यतया ये अपने पारम्परिक पर्व-त्योहारों में मिथुन की बलि पूरी श्रद्धा से देते हैं और स्थानीय शराब 'अपुङ' को प्रसाद के रूप में ग्रहण या वितरण करते हैं। अरुणाचल की लोक-कलाओं का बहुविध रूप आकर्षक, मोहक और अनेकानेक विशेषताओं से सुसज्जित है। वे अत्यन्त सजीव और प्रभावशाली हैं। सांस्कृतिक रूप से समृद्ध और परम्पराबद्ध अरुणाचली लोक-कला में नृत्य, संगीत एवं सामूहिक प्रस्तुति का विधान सबसे ज्यादा है। यह सामूहिकता जनजातीय समाज की मुख्य पहचान है जिसकी अभिव्यक्ति और प्रस्तुति कई ऐसे विशेष मौके पर होता है जो उनकी उत्सवधर्मिता का पर्याय है। यथा : नई ऋतु का स्वागत, नए फसलों के आने या उनके पक जाने पर, बच्चे के जन्म, विवाह, पर्व-त्योहार इत्यादि के मौके पर। अरुणाचल की मुख्य त्योहारों में कुछ नाम लिए जा सकते हैं - सोलुङ (आदी), न्योकुम (न्यीशी), गोपिन (गालो), द्रि (आपातानी), रेह (आदी), लोसर (आदी), तामालादु (दिगारू मिश्मी), खान (मिजी), मोल (ताङसा) इत्यादि। अरुणाचल प्रदेश के दैवगाली, तिराप में सहायक प्राध्यापक पद पर कार्यरत डॉ. दोन्चा तोंलुक अपने यहाँ की प्राकृतिक सुषमा और मनोहारी सौन्दर्य को बयां करती हुई कहती हैं, "अरुणाचल प्रदेश को 'छिपा हुआ स्वर्ग' या भारत का स्वर्ग कहा जाए तो भी इसमें कोई अतिश्योक्ति नहीं होगी।"[2] डॉ. दोन्चा अपने प्रदेश को स्वर्ग कहने के पीछे का कारण भी बताती हैं। उनकी निगाह में अरुणाचल का जनजातीय समाज अपनी चेतना में आधुनिक-दृष्टि से लैस है। यहाँ के नोक्ते जनजाति की स्त्रियों पर वह लिखती हैं, "वैसे तो हिन्दू समाज में समग्र नारी जीवन पुरुष वर्ग के तिरस्कार, दमन तथा उपेक्षा का शिकार है, लेकिन सबसे अधिक शोषण की प्रतिमूर्ति एकमात्र विधवा ही होती है। विधवा का यह दयनीय जीवन विशेषकर मध्यवर्गीय परिवारों में बड़ा करुण है किन्तु हम नोक्ते जनजाति में इसके विपरीत रूप देखेंगे। अर्थात नोक्टे जनजाति की स्त्रियाँ पति के मृत्यु के बाद वह चाहे तो पुनर्विवाह कर सकती है। उनके लिए ऐसा कोई बंधन या कानून नहीं है कि वह उम्र भर एक विधवा जीवन-यापन करें।"[3] अरुणाचल की अन्य कई जनजातियों में स्त्री के अन्तर्जगत और उसके अनुभवजगत

को विशेष मान दिया गया है। युवा कवि तारो सिन्दिक तागिन जनजाति द्वारा गाये जाने वाले लोकगीतों को लक्ष्य करके कहते हैं, "इन गीतों में नारी के विशिष्ट गुणों को उजागर किया गया है। नारी सिर्फ एक पत्नी ही नहीं और न ही सिर्फ बच्चा पैदा करने की मशीन है। इन सबके अलावा उनका एक भाव-जगत भी होता है। जिसकी तह तक जाना किसी भी साधारण व्यक्ति के वश की बात नहीं होती है। नारी का सम्मान करना उन भावनाओं का सम्मान करना है।"[4]

पूर्वोत्तर भारत के सामाजिक,सांस्कृतिक, भाषिक एवं साहित्यिक पक्षों के जानकार वीरेन्द्र परमार की दृष्टि में, "अरुणाचल प्रदेश अपने नैसर्गिक सौंदर्य, सदाबहार घाटियों, वनाच्छादित पर्वतों, बहुरंगी संस्कृति, समृद्ध विरासत, बहुजातीय समाज, भाषायी वैविध्य एवं नयनाभिराम वन्य-प्राणियों के कारण देश में विशिष्ट स्थान रखता है।...इसके पश्चिम में भूटान और तिब्बत, उत्तर तथा उत्तर-पूर्व में चीन, पूर्व एवं दक्षिण-पूर्व में म्यांमार और दक्षिण में असम की ब्रह्मपुत्र घाटी स्थित है।...लोक-साहित्य की दृष्टि से यह प्रदेश बहुत समृद्ध है। लोक-साहित्य में भी अरुणाचली समाज लोकगीतों से अधिक अनुराग रखता है। इस प्रदेश का अधिकांश लोक-साहित्य गीतात्मक है। मौखिक परंपरा में उपलब्ध इन गीतों में प्रदेशवासियों की आशा-आकांक्षा, विजय-पराजय, हर्ष-वेदना तथा विधि-निषेध सब कुछ समाहित है। सदियों के अनुभव लोकगीतों की कुछ पंक्तियों में सिमटे होते हैं। इन गीतों में पूर्वजों से संबंधित आख्यान, मिथक, सृष्टि की उत्पत्ति विषयक दंतकथाएँ, जनजातियों का उद्भव एवं देशांतरगमन, विभिन्न प्राणियों की उत्पत्ति सम्बन्धी कथाएँ वर्णित होती हैं। शिकार और जंगल से संबंधित पूर्वपुरुषों के अनुभवों को भी लोकगीतों का आधार बनाया गया है। अनेक प्रकार के नीतिपरक गीतों के द्वारा समाज को अनुशासित जीवन व्यतीत करने की शिक्षा प्राप्त होती है। वन्य-जीवन से सम्बन्धित गीतों में प्रकृति का धूपछांही सौष्ठव दृष्टिगोचर होता है। कहा जाता है कि अरुणाचलवासियों के लिए हवा-पानी की भाँति ही नृत्य-गीतों की भी अनिवार्यता है। उनके निर्दोष और सरल हृदय की मसृण भावनाएँ इन गीतों के रूप में प्रकट होती हैं। अरुणाचली लोकगीतों में अरुणाचली समाज, संस्कृति और परंपरा का मणिकांचन संयोग है।"[5] इस बात की पुष्टि राजीव गाँधी विश्वविद्यालय की शोधार्थी आईनाम ईरिंग भी करती हैं। वह आदी जनजाति के लोकगीतों के सन्दर्भ में अपनी बात रखते हुए कहती हैं कि - "आदी समाज में रोजमर्रा की ज़िन्दगी को प्रभावित करने वाली लोक-कथाएं, लोक-गाथा, लोकगीत, लोक सुभाषित इत्यादि भी उपलब्ध हैं। यहा जीवन के हर पहलू में गीत गाये पाये जाते हैं। अनेक प्रकार

के गीत जैसे धार्मिक, कृषि-सम्बन्धी गीत, प्रेम गीत, जीविका और आखेट सम्बन्धी गीत, पशु-पक्षियों से सम्बन्धित तथा लोरी आदि प्रमुख हैं। मानव हृदय में स्पन्दित होने वाले विविध भाव लोकगीतों के प्रेरणास्रोत हैं। कुछ महत्त्वपूर्ण आदी लोकगीतों के उदाहरणों द्वारा हम आदी जनजाति के सामाजिक एवं सांस्कृतिक विशेषताओं से परिचित हो सकते हैं।''[6] अरुणाचली साहित्य में प्रकृति के साथ सहजीविता एवं साहचर्य के उदाहरण बहुतेरे मिलते हैं। आईनाम ईरिंग मानती हैं कि, ''प्रकृति के बहुत करीब रहने के कारण अनेक प्राकृतिक गीत भी उनके लोकगीत में मिलते हैं। उनके लोककथाओं में उनके आस-पास पाये जाने वाले सभी जीवों और पेड़-पौधों पर आधारित कथाएँ मिलती हैं। अनेक ऐसे लोकगीत हैं जहाँ उन कथाओं को गीतों में लयबद्ध करके प्रस्तुत किया गया है। आदी समाज में पहले उपजनजातियों के मध्य युद्ध होते रहते थे। अतः अनेक लोकगीत भी हैं जहाँ युद्धों का वर्णन मिलता है।''[7]

बहुविध भाव, संवेदना, ऋत-व्यवस्था, विचार-अभिव्यक्ति, दंतकथा-पुराकथा, लोकगाथा-लोककथा इत्यादि को स्वयं में समेटे अरुणाचल का एकात्मक स्वरूप-'अनेकता में एकता' का है। विशेषकर भाषा वह मुख्य उपादान है जिससे अरुणाचलवासी सर्वाधिक लगाव और निकटता महसूस करते हैं। अरुणाचली लोक-साहित्य में प्रयुक्त भाषा दीर्घजीवी होती हैं। भले ही वह अरुणाचली लिपि (हाल के दिनों में कुछ जनजातियों द्वारा विकसित एवं परिष्कृत) में न के बराबर लिखी जाती हों, पर उनका असल रूप और ठाठ वाचिक ही है। यह और बात है कि अंध-आधुनिकता के प्रत्यक्ष-परोक्ष दबाव में हम अपनी भाषा का निज-घर और चेतस-मन लगातार खो रहे हैं। कई बार इरादतन हम अपनी मातृ-बोलियों एवं भाषाओं की अनदेखी करते हैं जिससे उनके आगे बचे होने की उम्मीद भी क्षीण हो जाती है। रमणिका गुप्ता स्पष्ट शब्दों में कहती हैं कि, "भाषाएँ मरा नहीं करती, भाषाएँ मार दी जाती हैं। भाषा बोलने वाले मारते हैं या सरकार मारती है। बोलने वाले इसलिए मारते हैं क्योंकि उनको रोजगार नहीं मिलता और भाषाओं में रोजगार मिलने लगे तो भाषाएँ ज़िन्दा रहेंगी, भाषाएँ समृद्ध होंगी, आपस में सहयोग करेंगी, आपस में एक-दूसरे से शब्द लेंगी और विकसित होंगी। इस तरह दुनिया भर में भाषाएँ बढ़ेंगी, मरेंगी नहीं।''[8] भाषाओं के बचने-बढ़ने की यह कामना जरूरी है, क्योंकि वाचिक अथवा मौखिक रूप में विद्यमान ये शब्द-शक्तियाँ किसी संस्कृति-विशेष का वास्तविक कोठार हैं, कुल जमापूँजी हैं। अतएव, सभ्यता का आद्यरूप इन्हीं में वर्तमान होता है। जातीय स्मृतियों की सामूहिक चेतना इन्हीं के माध्यम से बुलंद

तथा दीर्घजीवी बनती है। अरुणाचली धर्म और संस्कृति के मुख्य स्रोतों और इस प्रदेश के पुरा कवि तारो सिन्च्यि लिखते हैं, "यह बहुत ही दिलचस्प बात है कि अरुणाचल में सभी जनजातियों की अपनी-अपनी भाषा एवं बोलियाँ, धार्मिक आस्थाएँ, वेश-भूषा, सामाजिक रीति-रिवाज, संस्कृति, जीवनशैली एवं व्यवहार है। इतनी सारी विविधताएँ होने के बावजूद अरुणाचलवासी शांतिपूर्वक अपना जीवन व्यतीत करते आ रहे हैं। 'विविधता में एकता' जिस तरह भारत को विश्व में अलग पहचान दिलाती है, वही अरुणाचल प्रदेश को भारत में। इसी कारण अरुणाचल प्रदेश को 'लघु भारत' की उपाधि प्राप्त है।"[10] अरुणाचल के सभी वाशिंदे अपनी जीवन-दृष्टि, परम्परा-बोध और इतिहास-दर्शन में तमाम तरह के बदलावों और आधुनिक क्रियाकलापों को आत्मसात किए हुए हैं। प्रोफेसर एम. वेंकटेश्वर के नजरिए से देखें, तो - "यहाँ की जनजातियाँ अपने मौलिक जीवन विधान के लिए मशहूर हैं। इन सभी जनजातियों में शिक्षा का प्रसार तेजी से हो रहा है। इन लोगों की जीवनशैली में आधुनिकता का प्रवेश हो चुका है। ये सभी जनजातियाँ आधुनिक जीवनशैली को अपना रही हैं किन्तु अपनी सांस्कृतिक और सामाजिक परम्पराओं का ये कट्टरता से पालन करती हैं। जन्म, विवाह, मृत्यु के संस्कार सभी जनजातियों में भिन्न-भिन्न विधियों से सम्पन्न किए जाते हैं। इन संस्कारों की अपनी विशेषताएँ हैं और इन्हें सभी लोग बहुत ही आदर और भक्ति-भाव से सम्पन्न करते हैं। इनके संस्कारों में अंधविश्वास और प्राचीन रूढ़िवादिता की मौजूदगी आश्चर्य पैदा करती है। अनेक जनजातियों में धार्मिक अनुष्ठानों में पशुबलि की प्रथा मौजूद है। अरुणाचल की न्यायिक प्रणाली जनजातीय नियम-कानूनों का परिपालन करती है।"[11] प्रोफेसर ओकेन लेगो आदी जनजाति का सन्दर्भ देते हुए कहते हैं - "आदी समाज पूर्ण रूप से जनतांत्रिक समाज है, जिसकी नींव में केबांग है। केबांग वह संस्था है जिसके द्वारा आदी समाज नियंत्रित होता है। केबांग के द्वारा ही आदी समाज की दैनंदिन गतिविधियाँ तथा विभिन्न क्रियाकलाप आदि प्रबंधित एवं नियंत्रित होते हैं। केबांग शब्द का व्यवहार आम बैठक, सम्मेलन तथा आम विचार-विमर्श आदि के लिए भी किया जाता है। आदी समाज में न्याय व्यवस्था की संस्था का नाम केबांग है। आदी समाज के लिए केबांग वास्तव में वह आचार-संहिता है जो समाज की विभिन्न गतिविधियों तथा विभिन्न पहलुओं में मनुष्य के लिए आचरण का ढाँचा तैयार करती है।"[12]

राष्ट्रीय अखण्डता और अखिल भारत का स्वरूप निर्मित करने में इस तरह

की सोच एवं चिंतन आवश्यक है। यही मुतभाव भारत की सामासिक संस्कृति का द्योतक है जिस बारे में राष्ट्रकवि रामधारी सिंह दिनकर ने अपनी पुस्तक 'संस्कृति के चार अध्याय' में विस्तारपूर्वक लिखा है। उत्तर-पूर्व का जनजातीयबहुल समाज इस तरह की सांस्कृतिक सामासिकता से गहरे जुड़ा-बँधा हुआ है। खुद अरुणाचल प्रदेश में तकरीबन सौ जनजातियाँ एवं उप-जनजातियाँ निवास करती हैं। इस प्रदेश में जनजातियों की संख्या सर्वाधिक होने के कारण यहाँ की लोक-संस्कृति, जीवन-शैली, बोली-वाणी, भाषा, रहन-सहन, खान-पान, कला, वेश-भूषा, रंग-ढंग आदि एक-दूसरे से परस्पर भिन्न होते हैं। इन बहुभाषिक भिन्नताओं को निकट से देखें, तो हर एक भाषा स्वयं में एक स्वतन्त्र तथा समृद्ध जनजातीय संस्कृति का संवाहक है। यहाँ कई ऐसे धार्मिक-सांस्कृतिक स्थल हैं जिन्हें देखकर हर एक भारतीय को गौरव होता है और अभिमान भी। प्राकृतिक सौन्दर्य की बात करें, तो समूचा अरुणाचल पहाड़, जंगल, घाटी, नदी, खेती आदि से भरा-पूरा प्रदेश है। वीकिपीडिया जैसे आधुनिक वेब-अभिलेखागार तक को यह मालूम है कि "अरुणाचल प्रदेश के नागरिकों के जीवनयापन का मुख्य आधार कृषि है। इस प्रदेश की अर्थव्यवस्था मुख्यतः 'झूम' खेती पर ही आधरित है। आजकल नकदी फसलों जैसे-आलू, और बागबानी की फसलें जैसे सेब, संतरे और अनन्नास आदि को प्रोत्साहन दिया जा रहा है। अरुणाचल प्रदेश के पहाड़ी लोग खेती की पारंपरिक विधि शिइंग (झूम) का प्रयोग करते हैं। इस कृषि विधि की मुख्य पैदावार चावल, मक्का, जौ एवं मोथी (कूटू) हैं। अरुणाचल प्रदेश की मुख्य फसलों में चावल, मक्का, बाजरा, गेहूँ, जौ, दलहन, गन्ना, अदरक और तिलहन हैं।"[14] तोको यानी लिखती हैं, "प्राकृतिक छटाओं के बीच बसे अरुणाचल प्रदेश का इलाका पहाड़ी, तो मार्ग बेहद दुर्गम है। इसलिए यहाँ हर जगह खेती एक ही तरीके से किया जा सकना संभव नहीं है। अरुणाचल में झूम खेती के साथ पानी खेती अधिक होते हैं जो महीने और मौसम के अनुसार किए जाते हैं। प्रायः झूम खेती में मिर्च, अदरक, मकई, संतरे तथा तरह-तरह की सब्जियाँ उगाई जाती हैं जबकि पानी खेती में धान उगाई जाती है।"[15] यानी इस प्रदेश की ऐतिहासिकता पर विचार करते हुए कहती हैं, "अरुणाचल प्रदेश के ऐतिहासिक पृष्ठभूमि को देखें, तो इसका परिप्रेक्ष्य व्यापक और भारतीयता के पहलू से अंतरंग सम्बन्धित है। अब तक ज्ञात जानकारी के अनुसार, भारत में कुल 3 तरह की प्रजातियाँ पाई जाती है वह है-आर्यन, मंगोलियन, द्रविडियन। इन तीनों प्रजातियों में से अरुणाचल प्रदेश के लोगों को मंगोलियन जनजाति का माना

जाता है। अरुणाचल की भूरचना अहोम साम्राज्य की स्थापना से शुरू होती है। तेरहवीं सदी में सुखाफा ने असम के शिव सागर नामक जगह पर बसना कर अहोम साम्राज्य की स्थापना की। अहोम साम्राज्य के पतन के बाद अंग्रेजों का शासन शुरू हो गया। सन 1826 तक आते-आते अंग्रेजों ने अहोम साम्राज्य पर पूरी तरह कब्जा कर लिया। 19वीं सदी में ही चीन और भारत के बीच शिमला समझौता (1890) हुआ, जिसमें एक सीमा निर्धारित की गई। इस सीमारेखा को सर हेनरी मैकमोहन के नाम से 'मैकमोहन लाइन' नाम दिया गया। जब अंग्रेजों ने देखा कि उत्तर भारतीय संन्यासी और नीडो जनजाति के लोग अपने धन, जमीन और जंगल के लिए अंग्रेजों के खिलाफ खड़ा हो सकते हैं तो उनको यह अंदेशा हुई कि अरुणाचल के जनजातीय लोग भी ऐसा कर सकते हैं। अरुणाचल में प्रवेश सम्बन्धी अधिकार सुनिश्चित करने के लिए अंग्रेजों ने ही 'इनर लाइन परमिट' (Inner Line Permit) की अवधारणा रखी। सन् 1873 में अंग्रेजों ने इनर लाइन परमिट बनवाई जिसमें यह नियम लागू किया गया कि बाहर से आने वाले लोग इस पहचान-पत्र के बिना अंदर नहीं जा सकते हैं।[पृ.16]

यद्यपि आर्द्रभूमी की व्यवस्था आज भी अरुणाचल में प्रचलन में है। इस व्यवस्था के कारण वहाँ आने वाले बाहरी लोगों की संख्या कम है और यह परिक्षेत्र शहरीकरण अथवा अतिशय विकास की मार से अब तक बचा हुआ है। किन्तु समय के साथ स्थितियाँ-परिस्थितियाँ तेजी से बदल रही हैं। आर्थिक सुधार एवं विस्तार ने इस प्रदेश को भी वैश्विक भारत की बदली हुई नई छवि से तालमेल या फिर संतुलन बिठाने हेतु विवश कर दिया है। पूँजी संग्रह और निवेश द्वारा सुनाई दे रही समृद्धि का पर्याय मान चुके आधुनिक अर्थव्यवस्था को अरुणाचल का जनजातीयबहुल समाज भी अपना 'आदर्श' मानने लगा है। इस कारण यहाँ की निज-संस्कृति और भाषा पर संभावित खतरे आये दिन नुकीले और तीखे होते जा रहे हैं। यह बात अलग है कि अरुणाचल की जनजातियों की आन्तरिक संरचना, बनावट-बुनावट आदि में जातीय स्मृतियों तथा पारम्परिक आख्यानों की भूमिका सर्वोपरि है। वे अनेकानेक बिम्ब, रूप, छवि इत्यादि के रूप में इनसे गहरे जुड़े हैं। लोक-संस्कार की इस संस्कृति को देखते हुए नहीं लगता है कि बाज़ार की दादागिरियाँ अथवा साम्राज्यवादी आक्रमण इतनी आसानी से अपने मकसद में कामयाब हो सकता है। प्रो. नन्दकिशोर पाण्डेय की दृष्टि में "पूर्वोत्तर की भाषा, संस्कृति और लोक-साहित्य आज भी प्रचुरता में उपलब्ध हैं या बाहरी दबाव के

बावजूद बची हुई हैं, तो उसका मुख्य कारण है कि यहाँ के लोगों ने इनको अपनी दाँत से कस के पकड़ रखा है। भाषा के संरक्षण-सुरक्षा के लिए प्रेम और समर्पण अनिवार्य है।''[15]

इस अनिवार्यता पर बल दिया जाना इसलिए भी आवश्यक है, क्योंकि अनपेक्षित घटनाएँ लगातार घट रही हैं; अवांछित घुसपैठ तेजी से बढ़ता ही जा रहा है। यह बदलाव नैसर्गिक, प्राकृतिक अथवा शाश्वत नहीं है; बल्कि यह पूर्णतया प्रायोजित है। आदिवासी जनसमाज के ऊपर शोध एवं अकादमिक लेखन करने में जुटे डॉ. अभिषेक कुमार यादव की दृष्टि में ये परिस्थितियाँ अत्यन्त चिन्तय एवं त्रासद हैं - ''उत्तर-पूर्व के राज्यों में आदिवासी समाजों के सामने दूसरी विकट परिस्थितियाँ मुँह बाये खड़ी हैं। जहाँ एक तरफ आर्म्ड फोर्स स्पेशल पॉवर एक्ट है, तो दूसरी तरफ निजीकरण और भूमंडलीकरण का तेज हमला है। इसने उनकी भाषा-संस्कृति पर जोरदार प्रहार कर दिया है। एक वर्गहीन समाज में तेजी से कई वर्ग बनते जा रहे हैं। कुल मिलाकर कमोबेश हालत यह है कि आदिवासी समाजों की अस्मिता और अस्तित्व पर ही खतरा उत्पन्न हो गया है।''[16] दरअसल, मनुष्य की जन्मजात प्रकृति है कि उसमें अभिव्यक्ति के साथ अभिव्यंजना-शक्ति भी है। इस नाते कई बार वह सचाई को यथार्थपूर्ण नज़रिए से देखने की बजाय एक तरह की रोमांटिसिज़्म में प्रत्यक्षीकृत करता है। उसका बड़ा नुकसान यह है कि कमियाँ ढँक जाती हैं। ऐसे में जो दिख अथवा दिखाया जा रहा होता है वह या तो लबादा होता है अथवा अस्थायी निर्माण जिस मुलम्मे के उतरते ही देर-सवेर वास्तविकता सामने आ ही जाती है। डॉ. अभिषेक इस ओर संकेत करते हुए कहते हैं, ''आदिवासी समाजों को देखने की जो दो निगाहें हैं एक बेहद रोमांटिक तरीके से और दूसरी दुश्मन की तरह।''[17] इसके लिए वह अरुणाचल के सुप्रसिद्ध लेखक येशे दोरजी थोंगछी के उपन्यास 'सोनाम' का जिक्र करते हैं जो मूल असमिया में लिखा गया है और अब उसका हिंदी अनुवाद भी उपलब्ध है। लेखक के संवेदनशील प्रकृति के बारे में बात करते हुए वे कहते हैं कि, ''लेखक इन दोनों निगाहों से दूर है। वह ब्रोकपा समुदाय की अपनी कमजोरियों को भी पकड़ रहा है पर उसे हीन साबित करने के लिए नहीं बल्कि बेहद अपनापे के साथ। साथ ही वह ब्रोकपाओं के लिए किसी रोमांटिक निगाह से बचते हुए उनकी बदल रही सामाजिक-व्यवस्था, आर्थिक-व्यवस्था को भी चिन्हित कर रहा है। यह वह विचार-प्रक्रिया है जिसकी आज आदिवासी साहित्य को सख्त जरूरत है।''[18]

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एक विमर्श

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इग्नू रोड, नई दिल्ली-110068
पंजीकृत कार्यालय, सानेवाड़ी, वर्धा
महाराष्ट्र-442001
ई-मेल : themarginalised@gmail.com
संपर्क : + 91-8130284314, 9650164016

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राजीव रंजन प्रसाद

मातृभाषा में अहम भूमिका जिस चीज की सबसे ज्यादा होती है, वह है—जन्मना लगाववृत्ति। अपनी स्वतंत्र पहचान संग जीने की चेतना, संकल्प और अभिलाषा हमें मातृभाषा प्रदान करती है। ज़ाहिर तौर पर लोकाचार और लोकायत आधारित भाषा ऐसे अर्जित संस्कार हैं जिनमें भारतीय जीवन-दृष्टि और जन-मूल्य समाहित होता है। वस्तुतः मातृभाषा के बाने में लिपटा जन-मन का साहित्य काल से संग्राम करने के लिए नहीं; अपितु वह काल से अपनापा गाँठने हेतु लिखा गया होता है। वह कालजयी इन्हीं अर्थों में होता है कि वह लोकशासित और पूर्णतया लोकाश्रयी होता है। जनचेतना और जन-पक्षधरता लोक-साहित्य के मुख्य स्वर हैं। इसका आद्यरूप (Architype) आदिम-चेतना तथा जन-संस्कृति से नाभिनाल सम्बद्ध है। अस्तु, लोक-परम्परित (वाचिक, श्रुत, गीति-प्रधान आदि) साहित्य आमजन का अनुग्राहक है और अनुश्रवणकर्ता भी। साहित्य के लिखित विधान की बात करें, तो वेद, उपनिषद, पुराण, भाष्य आदि लोकमंगल का हेतु बनते हैं; जन-मन की पीड़ा, वेदना, मूल्य, विचार, सरोकार, सम्वेदना इत्यादि का संवाहक साबित होते हैं; तभी वे स्वीकार्य और अनुकरणीय हैं। अन्यथा ग्रंथों और पोथियों से ज्ञान प्राप्य नहीं है। इन अर्थ-सन्दर्भों में लोक-साहित्य का सृजन विशेषतौर पर अपनी मातृभाषा में किया जाना अनिवार्य मानवीय उपक्रम है। इस रचाव-बनाव, संरक्षण-समाहार में भारतभूमि सम्पूर्णतया शामिल है। यानी दक्षिण-पश्चिम अथवा उत्तर-पूर्व का मसला बिल्कुल नहीं है। जहाँ तक अरुणाचल का प्रश्न है, तो अरुणाचल की जनजातीय अस्मिता

को जीवित तथा जीवंत बनाए रखने में यहाँ की मातृभाषाओं का योगदान अतुलनीय है। यहाँ का जनजातीय समाज अपनी लोक, भाषा एवं साहित्य से गहरे जुड़ा हुआ है। सर्वग्राह्य एवं सर्वमान्य लिपि नहीं होने के कारण उनकी भाषा आज संकट में है और वे खुद भी भली-भाँति इस भाषायी विपदा से अवगत हैं। पूर्व में भी यहाँ की भाषाओं को बचाने हेतु कई अग्रणी संस्थाएँ आगे आई थीं, लेकिन उनके उल्लेखनीय योगदान के बावजूद खतरा अभी टला नहीं है। यहाँ की विभिन्न जनजातियों की मुख्य चिंता उन भाषाओं, उप-भाषाओं और बोलियों को बचाने के लिए सर्वाधिक है जो विलुप्त होने की सीमा तक जा पहुँचे हैं।

अरुणाचल का लोक-संसार

हमारा राष्ट्रीय मानचित्र दो दर्जन से अधिक राज्यों से मिलकर बनता है। समरसता और सद्भाव के साथ सामूहिकता में एकसाथ जुटे इस जनतांत्रिक देश की सबसे बड़ी अच्छाई विभिन्न राज्यों का परस्पर समुच्चय में होना है। इसी तरह भारतीय लोकतंत्र को 'गणतंत्र' शब्द से अभिहित किया जाना श्रेयस्कर है क्योंकि यहाँ केन्द्र और राज्य की सत्ता स्वतन्त्र होते हुए भी अभिन्न है। संघीय ढाँचा में सामाजिक-सांस्कृतिक बहुलता, बहुभाषाभाषीपन, भौगोलिक-प्राकृतिक रचाव-बसाव आदि प्रमुखता से आते हैं। हाल के कुछ वर्षों में राजनीतिक अंतर्विरोध गाढ़ा हुआ है, तो सामाजिक-सांस्कृतिक ताना-बाना बुरी तरह बिगड़ा है। अजनबीयत एवं अलगाव मानव स्वभाव, व्यक्तित्व एवं व्यवहार का स्थायी भाव बनते जा रहे हैं सो अलग। इस दूषित वातावरण में अरुणाचल की सांस्कृतिक बहुलता और भाषायी विविधता लुभाती है और हमें इस जनजातीय-समाज की परम्परा, विरासत और लोक-साहित्य को समझने हेतु उत्प्रेरित करती है। दरअसल, भारत के उत्तर-पूर्व क्षेत्र में बसा अरुणाचल, जहाँ सूरज की प्रथम किरणें पड़ती हैं, कई अर्थ-सन्दर्भों में महत्त्वपूर्ण है। यह प्रदेश बहुभाषिक और जनजातीयबहुल राज्य है। भारत के 29 राज्यों में से अरुणाचल प्रदेश एक है। इसे पहले नेफा (North East Frontier Agency) के नाम से जाना जाता था। 20 जनवरी, 1972 को इस प्रदेश का नाम अरुणाचल प्रदेश रखा गया, जो बाद में 20 फरवरी, 1987 को इसी नाम से भारत का एक स्वतन्त्र राज्य घोषित हुआ। ऐतिहासिक रूप से अरुणाचल के बारे में जानने का प्रयास करें, तो अरुणाचल के पूर्व राज्यपाल रह चुके माता प्रसाद जी की लिखी पुस्तक 'मनोरम भूमि अरुणाचल' से बहुत सारे तथ्य एवं जानकारियाँ प्राप्त होती

हैं। उनके अनुसार, सातवीं शताब्दी के सुप्रसिद्ध कश्मीरी कवि कल्हण ने अपनी कालजयी रचना 'राजतरंगिणी में उदयाद्रि का वर्णन किया है। इसमें संदेह नहीं वह उदयाद्रि ही आज का अरुणाचल है। पूर्वोत्तर के राज्यों में अरुणाचल क्षेत्रफल की दृष्टि से सबसे बड़ा है, जबकि आबादी घनत्व सबसे कम है। अरुणाचल प्रदेश में तकरीबन सौ जनजातियाँ एवं उप-जनजातियाँ निवास करती हैं। इस प्रदेश में जनजातियों की संख्या सर्वाधिक होने के कारण इनकी लोक-संस्कृति, जीवन-शैली, बोली-वाणी, भाषा, रहन-सहन, खान-पान, कला, वेश-भूषा, रंग-ढंग आदि एक-दूसरे से परस्पर भिन्न होते हैं। प्रथम द्रष्टया, भारत के अन्य राज्यों से यहाँ की भाषा, संस्कृति और लोक-विधान सर्वथा भिन्न मालूम पड़ते हैं, किन्तु इसकी अंतःसंरचना में भारत का विराट-दर्शन होना स्वाभाविक बात है। इन बहुभाषिक भिन्नताओं को निकट से देखें, तो हर एक भाषा स्वयं में एक स्वतन्त्र तथा समृद्ध जनजातीय संस्कृति का संवाहक है। यहाँ कई ऐसे धार्मिक-सांस्कृतिक स्थल हैं जिन्हें देखकर हर एक भारतीय को गौरव होता है और अभिमान भी। प्राकृतिक सौन्दर्य की बात करें, तो समूचा अरुणाचल पहाड़, जंगल, घाटी, नदी, खेती आदि से भरा-पूरा प्रदेश है। अरुणाचल प्रदेश के बारे में अरुणाचल के पूर्व राज्यपाल रह चुके महामहिम माता प्रसाद ने अपनी पुस्तक 'पूर्वोत्तर भारत के राज्य' में अरुणाचल के लिए अद्‌भुत पंक्ति लिखा है—'रवि दर्शन भारत प्रथम, अरुणाचल है नाम। जनजातियां संस्कृति मुखर, प्रकृति छटा ललाम।' हम इस बारे में समग्रता से विचार करेंगे, उससे पूर्व लोक, साहित्य एवं भाषा के सम्बन्धों पर दृष्टिपात किया जाना जरूरी है।

साहित्य-सृजन और लोक-धारणा

लोकमंगल और जनकल्याण साहित्य का मुख्य अभिलक्ष्य है। यह बात हमारे अंतरतम में गहरे पैठी होनी चाहिए। यह विश्वास होना जरूरी है कि साहित्य हमारे अन्दर मूल्य-निर्माण और मूल्य-निर्णय का काम करता है। सनद रहे, साहित्य शब्दों की मुनीमी नहीं है, वह तो सामूहिक चेतना का कोठार है। अनुभव आधारित स्मृतियों की धूपछाँही यहल्ल देखी जा सकती है। अर्थात् यह एक ऐसी सामाजिक-सांस्कृतिक परिसम्पत्ति है जो गाँव-देहात, कस्बा-शहर, नगर-प्रवास, समाज-समुदाय, संगठन-संस्थान, मजदूर-किसान, अनपढ़-नासमझ, पढ़ा-लिखा, स्त्री-पुरुष, धर्मावलम्बी-मतावलम्बी सबको जाग्रत करे और मनुष्यता के चरम उत्कर्ष का संकेत दे। दरअसल, लोक-सम्वेदित साहित्य अपनी ही आँखों से ढुलके आँसू की तरह है जिसका स्वाद

तीखा और खरा होता है। यह तो अपनी ही हथेलियों के रगड़ से पैदा हुई ऊष्मा की तरह है, जिसकी काया संघर्षशील और प्रतिरोधी हुआ करती है। इसीलिए साहित्यमना व्यक्तित्व किसानों-मजदूरों के संघर्ष एवं प्रतिरोध का सचेत गायक होता है, तो नगरीय त्रासदी और उत्तर शती द्वारा ऊपजाई गयी कठिनाइयों को समझने वाला अगुवा नायक। साहित्य उनके द्वारा लिखा जाता है जो भाषा के प्रति संवेदनशील होते हैं; और लोक के प्रति आग्रही एवं पूर्ण समर्पित। लोकचित्त से संस्कारित रचनाकार भाषा को अपने अनुभवों की अभिव्यक्ति के लिए महज़ प्रयोग ही नहीं कर रहे होते हैं, अपितु उन्हें सहेजते-संजोते और रचते-सँवारते भी हैं। अर्थात् साहित्य एक ऐसी कला-विधि है जिसका लोक-संविद्य लेखक सिर्फ भाषा-प्रयोक्ता की भूमिका में नहीं होता है; बल्कि भाषा की उपयोगिता एवं उसकी उपादेयता को सिद्ध भी कर रहा होता है। नवजागरणकालीन चिंतक बालकृष्ण भट्ट ने उपयुक्त ही कहा है कि, 'साहित्य जनसमूह के हृदय का विकास है। वह जनसमूह के चित्त का चित्रण है।' आचार्य रामचन्द्र शुक्ल मानते हैं, "किसी भी सभ्य देश की शब्द-परम्परा और अर्थ-परम्परा के सामंजस्य-विधान से ही उसके साहित्य का स्वरूप निर्दिष्ट होता है। यदि इस सामंजस्य में बाधा पड़ेगी अर्थात् मनमाने ढंग से विदेशी शब्दों के विचारों का बड़े पैमाने पर आयात होगा तो साहित्य देश की प्राकृतिक जीवन धारा से विचिछन्न हो जाएगा।"

मातृभाषा का महत्त्व और लोक-संवेदनाएँ

पश्चिमी विचारकों की पारिभाषिक विचारधाराओं को, मंतव्यों को, उनके ज़िरह-तफ़्शीश, बहस-मुबाहिसों आदि को देखना जरूरी है, लेकिन उसे पचाना तो अपनी ही मातृभाषा में होगा। यह कैसे हो सकता है कि हम उनके ही चश्मे को अपनी निगाहबानी मान लें; उनकी ही धुरी और केन्द्र को अपनी वैचारिक-यात्रा का पतवार मान लें। यह तो बौद्धिक दासता है, शैक्षणिक गुलामी जिसका बँधन जंजीर या सलाखें न होकर दिमागी और मनोवैज्ञानिक आरोपण-प्रक्षेपण है। संकल्प-विकल्प की क्षमता रखने वाले भारतीय लोक को भला यह कहाँ और कैसे रास आने वाला है! अतीत-गुणगान के शास्त्रीय 'अप्रोच' को छोड़ दीजिए, किन्तु अपनी चीजों और परम्पराओं के प्रति एक सम्यक दृष्टिकोण तो रखना ही होगा। देश-देशांतर तक अपनी खोज, सिद्धान्त और नवप्रयोगों का लोहा मनवा चुका यह राष्ट्र एकदम अचानक से उठ खड़ा नहीं हुआ है। स्त्री, दलित, आदिवासी जनसमाज को लेकर

विमर्शात्मक चेतना तथा प्रतिरोध सिर्फ आज के खड़े किए हुए नहीं हैं। असल में, रचनाकार जो कोई हो, लेकिन कीर्ति-पताका तो उसकी ही फहरती आई है जिसकी रचनाएँ लोकप्रिय मुहावरे, मुलम्मे, मसख़रेपन से नहीं; लोक-मर्म तथा लोक-रस से पूरित है। सूर, तुलसी, मीरा इन्हीं कारणों से लोकचित्त के कवि हैं। नहीं तो हम ऐसे कितने लेखकों, कवियों, आलोचकों, गीतकारों आदि को जानते हैं जिनका लिखा आज भी हम पर जादू-सा असर किए हुए है? वहीं लोक-साहित्य अपनी वाचिक परम्परा में ही सही, लेकिन जीवित और जीवंत मालूम देता है। सच्चाई तो यही है न, लोक अपनी रेग और टेक में भारतीयता के पूरेपन से बँधा हुआ है; इसलिए उसे अपनी पहचान और अस्मिता के मूल्य मालूम है; इन्हीं के बरअक़्स नगरीय-कस्बाई युवक-युवतियों को देखें, तो वह कौड़ियों के भाव बिकने को लालायित है। वह 'पैकेज' और 'प्रमोशन' की लालच में बाज़ारवाद की गिरफ़्त में है। जरा सोचकर देखिए, यदि बाहरी दबाव और आरोपण के बीच हमने अपना लोक-मन भी खो दिया, तो फिर बचेगा क्या जिसको हम भारतीय कह सकें? 55 फीसदी युवा आबादी वाले इस राष्ट्र का सम्यक् मार्गदर्शन किया जाना साहित्य का धर्म है और साहित्य-ज़मात का लेखकीय कर्तव्य। इस जगह हमें अपनी भाषाओं की ओर मुड़ना होगा। उनके बचे होने की मिन्नत करनी होगी। हमारी लोक-सम्वेदित भाषाएँ न सिर्फ ज़बान के लिए जरूरी है, अपितु अपनी सामाजिक अस्मिता तथा सांस्कृतिक गौरव को बचाए रखने हेतु भी उनका बचना-बढ़ना अत्यावश्यक है। भारतीय साहित्य सदैव प्राची-प्रतीची के सहमेल, सद्भाव और विरुद्धों के सामंजस्य पर टिका रहा है। इसे देख पाने की समग्र दृष्टि और उदात्त भावना का होना आवश्यक है। साहित्य लोकचित्त के लिए धरोहर है, तो लेखकीय समाज के लिए सांस्कृतिक पूँजी। लोक-आख्यान से सुपरिचित रचनाकारों की रचनाओं में लोक-दर्शन अपने तईं व्याप्त है, इरादतन निर्मित या निर्माणाधीन नहीं है। बीते दौर की विभिन्न प्रवृत्तियों का अध्ययन-विश्लेषण करें, तो स्पष्टतया भारतीय साहित्य ने जन-सामान्य की भाषा में सामाजिक असंतोष-आकांक्षा, जटिलता-संघर्ष, अन्तर्विरोध-द्वंद्व आदि को उपयुक्त वाणी प्रदान किया है; राजसत्ता से सीधे टकराने के अतिरिक्त राजनीतिक चेतना एवं सामूहिक प्रतिरोध के निर्माण में भी सार्थक योगदान दिया है। भारतीय सन्दर्भ एवं परिप्रेक्ष्य में नवजागरण का समय आधुनिक परिपाटी तथा आधुनिकता-बोध के निर्माण का क्रांतिक-बिन्दु रहा है। लेकिन आज का समय आभासीपन और कृत्रिमता की साख पर उल्लू-सा बैठा है। आज की सर्वाधिक चिंताजनक पहलू यह है कि वैश्विक घुसपैठ

ने आमजन के ऊपर राजनीतिक जोर-बल-दाब इतना बढ़ा दिया है कि जनता, लोकतंत्र और साहित्य का भीतरी अंतःसम्बन्ध ख़त्म-सा हो गया है। आज 'कर्म' और 'वचन' के बीच दूरियाँ बढ़ रही है।

बदलता लोकवृत्त और अरुणाचल

संवेदनहीन होते भारतीय लोकवृत्त और स्पंदनहीन बनते सामाजिक-सामुदायिक तंत्र में भाषाएँ कैसे बचेंगी; यह एक चिंताजनक पहलू है। हाल के दिनों में कुछ परिवर्तनकामी संवाद-विमर्श अवश्य सामने आये हैं पर वे अपर्याप्त हैं। विचार और विचारधारा के केन्द्र में ऐसी भाषाओं की भूमिका बढ़ी हैं जो कल तक हाशिए पर थल यानी जिन्हें इरादतन केन्द्र से बाहर रखा गया था; अब वे नए मोर्चे और विकल्प के साथ लोकचित्त की भाषिक अभिव्यक्ति बन रही हैं। आज पूरे देश में लोग भाषायी बहुलता की भारतीय संस्कृति को भली-भाँति समझ एवं उन्हें अपना रहे हैं। आपसी मनभेद ख़त्म हो रहे हैं और सभी मिलजुकर स्त्री-विमर्श, दलित-विमर्श, आदिवासी विमर्श के नए अनुभवों, स्मृतियों, विचारों आदि को खुलकर साझा कर रहे हैं। अपनी भाषा और लोक-साहित्य के संरक्षण-सुरक्षा में आज दृढ़निश्चयी प्रवृत्ति के ऐसे लोग उठ खड़े हुए हैं जिनके पास पद-प्रतिष्ठा, शिक्षा, जागरुकता, अस्मिता-बोधा और सामूहिक आकांक्षा प्रचुर मात्रा में है। ऐसे ही लोगों से यह अपेक्षा भी की जा सकती है कि, "नयी सूचना-व्यवस्था के इस युग में उन्हें न सिर्फ संचार-असंतुलन के विरुद्ध मोर्चा लेना चाहिए, बल्कि तृतीय विश्व के देशों की पुरातन संस्कृतियों, दार्शनिक मूल्यों और सामाजिक आस्थाओं के प्रचारक-प्रसारक के रूप में विकसित भी किया जाना चाहिए। ताकि सूचना-संस्कृति आधारित नवउपनिवेशवाद के विरुद्ध तृतीय विश्व में प्रबुद्ध जनमत विकसित किया जा सके।" यह महती कार्य किया जाना इसलिए भी आवश्यक है कि "लोक-मन अथवा लोक-वार्ता केवल लोककथाएँ, परिकथाएँ, पुराकथाएँ, पशुकथाएँ मात्र नहीं हैं, अपितु लोक-जीवन की समूची अभिव्यक्तियाँ इसके अध्ययन का विषय है। जैसे-लोकगीत और इसके अनेक रूप, चुटकुले, धार्मिक संस्कार, लोक-जीवन की पारम्परिक विधाएँ एवं लोक-विश्वास आदि। सम्पूर्ण लोक-मानस उनकी गहराइयाँ, प्रवृत्तियाँ, शक्तियाँ-इन सभी का अध्ययन और अपनी स्मृति में स्थान देना अत्यावश्यक है।" इन बातों को यदि हम अरुणाचल की मौजूदा स्थिति से जोड़कर देखें, तो हम पायेंगे कि "यहाँ की मुख्य जनजातियाँ जो 26 से अधिक हैं; अपने भिन्न प्रकार के उपभाषा और अपनी भिन्न

संस्कृति के साथ जीते हैं, तथा अपने इसी अस्तित्व के पृथक पहचान को कायम रखते हैं। अरुणाचल में बहुत सारी जनजातियाँ तथा उपजनजातियाँ अपनी विशेष भौगोलिक वितरण के साथ रचे-बसे हुए हैं। यहाँ की मुख्य जनजातियाँ हैं—गालो, आदी, मिन्योंग, न्यीशी, अका, बुगुन, आपातानी, सिङफो, मेम्बा, मिस्मी, मिजी, ताङसा, मोन्पा, शेरदुकपेन, तागीन, खाम्ति, वाङचू, नोक्ते, हिल मिरी, लीसू, पूरोईक इत्यादि है।...अरुणाचल की अनेक जनजातियों के गुण-विशेष पर आधारित संस्कृति और सर्वात्मवादी विश्वास भारत के मुख्यधारा की उपनिवेशी संस्कृति से थोड़ा-बहुत समान मालूम देता है। फिर चाहे वह उन लोगों के खाने-पीने की आदत हो, परम्परागत पहनावा या फिर उन लोगों का धार्मिक आस्था-विश्वास। अरुणाचल प्रदेश की अनेक जनजातियाँ हमेशा से जंगलों इर्द-गिर्द रहे हैं। वह भी पारिस्थितिकीय-तंत्र को बिना खतरे में डाले हुए। इनमें प्रकृति के साथ नजदीकी एवं मैत्रीपूर्ण सम्बन्ध बनाए रखने के प्रति परम्परागत सिद्धान्त के अभ्यास का जड़ बहुत ही गहरा है। कला एवं शिल्प में उनके समृद्ध और गौरवशाली विरासत का दर्शन होता है।" ध्यातव्य है कि अरुणाचल प्रदेश के प्रत्येक जनजाति में उप-जनजाति का विधान है और इनमें भी आपस में बोली, रीति-रिवाज, खान-पान, परम्परा, वेश-भूषा आदि के स्तर पर कमोबेश अन्तर या कहें विविधता देखने को मिलते हैं। यह प्रदेश विविधताओं में एकता का प्रतीक है। पीढ़ी-दर-पीढ़ी से चली आ रही परम्पराओं को लोग आज भी बड़े धूमधाम से मनाते हैं। लेकिन कुछ परम्पराओं को लोग अब छोड़ने लगे हैं या उनके प्रति उदासीन हो गए हैं। कुछ ग़लत प्रथाओं से लोगों ने समय के साथ दूरी बना ली है या उन पर रोक लगा दिया है। इसके पीछे कारण यह है कि लोग अब शिक्षित हो गए हैं। जैसे अब बहुविवाह बहुत कम चलन में है। पीढियों से चली आ रही लोककथा, लोकगीत, लोकनृत्य, लोकोक्तियां और कहावतें आज भी अरुणाचल के सुदूरवर्ती इलाकों में प्रचलित है या कहें, उन जगहों पर अब भी जारी हैं जो घने जंगलों के बीच बसे हुए हैं। लेकिन शहरी अथवा कस्बाई इलाकों के लोग धीरे-धीरे अपनी परम्पराओं को भूलते जा रहे हैं। जैसे ईटानगर, नाहरलागुन, पासीघाट, तवाङ, तेजू, दोईमुख आदि। अरुणाचल का भाषायी वातावरण भी घोर असंतुलन का शिकार है। अधिसंख्य जनजातियाँ हिन्दी और अंग्रेजी के प्रभाव में खतरनाक तरीके से अपनी बोली-वाणी, व्यवहार-प्रयोग से दूर होती जा रही हैं। यहाँ की मुख्य भाषाएँ हैं—आदी, न्यीशी, मोम्पा, आपातानी, गालो, तागिन, इदु मीश्मी इत्यादि।

अरुणाचलवासी हृदय से कोमल, तो स्वभाव से शांत प्रकृति के हैं। यह और बात है, परिस्थितियों के दबाव और देशकाल के लगातार बदल रहे पृष्ठभूमि ने उनमें ढेरों बदलाव किए हैं। कुछ जनजातियों को स्वभाव से उग्र और आक्रामक भी माना जाता है जिसकी मुख्य वजह उनकी प्राकृतिक संसाधनों तथा सांस्कृतिक रवायत पर बाहरी तत्त्वों की घुसपैठ या फिर सरकारी हस्तक्षेप का बढ़ता दायरा है। इन सब कारणों से वे अपनी भाषा-बोली के लिए जागरूक हुए हैं, तो अपनी भाषाओं पर मंडरा रहे खतरों को देख चिंतित भी बहुत हैं। अरुणाचल के रहवासी इस बात से पूरी तरह वाकिफ हैं कि उनके भाषिक-बोध और ज्ञान-विधान को सिर्फ और सिर्फ उन्हीं की भाषा, उपभाषा या बोली ने सबसे अधिक सहेजा है। पुरखों की स्मृति और चेतना उनकी अपनी मातृभाषा में ही सर्वाधिक सुरक्षित और स्थायी हैं। इन्हीं सब कारणों से वे अपनी मातृभाषा को अपना धरोहर मानते हैं जिस संचित पूँजी के नष्ट-विनष्ट होने का मुख्य कारण आधुनिक रद्दोबदल है जिसमें अन्य दूसरी भाषाओं (हिन्दी, अंग्रेजी, असमिया आदि) के महत्त्व बढ़े हैं; वहीं उनकी भाषाएँ या कि बोलियाँ दिन-ब-दिन सिकुड़ती-सिमटती जा रही हैं। सरकार ने काफी पहले योजना आयोग के माध्यम से 'भारत भाषा विकास योजना' शुरू करने के बारे में सोचा था, लेकिन यह योजना ज़मीनी आधार नहीं प्राप्त कर सकी। ध्यातव्य है कि "इस समय देश में संकटग्रस्त भाषाओं की संख्या तकरीबन सौ है जिनमें अरुणाचल का नाम अग्रणी है। संयुक्त राष्ट्र शैक्षिक, वैज्ञानिक एवं सांस्कृतिक संगठन (यूनेस्को) ने आठवीं अनुसूची के बाहर की इन सौ भाषाओं में से 62 के अस्तित्व को खतरे में माना है।" यूनेस्को की रिपोर्ट के अनुसार, "संकटग्रस्त भाषाओं में सबसे ज्यादा 28 पूर्वोत्तर की भाषाएँ हैं।" हैरत की बात यह है कि आजादी के साढ़े छह दशक बाद भी सरकारों को नहीं मालूम कि पूर्वोत्तर राज्यों में कितनी तरह की भाषा और बोलियाँ प्रचलित हैं। कुछ समय पहले विश्व-प्रसिद्ध भाषा वैज्ञानिक डेविड हैरिसन ने एक किताब लिखी थी–'द लास्ट स्पीकर'। हैरिसन लिखते हैं, "मैं दुनिया भर की लुप्तप्राय भाषाओं की खोज कर रहा हूँ। इस क्रम में मुझे कई ऐसे लोग मिले जो अपनी भाषा के आखिरी प्रवक्ता थे।" गौरतलब है कि हैरिसन जब अपनी खोज के क्रम में भारत के पूर्वोत्तर राज्य पहुँचे तो उन्हें कई ऐसी अज्ञात भाषाएँ मिलीं, जिससे सम्बन्धित राज्य की सरकारें भी अब तक अनजान थीं। हैरिसन ने ही दो साल पहले (2010 ई.) अरुणाचल प्रदेश में 'कोरो' नामक जनजातीय भाषा की खोज की थी जो तेजी

से लुप्त हो रही है।" इस तरह की खतरनाक परिस्थिति में जीवनयापन करते अरुणाचलवासियों के लिए अपनी भाषा-बोली को बचाने हेतु किस तरह के सरकारी अथवा गैर-सरकारी उपक्रम किए जाने चाहिए, यह जानना और तत्काल प्रयत्न करना आवश्यक है। ऐसा नहीं है कि इस सम्बन्ध में कुछ भी नहीं हुआ है; हाँ, वे खानापूर्ति तक ही सीमित हैं—यह सच्चाई है। इसके कई उदाहरण हैं : जैसे कि कुछ वर्ष पहले राजीव गाँधी विश्वविद्यालय के हिन्दी विभाग और नागरी लिपि परिषद द्वारा आयोजित नागरी लिपि सम्मेलन में यह मुद्दा उठा कि अरुणाचल के लोगों को हिन्दी की देवनागरी लिपि को स्वेच्छापूर्वक अपना लेना चाहिए; ताकि उनकी भाषा-बोली के प्रचुर मात्रा में उपलब्ध साहित्य का डिजिटलीकरण किया जा सके। पर सबसे बड़ी दिक्कत यह आ रही थी कि अरुणाचल में प्रचलित कुछ खास ध्वनियों के लिए हिन्दी की देवनागरी लिपि में कोई विकल्प ही नहीं मौजूद है। इसी तरह अरुणाचल की अधिसंख्य भाषाओं, उपभाषाओं और बोलियों में 'सघोष महाप्राण' प्रचलन में नहीं है। अर्थात् यहाँ की भाषा एवं बोली में कोमल ध्वन्यात्मक उच्चारण वाले 'अक्षर' (क, ग, घ, ज, ट, ड, त, द, प, ब इत्यादि) ही ज्यादा प्रयोग, प्रचलन एवं प्रभाव में हैं। इस कारण उनके बीच होने वाला ध्वन्यात्मक संचार हिन्दी में उसी तरह लिपिबद्ध किया जा सकना संभव नहीं है, जैसे वह बोला-बरता जाता है; अपितु इसके लिए हिन्दी भाषा का आवश्यक ज्ञान एवं सामान्य व्याकरण पर अधिकार होना जरूरी है। अंग्रेजी के साथ भी इसी तरह की कठिनाई है। अतः अरुणाचली भाषाओं की पूर्णतया 'शिफ्टिंग' हिन्दी अथवा अंग्रेजी या फिर दोनों में हरगिज़ संभव नहीं है।

अंत में निष्कर्ष

उत्तर-पूर्वी जनसमाज के बारे में अधिसंख्य भारतीयों की समझ, सोच और दृष्टि पुस्तकीय ज्ञान पर आधारित अधिक है। हममें से अधिसंख्य यह नहीं जानते हैं कि उगते हुए सूरज की दिशा में बसे राज्यों के नागरिक कैसे जीवनयापन करते हैं? हमें यह भी नहीं पता है कि यहाँ के बहुसंख्यक लोगों की असली दिक्कतदारी क्या है? स्त्री-पुरुष सम्बन्ध से लेकर खान-पान, रहन-सहन, बोल-बर्ताव, परिधान, प्रथा, मान्यता, लोकाचार, लोक-परम्परा आदि को उत्तर-पूर्वी समाज किस प्रकार जीता और उसे अपने भीतर समोता है? ध्यान दें, अपनी सामाजिक-सांस्कृतिक चेतना में खुशहाल एवं उत्सवधर्मी पूर्वोत्तरवासियों का साहित्य के प्रति राग-अनुराग जबर्दस्त है। मौखिक साहित्य का उनका लोक-वितान व्यापक और बहुआयामी है, तो उनके

भीतर अनुस्यूत लोककथा, लोकगाथा, लोकगीत, जनजातीय भाषा में प्रचलित मुहावरे, लोकोक्तियों आदि से सम्बन्धित सामग्री प्रचुर मात्रा में विद्यमान है। आदिम जीवनराग की आधुनिक अभिव्यक्ति इतनी स्वच्छ, निर्मल, स्वार्थ एवं वासनारहित हो सकती है, यह सुनना-जानना हमारी सामान्य समझ के लिए सचमुच अचरज का विषय हो सकता है। इन दिनों अरुणाचल की मुख्य समस्या यहाँ की भाषाओं, उपभाषाओं एवं बोलियों पर मंडरा रहा खतरा है जिस बारे में राष्ट्रीय-अन्तरराष्ट्रीय भाषाविद् लगातार आगाह करते रहे हैं। अरुणाचल की कई भाषाएँ प्रयास के अभाव में लुप्त हो चुकी हैं, तो कई लुप्तप्राय होने की सीमा-रेखा पर हैं। विडम्बना यह है कि हाल के वर्षों में रस्मी चर्चाओं के बीच अरुणाचली लोक-साहित्य और सांस्कृतिक विरासत को सहेजने-समोने की बात बढ़-चढ़ कर की जाती है; पर इस प्रयास की गति अत्यंत धीमी है अथवा बिल्कुल अपर्याप्त है। अरुणाचली जनसमाज की अपनी भाषा हेतु किसी एक सर्वमान्य लिपि के नहीं होने से जो भी सहयोगी प्रयास हो भी रहे हैं, तो कुछ गिनी-चुनी भाषाओं में। यथाः हिन्दी, अंग्रेजी, असमिया आदि। आश्चर्य है कि हिन्दीतरभाषी प्रदेश होने के बावजूद हिन्दी यहाँ सम्पर्क भाषा के रूप में व्यवहृत है। अरुणाचल की हिन्दी अपने विशेष उच्चारण-शैली, लहजे एवं उतार-चढ़ाव के कारण 'अरुणाचली हिन्दी' के रूप में लोकप्रिय है। इसी तरह एक बार सीआइआइएल ने घोषणा की थी कि—'वह जल्द ही लुप्तप्राय भाषाओं पर श्वेत पत्र जारी करेगा। इसमें दस हजार से कम लोगों की भाषा/बोली को संकटग्रस्त भाषा मानने की बात कही गयी थी।' गंभीरतापूर्वक किन्तु समग्रता में किए जाने वाले इस तरह के प्रयासों का परिणाम दूरगामी होता है। अतएव, इस संकट से उबरने के लिए सबसे पहले हमें अपनी सोच बदलना होगा कि सरकारी निराकरण से लुप्तप्राय होती जा रही भाषाओं, उपभाषाओं, बोलियों आदि का संरक्षण या कि उनकी सुरक्षा संभव है। दूसरी बात, इस तरह के संकट को भारत की सांस्कृतिक बहुलता में ह्रास और भयानक घटोतरी के रूप में भी दर्ज किया जाना जरूरी है जिससे भारत की छवि एक एकीकृत-समाजीकृत राष्ट्र के रूप में उभरती है और हम जिसे 'अनेकता में एकता' के रूप में पहचानते हैं।

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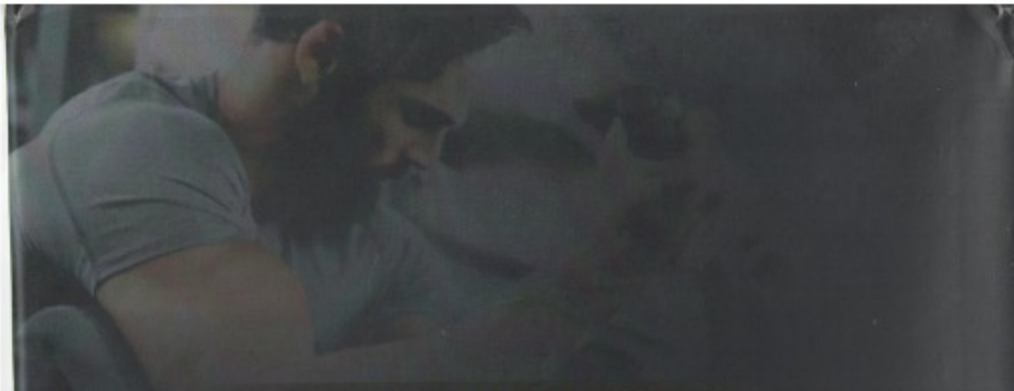

ABOUT THE AUTHOR

Availability of sports talent, application of appropriate means and methods to identify talent and presence of technical persons who are aware of the scientific methodology to groom the talent are the important pre-requisites in case an institution or a country even thinks of having sports teams or sports person who can match the national and international standards. The coaches has to systematically monitor the important features of outer training load. In view of this the coaches and trainer has to understand the process of adaptation.

ABOUT THE AUTHOR

Dr. Sambhu Prasad, Assistant professor, Rajiv Gandhi University, Arunachal Pradesh was a good sportsperson during his school and college days. He completed undergraduate post graduate and doctoral in physical education from Lakshmibai National Institute of Physical Education, Gwalior. He has been engaged both in teaching and research for then 10 years in India as well as abroad and has published over 20 research paper in reputed National and International journals. He served as Assistant Professor in Mekelle University, Ethiopia and was also associated with University Coaching Camp in track and Field for two years.

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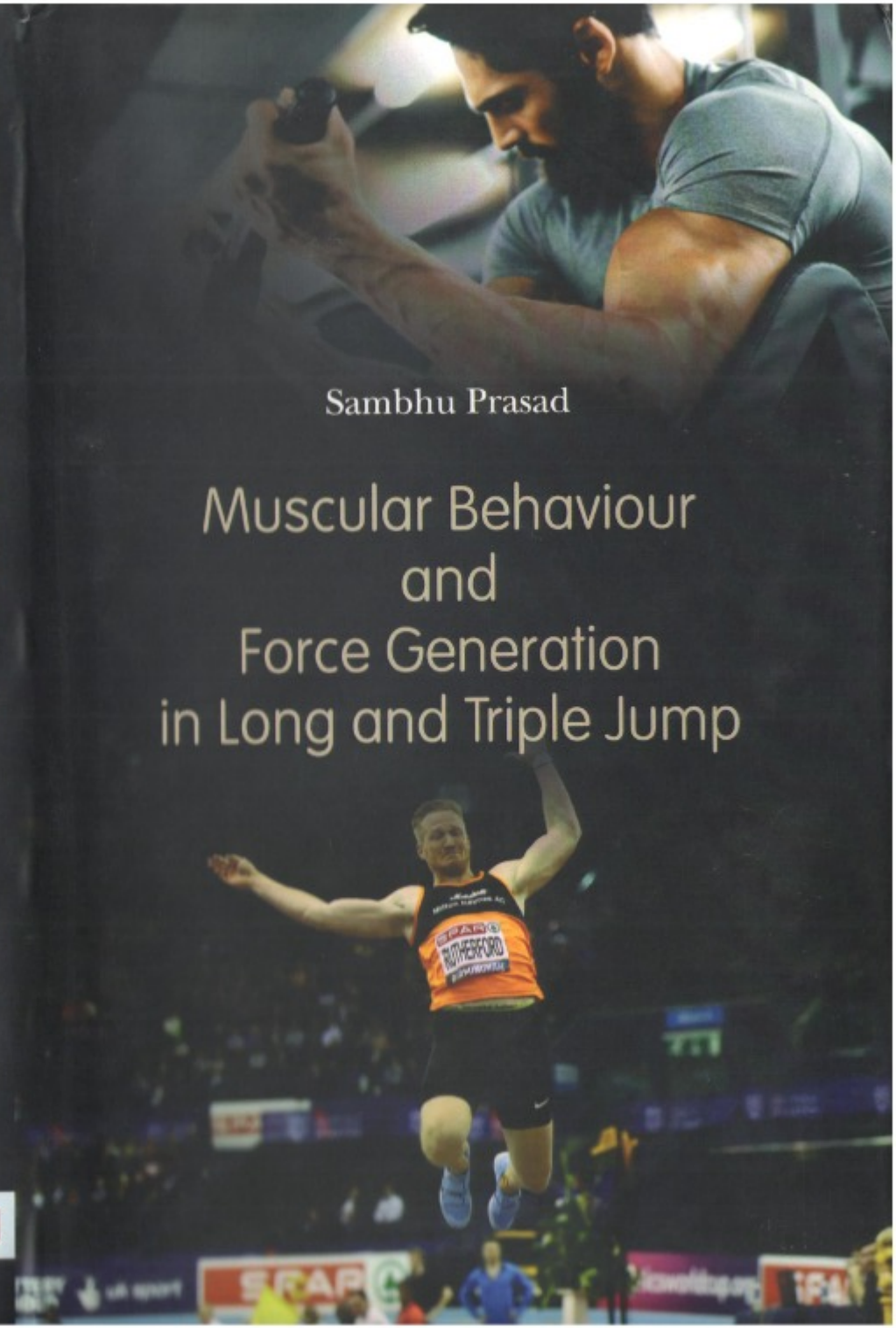

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PREFACE

Availability of sports talent, application of appropriate means and methods to identify talent and presence of technical persons who are aware of the scientific methodology to groom the talent are the important pre-requisites in case an institution or a country even thinks of having sports teams or sports person who can match the national and international standards. The coaches has to systematically monitor the important features of outer training load. In view of this the coaches and trainer has to understand the process of adaptation.

Preparing teachers/Coaches for their service in modern science is a challenge for Higher Educational Institutions and it is understandable that there will be differences between nations and cultures because of their individual traditions and historical backgrounds. In this context Physiology is a complex process which is determined by various chemical changes and pedagogical influences. Indeed, numerous books have been written on each of these subject areas.

It is understood that, because of the limited space the book was permitted, there might be some issues and areas which have not been covered in detail or not mention at all and I apologize for any exceptional omissions. The mistakes are solely mine. Having said this, it should also be noted that this book is intended as a starting point: a platform for providing coaches,

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Bridging Culture and People

Edited by
Tarun Dutta

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1

Road Communication and Its Development in North-east India and Beyond within a Historical Framework

Sarah Hillaly

Introduction

The historiography of South Asia in the realm of transport has been built on the premise of how improved means of communication through the network of roads, railways and canals were 'public works', sought to improve the lives of the people. Lack of transport and communication in conjuncture with trade facilities has been viewed as being in a state of 'barbarism' within colonial historiography. Transport facilities for commercial purposes came to be viewed as a measure of triumph for western techno-science, fostering regional development on one hand, while unifying regions to the world trade cycles—particularly in the railways. It was linked with ideas of material and moral progress rendered by the efficient road communications. The debates on economic nationalism too rested on whether transport and communication of all kinds were beneficial to the British or the Indian nation.

These ideas failed to take into consideration as to how imperial techno-science interacted with specific local realities and emerged as the science of the empire. According to critiques like Sandra Harding the progress of European science is chiefly attributable to the "military economic and power of European cultures" rather

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than to claims of possessing greater rationality or commitment to the pursuit of disinterested truth.[1]

The unification of regions or fostering of regions created new socio-economic constellations within which the indigenous business interacted. Ravi Ahuja in his book *Pathways of the Empire: Circulation, 'Public Works' and Social Space in Colonial Orissa, c. 1780–1914* tries to argue that each of these infrastructure modes have been studied, de-contextualised from its historical contexts and considered to have no specific context. It was presumed that both roads and railways catered to a wide range of social actors and hence were all-pervasive in its impact. He further states that colonial sources were extremely laden with data on railways and canals, with a corresponding paucity of data on roadways and waterways. To him it reflected the dominance of certain social interests.[2]

Within the history of South Asian transport and infrastructure Jean Deloche's *Transport and Communication in India Prior to Steam Locomotion*, 2 Vols., (New Delhi: Oxford University Press,1993-1994) has been significant in tracing the pre-colonial modes of transport. Such modes of transport within the historiography have received very little attention, except in terms of alluding to roads as gleaned from the *Arthashastra* of pack bullocks wherein comparisons are made of its relative costs and contrasting it with savings achieved by the coming of railways.[3]

A recurring trope among historians of South Asia's transport infrastructure continues to be mediated by notions of pre-colonial self-sufficient villages in a permanent state of stasis. The argument stemming from it is that all means of communications—roads, railways and canals—was the handiwork of the colonial state. Jean Deloche "reconstructed spatial patterns and technological modes of transport in pre-colonial South Asia proving beyond doubt that road engineering and bridge building pre-dated British innovations."[4] Fernand Braudel too in his work on the Mediterranean had pointed out that roads were "no mere tapes unrolled over land." They were rather contingent on the existence on modes of economic, political and cultural institutions, which included "ports and towns, fairs and markets, pilgrimages and festivals, caravan serais and mail services, toll stations and police posts".[5]

Within the historical context, development of transport infrastructure is essentially entwined with the socio-economic,

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political and cultural processes of the corresponding period. Ravi Ahuja alludes to road-building measures by the 'little kingdoms' of the early nineteenth century was directed to serve political and cultural needs of the polities, rather than to seeking to centralise control. The lack of a vibrant road network was therefore not to be construed as 'neglect' of infrastructure by the earlier regimes. Tarashankar Banerjee while reflecting on the importance of roads remarks that, "roads are a vital factor in the national economy. They link industry with agriculture, producer with consumers, and the external market with the internal one."

The Context

In the context of colonial Assam my book on *The Railways in Assam 1885-1947* (Varanasi: Pilgrims Publishing, 2007) which emerged out of my Ph.D. dissertation, is a maiden history of transport history. It was framed within the discourse of transport and communication, where the railways visualised within the older frame of discourse as a harbinger of major technological changes. The commonalities and the distinctiveness of the railway policy in terms of its introduction is dealt with. As a 'public work' the role of railways in all sectors of the economy, urbanisation and immigration as a concomitant has been explored. The social effects too have been explored in the work. A limited critique of the colonial policies has been attempted to account for the lopsided development concomitant to the growth of an "enclave economy" centred around the plantation, petroleum and coal mining industries. The broader framework was to view railways as a "productive public works". Beyond the purely economic implications the study has not taken into account its core social and cultural implications.

One of the chapters however has dealt with the pre-railway communication and transport, wherein a sketch of the pre-colonial roads and waterways has been made. It also discusses the roadways constructed by the British and the limited expansion of steam shipping. Their role not only in the "opening-up of the country" but to meet "strategic needs" have been highlighted. Despite an attempt to draw continuities from the pre-colonial modes of transport, the circulatory regime and its social context has not been investigated.

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Roadways in North-east India

The pre-colonial period in Assam under the Ahom and Koch rulers witnessed the construction of large sections of embankment-*cum*-roads, which sustained internal communication within the Province. This network of roads impresses John M'Cosh an administrator ethnographer in his early travel writings. He writes thus :

> Very few provinces in India have been provided with such a splendid system of public roads as in Assam and from the great highways, which were carried uninterruptedly through the whole country to the great cross-roads, between the principal towns and their minute ramification, which connected the villages.[6]

M'Cosh alludes to Assam's earliest commercial relations with the outside world sustained through the Brahmaputra River. In addition, he refers to the existence of three overland routes to Bengal:

> The first was *via* Murshidabad, Malda, Dinajpore, Rangpore, (*sic*) Bugwah and Goalpara ... the second road was *via* Dacca, Dumary, Pacualoes (*sic*), Jumalpore, Singimari and Goalpara. The third *via* Sylhet, Cherra, Mophlung, Nungkhlow, Ranigodown, Canneeymookh and Guwahati ...[7]

These imperial road-*cum*-embankments had fallen into disarray, mostly being over-grown with jungles, which rendered them useless. This infrastructure had been built and maintained through collective efforts of a huge militia of freeman or *paiks*. Such *paiks* were under obligation to offer labour-rent to the state as a workforce in agriculture, and undertaking large-scale public works like building roads and tanks. The most significant ones constructed in the medieval period were the *Gosain Kamal Ali, Dhodar Ali, Dhai Ali* and the *Bar-Baruah Ali*.[8]

Modes of exchange with the overland neighbours, particularly the hills in the north and east were sustained through this network. Both inter- and intra-regional trade was clearly discernible through

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the networks, though its volume was small and constrained by the socio-political and economic structures of the medieval regimes. Each road network marked the convergence of social interests rather than purely commercial ones. Such networks were sustained through fragile 'pathways' which mediated flows of humans, goods and ideas.

The colonial intervention from 1826 inaugurated newer modes of economic control. The initial years were focused on maximizing revenues on land through commercialization of agriculture and subsequent monetization of the economy. Captain Jenkins, the Agent to the Governor General visualized expansion of trade in raw-produce as a concomitant to agricultural expansion. An imperative to such an expansion could only happen with a consequent improvement of the existing communication networks by land and water. In his letter to A.J.M. Mills in 1853, he emphasized on the need of improved communications thus:

> The measure for accelerating the progress of the Province.... A systematic improvement of the main roads is one of the obvious means we have.... A great obstacle now to the clearing of wastes is the want of communication between these tracts and the cultivated districts.... The outlay on the roads, if the works be regularly conducted and permanently established and be not again allowed to fall to disrepair, will as certainly be returned to Government by increase in revenue.... The people cannot [live] amongst wastes that are cut off from all communication with the present villages, but wherever the jungles are opened out, colonization does and will take place.[9]

In the colonial schema, the presence of good roads was linked to notions of permanence, civility and superiority of civilization.[10] Hence, communication becomes a site and a medium of grappling with the shifting economic structures; to understand trade and travel read with ideologies and discourses of colonial rule.

Responsibility of building roads and maintenance in India was vested with the Military road in each Presidency until 1854, The roads constructed though patchy with the exception of a few arterial ones were because of military requirements. In 1854, Lord

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Dalhousie constituted a separate Public Works Department.[11] As 'public works' was no longer under the Military Board, increasing attention was paid to 'civil works' particularly civil buildings, roads, establishments, canals and irrigation works. In the preceding years, funds available for public works was a paltry Rs. 60 lakhs in 1849-50, which rose to nearly Rs. 2.25 crores in 1856-57.[12] Therefore, the East India Company which had totally neglected 'public works' for the greater duration of its rule showed a spate of activity in road building during the last years of its rule.

During the earlier colonial period, focus on road constructed was to enable speedy movement of troops, in the eventuality of renewed Burmese attacks and incursions from frontier tribes. Here too public works were vested with the Military Board. The initial years were spent on restoring "portions of the great roads of Upper Assam."[13] As Assam continued to be administered from Bengal in 1835 an Executive Officer operating from Dacca was appointed to oversee the communication network. Faced with delays and difficulties in execution Captain Jenkins demanded for employing an European overseer in Assam to ease the matter. Finally, in 1840 a Division of Public Works was created with Executive Engineer appointed for Upper Assam and an Executive Officer for Lower Assam, both subordinated to the Chief Engineer in Bengal.[14]

These military roads remained unmetalled, in most cases, cleared, and repaired, just enough for the passage of troops and elephants. These roads, because of their temporary nature, had to be constantly repaired. As the political situation gradually stabilized, roads for purely military purposes were rarely constructed. Construction and main tenance of all *kutcha* roads were left to the local authorities considered better equipped with the local milieu hence could provide local assistance in the form of land grants, labour and revenue. This was because the demands on the "Imperial revenue" was substantially heavy. The Government encouraged raising of funds through public subscriptions too Military roads continued to be managed from ferry funds raised in each district.

The Government encouraged raising of funds public subscriptions too. Public works undertaken by public money were not thoroughly executed by the Government officers. The public too, after having paid the money, showed no interest in its execution. In Upper Assam, many old and minor roads were

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cleared of jungles and repaired with the help of tea planters in the immediate vicinity of their gardens.

Paucity of funds remained a constant hindrance for local improvements. In order to tap alternate sources of funds, in 1861 Henry Hopkinson, the Commissioner of Assam, proposed to double land tax, so as to devote the excess so obtained, for works of public utility. The Board of Revenue did not consider it expedient to double the land tax.[15]

The Revenue Board extended the provisions of the Government Order No. 1847, of 28th July, 1859, sanctioning "the appropriation of 3 per cent on the collections to purposes of local improvements."[16] In 1862, the Government permitted the use of "the surplus proceeds of 1 per cent on the Income Tax Collection."[17] The creation of a full-fledged Public Works Department for Assam in 1868 ensured financial stability and streamlined its working. Further, by the Act X of 1877 District Road Cess was levied on all immovable property, within the district for raising funds for construction and maintenance of roads. It also provided for the constitution of 'Local District Committees' for the assessment and management of the "Road Cess."[18] The funds for the Trunk roads and Military Roads were drawn from the "Imperial Funds."

In the early years of British rule road alignments were decided on their military feasibility. These military roads were to provide render speedy troop movement, in the eventuality of renewed Burmese attacks or incursions of the frontier tribes. The initial focus was therefore on restoring "portions of the great roads of Upper Assam."[19] In 1840, alarmed by reports of Burmese attempts to open a road through the Naga Hills from the Kyendween (*sic*) river, made it imperative to improve the line of communication between the Muttock country and the troops reserve at Sibsagar.[20] Repairs were undertaken on the *Bar Baruah Ali*, the high road from Sibsagar towards Dibrugarh through Chokey Hat on the Buri Dehing. Portion of the high roads between Jaipore and Sibsagar was opened. This road was to be:

> ...of great political importance, as affording the means of moving troops and of controlling the Nagas as well as highly valuable as one of the roads of internal communication on a line, by which much traffic in salt is conveyed.[21]

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The other roads repaired were from Dibrugarh to Saikwah and Jaipore to "facilitate movement of the Assam Light Infantry which has (*sic*) to guard the extensive frontier."[22] The *Bund* road from Sibsagar to Dikhu-mookh, according to Jenkins was of "highest utility in a military and political view."[23] Captain Butler, the Principal Assistant of Nowgong in a letter to Jenkins urged on the opening of two separate roads along the frontier of the district in view of the operations against the Nagas. The first alignment was to be from Nowgong *via* Samuguting to Dimapur, the other from Golaghat to Dimapur.[24] To complete the line of communication along the frontier posts, a road was constructed between Dum-duma and Makoom.[25] A small stretch of road between Golaghat and Nagorah was opened, as it was "much frequented by the Angami Nagas and our traders and troops."[26] These military roads were unmetalled, in most cases, cleared, and repaired, just enough to enable the passage of troops and elephants.

The Government too put in its effort to open branch roads from the main line of the tea gardens to the landing places (*ghats*) on the Brahmaputra. In the district of Sibsagar, portions of the *Dhai Ali* between Sibsagar to Buri Dihing Mookh; *Barpatra Gohain Ali* from Sibsagar to Disang, and the *Sologuri Ali* from Disang to Buri-Dehing were constructed.[27]

The Government emphasized on the need for road building into the hills, to establish markets and develop them, as "roads and markets ought very speedily to create a social revolution in the hills."[28] A road was constructed between Udalguri in the Kureaparah Doar and Mangaldoi on the banks of the Brahmaputra, with the object of "inducing the Bhutias to come down to Mangaldoi (*sic*) for the annual fair."[29] A road was opened from Goalpara to the eastern *hats* of Jirah, Damrah and Nibari. The road was of much importance to the merchants of Goalpara as there was a large trade in cotton.[30]

The principal roads in the well-populated parts of Kamroop were repaired. Repair of the great western road, connecting Guwahati to Goalpara and therefrom to Bengal was taken-up. The *Gosain Kamal Ali* was restored between Manas and Bur-Nadi. The high *bund* road extending from Guwahati through East Dimarua to Raha, across the Kullung along its right bank crossing Nowgong, continuing up to Jorhat and Sibsagar was restored.[31]

The tea industry around which all the developmental activities

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in Assam centred, played a crucial role in the growth and development of roadways:

> As early as 1845, the Assam Company claimed with some exaggeration, that it had opened or repaired some 1,280 kilometres of public road, had erected 266 bridges and established several ferries across the rivers.[32]

The roads mostly linked the gardens to landing places (*ghation*) on the Brahmaputra from where country boats shipped them to Calcutta. Roads linked the gardens with their neighbouring villages, which enabled cultivators increased facilities for disposing of the produce of their lands.

The first road, conceived for external communication connecting Guwahati with Sylhet was considered crucial for troop movements in case of fresh Burmese incursions. As early as 1826, David Scott persuaded the Khasi Chiefs of Khyrim and Mylliem to agree on the construction of a road through their territory.[33] Work commenced on the route in 1829, but had to be stalled because of the murder of Lt. Burlton and Beddingfield, who were in charge of the construction. Following the annexation of Khasi Hills in 1832, interest was renewed on the project. However, the military imperative changed after 1840, when Jenkins insisted on the road aligned through the Khasi Hills was: "the road was of highest importance to the bordering countries in a commercial point of view...also equally good with any other if not the best for military operations of any unforeseen exigencies".[34]

Colonel Hopkinson in 1862, in a letter to the District Officers on the issue of opening-up of trunk lines through the province favoured an early construction of the Guwahati -Sylhet road, as he perceived that:

> communication with Bengal will be sooner established by it, because with the railway to Dacca, it will probably be the quickest route of the Presidency, as for mails to reach as from Calcutta, because it at once renders accessible large tract of country perfectly suited to European colonization and because of the community of interest between Cachar and Assam which a road also uniting the two provinces together will so well serve.[35]

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The alignment was finally decided upon and sanctioned in 1863. The route selected was between Guwahati in Assam *via* Shillong to Chattak on the River Soormah (*sic*), a distance of 104 miles. In 1866, a grand project for a 'Trunk Road' running through all the districts of Assam was conceived. The project was formulated on a much larger scale than funds could permit. After assessing the financial implications of the project and based on the availability of funds, the idea of a "railway formation for the Trunk Road was given-up and orders were issued to continue work on a smaller scale of a sixteen feet top width." [36] Carrying regular mails, toll stations constituted as one of the important practices.

Till the end of the nineteenth century, the reports of the Assam Tea Association featured complaints on status of the existing roads, where the proportion of the metalled roads to unmetalled was insignificant. Since 1896 cart traffic played a significant role with Manipur and its neighbouring areas. Despite bad communication, the trade from the uplands north of Assam and the Lushai and Naga Hills including Hill Tipperah approximated at about Rs. 13 lakhs.[37]

In 1911, the Indian Tea Association stressed on priority being acceded to development of roadways. With the revocation of the first partition of Bengal in 1912 emphasis was laid on development of roads wherein Rs. 41 lakhs as special grants for roads were released. The first passenger service was inaugurated between Guwahati and Shillong in 1916. However, its reach was limited to goods carried for the Planters' Stores Limited. The condition of the aforementioned road led to a poor response by a Calcutta firm to run a passenger service.[38] Finally, in 1922, the first passenger bus service was started between Jorhat and Jhanji in Upper Assam. Both mail and passengers to Shillong were carried by *Tongas* till the introduction of mail service in 1922. Close to 400-600 bullock carts, with a carrying capacity of 15-20 maunds carried provisions like salt, cloth and other essential services, in return bringing back potatoes and oranges. [39]

During the Second World War, road construction received priority to meet the defence requirements. By the end of 1942, an acute shortage was witnessed as all vehicles were requisitioned by the Assam Transport Organisation. A private enterprise under European management stepped in to increase its fleet to 400 vehicles and employed 1,100 people within a span of six months.

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During the entire duration of the war about 90 per cent of its fleet was engaged in providing logistical support to the military, while the rest catered to civil supplies. As the war ended Assam Transport Organisation went on the verge of liquidation. Government decided to intervene and on the recommendations of a Committee they renamed it as State Transport Corporation in 1948.[40]

The history of the Stilwell road as a part of the war effort against Japan, to maintain American-British link with China is one of the significant infrastructures created during the war.

The Trajectory of Transport History

With the spatial turn in historical debates, the idea of production of space of Henri Lefebvre is being used for analysing issues of circulation and transport. The rise of railways and steamshipping as modes of transport in the 19th century not only ushered in a revolution, but contributed crucially to transformation in social space.[41] The conception of annihilation of space and time was evident in the early discourses on road building across India where the entire country was viewed as a blank slate with roadless plains and impassable rivers. It was colonial imperative to open-up these spaces to civilization, where the new recreation of spatial environment in the form of roads were planned, thus making claims to creating new modes of circulation. The pre-colonial modes of transport found little recognition as they were always mentioned in the passing.

Currently, the term communication has acquired a disembodied character with the waves. Therefore, the construction and utilization of roads, waterways and railways become spatial practice of 'transport'. The ideas promoted were that new forms of transportation in concrete historical terms brought in social domination by privileging ideas of spaces, fortifying dominant interests, which subordinated interests were undermined. Such ideas fails to encapsulate the contradictions inherent in terms of the multilayered historical inheritance and polyvalence of the built environments. An effective study should be able to not only look at polyvalence at level of the nation, but in regional and local settings and also include the socio-economic and cultural fieids wherein all daily experiences are wherein such transport infrastructure was used very sparingly.

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Arguments like infrastructure helping to link all local networks into the world trade cycles can be re-examined in terms of looking at the process of fission/departure by micro-level studies. All practices of space is defined by rhythmic cycles of nature specific to each area. Periods of circulation were defined by seasons, largely agricultural/non-agricultural, religious gatherings, fairs and festivals. Even public works like building roads, ponds, bridges etc. tried to follow the seasonal cycles though at times such norms were deviated from. The creation of new transport infrastructure which was characterized by the productive and reproductive cycles of capital imposed its own cycles over that of nature. One can therefore study circulatory flows of goods, ideas and human movements not to understand the linearity of the flows, but the negotiations with newer modes of transport and creation of mediated flows.

Notes

1. Celia Roberts and Adrian Mackenzie, 'Science' in *Theory, Culture & Society*, Vol. 23(2–3), 2006, p. 158.
2. Ravi Ahuja, 2009, *Pathways of the Empire: Circulation, 'Public Works' and Social Space in Colonial Orissa, c. 1780–1914*, New Delhi: Orient Black Swan, p. 3.
3. Ravi Ahuja, *Pathways of the Empire*, p. 4.
4. Ravi Ahuja, 2004, "Opening up the Country? Patterns of Circulation and Politics of Communication in Early Colonial Orissa", *Studies in History*, 20:1, p. 73.
5. *Ibid.*, p. 74.
6. The brother of the great Koch King Nara-Narayan, after whom the road was named, constructed the *Gosain Kamal Ali*. It extended from Sadiya to Kooch Behar, a distance of 350 miles. The *Bangal Ali* stretched from North-East Darrang to North Guwahati . The *Dhodar Ali* was in the southern portion of the Sibsagar district and the *Dhai Ali* was from Rangpur to Jaipore.
7. J. M'Cosh, *op. cit.*, pp. 8-9.
8. Sabyasachi Bhattacharjee, *Financial Foundations of the British Raj* (Shimla, 1971), p. 114.
9. A.J.M. Mills, *op. cit.*, Appendix 'B', No. 275 of 1853, from Colonel Jenkins to A.J. Moffat Mills, Para 2.
10. Nitin Sinha, 2012, *Communication and Colonialism in Eastern India: Bihar 1760s—1880s*, London: Anthem Press, p. xvii.

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11. *Ibid.*
12. *Ibid.*
13. Assam State Archives (ASA), *Letters Issued to Government* (LIG), Volume No. 9, January-September 1840, No. 23, 28th January, 1840.
14. *BJC*, (Criminal), 1838, August 7th, No. 106.
15. B.G. Papers, 1861, File No. 388, Nos. 1-6, No. 494, dated 6th July, 1861.
16. *LIG, op. cit.*
17. *LRG*, Volume No. 44 (d), January 1859-1864, No. 931, 3rd March, 1862.
18. B.G. Papers, File No. 42/50 of 1873.
19. *LIG*, Volume No. 9, January-September 1840, No. 23, 28th January, 1840.
20. *LIG*, Volume No. 9, January-September 1840, No. 85, 4th May, 1840.
21. *LIG*, Volume No. 9, January-September 1840, No. 147, 28th August, 1840.
22. *LIG*, Volume No. 10, No. 131, 9th March, 1852.
23. *BJC*, (Criminal), No. 40, 19th September, 1842.
24. *LIG*, Volume No. 15, No. 112, 21st September, 1850.
25. *LIG*, Volume No. 15, No. 152, 28th November, 1850.
26. *Ibid.*
27. A.J.M. Mills, *op. cit.*, Appendix F-1-23, "List of Principle Roads in Sibsagar District".
28. B.G. Papers, Nos.1-3, File No. 15/18 (1873), *cf.* S.B. Medhi, *Transport System and Economic Development in Assam*, (Guwahati, 1975), p. 42.
29. *LIG*, Volume No. 16, No. 320, 10th August, 1852.
30. Goalpara Papers 1873, File No. 981, Serial No. 122, 28th February, 1873.
31. *BJC, (Criminal)*, No. 4, 13th October, 1835.
32. Amalendu Guha, MECA, p. 160.
33. For details of David Scotts' policy in the Khasi Hills, refer to Nirode K. Barooah, *op. cit.*
34. Ravi Ahuja, *op. cit.*, p. 27.
35. Letters issued to District Officers, Volume No. 9 (a), 1861-1864, No. 32, 31st January, 1862.
36. W.W. Hunter, *op. cit.*, p. 55.
37. S.B. Medhi, *Transport System and Economic Development in Assam*, Guwahati· Publication Board, 1978, p. 42.
38. *Ibid.*
39. *Ibid..*
40. *Ibid.*
41. Ravi Ahuja, *op. cit.*, p. 27.

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THE FALLING POLITIES

Crisis and Decline of States in North-East India in the Eighteenth Century

Edited By
Tejimala Gurung

DVS PUBLISHERS
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6

Political Formations in Eastern Arunachal Pradesh in the 18th Century

Sarah Hilaly

The dominant State in early 18th century India i.e. the centralized Mughal Empire incorporated within it most part of the subcontinent. The exclusions were Kabul in the Northwest frontier at one end to Assam in the east. Aurangzeb made repeated attempts to bring the rulers of Assam within its fold which was repulsed in 1680 leaving it out of the sphere of Mughal domination. By the middle of the 18th century the territorial limits of the Mughal Empire shrunk to an extreme level. British power in India was on the ascent with the Battle of Plassey in 1757. By the end of the same century British domination over the whole of South Asia was absolute.

To historians the 18th century is marked by cataclysmic changes in all spheres of social life, polity and the economy spanning across continents. The developments impacted the world in a multitude of ways. The Mughal Empire, one of the four large Oriental Empires too faced its nemesis in crisis and decline during the same period. The convolutions which marked this period which has been characterized as

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'revolutionary' was felt all over India. The imperial historians beginning with James Mill projected a backward society of the subcontinent plunged into greater chaos in the last days of Mughal rule impelling the East India Company to assume direct administrative responsibilities. The Utilitarians and Evangelists deviated from Mill infusing the colonial state in India with a moral mission of enlightened Britain to ensure order and progress to the benighted subcontinent.

Nationalist historians perceived the historical moment of British conquest as disjunctive. While conceding to the chaos in the eighteenth century attending the dissolution of Mughal order, British rule was said to have foreclosed any room for return to an older trajectory. The emergence of new economic relations under foreign domination was said to be responsible for India turning into a land of perpetual poverty and famine. Eric Stokes substantially modified the historiographical legacy. He rejected the idea of an 'oppositional conjuncture' as proposed by both the imperialist and nationalist historians. He proposed a 'harmonious conjuncture' which was represented "by the congruence of historical trajectories that accounts [sic] for both the ease of the British conquest and the continuity of pre-colonial forms during the first century of the colonial regime in India to about 1857".[1] The eighteenth century, therefore, features as a 'dark century' of modern Indian history.

Over the past thirty years these viewpoints have undergone a metamorphosis. The two dominant occurrences of that century have been the decline of the Mughal Empire and the emergence of the British territorial Empire. The 'revisionist' literature tries to move away from the centrist view that decline of the Mughal state was 'catastrophic' with new perspective from the 'periphery'. The decline is attributed to the rise of new economic and political power, which the weakened Mughal Empire was unable to control. New centres of political power developed around the surplus

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producing regions, which though were autonomous, continued to maintain the cultural and ideological framework of the Mughal state.

The imperialist expansion was viewed by the revisionists as a conjuncture, as a single coeval process created out of the interaction of two independent historical processes. This harmonious divide across the pre-colonial and the colonial was visible in the writings marked by the sobriquet 'Cambridge School' the tone of which was set by Anil Seal.[2] The theories of the 18th century focused not only on the polities but also on the economy. Irfan Habib subscribes to the idea of a dark century when he describes it as a period of 'reckless rapine, anarchy and foreign conquest' in short a period of crisis. C. A. Bayly challenged this conception. He generally agreed to disruptions caused by Mughal decline as well as the external invasions of Nadir Shah. However he contended that a large section of the indigenous gentry and financial magnates flourished. As the British territorial acquisitions expanded it hurt certain groups but there was a smooth adaptation to British rule which marked continuity in the economic sphere and not a disruption. Frank Perlin, David Washbrook and Burton Stein too subscribed to the same theory of smooth transition. The dominant historiography on political change in the eighteenth century was in the successor states that emerged. The other polities like that of the Marathas and Punjab retained facets of the older empire within its political and economic structures.

Large areas, however, remained outside the ambit of Mughal rule altogether or on the fringes of its effective administrative reach. Though a semblance of Mughal governance was visible, but there was no direct Mughal inheritance and different patterns of rule had evolved. Even in the heartlands of Mughal rule in northern and central India large tracts remained beyond the pale of fixed cultivation and village settlement on which their

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administration was based.[3] Smaller kingdoms survived on the eastern coast of the Bay of Bengal well into the eighteenth century. The northeastern frontier of Mughal India was ruled by the Ahoms and the state was sustained by the ideology of Hindu kingship. There other smaller regional formations like the Dimasa, Koch, Jaintia, Tripura and Manipur which had their active presence from late 15th century too were based on the Hindu state ideology. The Mughals made several attempts through the 17th century to extend their sway over Ahom territory which was halted and rolled back in the 1680s.The Koch state however had to submit to Mughal inroads. The Jaintia state paid a tribute to the Mughal administration in South Bengal. Therefore, to understand the nuances of change or continuity in the eighteenth century in Northeast India one would not follow the same trajectory.

Problems of Formulation for Northeast India

From the earlier discussion it is evident that there had been several points of contact between the Ahom state and the Mughal state. In fact, remnants of the land revenue policy of the Mughals which had been introduced over portions of Lower Assam after the Koch state came under their hegemony continued till British annexation in 1826.

The formulation on the 18th century revolves around the structures of the centralized Mughal polity which controlled a major part of India. Limited encounter makes it difficult to view the events in 18th century Northeast India as a part of the organic process. To accept the formulation in its entirety for this region becomes problematic. The polity formations in this region sustained from early 15th to the 18th century was independent of the centralized Mughal state system. Without being a successor state in real terms the polities survived the turmoil of early 18th century faced by the Mughal state.

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It was in the last quarter of the 18th century that the larger formation of the Ahom state witnessed a period of crisis. The peasant uprising in the garb of a religious rebellion in 1792-93 weakened the state, which was magnified by Burmese intrusions in early 19th century. This disrupted the smaller polity formations in the region. From the perspective of the time period of the crisis it would be difficult to link it to the disruptions in the Mughal polity. To use the construct of the revisionist historians of sustenance in the 'continuity' of the Mughal political structures in the successor states would also not apply completely to this region. Neither did the colonial government find the economic structures in the Northeast, as vibrant or restructured as well which provided the basis for a smooth transition. However, during the period of weakening of the Ahom state had brought in fresh migrations into the region. The smaller groups who migrated in mid-eighteenth and appropriated spaces in the power vacuum did galvanize into centralized polities. They were, however, unable to replace the Ahom political structure, nor did they represent any continuity.

It is in this context that the paper deals with the Khampti and Singpho migrations into portions of now Arunachal Pradesh and Assam. It is in the period of crisis that these disparate formations accelerated the decline of the central Ahom state.

Structures of the Ahom Polity

A brief reference may be made of the salient features of the Ahom polity in early 13th century as they entered Assam. It was modelled on the Shan political system prevalent in the Chinese Shan and Hkhampti Shan states of Northern Burma (Myanmar).According to Amalendu Guha the Tai-Shan myth which legitimizes the polity, considered that the state emerged as an agency to reconcile social contradictions which were divinely ordained. This legend also hints at the

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superiority of plough using Tai agriculturists over their non-Tai neighbours practicing slash and burn agriculture.[4] The Ahoms as they entered Assam under Sukhapa in the 13th century represented the traditional polity of the Shans in the region of Upper Burma. Edmund Leach in his *Political Systems of Highland Burma: A Study of Kachin Social Structure,* writes about the stratified society amongst the valley Shans.[5] According to Amalendu Guha the polity of the Ahoms as they entered eastern Assam could be classified into a tribal chieftainship with power being shared with two counsellors.

All Shan settlements in their traditional homeland were associated with wet rice cultivation. Therefore, a rough equation could be drawn between culture and the level of sophistication. Leach attributed this relative sophistication to their neighbours to environmental circumspection which in turn provided the basis of a stable political formation.

In the formative years of the Ahom polity the rulers had to contend with the ambition of the smaller Shan formations.[6] Till the end of the 14th century the Ahom rulers paid tribute to the Hkhampti Shan state of Mogaung.[7] It would be pertinent to mention that the delimitation of the boundary between Mogaung (Nara) and Assam as the Patkai took place in 1401.Yet as late as 1576 Sukhampa signed a treaty with the Nara Raja agreeing to pay a tribute of Rs.16,000.

Leach mentions that the Shan loyalty was strongly rooted in their habitat which can be gleaned from the following statement "I and my ancestors are Mong Mao people and we have tilled the same fields at Ho Nawng as long as anyone can remember".[8] This holds the key to the filial links maintained by the Ahom ruler with the rulers of Mogaung, Maulung, Mantara and Mungkong.[9] The continuity of this relationship is apparent from the migration of Shan groups to Assam at the behest of the state.[10] This trend continued well into the middle of the eighteenth century. The Tai-

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Phakes migrated into Assam in1760 settling on the banks of the Buri-Dehing. The Ahom rulers resettled them near Jorhat.The Khamptis who belonged to the Shan stock shared a common ancestry with the Ahoms. Lakshmi Devi cites Elias Ney's *History of the Shans* dating their migration to the banks of the Tengapani in 1751. The initial settlement numbering 5000 secured permission to settle by the Ahom ruler Pramatta Singh. The concept of territoriality in this case can be explained in the light of that applied by B.D.Chattopadhyaya to understand state formation in early medieval India.[11] The extent of the kingdom was not defined in concrete territorial terms. The state was not static but dynamic with the 'sacred domain' of power being defined by temporal power. This concept helps us to understand the composition of states in the post Gupta period when strict territorial demarcation was absent. Instead, certain nodal points become markers of territory.

It is pertinent here to understand the political pressure faced by the Shans in Northern Burma during the corresponding period. Till the middle of the 18th century the Shan states enjoyed a substantial degree of independence, aligning their lot either with the Chinese or the Burmese state.[12] As the principalities in the upper Irrawady region were aligned to the Chinese, they suffered in the hands of the resurgent Burmese state and its army.The levels of oppression were so immense that by the end of the 18th century no regular Shan princes survived in these states. It was during this period of political turmoil that the Khamptis entered Assam. The sequence of migration continued well into the 19th century when a group of 500 Moonglary Khamptis joined the original settlers in Upper Assam.

Structures of Khampti Society

An insight into the structures of society would help us identify the variations in the structures as they settled in

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new territory in Northeast India. It could help us to understand whether these polities as they found spaces were able to take new forms or draw sustenance from the exiting decaying state formations. Traditional Khampti society was hierarchical like any other Shan polity. Their feudal dependencies included other communities of wet rice growing Shans and also a variety of Non-Shans and those practicing *taungya* (slash and burn cultivation).[13]

The society had an exaggerated awareness of hereditary classes. They were the nobility which laid claims to genealogical links with the ruling *Chaofa*. The commoners who formed the bulk of the farming class were on the second rung of the hierarchy. The lower class consisted of fisherman, butchers, pig breeders and liquor dealers, occupations forbidden in the scale of Budhhistic code. Commoners of Non-Shan origin were assimilated into the Shan fold. The Khamptis had a tradition of subjugating communities as slaves known in their parlance as *Lok-kha*. Intermarriage with them was strictly avoided.[14]

The Khampti exodus to Assam was a part of the Shan migrations that were allowed by the Ahoms throughout their rule which was stable till about 1770, thereafter peasant revolts became endemic which the ruling class could not reconcile to. Settled initially on the banks of the Tengapani, they were dislodged as the Singphos from Hukwang Valley pushed them to the region of the Buri-Dehing River. The situation of internal instability of the Ahom regime and the contest for space with the Singphos, made them aspire for a stable political and economic space. In 1794, the Khamptis forcibly occupied the Sadiya region, ousting its Ahom frontier Governor or the Sadiya-Khowa Gohain.The Khampti chief usurped his official name and jurisdiction enjoying greater control of the Assamese peasants living in the area. Many of the Assamese peasants were enslaved. The weak Ahom ruler Gaurinath Singha was compelled to acquiesce. The

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Buranjis recorded that the Khamptis were helped by their fellow Shans like the Pani Naras and Phakials.[15]

The polity of the Khamptis in eastern Arunachal Pradesh, on the fringes of the Ahom state had continuity in the form of the traditional Shan polity. They sustained their practice of wet rice cultivation on the services of the enslaved Assamese peasants. Slavery as an institution of their political economy continued. They also levied taxes on the peasantry living within the jurisdiction of the Sadiya Khowa Gohain. On the one hand, they escaped the dominance of the Kachins in 18th century Hukwang valley and in the new territorial space perpetuated their traditional polities. The river valleys in which they settled provided them the physical environment for sustaining their economy. The availability of a dependent population in bondage became a source for economic survivability.

Structures of Singpho Society

The Singphos belonged to the Tsasen clan of the Kachin or Jingphaw speaking people of highland Burma. Throughout the 18th and 19th century the Shan stable polities were overrun in the region close to Assam. Traditional practitioners of shifting cultivation (*taungya*) the hill Kachin culture, society and polity was circumspect to the physical environment. As they moved into the Hukwang Valley, the necessity of survival in the new physical space led to the adoption of wet rice cultivation techniques by the Kachins.[16] Edmund Leachs' primary focus is on understanding two important political structures among the Kachins.The *gumsa* a stable polity, was considered akin to the Shan polity in contrast to the *gumlao* or unstable polity. This was because their habitats in Upper Burma coalesced and overlapped. To him the Hukwang valley was a zone which accommodated both of the political forms. Linguistically he finds a marked variation in the Jingphaw spoken in the Valley by the

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Singphos.This valley, apart from the main Shan and Kachin groups had sections of population claiming Assamese origin.

The social structures of the Kachins represented the working of a class stratified and segmentary society.[17] The society was divided strictly divided on status by birth or lineage. The population was divided into a hierarchy of aristocrats and commoners. In the pre-British days a very high proportion of the population –at places more than half- were categorized as *mayam* or slaves.[18] Neufville's report in 1828 presumes that in the period before Burmese ascendancy, Kachin lands were cultivated by groups of their own kinsmen or Shans under voluntary servitude. They were believers in the *madai-nat* or the ancestral spirit. Much after the Khamptis they also adopted Buddhism and maintained it as a syncretic faith.

The Singphos entered Assam during the course of the Moamaria rebellion in 1794. They drove out the Khamptis from the lowlands under the Patkai hills and settled on the banks of the Tengapani, east of Sadiya.They also spread their habitations to the tract of the Upper Buri-Dehing in Namrup.Their settlements were drained by the major rivers in the region making it one of the fertile stretches of territory.Chandrakanta Singh had to acquiesce to their territorial acquisitions and their chiefs Gakeen Too and Daipha Gam in the fringes of Assam. To put a stop to further encroachments a fort was constructed at Dighalaghat on the Buri-Dehing.

As they entered Assam the chiefs belonged to Tangai sub-lineages of the Tsasen clan like the Hpungin Wakhyet, Sharaw, Ningkhrawp, Latao, Numbrang, N'Gaw, Ningroo, Hkawtsu, Gasheng Pyisa and Daipha.In early 19th century Pyisa Gam was the dominant chief in Assam and provided leadership to the allied Tangai sub-lineages. Daipha was the most influential chief of the Hukwang valley who is said to have maintained his power with the aid of Burmese

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troops. He was dominant during the late 18th and first half of the 19th century. When they settled in the fringes of Assam the Singphos perpetuated the socio-political structures carried from the Hukwang valley. An economy heavily dependent on Assamese slaves also continued.

Trajectories of Polity Formation in the 18th Century

From an understanding of social formation of the Khamptis and Singphos in their homelands it is evident that the early part of the 18th century was crucial to their fruition into maturity. End of Shan dominance in the region of Upper Burma acted as a driving force in the westward movement of the Khamptis.This was coupled with the flexible notions of territoriality of the Ahom state throughout its rule. This was in conformity with the Shan tradition of maintaining filial links signified by their homeland across territorial divides. Hence there were continuous migrations of Shan groups into Assam. This concept gels with B.D.Chattopadhaya's idea of the temporal domain not being rigidly fixed and more of an extension of the sacred domain.

The Khamptis and Singphos retained their social organization, political structures and religion into the new spaces under their control. The only exception was that though the tradition of bondage perpetuated, the composition of this population changed. This was a necessary corollary to their economic organization based on wet rice. The overthrow of the Sadiya Khowa Gohain provided the space for political sustenance in the tumultuous surroundings.

The Singpho segmentary lineages took advantage of the political turmoil of the Moamaria rebellion. The lineages fighting for political space found the conditions in Assam and its fringes conducive for westward expansion. The basic structure of their polity remained the same as in the Hukwang valley. The facets of a stratified and ranked society

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too continued. However, the system of ultimogeniture in the choice of Kachin chiefs was replaced by the policy of primogeniture as they moved out of the original habitats. The polities continued with strongly centralized tendencies.

The 19th Century in North-East India

The decline of the Ahom state went well into the first quarter of the 19th century. The kingdom had been wreaked by a peasant rebellion in the garb of a religious uprising in the last decade of the 18th century. The final nail in the coffin was the Burmese interlude between 1818 and 1822- a fall out of internal dissensions. The First Anglo Burmese war was fought in 1824-1826 wherein the British emerged victorious and the Treaty of Yandaboo was signed. As victors the British secured the territories of Assam, Cachar and Manipur. To understand the trajectory of polity formation of the Khamptis and Singphos, it would be appropriate to extend the study to the early years of colonial rule in Assam.

(a) Khamptis

The military occupation of Upper Assam brought the British into close contact with the tribes on the turbulent Burmese border. Prominent amongst the tribes were the Moamarias (Muttocks), Khamptis and Singphos.As the colonial administration had yet to stabilize in the region in terms of military deployment, during the initial years evolved a strategy to involve the local communities on the borders. The idea of creating a buffer zone was thus mooted. It was a paradoxical situation as these tribes had previously sided with the Burmese. The Khamptis and the Singphos in particular shared filial links with their core community within Burmese territory. There was also renewed interest of the Burmese under the leadership of Boglee Phukan to involve these tribes in a joint resistance against the British. A detachment of the 42nd Native Infantry was sent to support

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the Khampti chief against Boglee Phukan.

Early in 1825 David Scott the Political Agent to the Governor General for the North-Eastern Frontier was faced with the dilemma of providing a viable and secure border with Burma. The first option was to establish frontier posts at Borhat, Dighalighat and Sadiya or else to arm contingents under the frontier chiefs. As the proposed posts were too distant from the base of operations, arming of native contingents was thought to be a feasible option. The contingents supplied by the chiefs of the Khamptis were armed and the militiamen were provided with muskets and regularly trained under officers of the Regiment.[19] In 1828 the British appointed an officer permanently at Sadiya as a Political Agent in charge of the Assam Light Infantry.[20]

The official position of the Sadiya Khowa Gohain as a legitimate representative of the Khamptis was recognized. He was not under commitment to pay any revenue and continued to raise poll tax from his Assamese subjects. An Intelligence Department was set up under the Cheering Barua a former officer under the Ahom Government at Sadiya. Under the facade of friendship with the tribes it was a measure to make the steady presence of British felt in the region. Visits to cultivate friendship and tours were made imperative on the frontier officials. Facilities for trade were extended as a measure for the economic upliftment of the community.

In the 1830s fresh movements of population of the Singphos from the Bor-Khampti region to areas in the south of the Brahmaputra were repulsed by the British. Khampti complicity in these movements was apparent. In 1835 about 230 Moonglary Khamptis reached Sadiya and demanded similar privileges of receiving arms and tax exemptions for 10 years, from the British[21]. With little possibility of assessing the loyalty of the migrants the British proceeded very cautiously. They were allowed tax exemptions for three years,

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without being provided with arms.

Soon the new Sadiya Khowa Gohain was embroiled in a contest over land held by the Muttocks. This was construed as a violation of the territorial rights of a British protectorate. Coupled with rumours of complicity with fresh batches of migrant Singphos the Sadiya Khowa Gohain was removed from his post and interred to Guwahati on paltry subsistence allowance. The British took over all charges attached to his post. Apparently there was no show of disaffection within the Khampti community. Later on the Khowa Gohain was allowed to come back but in a private capacity. The release of slaves on which their economy was dependent was unacceptable to the Khamptis.The latent disaffection manifested itself in a full-fledged rebellion during a friendly mission under the command of Colonel White in January 1839. He was murdered and the military lines were razed to the ground. The magnitude of assault left the colonial administration perplexed.

A joint expedition with the aid of the Abors (Adis), Singphos, and Muttocks managed to contain further damage. Mishmis were, on the other hand, pressurized to help the British in securing the surrender of the Khamptis. Finally in 1840 the surrender of 900 Khamptis along with arms broke their resistance. The entire population was dispersed along the region from Sadiya to Lakhimpore in 1844 to prevent any serious resistance. The community settled in the vicinity of Sadiya was exempt from paying tax, while the rest of the community had to pay land revenue at rates at par with the peasant in the plains.

(b) Singphos

The British tried to use the Khamptis for keeping a check on the activities of the Singphos, yet on numerous occasions we find that they worked in tandem as their anti-colonial interests overlapped. The attempt to maintain a well defined

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international border was not comprehensible to both the Khamptis and Singphos.They continued to retain links with their traditional homeland in Burma. Therefore, migrations amongst the Singphos and Khamptis settlements continued unabated. Loyalty to the colonial masters thus remained extremely unstable.

As mentioned earlier there were a number of chiefs representing various clans among the Singphos.The initial attempt to placate the Singphos was to ensure that they refrain from presenting a joint front against the British. David Scott sought to placate the chiefs by encouraging them to enter into engagements and grant them annual stipends .This was under "the pretence of employing them to defend the passes of Patkoi and as a measure aimed at dissuading them from indulging in depradations in the lowlands".[22] It was suggested that the willing Singpho chiefs be encouraged to settle on wastelands in the plains of Rangpur. In 1825 they had aligned with Boglee Phukan the discredited Burmese general, but very soon surrendered to the British. Though aware of the possibility of the chiefs changing sides, yet the compulsions of a stable frontier dissuaded them from taking measures of subduing them.

The next British measure was to liberate 3000 slaves who were a crucial component of the Singpho economy. There was an attempt to rally the chiefs in a build-up to an anti-British alliance aligning with the Burmese. The British moved in to thwart such a move and Beesa Gaum the dominant chief was forced to surrender his slaves. Consequently David Scott in 1826 initiated measures to bring a significant number of the chiefs to enter into treaty engagements. Of the twenty eight, sixteen chiefs were brought under the agreement where they undertook to surrender Assamese slaves.Beesa Gaum was to have control over the rest of the chiefs and the jurisdiction of the local officers in resolving local disputes had to be acknowledged.

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Yet we find that it was not until 1845 that the Singphos accepted colonial rule. The imperatives of a stable border coupled with the opening of communication lines to the region reduced British dependency on the tribes as a buffer. In the aftermath of the Khampti uprising in 1839 and the dispersal of its population the strength of the Singpho alliance diminished. Yet we find that in the initial years of colonial rule in the region it had to contend with the resistance from these organized polities.

Conclusion

The formulation of the 18th century in terms of crisis of the centralized state can be applicable to the North-eastern region. However, in terms of the time period we do not find a congruity as in the Ahom state it was the last two decades of the 18th century which was tumultuous. To see it in terms of following the exact trajectory of the decline of the Mughal polity seems problematic too. There were spaces which were taken up by centralized chieftainships, but they did not draw succour from the central Ahom polity to emerge as successor states. Their economic systems too were not developed enough to provide a basis for a smooth transition into the colonial state. Therefore, to apply revisionist arguments in terms of sustenance and transition do not hold good for this region. Extension of the narrative well into the middle of the 19th century is to provide an indication of the maturing of these polity formations. It also helps us understand how organized the opposition to British rule was.

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4 Amalendu Guha, The Ahom Political System, in Surajit Sinha (ed.), *Tribal Polities and State Systems in Pre-colonial eastern and North Eastern India,* K.P. Bagchi, Calcutta, 1987, p.153.

5 They were stratified into aristocrats and commoners. The polity was organized into states (*mong*) each with its hereditary chiefs. At times these *mongs* existed in isolation, while they also acted as federated units of a larger *mong*.

6 They were the chiefs of Tipam, Khamjang and Aiton who were subdued in 1397 by Sudangpha.

7 The Ahom rulers according to Leach continued to use the routes from Hkhampti Long to Assam via the Hukwang valley regularly as the relationship with the Shan chiefs in the region continued. In most of the Buranjis the ruler of Mogaung is called the Nara Raja.

8 Edmund Leach, *Political Systems of Highland Burma: A Study of Kachin Social Structure,* London.1954, p.213.

9 Nirmal Kumar Basu in his *Assam in the Ahom Age* mentions that in times of crisis the Shan chiefs appealed to the Ahom rulers for help. The traditional priestly class too maintained steady contact with the polities in Upper Burma. Messengers appointed by the Ahoms to maintain diplomacy with Munkong were known as 'Tsai-Kams'and were settled at Namrup.

10 Aitonias, a section of the Mungkong Shans were allowed to settle at Borpathar and Sarupathar in Golaghat subdivision. The Tai-Turungs settled at Titabar in Jorhat and Borpathar in Golaghat.Naras too settled at Disangpani and Chalapathar. These communities were followers of Buddhism which permeated into their homelands in the 16th century.

11 B.D.Chattopadhyaya, "Political Process and the Structure of Polity in Early Medieval India" in Herman Kulke (ed.), *The State in India,* O.U.P, New Delhi, 2004,p.212-213.

12 The Hkhampti Long or (Great Khampti) a confederation of seven units were dependencies of Mogaung till the early 18th century.

13 Edmund Leach, *Political Systems of Highland Burma*

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op.cit, p.35.

14 The Khamptis were adherents of the Buddhist faith. They were in possession of splendid literature on Buddhism dealing with the Buddhist tenets, way of life, cosmogony and mythology.One treatise contained the complete Criminal Code.

15 The Tungkhungia Buranji mentions that in 1799 the Khamptis were defeated by a relative of Purnananda Buragohain and later officiated as the Sadiya Khowa Gohain.This version is not corroborated by any other source.

16 The British first came into contact with the Singphos in Assam in 1824.By 1837 the British military intelligence amassed reports of their kinsmen residing in the Hukwang Valley and Northeast of Mogaung.

17 Leach explains this in terms of the gumlao polity where the elder son of the chief who is traditionally not entitled to inheritance could claim his right over the family deity or the *madai-nat*.In the normal scheme of ultimogeniture the elder son becomes the head of a new segment of the community with a new territorial space. Unlike the Shans their loyalty to their original homeland was not present.

18 In the 19th century most Kachin slaves were of Assamese origin who had been captured in the period of British ascendancy in Assam before 1824.This phenomenon was visible across regions of Bhamo, Upper Chindwin as late as the 20th century. There were Kachin bond slaves too.

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Cultures, Identities, Multiculturalism and Beyond

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S. Gregory • Sarit K. Chaudhuri

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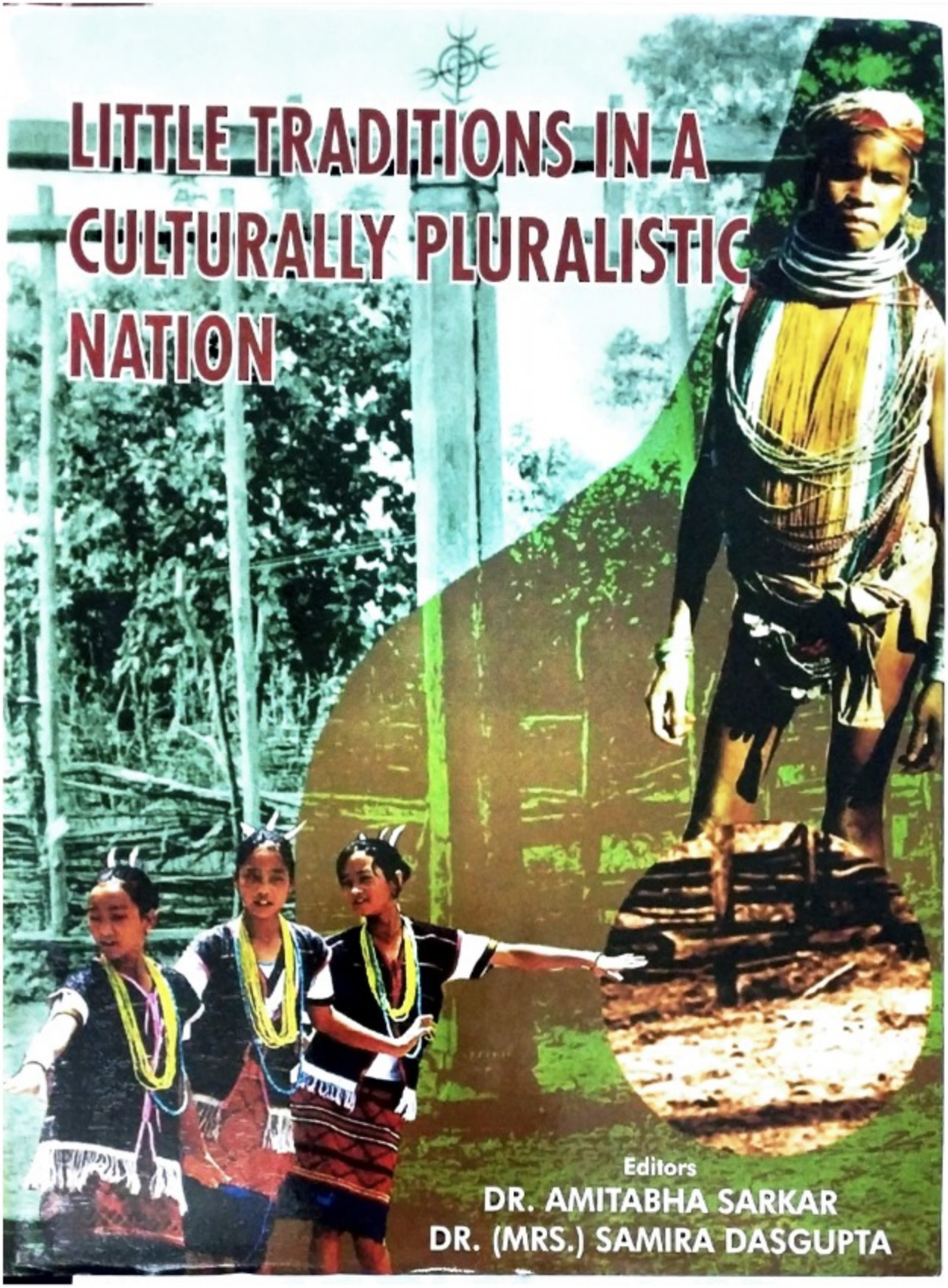
LITTLE TRADITIONS IN A CULTURALLY PLURALISTIC NATION



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Relocating Tribal Tradition: Wanchos of Arunachal Pradesh

Dr. Sarit K. Chaudhuri, Dr. Sucheta Sen Chaudhuri and Nokku Wangsuhum

Wanchos are one of the well-known tribes of Arunachal Pradesh primarily located in Tirap and in newly created Longding district bordering with Nagaland. Wanchos are more in focus in recent days because of the contested issues linked with demand of 'Greater Nagalim' that has placed them in a vulnerable situation as their habitation comes under 'disturbed areas' as per administrative strategy of the state. Otherwise, historically Wanchos are known for their Chieftainship, head hunting tradition, fascinating costumes, dormitories, woodcarvings, and profuse practice of body art irrespective of gender divide which they popularly call '*Huta*'. Like many other tribes of this border state they are also passing through the phase of transition. Their gradual exposure to the wider realities of life, interaction with emerging political economy of the state, large scale adoption of new religious faith and various others induced forces of change faded the functional value of some of the prime traditional markers of this tribe. In the present paper an attempt has been made to have a contextual understanding of some of such traditions, such as, dormitory, costume and tattooing, by locating their implications in their traditional life and their new meanings in the process. This paper also likes to argue that sometimes what we perceive in general parlance as diminishing tradition, some of them actually may be retained within societal base or rather redefined in overt or covert ways through symbolic forms and even in a given context community may like to project some of those diminishing traditions or traits selectively as the identity marker(s) to draw or redraw their cultural boundary in the wider cultural context of the state. The data was collected in various successive fieldworks since 1996 as teachers of a loan university of Arunachal Pradesh, which helped us develop long-term association with the Wanchos villagers, that continues even today. It may be mentioned here that as an impact of our field visits, some of the Wanchos studied anthropology

Tribal Livelihood

Editors
S.N. Chaudhary
Sarit K. Chaudhuri

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EASTERN

Advances in BOTANICAL RESEARCH in North East India

Editors
S K Borthakur
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The Book

The book is a collection of 27 articles on floristic, phytogeography, systematics, traditional knowledge, ecology and other aspects of botanical research in North Eastern India authored by different experts in their respective fields. The book is a noble attempt to fulfil the needs of post-graduate students, research scholars, teachers and researchers interested in botanical studies.

The Editors

Prof. S. K. Borthakur is a well-known field botanist of India particularly for his ethno-botanical and floristic works in North-Eastern India. During the last four decades Prof. Borthakur has carried out extensive botanical and ethno-botanical explorations in different parts of North-Eastern India and published more than 180 research papers and 10 books. He has attended a number of National and International Conferences in India and abroad. Several scholars have obtained their Ph.D. and M.Phil. degree under the guidance of Prof. Borthakur. He is the recipient of S.K. Jain and B.N. Mehrota Medals in 1998 and 2007 from Society of Ethno-botanists and act as member of several National and International professional bodies and editorial board of Journals.

Dr. Amal Bawri is a DST-National Post-Doctoral Fellow (NPDF) in the Department of Botany, Gauhati University, Assam, India. He obtained his M.Sc. and Ph.D. degree from Dibrugarh University, Dibrugarh and North Eastern Regional Institute of Science & Technology (NERIST), Arunachal Pradesh respectively. His area of research interest is Plant taxonomy and published several research papers in the journal of national and international repute.

Dr. Namita Nath is presently Associate Professor in the Department of Botany, Gauhati University. Dr. Nath has published 18 books, of which 5 B.Sc. level Text books, several popular articles and more than 30 research papers in both national and international journals.

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Medicinal Plants Used Against Malaria: A Case Study Among *Adi* Tribe of Arunachal Pradesh

Luk Bahadur Chetry
Farina Panyang
Summi Doming
Tapi Taka
Tonlong Wangpan

Abstract

An outsized number of plants having medicinal properties and their folk uses have remained confined to the Northeastern region of India. The Adi tribal community of Pasighat was explored to unveil the indigenous herbal remedy for malaria. Twenty five antimalarial plants belonging to 9 families were reported. The analysis revealed highest fidelity level (FL) value for *Crassocephalum crepidioides* (69%), *Ricinus communis* (65%), *Allium sativum* (64 %).The percentage of respondent's knowledge (PRK) about anti-malarial plants showed *C. crepidioides* (93.24%) as the most commonly known antimalarial species within this region. It was followed by *A. sativum* (94.12%) *and Piper nigrum* (91.53%). Root (34%) is the most commonly utilized in preparation of herbal formulation. All medicine preparations are made using water as the medium and are orally administered in the form of decoction, crude extract, powder and juice. Overall analysis suggested *C. crepidioides*, *R. communis*, *A. sativum* and *P. nigrum* to be used for the development of novel, economical, effective and ecofriendly herbal formulations for management of healthcare.

Keywords: *Medicinal Plant, Malaria, Adi Tribe, Arunachal Pradesh*

Introduction

Malaria is a parasitic disease caused by *Plasmodium falciparum* and *Plasmodium vivax* (Paul et al., 2013). So far, there has been very limited improvement in the control of this disease, leading to both economic and human mortalities (Shankar et al., 2012). It is one of the major devastating problems in Northeast India and this region was also labeled as 'malaria zone' by the Center of Excellence in Disaster Management and Humanitarian Assistance (COEDMHA) and Pacific Disaster Management Information Network (PDMIN) survey team within their report during 2005.

Since immemorial times, the use and knowledge of herbal medicines was a treasured possession and prominent culture in rural India. This treasured medico-lore is then passed down over many generations chiefly by oral transmission (Katuura et al., 2007). Many tribal communities worldwide use herbs to monitor different ailments, many of which are reported to be exceptionally effective and very promising (Shankar et al., 2012). North East India represents an extremely unique ecosystem treasured with medicinal plant wealth and rich tribal assortment related with folk knowledge, including traditional medicinal practices.

A huge number of plant species has been reported to be used in ethno-phytotherapy treatment of malaria worldwide. The North Eastern region of India alone uses at least 68 plants, belonging to 33 families, to treat malaria (Shankar et al., 2012). The success of the quinine as an antimalarial drug, and the synthesis of artemisinin, the most potent antimalarial drug from plant sources, has encouraged the study of plants as antimalarial agents (Saxena et al., 2003). Although several ethno-medicinal survey of North Eastern India has been done by different researchers, the utility of thoroughgoing traditional phytotherapy by ethnic communities is still unexplored (Chakraborty et al., 2012).

Over the past two decades, there has been a tremendous increase in the use of herbal medicine; however, there is still a significant lack of research data in this field. There are over 500 species of important medicinal plants used in different tribes of Arunachal Pradesh, and still more to be added. (Kongsai et al., 2011). The tribes of Arunachal Pradesh use these medicinal plants in their local health practices. The present study was carried out to access the medicinal plant and their uses in treatment of Malaria among *Adi* tribes Pasighat of the East Siang district of Arunachal Pradesh.

Material and Methods

Study Area

East Siang district of Arunachal Pradesh is spread over an area of 4005 sq.km and it is situated between latitude $27^{0}43^{/\!/}$ N and $29^{0}20^{/\!/}$ N and longitude

94°42// E and 95°35// E. This district was chosen as the study areas because of high incident of malaria cases. (Average malaria cases was 2817 in 2016 -279 in 2017). The district compromised 17 primary health center (PHC/community health center, CHC) that are equipped with diagnostic and treatment facilities for malaria and serves as reporting center for malaria borne diseases control program. The total population of East Siang district is found to be increased remarkably 87,397 as reported by 2001 census to 99'214 as given by 2011 census over the period of ten years. The district is bound by upper Siang in the North, Dhemaji district of Assam in south, West Siang in the west and Dibang valley in the east. The district is mostly covered by swampy dense forest, forested terrain and perennial stream which are congenial for rapid multiplication and longevity of malaria vector. Agriculture is the primary source of economy and most of the population in the district is engaged in agricultural activities.

Data Collection

The folk medicines or ethno medicinal studies the most reliable method is one involving field survey among the Adi community inhabiting Pasighat, Arunachal Pradesh. It involves meeting with the herbalist and expert in the field for getting firsthand information. The detailed information about the plant and part used in the treatment of different ailment were collected using standard questionnaire. The informants were 100 in total that are actively using herbal medicine in daily use. Moreover, the herbal medical practitioner were also interviewed.

The interviewed population comprised of herbal medicine sellers, traditional herbal medicinal practitioners, housewives and farmers. Though individual from all age group (except children below 18 years) were to be interviewed on their knowledge of plant used in the treatment of malaria, most of the mainly to families which have a strong connection with traditional agricultural activities, majority of the respondent were females including herbs seller, farmer and housewives, some of whom were involved in farming, while the male were mostly traditional doctor and farmers.

Data Analysis

The following quantitative and qualitative ethnobotanical methods were used for data analysis. Fidelity level (FL) was calculated to know the percentage of informants claiming the use of a plant species for the same major purpose. It was calculated for reporting ailments as:

$$FL\ (\%) = Np/N \times 100$$

The Np is the total number of informants that are claiming to use a plant species to treat malaria and N is the number of informants that use the plants as a medicine to treat any disease (Alexiades, 1996).

The percentage of respondents having knowledge (PRK) regarding the use of a species (frequency of citation) in the treatment of malaria was estimated using the formula:

$$PRK\ (\%) = Np/Nt \times 100$$

The Np is the total number of informants that are claiming to use a plant species to treat malaria and Nt is the total number of individuals interviewed (Yaniv et al., 1987).

Results and Discussion

The present ethno-pharmacological survey result revealed a total of 25 plants species belonging to nine different families used by the local community of East Siang District Pasighat Arunachal Pradesh, for the treatment of malaria (Table 14.1). While, maximum contributions were reported from Lamiaceae (3 plants) and Asteraceae (3 plants) (Fig. 14.1). The respondent had good knowledge about malaria and could readily identify it from other fevers on the basis of locally accepted characteristics symptoms that included headache, fever, chills, joint

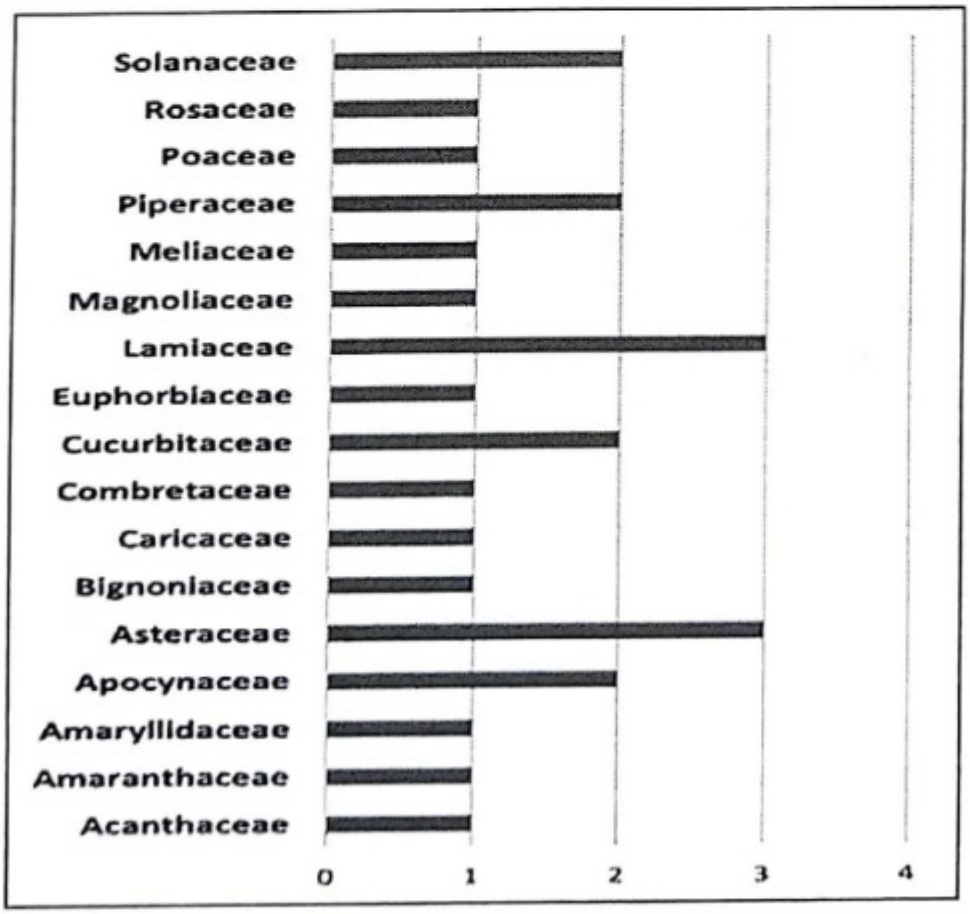

Fig. 14.1 Frequency of Families of Antimalarial Plant used by Adi Tribe of Eastern Himalayas

Table 14.1 Medicinal Plants Used to Treat Malaria Among the *Adi* tribe of Northeast India

Collection No.	Plants (Voucher No.)	Family (Habit)	Local name	Part used	Mode of preparation and administration
FP/APU/2017/01	*Achyranthes aspera* L.	Amaranthaceae (H)	Apamarga, Datiun	Rt, St	Decoction made of root and stem is taken orally thrice a day.
FP/APU/2017/02	*Ajuga integrifolia* Buch.-Ham.	Lamiaceae (H)	Nilakantha	Rt	One cup of root decoction assorted with honey and administered orally after breakfast.
FP/APU/2017/03	*Allium sativum* L.	Amaryllidaceae (H)	Bekkuk	Rt	Rhizomes are crushed into paste & boiled in water for 1 hour. Decoction is supplemented with sugar & taken orally twice a day
FP/APU/2017/04	*Alstonia scholaris* (L.) R. Br	Apocynaceae (T)	Chhatiwan	Br	The small piece of bark is boiled in 100 ml of water for half an hour. Approximately 20 ml of filtrate is recommended orally, twice a day for 2 weeks.
FP/APU/2017/05	*Andrographis paniculata* L.	Acanthaceae (H)	Kalmegh	Wp	Plant dried and kept overnight in water, taken internally as syrup.
FP/APU/2017/06	*Artemisia indica* Willd.	Asteraceae (H)	Titepati	Rt	Low concentration root decoction is mixed with honey. It is recommended to be taken once a day for 10 days.
FP/APU/2017/07	*Azadirachta indica* A.juss	Meliaceae (T)	Silly	Lf	Leaves are pounded into small globules (approx.sgn each) and mixed in 50 ml of water prior to oral administration. Globules recommended twice a day for 15 days. Sometimes the globules are also dried in sun to obtain powder.
FP/APU/2017/08	*Capsicum annuum* L.	Solanaceae (H)	Mirsi	Fr	Swallow four fruits 3 times a day for 3 days
FP/APU/2017/09	*Carica papaya* L.	Caricaceae (H)	Omrii	Wp	Powdered, juice & boiled. Taking raw fruits & as decoction
FP/APU/2017/10	*Catharanthus roseus* (L.) G. Don	Apocynaceae (S)	Belang appun	Rt	Decoction
FP/APU/2017/11	*Clerodendrum colebrookianum* L.	Lamiaceae (S)	Ongin	Lf	Leaves are boiled in water to make a decoction & taken twice a day
FP/APU/2017/12	*Crassocephalum crepidioides* (Benth) S. Moore	Asteraceae (H)	Gende	Wp	Decoction

contd...

FP/APU/2017/13	*Michelia champaca* L.	Magnoliaceae (T)	Singgum	Br	Juice is extracted from stem bark. Powdered bark or decoction is taken orally in water
FP/APU/2017/14	*Momordica balsamina* L.	Cucurbitaceae (H)	Kerala	Lf, Rt	Relish , especially during rainy season
FP/APU/2017/15	*Momordica foetida* schumach	Cucurbitaceae (H)	Baat Kerala	Lf	Relish , especially during rainy season
FP/APU/2017/16	*Ocimum tenuiflorum*L.	Lamiaceae (H)	Tulsi	Lf, Rt	Leaf & root decoction is supplemented with honey. It is recommended twice a day before meal
FP/APU/2017/17	*Oroxylum indicum* L.	Bignonaceae (T)	Aki rokmi	Rt , St	Powdered bark is taken for 5-6 days
FP/APU/2017/18	*Piper longum* L.	Piperaceae (C)	Pipla	Fr, Rt	Few pieces of fruit and root are grounded into powdered form and boiled in a liter of water until the volume is reduced up to 500 ml. 2-3 spoons of mixture are prescribed orally before meals.
FP/APU/2017/19	*Piper nigrum* L.	Piperaceae (C)	Jhaluk	Sd	5gm of seed powder are mixed in 10ml of hot water along with honey & taken orally thrice a day
FP/APU/2017/20	*Prunus persica* L.	Rosaceae (T)	Sibeng tambeng	Rt	Decoction
FP/APU/2017/21	*Ricinus communis* L.	Euphorbiaceae (H)	Aeri	Lf	Leaf decoction supplemented with sugar is administered orally once a day.
FP/APU/2017/22	*Saccharum officinarum* L.	Poaceae (H)	Ukhu, Kuwer	St	A glass of juice extract of stem portion is taken twice a day after meals.
FP/APU/2017/23	*Solanum spirale* Roxb.	Solanaceae (S)	Bangko	Lf , St & Fr.	Hot infusion
FP/APU/2017/24	*Spilanthes acmella* L.	Asteraceae (H)	Marshang	Wp	Powdered
FP/APU/2017/25	*Terminalia chebula* Retz.	Combretaceae (T)	Harro	Fr, Br	5-10 g of fruit and bark are cut into small pieces and dissolved in 100 ml of water. The decoction is taken orally before meal.

pains, sweating and loss of appetite, weakness, lethargy, vomiting, thirst, shivering and bitter taste in the mouth. The majority of the study informant's mentioned that nearly all plant materials were affordable and accessible for the treatment of malaria. Additionally, maximum contributions were reported from herb (Fig. 14.2).

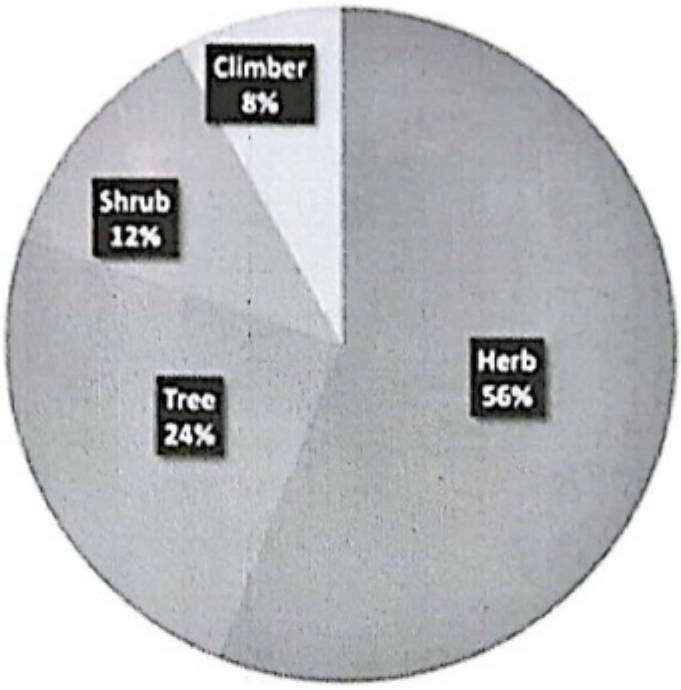

Fig.14.2. Plant Habit: Pie Chart Displaying the Life Forms of the plants used by *Adi* Tribe of Eastern Himalaya in Treatment of Malaria

The analysis revealed highest fidelity level (FL) value for *Crassocephalum crepidioides* (69%), *Ricinus communis* (65%), *Allium sativum* (64 %) (Table 14.2). The percentage of respondent's knowledge (PRK) about anti-malarial plants showed *Crassocephalum crepidioides* (93.24%) as the most commonly known antimalarial species within this region. It was followed by *Allium sativum* (94.12%) *and Piper nigrum* (91.53%).

Most of the herbal drugs were orally administered either as a crude plant extract or decoction in water medium supplemented with locally available honey. Root (34%) was the most commonly used plant parts (Fig 14.3). The crude extracts or decoction used for treating malaria was prepared from single plant species. The details on traditional mode of usage of each plant were depicted in Table 14.1. The fresh plant materials (10g fresh leaves/root in 1000ml, 20g, and whole plant in 1000 ml) were used for the preparation of decoction and the oral dose were variable. Maximum of the herbals drugs were administered twice a day

usually in morning and evening and the treatment continued until the patient's recovery. Different plant parts were used for making ant-malarial herbals formulation. However, root is the most prominently used parts of plant.

Table 14.2 Fidelity Level (FL) and Percentage of Respondent Knowledge (PRK) of Antimalarial Plants Used by *Adi* Community of Eastern Himalaya

Collection No.	Plants (Voucher No.)	FL%	PRK
FP/APU/2017/01	*Achyranthes aspera* L.	67.16	0.63
FP/APU/2017/02	*Ajuga integrifolia* Buch.-Ham.	93.24	0.69
FP/APU/2017/03	*Allium sativum* L.	90.28	0.65
FP/APU/2017/04	*Alstonia scholaris* (L.) R. Br.	94.12	0.64
FP/APU/2017/05	*Andrographis paniculata* L.	91.30	0.63
FP/APU/2017/06	*Artemisia indica* Willd.	88.57	0.62
FP/APU/2017/07	*Azadirachta indica* A.juss	90.77	0.59
FP/APU/2017/08	*Capsicum annuum* L.	82.09	0.55
FP/APU/2017/09	*Carica papaya* L.	91.53	0.54
FP/APU/2017/10	*Catharanthus roseus* (L.) G. Don	86.89	0.53
FP/APU/2017/11	*Clerodendrum colebrookianum* L.	86.67	0.52
FP/APU/2017/12	*Crassocephalum crepidioides*(Benth) S. Moore	84.75	0.72
FP/APU/2017/13	*Michelia champaca* L.	89.09	0.49
FP/APU/2017/14	*Momordica balsamina* L.	82.76	0.48
FP/APU/2017/15	*Momordica foetida* schumach	83.93	0.47
FP/APU/2017/16	*Ocimum tenuiflorum*L.	85.19	0.46
FP/APU/2017/17	*Oroxylum indicum* L.	71.19	0.42
FP/APU/2017/18	*Piper longum* L.	80.00	0.40
FP/APU/2017/19	*Piper nigrum* L.	68.52	0.37
FP/APU/2017/20	*Prunus persica* L.	77.78	0.35
FP/APU/2017/21	*Ricinus communis* L.	62.50	0.35
FP/APU/2017/22	*Saccharum officinarum* L.	75.56	0.34
FP/APU/2017/23	*Solanum spirale* Roxb.	73.33	0.33
FP/APU/2017/24	*Spilanthes acmella* L.	72.09	0.31
FP/APU/2017/25	*Terminalia chebula* Retz.	53.57	0.30

The traditional healing practices in *Adi* tribe of East Siang District Arunachal Pradesh were insufficiently documented and authors made effort to document. The healing practices used by *Adi*, community with detailed of methodology and dosages, to cope up with the objective authors made interaction with villager in different villages in Pasighat East Siang district of Arunachal Pradesh to know

about genuine and reliable traditional healer in the area and come in contact with 5 traditional healers who are engaged in herbal treatment. During course of interaction 20 different herbs and there were found using in various treatment.

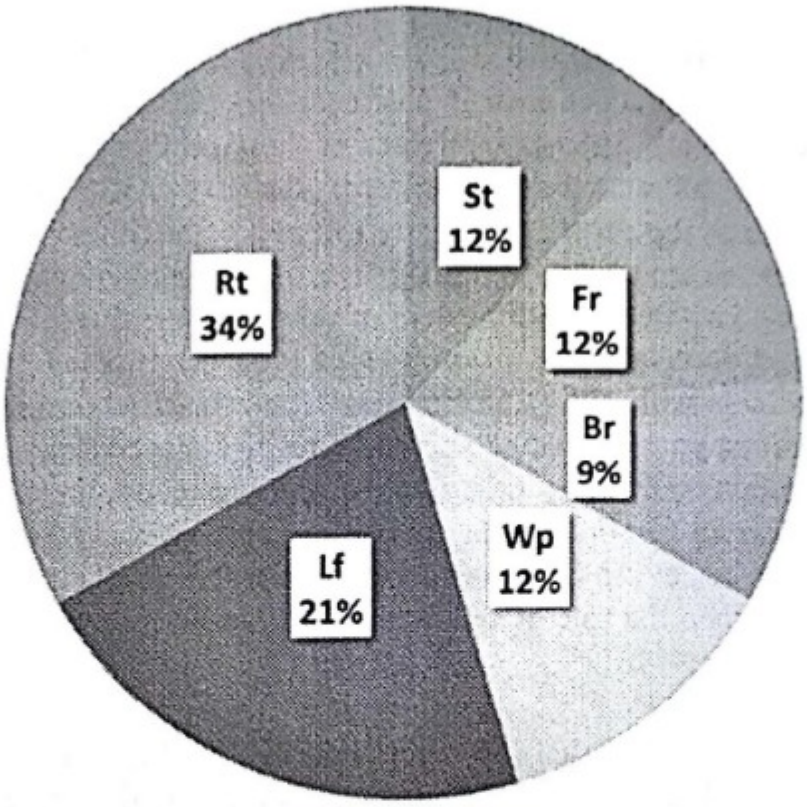

Fig. 14.3. Plant Parts Used: Pie Chart showing the Percentage of the Utilization of Different Plant Parts Against Treatment of Malaria Among the *Adi* Tribe of Eastern Himalaya
Note: Lf: leaves, Wp: whole plant, Br: bark, Fr: fruit, St: stem, Rt: root.

These herbs were belonging to herbs, shrubs and tree either from locally available sources or adapted through cultivation in their small herbal gardens. Prevalent disease are treated by the *Adi* healers are jaundice, malaria, menstrual disorder, joint pain, skin disease etc. prior to these certain other plants used by *Adi* tribes of Pasighat were described. However, most of the plant involved in traditional practice described in this paper is different and some of the plants are reported in this communication, they are for other disease.

The description of all above mentioned plant is on the basis of ethno medicinal knowledge. Plant is used by *Adi* community in different places on the basis of availability of that plant and the proper knowledge about efficacy of that plant against the particular disease. For safe uses of different medicinal plant, we need ran demised clinical trials for some of the manual therapies and further research is need to ascertain the efficacy and safety of several other practices and

medicinal plant. We have to develop a proper study about the traditional medicine and the ratio of curative measurement applied to different patients on the use of those plants. The study on such type of documentation is of great importance for North- Eastern Institute of Flock Medicine in the sense that the institute will get sufficient information on traditional healer and mode administration of medicine for treating ailments on one hand and sufficient tools for providing authenticity of drugs used in healing practice through pharmacology, phytochemistry and other pharmaceutical constants. Similarly, services of these traditional healers are of great importance to public as they are rendering their services to public in very remote places where the people are really in need of health services. These traditional healers need to be involved in all sorts of training to youngster as well as refreshing their knowledge with healers of other communities. Though they are acquiring and correlating their knowledge with established records and information available with other communities. The role of government for the existence of this system of medicine should be to give due recognition of their contribution and involvement, to delineate the specific scope, limit and role of traditional healers in public health promotion, to undertake research and development activities, to provide orientation and support to folk role healers, to monitor and strengthen the role of folk healers and to do proper follow-up.

Conclusion

The current work revealed the competency of traditional medicines in treatment of malaria. The knowledge on utilization of the medicinal plants and its properties is held by few traditional healers and commoners. So, there is a crucial need for detailed investigation of the knowledge held by tribal communities before they are lost in the debris of modernization. However, the efficacy of the reported medicinal plants needs to be evaluated further, using phytochemical and pharmacological methods. Plants with higher fidelity level and PRK should be given priority to carry out bioassay as well as toxicity studies. From the current study, it might be suggested that *Crassocephalum crepidioides, Ricinus communis, Allium sativum* and *Piper nigrum* are promising species that should be taken into account for further pharmacological studies. The results also suggest that this species may be used for the development of novel, economical and effective herbal formulations for healthcare management.

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ReverseRoute: An Application-layer Scheme for Detecting Blackholes in MANET using Mobile Agents

Amar Taggu, Abhishek Mungoli
NERIST, Nirjuli
Arunachal Pradesh, India
ataggu@gmail.com, mungoliabhishek81@gmail.com

Ani Taggu
RGU, Doimukh
Arunachal Pradesh, India
anitaggu@gmail.com

***Abstract*—Mobile Ad-Hoc Networks (MANETs) are prone to many security attacks. One such attack is the blackhole attack. This work proposes a simple and effective application layer based intrusion detection scheme in a MANET to detect blackholes. The proposed algorithm utilizes mobile agents(MA) and $wtracert$(modified version of Traceroute for MANET) to detect multiple black holes in a DSR protocol based MANET. Use of MAs ensure that no modifications need to be carried out in the underlying routing algorithms or other lower layers. Simulation results show successful detection of single and multiple blackhole nodes, using the proposed detection mechanism, across varying mobility speeds of the nodes.**

I. Introduction

A MANET is a decentralized, self-configuring and infrastructure-less wireless network of mobile devices. In MANET, each node can independently move in any direction and acts as a router helping in forwarding the network traffic. However, since there is no centralized control, MANET is susceptible to many MANET-specific attacks and hence, detection and mitigation of such attacks is crucial for successful functioning of MANET. Standard techniques like Intrusion Detection Systems(IDS) no longer applies to MANETs due to their infrastructure-less setup.

A blackhole refers to a malicious node which takes advantage of vulnerability in the routing protocols and causes huge drop in throughput and packet delivery ratio in a network. The malicious node informs other users in the network through route reply that it has a valid shorter route to destination node even though the route may be spurious. Once the victim node starts sending packets through the route containing the blackhole node, those packets are dropped. Malicious node responds to route requests normally but when packets are sent to it for transmission, it drops them. Thus it is a kind of Denial-of-Service (DoS) attack. Since black hole behaves normally to route requests, it's detection is hard. In this paper, an application-layer scheme ReverseRoute Detection is being proposed, which works primarily in the application layer. It uses mobile agents which work in the Application Layer, and hence, requires no lower-layer modifications. $wtracert$ application, which is a modification of standard Traceroute application, has been developed especially for MANET. It can be used to detect broken links in the network and also to find a reverse route from a destination node to the source node, if such a route exists, which is explained later in the paper. To the best of our knowledge, this is the first time that MAs have been used to detect blackholes in a MANET. In addition, use of a separate application-layer entity (MAs) ensures that no changes need to be made in the underlying routing protocols, which itself is non-trivial and impractical in a real-world scenario.

The rest of this paper is organized as follows: Section II consists of short review of related works. Section III elaborates on the Blackhole Attack. ReverseRoute is discussed thoroughly in Section IV. Section V presents the simulation results and analysis. Section VI indicates the possible directions for future work and also, concludes the paper.

II. Related Work

Taggu and Taggu [1] proposed TraceGray, a MA-based grayhole detection in MANET, which has influenced the current work to a large extent. The use of MA which uses a simple mechanism of two-steps-forward and one-step-backwards is a novel way of using MA for intrusion detection in MANETs. Taggu and Taggu [2] also proposed $wtracert$ which is a modified version of Traceroute application developed especially for MANET. $wtracert$ is much faster and more efficient for Wireless Ad-hoc network than the original Traceroute. The same is used in the current work for Blackhole attack detection. Kachirski and Guha [3] proposed a mobile agent based distributed multi-sensor IDS. Zhang et al [4] proposed a distributive and cooperative IDS architecture for MANET such that every node participates in the detection process by locally running an IDS agent and also participate in global

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intrusion detection. Many proposed schemes detect malicious nodes by enhancing the underlying routing algorithms. Marti et al [5] proposed two extensions to the DSR algorithm: the watchdog and the pathrater, that rely on the promiscuous mode in DSR algorithm to identify misbehaving nodes. In [6] and [7], Sen et al proposed algorithms in which every node monitor its neighbours to identify any abnormal activity and invokes a distributed algorithm to verify if a neighbour is malicious. In [8], Wei et al propose a solution against the gray hole attack using two related algorithms: a key management algorithm based on gossip protocol and the detection algorithm based on aggregate signatures. In [9], D. Djenouri and N.Badache propose a protocol wherein a component resides in network layer while the other component works in the MAC layer. Onashoga et al [10] have reviewed many of the existing current MA-IDSs. More recently, Mohamed A. Abdelshafy et al [11] proposed a Self-Protocol-Trustiness concept which clarifies that the detection of a malicious intruder is accomplished by complying with the normal protocol behaviour and lures the malicious node to give an implicit avowal of its malicious behaviour. In [12], Elbasher Elmahdi et al uses encryption to detect blackholes in MANETs running AOMDV protocol. The basic idea of this scheme is to split a message into many parts before the message is transmitted. Each part is then encrypted using homomorphic encryption method. The receiver decrypts the message send in parts. The proposed method claims to mitigate the blackhole attack.

III. Blackhole Attack

Intruders can exploit the vulnerability in route discovery procedures of on-demand routing protocols, such as AODV and DSR, when a node requires a route towards the destination. The node sends a RREQ and an intruder advertises itself as having a fresh and possibly, shorter route. By repeating this for route requests received from other nodes, the intruder may succeed in becoming part of many routes in the network. The intruder, once chosen as an intermediate node, drops the packets instead of forwarding or processing them, creating a blackhole in the network. The way the intruder initiates the blackhole attack and captures the routes, may vary in different routing protocols. For example, in AODV, the destination sequence number (dest_seq) is used to represent the freshness of the route. A higher value of dest_seq means a fresher route. On receiving a RREQ, an intruder can advertise itself as having the fresher route by sending a Route Reply (RREP) packet with a new dest_seq number larger than the current dest_seq number. In this way, the intruder becomes part of the route to that destination. A blackhole attack is one of the most devastating attacks in MANETs. It is also one of the most difficult attacks to detect due to the nature of the attack wherein all the packets are dropped.

IV. ReverseRoute: The Proposed Blackhole Attack Detection Mechanism

ReverseRoute Detection implements intrusion detection using mobile agents primarily because of the facility of code migration provided by mobile agents. Some custom enhancements are implemented over a typical MA design as described below. The proposed scheme requires only the next hop information and does not rely on any kind of promiscuous monitoring. ReverseRoute Detection mechanism can detect multiple black holes in a MANET. The proposed scheme succeeds in scenarios where a traceroute-like application fails. Use of $wtracert$ greatly improves the performance of the detection mechanism since the MAs are started only from the last working node in the route, instead of the original source node (sender).

A. Mobile Agents

Mobile agents(MA) are software entities that can physically travel across a network, and perform tasks on machines that provide agent hosting capability. This allows processes to migrate from computer to computer, or processes to split into multiple instances that execute on different machines, and to return to their point of origin, which is called the home context. Migration of MA essentially implies that some code with required data is transferred to another node for remote execution. In the current implementation, each mobile agent has been enhanced with a timer. This timer is currently a function of MA code size + MA data size where the values of MA code size and MA data size are shown in Table I. The basic premise in assigning the timeout period is based on the observation that during change of context of a MA, the size of the mobile code and data required for remote execution determines how large the timeout interval should be.

B. Pre-requisites

ReverseRoute requires that the next hop information be available to a node. With DSR routing, the proposed scheme uses route cache information to obtain the next hop information. Although the entire source route is available for a destination in the route cache, only the first hop node is used to avoid false positives. Furthermore, it is assumed that the intrusion detection process will start after a node suspects some abnormal activity, like extremely high packet dropping in the network. Many mobile agents can be started by the nodes at the same time or at different times, as required.

C. Blackhole Detection Algorithm

A node that suspects abnormal activity runs $wtracert$ to trace the current path upto the destination node to check the correctness of the whole route as shown in Fig. 1. $wtracert$ gives a clear picture of the current route till the last working node. If the entire route till the destination node is traced successfully using $wtracert$, then it means the route is up and destination is ready to receive the packets. However, if $wtracert$ fails to trace the complete route upto the destination, then it can either mean that

1. The route is broken because of which the $wtracert$ was unsuccessful in tracing the complete route, OR,
2. One of the nodes is a blackhole node and hence, it is dropping all packets including the ICMP packets (used in $wtracert$)

In either case, ReverseRoute is initiated to come to a conclusion. The algorithm is given below.

Algorithm ReverseRoute Algorithm

1: From the last working node as returned by running $wtracert$, a MA is started to go to the next one-hop node (**Fig. 2**)
2: Once the MA reaches the next hop node successfully, it attempts to go back to the previous node
3: **if** MA can reverse back to its original sender node (the previous node) **then**
4: The current sender node of the MA is a blackhole (**Fig. 3**)
5: **else**
6: Route Broken (**Fig. 4**)
7: **end if**

Step 3 of the above algorithm is explained further here. A blackhole node is usually configured to drop routing packets. When a MA, which is not a routing packet, is received at the blackhole node, the MA will initiate its reverse routing from the blackhole node to the previous node. Since the route is not broken (as the MA just reached the blackhole node), the MA will be able to go back to to previous node. Thus, the current node will be labelled as a blackhole.

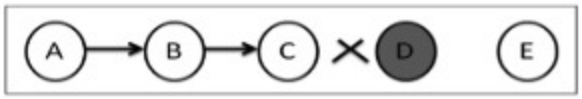

Fig. 1. Working of $wtracert$

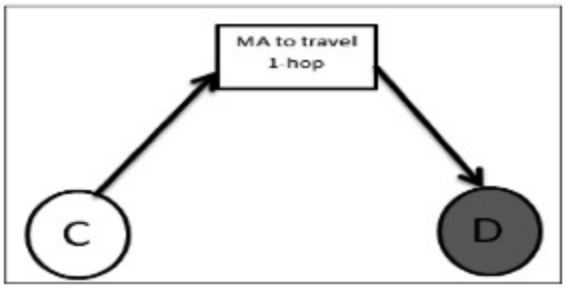

Fig. 2. Node C initiates MA to travel 1-hop distance to Node D

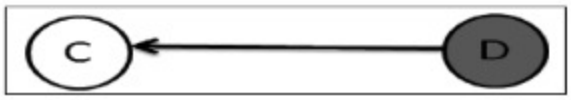

Fig. 3. MA attempts reverse routing from Node D(Blackhole)

V. Simulation and Results

ReverseRoute has been implemented in the NS-2 simulator with Mobile Agent implementation modified according to our requirements. Two metrics used in analysing the results are:

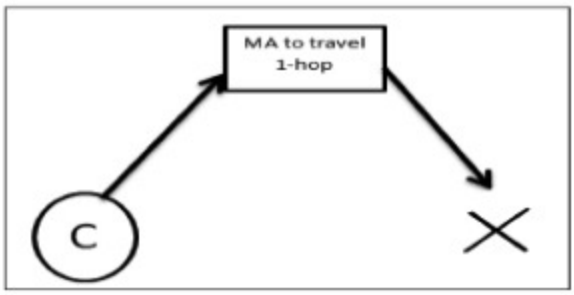

Fig. 4. Broken route

TABLE I
Simulation Environment

Parameter	Value
Simulator	NS-2 (2.35)
Simulation Area	1000x1000 sqm
Simulation Duration	10000 seconds
Number of mobile nodes	100
Tranmission Range	250 m
Maximum Speed	20 m/s
Tranmission Range	250 m
Traffic Type	CBR
Data Payload	250 bytes/packet
Packet Rate	40 packets/sec
Mobile Agent Code Size	100 bytes
Mobile Agent Data Size	5000 bytes
Tranmission Range	250 m
Maximum number of Blackholes	20%

- Packet Delivery Ratio (PDR): The ratio of packets that are successfully delivered to a destination compared to the number of packets that have been sent out by the sender.
- Throughput: The number of data bits delivered to the application layer of destination node in unit time measured in bps.

In normal network without any blackholes, PDR and throughput are very high. Fig. 5 and Fig. 6 respectively show that PDR and throughput decreases abruptly in the presence of blackhole node. With increase in the number of blackhole nodes, PDR and Throughput shows further drop. This is as expected since the attack is targeted specifically at dropping packets at the blackhole. More malicious nodes result in higher packet drop. Fig. 7 shows how the detection time varies with respect to increasing number of blackhole nodes across varying mobility speeds. Detection time is the time to detect the blackhole node in the network. Detection time is improved to great extent by using $wtracert$ instead of standard Traceroute application. Total detection time taken by ReverseRoute detection mechanism is the sum of time taken by $wtracert$ plus MA to travel 1-hop distance and perform its task. As expected, detection time increases with increase in the number of nodes in the network and increase in mobility

of nodes as shown.

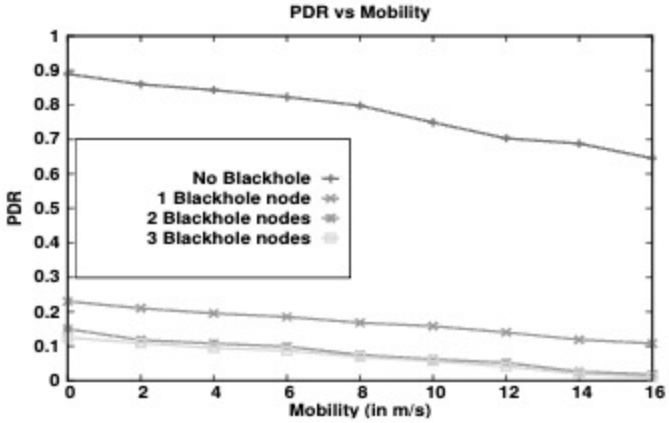

Fig. 5. PDR vs Mobility

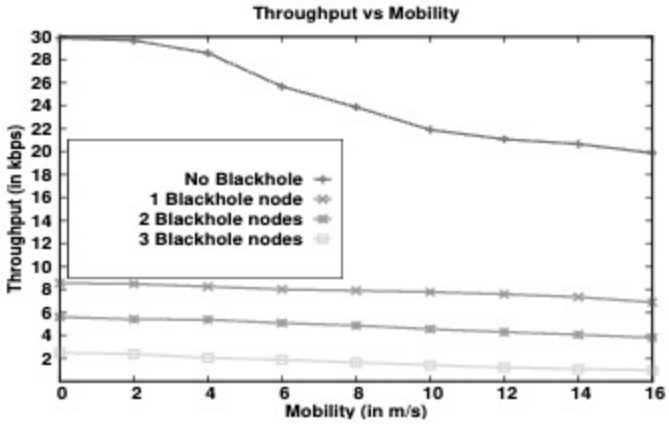

Fig. 6. Throughput vs Mobility

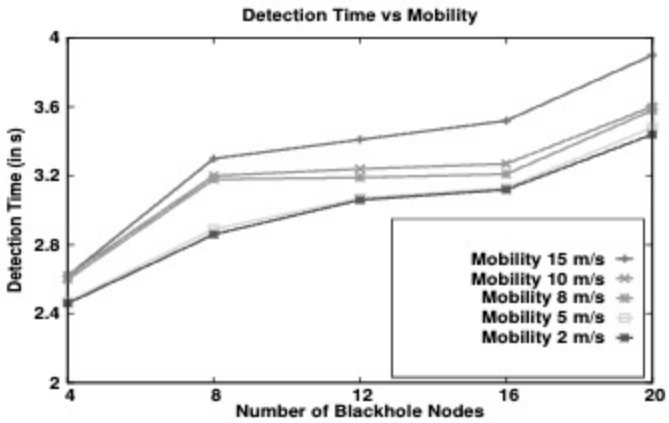

Fig. 7. Detection Time vs Number of Blackhole Nodes

VI. Conclusion and Future Work

To make the process of intrusion detection more accurate and faster, $wtracert$ is run prior to detecting the presence of blackholes in the network. Next, ReverseRoute detection mechanism is utilised to detect blackholes in the network, if any. Use of light-weight mobile agents which are Application-layer entities is an idea which can used in detecting other attacks in MANETs. Since no underlying lower layer protocols need to be modified, the proposed mechanism could be incorporated as practical security add-on in real-world implementation. The simulation results show that ReverseRoute can detect multiple blackholes in the network successfully across varying mobility speeds and the ingenious use of $wtracert$ prior to running the ReverseRoute algorithm has significantly improved the detection time of malicious nodes in the network.

ReverseRoute may be used to detect other attacks in MANETs, in particular and any wireless ad-hoc networks, in general. Owing to the use of light-weight application-layer mobile agents, the usage scenarios of the proposed mechanism are many, especially in the area of security in networks.

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अनुक्रमणिका

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सहायक आचार्य, हिंदी विभाग, राजीव गाँधी केन्द्रीय विश्वविद्यालय, ईटानगर, अरूणाचल प्रदेश

विश्व की प्राचीन संस्कृतियों में से एक भारत की संस्कृति कर्म प्रधान संस्कृति है। यहाँ समाज निर्माणकारी परम्पराओं से विलग नहीं है भारतीय संस्कृति परम्पराओं से तथा समाज से निर्माण की अपेक्षा रखती है। प्राचीन काल से सम्पूर्ण समाज में इस निर्माणकारी व्यवस्थाओं की सुनियोजिन आधारशिला रही, यह सही है कि राजसत्ता तथा देशद्रोहियों के क्रियाकलाप से तथा विदेशी आक्रान्ताओं के षड्यंत्रों के कारण इसे क्षति अवश्य पहुंची है किन्तु अवैज्ञानिक सोचों के कारण हमने ही इसकी निंदा स्वयं करनी प्रारंभ की जिससे पश्चिम को चिल्लाने का अवसर प्राप्त हुआ। भारतीय सस्कृति के निर्माण में विशेष बिन्दुओं का महत्तम योगदान रहा है। भाषा, धर्म, समाज, परिवार, परम्परा एवं रीति, त्यौहार, भोजन, वस्त्र–धारण, साहित्य, इतिहास, काव्य, महाकाव्य, कला, संगीत, नृत्य, नाटक और रंगमंच, दृश्य–कला, चित्रकारी, मूर्तिकला, वास्तुकला, मनोरंजन और खेल, दर्शन शास्त्र, पशु–पक्षी, पर्वत नदियाँ, पहाड़ तथा विभिन्न प्राकृतिक उपमानों के साथ जीवजगत के अलावा जड़ पदार्थों तक सम्मिलित हैं ।

भारतीय संस्कृति में प्राचीन संस्कृति और टूटते पारम्परिक मानदण्ड़ों के मध्य एक त्रिशंकु संस्कृति का उत्कर्ष हुआ, जो परंपरा के टुटन का भयावह रूप है जो न तो पाश्चात्य संस्कृति की गतिशीलता को ही अपनाता है और न ही भारतीय संस्कृति की स्थिरता को। जिस पर विचार करते हुए श्यामाचरण दूबे जी कहते हैं– "भारत में भोगवादी समाज विकसित हो रहा है, जो पश्चिम के अनुकरण में नये–नये उत्पादनों का अधिक से अधिक उपभोग करना चाहता है। उसकी जीवन शैली का आधार ही उपभोक्तावाद है, वह सुख की व्याख्या परिग्रह और उपभोग के मानकों से करता है उसे सर्वसुविधायुक्त भव्य आवास चाहिए, पांच सितारा होटलों का ऐश्वर्य चाहिए। इस जीवनशैली में उपभोग के साथ प्रदर्शन और प्रतिस्पर्धा की भावना भी जुड़ी होती है जो दूसरे के पास है, हमारे पास उससे अधिक और अच्छा होना चाहिए। संस्कार और व्यवहार प्रतिस्पर्धा के अवसर बन जाते है। उनमें इतना खर्च हो और ऐसी चमक हो कि लोग भी याद रखें। यही लिप्सावादी वर्ग देश की दुर्दशा की चर्चाओं में बार–2 गाँधीजी की दुहाई देता है। अपने आपको आधुनिक और वैज्ञानिक जीवन दृष्टि सम्पन्न मानने वाला यह वर्ग मंत्र और तंत्र, ज्योतिष और भृगु संहिता, बाबाओं

और अवतारी पुरूषों में भी अंधश्रद्धा रखता है। आर्थिक सफलता और समृद्धि की [illegible] में यह वर्ग लक्ष्यों और उन्हें प्राप्त करने के साधनों का मूल्यांकन करना भी भूल [illegible] है। दुर्बल आस्थाओं वाली यह श्रेणी ईश्वर और धर्म को भी अपने भौतिक लक्ष्यों [illegible] प्राप्ति का साधन बना लेना चाहती है। ये वे लोग हैं, जो विदेशों में भारतीय और [illegible] में विदेशी जीवनशैली और मूल्यों के साथ जीते हैं, उनकी जड़े भारतीय परंपरा में [illegible] होती, पर साथ ही उनका पश्चिमीकरण भी बहुत ही सतही स्तर वाला होता है। [illegible] पश्चिम की संस्कृति वाह्य लक्ष्यों का तो अनुकरण तो करते हैं, पर गहराई में जाकर उसकी आत्मा के साक्षात्कार करने से कतराते हैं। साथ ही वे पश्चिमी संस्कृति के [illegible] सुविधाएं और स्वच्छन्दता तो चाहते हैं, पर उनसे होने वाला सांस्कृतिक अवमूल्यन उन्हें चिंचित करता है, वे जो है उसे न जीना और जो नहीं है उसे जीना, उनकी निर्दिष्ट है। अपनी विभाति मानसिकता के साथ वे एक अनिश्चित और दिशाहीन प्रवाह से जुड़ जाते है। यह प्रवृत्ति उनमें और देश के मान्य जनजीवन में अलगाव उत्पन्न करती है और वे साभाजिक सरोकारों से प्रायः कट जाते हैं। उनका अभिजात्य मध्यम वर्ग को आकर्षित करता है और उसकी छाया निम्न मध्यवर्ग और नगरोन्मुख निम्न वर्ग पर भी पड़ती है। सीमित क्षेत्र में इन वर्गों में भी अनुकरण की प्रवृत्ति बढ़ती है। सिनेमा और टी0वी0 इस प्रवृत्ति को बढ़ावा देते हैं। अब तो डिश एन्टेना और केबल भी छोटे-[illegible] शहरों और कस्बों में पहुंच गये हैं और वहाँ अपसंस्कृति की बौछार कर रहे है।

परंपरावादी दृष्टिकोण में आये नये परिवर्तन और तेजी से बदलते उसके स्वरूप के बारे में विचार किया जाय तो भारतीय पक्ष में हम कह सकते हैं, भारत की स्थिति तेजी से बदल रही हैं, लोक संस्कृतियों के विशाल सागर में अभिजात्य के द्वीप पनप रहे है। कभी ये राष्ट्रीय चेतना और नवजागरण के दीप स्तम्भ थे, आज उनमें व्यक्तिगत स्वार्थ और उनसे उत्पन्न विकृतियाँ पनप रही है। समाज अब परंपरा निर्देशित नहीं रहा। उसमें अन्तःकरण निर्देशन भी क्षीण हो रहा है, उसमें अन्य निर्देशन बढ़ रहा है जो व्यवसायिक हित साधन में पश्चिम की उत्तरदायित्वहीन अनुकृति मात्र हैं।

भारतीय संस्कृति में समन्वय और सहयोग की प्राचीन भारतीय परम्परा अपने लिए कए अनूठी मूल्य सार्थकता को प्रदर्शित करती है। यहाँ का सहयोग और समन्वयकारी विश्लेषण बिन्दु समस्त विश्व में अपना परचम लहराते है। सांस्कृतिक आदान–प्रदान की परंपरा केवल भारत में ही नहीं, वरन सम्पूर्ण विश्व में प्रसिद्ध है। समन्वय और सहयोग का एक उत्कृष्ट उदाहरण हमें हिन्दू धर्म और हिन्दू समाज के विकास में मिलता है, वैसे हिन्दू शब्द का समाज के विकास में मिलता है, वैसे हिन्दू शब्द का प्रयोग शायद पहले पहल अरबों ने आठवीं ई0 में उन भारतीय के लिए किया

था, जो सिन्धु नदी के उस पार पूर्व में रहते थे। इस धर्म को वैदिक मूल का माना जाता है। इसकी शास्त्रीय परम्परा के स्रोत वेद, ब्राह्मण, अरण्यक, उपनिषद और धर्म सूत्र तथा पुराण माने जाते है। हिन्दू समाज व्यवस्था के आदर्श प्रारूप के रचनाकार होने का श्रेय मनु को दिया जाता है। यह शास्त्रीय परंपरा निःसंदेह महत्वपूर्ण थी, क्योंकि इसने उत्तर से दक्षिण तक और पूर्व से पश्चिम तक फैले समुदायों को एक सीमा तक धार्मिक और सामाजिक एकरूपता दी। परन्तु व्याबहारिक हिन्दू धर्म ने क्षेत्रीय और स्थानीय लघु परंपराओं की अस्मिता को स्वीकार कर उनसे समझौते किये और उनके सांस्कृतिक तत्वों को ग्रहण किया। हिन्दू समाज का जो स्वरूप उभरा, उसमें शास्त्रीय महान परंपरा जितनी महत्वपूर्ण है, उतनी ही महत्वपूर्ण क्षेत्रीय और स्थानीय लघु परंपराएं भी है। भारत के अभिकरण की प्रक्रिया अत्यन्त जटिल थी। आर्य–परंपराओं और क्षेत्रीय जातीय परंपराओं के संघर्ष ने समन्वय की शक्ति बढाई। आर्य–परम्परा ने व्रात्य परंपराओं को ग्रहण किया और क्षेत्रीय जातीय परंपराओं के तत्व स्वीकार किये। सूत्रों द्वारा निर्धारित वैवाहिक और वंश–निर्धारण के नियमों के अपवाद स्वीकार किये गये। अनेक समुदायों में भाई–बहन की संतान में विवाह मान्य हैं, आन्ध्र और कर्नाटक की कई जातियों में जिनमें ब्राह्मण भी हैं, वंशी परिवार भी हिन्दू समाज में स्वीकार किये। धर्म की व्याख्या देशकल पात्र के संदर्भ में करने की प्रवृत्ति ने सामाजिक प्रक्रियाओं को लचीलापन दिया और समाज को जड़ता के दोष से बचाया। वैष्णव, शैव और शाक्त परंपराएं समान रूप से हिन्दू धर्म को स्वीकार हुई, स्यार्त शाखा ने तीनो को एक साथ अपनाया। अंतर्विरोधी को भी हिन्दू समाज ने आत्मसात किया। आजीवक लोकायत और तांत्रिक परंपराएं असहमति और विरोध के स्वर के रूप में उभरी, पर उन्हें भी हिन्दू समाज ने अपना लिया।[2]

इस तरह धार्मिक मूल्यों के बीच परंपरागत स्वरूप को या परंपरागत धार्मिक स्वरूप को देखा जाय तो भारत की परंपरागत आत्मा और सांस्कृतिक मूल्य एकमेव स्थिति में देशी–विदेशी प्रभाव से मुक्त होकर अपने अनूठेपन को बरकरार रखी है। जिसकी समन्वय भावना विदेशी मूल के धर्मों को भी सहयोग किया। सर्वधर्म समन्वय की भावना ओतप्रोत भारतीयों ने देश में पहले–पहल आने वाले इसाई प्रचारकों को सम्पूर्ण सम्मान दिया। सोलहवीं शताब्दी में सेंटपाल क्रिश्चियनों को, जिन्हें नजरानी कहा जाता था, ब्राह्मणों के समकक्ष माना गया। इन प्रचारकों में से कई ने भारतीय धर्मों का गहन अध्ययन किया और हिन्दू सामाजिक संरचना को भी स्वीकार किया। परिणाम यह हुआ कि उन्होंने परोक्ष रूप से जाति–प्रथा और अस्पृश्यता को भी स्वीकार कर लिया। दक्षिण में यह स्थिति आज भी बनी है। इस्लाम भारत में तलवार के जोर से नहीं आया। पश्चिमी तट के उत्तरी भाग में विल्हारा राजवंश ने और मलाबार के

जमेरिन ने मुस्लिम व्यापारियों का स्वागत किया और उन्हें पूरी धार्मिक स्वतंत्रता
अनेक मुस्लिम संत और सूफियों ने इस्लाम का प्रचार किया, पर उनके गुणों से प्रभा
हिन्दू आज भी श्रद्धापूर्वक उनकी मजारों को नमन करते है। धर्मांध मुस्लिम शास
के आक्रामक रूख ने असंतोष और संघर्ष की स्थितियां उत्पन्न की, किन्तु हमें यह
नहीं भूलना चाहिए कि अकबर और दाराशिकोह भारत की सहिष्णुता, धार्मिक सम
समन्वय और सहयोग की परंपरा के उज्ज्वल प्रतीक हैं।

भारतीय संस्कृति परंपरा की एकता और विविधता को इसी परिपेक्ष में देख
आवश्यक है। भारत में जातीय और स्थानीय परंपराएं हमेशा सशक्त रही है। छोटे
जनजातियों को अपनी सांस्कृतिक अस्मिता पर गर्व रहा है। ग्राम समूहों जनपदों
सांस्कृति वैशिष्टय और गरिमा के अनेक उल्लेख प्राचीन ग्रन्थों और विदेशी यात्रि
के वर्णनों गें मिलते है। क्षेत्रीय सांस्कृतिक व्यक्तित्व भी भारतीयता की छवि में अप
अलग पहचान रखते थे। इतिहास, भाषा और परंपराओं ने इन्हें पृथक पहचान
गरिमा दी और ये संस्कृति क्षेत्रों के रूप में स्वायित्व पा सके। क्षेत्रीय संस्कृतियाँ
परंपराएं एक सीमा तक स्वतंत्र होकर भी एक–दूसरे से असम्बद्व और असम्पर्क
थी। यदि उत्तर की गंगा और यमुना पवित्र थी, तो देश की मध्यवर्ती नर्मदा और दक्षि
की गोदावरी, कृष्णा और कावेरी.भी उतनी ही पवित्र थी। अपने संस्कृति क्षेत्रों के लि
ही नहीं, अन्य सुदूर संस्कृति क्षेत्रों के लिए भी। हिन्दूओं के चार धाम, चार अलग-
दिशाओं में थे। पावन तीर्थों का वितरण भी देशव्यापी था। इनकी चुम्बकीय शक्ति
देशभर में अस्थावान यात्रियों को अपनी ओर खींचती थी। शास्त्रीय परंपरा का फैलाव
विशेषकर स्थानीय और क्षेत्रीय संत कवियों द्वारा जन मुहावरे में उनका लोक–व्यापीकर
सांस्कृतिक एकता का महत्वपूर्ण स्रोत था। भारतीय मूल के देशज धर्मों जैसे बौद्ध, जै
और सिक्ख धर्म में आपकी सहयोग भी हुआ, संघर्ष भी, पर शीघ्र ही उनमें सहअस्तित्व
के समीकरण निर्धारित हो गये। इसी तरह ईसाइयत, इस्लाम और यहूदी धर्म जो
देशज मूल के नहीं है, भारत में प्रवेश के बाद अपने आस्था विश्वास और परंपरा के
साथ कई दशकों तक शान्ति और सम्मान से इस देश में रहे और विकसित हुए।

इस तरह सांस्कृतिक एवं राजनीतिक एकता की परंपरा भारत की समन्वयवादी
धारा पर फलती–फूलती रही। फिर भी भारत की अन्तस्चेतना अपनी सांस्कृतिक एकता
के लिए उन परम्पराओं के प्रति एक मूल्यात्मक व्यवहार के लिए जानी जाती है।
धार्मिक और पारम्परिक अस्मिताओं का संघर्ष तो सम्पूर्ण विश्व की जटिल समस्या है
फिर भी इसकी लड़ाई, सामाजिक, राजनीतिक स्तर से हटकर संवैधानिक और
न्यायिक स्तर पर लड़ी जा रही है। चाहें वह मध्य और उत्तर मध्य का उपनिवेशिक
काल रहा हो, या आज का सूचनातांत्रिक अधिकारपूर्ण समय। चाहे वैदिक श्रद्धालुओं की

परंपरापूर्ण आधिकारिक सुक्तियाँ हो, या धर्म, अर्थ, काम, मोक्ष की धार्मिक विचारधारा या नव हिन्दुत्ववाद की भविष्य के प्रति चिन्तित विचारधारा सबमें विघटन का दौर व्याप्त है।

बदलते परिवेश में परंपराओं का विघटित स्वरूप हो या मूल्यों का ह्रास, संस्कृति हो, प्रतिसंस्कृति हो या अपसंस्कृतिक, दशा और दिशाएं बदल चुकी है। यहाँ पर विराट, संस्कृति के इतिहास में प्रति संस्कषति 'काउण्टर कलचर' की धाराएं फूटती है ये उसके लक्ष्यों और साधनों को पुर्नपरिभाषित करती है और समय ही मांगों और सामाजिक दबाव से प्रेरित हो उसमें परिवर्तन की दिशा और गति निर्धारित करती है। जबकि बदलते सांस्कृतिक परिदृश्य का भयावह पहलू है अपसंस्कृतियों का उदय। इनकें प्रभाव से समाज के कुछ विशेषाधिकार प्राप्त अंग सामाजिक सरोकारों से कट जाते हैं और व्यक्ति केन्द्रित भोगवादी जीवन दृष्टि से नियंत्रित होने लगते है। जिससे समाज दिशाहीन और धूरीहीन हो जाता है।

उपभोक्तावाद की इस संस्कृति में धीरे–2 सब कुछ बदल रहा है। परंपराओ के टूटन में नयी जीवन शैली अपना वर्चस्व स्थापित कर रही है। हम सांस्कृतिक अस्मिता की बात कितनी ही करें। परंपराओं का अवमूल्यन हुआ है, आस्थाओं का क्षरण हुआ है, कड़वा सच तो यह है हम सांस्कृतिक अपनिवेश बन रहे हैं, हमारी नयी संस्कृति अनुकरण की संस्कृति है, जो हमें अपनी मूल से अलग करती हुई प्रताड़ित कर रही है। इस पृष्ठभूमि में प्रताड़ित परंपरा ने अपना आक्रोश अभिव्यक्त किया। धार्मिक कट्टरवाद और जातिय भावना (एथनीसिटी) के विस्फोट के रूप में साथ ही प्रजातीय, भाषायी, धार्मिक और सांस्कृतिक अस्मिताएं आक्रामक रूप में उभरी। अन्तर्राष्ट्रीय धरातल के विकास और परंपरा के अन्तःसम्बन्धों पर नयी बहस शुरू हुई है। मार्क्सवादी भी नये संदर्भ में आस्था और परम्परा का पुनर्मूल्यांकन कर रहे है।

श्यामाचरण दूबे ने स्पष्ट रूप से कहा हैं– " आस्था और विश्वास, लक्ष्य और मूल्य, साधन और क्रिया में अतीत से वर्तमान तक चली आयी निरन्तरता की धाराओं को हम परंपरा कहते है। ये धाराएं समय द्वारा परिक्षित होती है, उपयोगी और उपादेय भी, इनमें समय के साथ एक रहस्यमयता आ जाती है, जो उनकी सर्वस्वीकृति को सशक्त करती है और उन्हें एक प्रकार की सम्प्रभुता और अनिवार्यता प्रदान करती है। परंपरा से समाज की पहचान बनती हैं, उसके माध्यम से समुदाय, विचार और व्यवहार का एक स्थिर आधार पाते है, समाज का एक बड़ा भाग परंपराओं को सहज भाषा स्वीकार करता हैं, क्योंकि उनके कोई विकल्प उसके सामने नहीं है। लीक से हटने का मतलब सामाजिक आलोचना से लेकर सामाजिक बहिष्कार हो सकता है। प्रबुद्ध विचारक और वैज्ञानिक अपने विरोधी तर्कों के बावजूद विशेष स्थितियों में परंपराओं

की स्वीकृति के लिए बाध्य होते है। व्यापक परिवर्तन सामान्यजन से सामाजिक
का आधारहीन लेते है और विचार और व्यवहार के क्षेत्र में एक अराजक शून्य
कर देते है यह स्थिति अनपेक्षित प्रतिक्रियाओं को जन्म देती है। जिनका पूर्वानु
कठिन होता है। क्रान्तिकारी अन्ततः अप्रभावी और विघातक सिद्ध होते है। विकास
असफलताएं और आधुनिकीकरण की विकृतियाँ परंपरा की ओर वापसी की
प्रेरणाएं बनती है।

वैसे तो आज के संवाद में परंपरा और विकास प्रायः विपर्यायवाची शब्द
गए हैं, उनका उपयोग दो विपरीत ध्रुवीय समप्रत्ययों के रूप में किया जाने लगा
परंपरा की जड़ और विकास को गतिमान मानना हमारी विचार प्रक्रिया में रूढ़ हो
है। यह स्थिति अत्यन्त भ्रामक है। परंपराएं अतीत के गत प्रयोग जीवाश्म प्रकट
होती। उनमें प्रकट और प्रच्छुन्न ऊर्जा होती है। उनके बिम्ब और प्रतीक मूल्य और
वर्तमान के लिए प्रासंगिक होते हैं, भविष्य के लिए भी। वर्तमान की जड़े अतीत में
है और भविष्य वर्तमान का विस्तरण होता है। बदलते संदर्भों में भी परंपराएं समाज
जीवन क्षमता और दिशा संकेत दे सकती है क्या विकास की प्रक्रिया परंपरा
असम्पृक्त रह सकती हैं?

परंपराओं को अर्थ और जड़ मान लेना भी बहुत गलत है, उनमें अनेक
परीक्षित और उपादेय तत्व हो सकते हैं, उनमें गत्यात्मकता और अनुकूलन क्षमता
होती है, वे समय की चुनौतियों से साक्षात्कार करती हैं, अमुपयोगी मानकर उनका
परित्याग करना एक सशक्त और ऊर्जावान संसाधन से अपने आपको बिलग करना
होगा। परंपराएं बदलती है पर यह प्रक्रिया समय साध्य है। प्रौद्योगिक परिवर्तन और
अधिक विकास के साथ परंपराओं का रूपान्तरण होता है पर यह संभव नहीं है कि
हम सामाजिक संरचना, आस्थाओं और मूल्यों को पहले बदलें और तब विकास
कार्यक्रम हाथ में ले। आयातीत संस्थाएं और मूल्य किसी समाज पर थोपे नहीं जा
सकते, उनके लिए समाज की अन्तःप्रेरणा और स्वीकृत आवश्यक हैं। इसमें अनिवार्यतः
लगता है, स्थापित परंपराओं से सीधा टकराव विघातक हो सकता है, परंपरा को
प्रतिक्रिया विकास कार्यक्रमों को विश्रृंखलित कर सकती हैं। आस्थाएं और परंपरा
असाधारण रूप से जीवनक्षम होती हैं। स्वैच्छिक आधार पर या दबाव के कारण
परिव्यक्त अनेक परंपराए पुनः वापस लौट आती हैं, कानून से परंपराओं का अन्त करना
भी कठिन होता है। खुले बाजार की नीति और उपभोक्तावादी अपसंस्कृति आजकल
भोगवादी मानसिकता को जन्म दे रही है, यह भोगवादी मानसिकता समाज की
उन श्रेणियों में बहुतसंख्य जनों में भी जागृत हो रही है, जिसके पास विलास
वस्तुओं के लिए साधन नहीं है। संचार साधन इस उपभोक्तावाद का प्रचार कर

मानसिकता फैला रहे हैं। समाज इस तरह 'स्वविवेक निर्देशित' या 'परंपरा निर्देशित' न रहकर 'अन्य निर्देशित' होता जा रहा है। यह कह देना की परंपरा मूल्यवान है काफी नहीं है। परंपरा में अपनी बिडम्बनाएं और विरोधाभाष भी होते है। नरबलि, सीतप्रथा, शिशु की भ्रूण हत्या, दहेज और उसके अभाव में स्त्री के साथ नृशंस व्यवहार, अस्पृश्यता आदि ऐसी परंपराएं हैं, जिनका समर्थन नहीं किया जा सकता, परन्तु ऐसी स्वतः स्फूर्त और समाजजन्य परंपराएं हैं, जो आज के माहौल की अमान्य परंपराओं का पहले से विरेध करती आयी हैं। असहमति, विरोध और सुधार की इन परंपराओं को पुष्ट करना आवश्यक है। कानून की अपनी सीमाएं होती हैं, पर शिक्षा, संचार और सामाजिक आन्दोलनों से ये बुराईयाँ भी दूर की जा सकती है।

पहली उलझन उस समय उत्पन्न होती है, जब हम परंपरा का प्रतिरूप निर्धारित करने का प्रयत्न करते हैं। आरम्भ किस काल और स्थिति से करें? आघ संस्कृति के संकलक आखेटक स्तर से? या किसी स्वर्णयुग के कल्पित चित्र से? एक गत्यात्मक प्रतिक्रिया के किस स्तर पर इस प्रतिरूप को घनीभूत और स्थिरिकृत करें? जहाँ परम्परा की एक से अधिक धाराएं हो? उनका तुलनात्मक मूल्यांकन किस आधार पर किया जाय? उनमें प्रमुख कौन हैं? गौण कौन? इसका निर्धारण कैसे हो? परंपरा की हर छवि एक पुर्ननिर्माण होती है, काल, संदर्भ और तात्कालिक आवश्यकताएं परंपरा निर्धारण को प्रभावित करती हैं। अहम् की टकराहट छवि को विकृत कर सकती हैं, दूरदर्शिता, विवेक और संयम का अभाव अनेक समस्याओं को जन्म दे सकता है। दूसरा खतरा है परंपरा के अति रहस्यीकरण का, जो उन्हें ऐसे ढंग से प्रस्तुत करता है, जिसका कोई तथ्यात्मक तथा ऐतिहासिक आधार नही होता। सहय प्रवृत्ति अनावश्यक क्षेत्रीय, सामुदायिक और साम्प्रदायिक तनाव पैदा कर सकती है। शुद्ध परंपरा की खोज हमें अंधी गली में ले जा सकती हैं क्योंकि संस्कृतियों के बीच व्यापक आदान–प्रदान एक स्वीकृत ऐतिहासिक प्रक्रिया है क्या सम्पर्क सूत्रों की अवहेलना की जा सकती है? फिर कोई भी परंपरा संसार की सभी समस्याओं का हल प्रस्तुत नहीं कर सकती। कुछ नयी समस्याएं नये हलों की मांग करती है। विश्वव्यापी समस्याओं के विश्वव्यापी हल जरूरी होते हैं, जो किसी एक परंपरा में उपलब्ध नहीं होते। परंपरा का राजनीतिकरण जो सत्य, असत्य, अर्धसत्य का सहारा लेता, तात्कालिक राजनीतिक लाभ तो दे सकता है, पर यह वैनमस्य, टकराव और हिंसा को भी प्रेरित कर सकता है। संस्कृतियों की स्वायत्तता स्वीकार करने का पूरा लाभ तभी होगा जब हम अन्तर सांस्कृतिक सौहार्द्र और सहयोग के सेतुओं का निर्माण भी करेंगे जो उन्हे ऐसे ढंग से प्रस्तुत करता है, जिसका कोई तत्थात्मक तथा ऐंतिहासिक आधार नहीं होता। यह प्रवषत्ति अनावश्यक क्षेत्रीय, सामुदायिक और साम्प्रदायिक तनाव पैदा कर सकती है।

शुद्ध परंपरा की खोज हमें अधी गली मे ले जा सकती हैं, क्योंकि संस्कृतियों के व्यापक आदान–प्रदान एक स्वीकृत ऐतिहासिक प्रक्रिया है। क्या सम्भव है अवहेलना की जा सकती है? फिर कोई भी परंपरा संसार की सभी समस्याओं को प्रस्तुत नहीं कर सकती। कुछ नयी समस्याएं नये हलों की मांग करती है। विश्व समस्याओं के विश्वव्यापी हल जरूरी होते हैं, जो किसी एक परंपरा में उपलब्ध होते। परंपरा का राजनीतिकरण जो सत्य, असत्य, अर्धसत्य का सहारा लेता, तात्कालिक राजनीतिक लाभ तो दे सकता है, पर यह वैमनस्य, टकराव और हिंसा को जन्म देकर कर सकता है। संस्कृतियों की स्वायत्तता स्वीकार करने का पूरा लाभ तभी होगा जब हम अन्तर सांस्कृतिक सौहार्द और सहयोग के सेतुओं का निर्माण भी करेंगे।

भारतीय संस्कृति में परंपरा की अन्तरनिहित ऊर्जा और क्षमता की अद्भुत है। परंपरा हमें साधन भी देती है, लक्ष्य भी। निःसन्देह परंपरा और विकास के सम्बन्ध समस्याग्रस्त हैं, उनमें से न एक को छोड़ा जा सकता है, और न दूसरे को विकास आज की अनिवार्यता है, पर परंपरा में भी अदम्य जीवन शक्ति है, जो कभी आप को विकास यात्रा के हर मोड़ पर प्रमाणिक कर उनके शासनकाल में देश की विकास दर जापान के विकासदर से भी अधिक थी। उस समृद्धि का क्या हुआ आयातुल्ला खुमैनी के आन्दोलन के कुछ कदमों ने उसे रेत के घरौंदों की तरह बिखेर दिया। यह परंपरा की विजय थी। सोवियत संघ का क्रान्तिकारी प्रयोग भी जातीय और क्षेत्रीय परंपराओं का क्षरण नहीं रह सका। चीन की सांस्कृतिक क्रान्ति में कन्फ्यूसियस, लावोत्सू और बुद्ध को अपदस्थन नहीं सकी। उसके मध्य एशियाई क्षेत्र में पुनः इस्लाम की लहर सशक्त है। जातीय भावना, जिसकी जड़े परंपरा में है, आज सारे विश्व में उत्कर्ष पर हैं। एक गणना के अनुसार दुनिया में चार सौ से अधिक जातीय भावना से प्रेरित आन्दोलन चल रहे हैं। इन उदाहरणों से स्पष्ट है कि परंपरा और विकास को सुसंगत बनाए बिना न शान्ति संभव होगी न प्रगति। 'एक ग्रह एक मानवता' का नारा आज एक चालू मुहावरा बन गया है। अस्तित्व के संकट का सामना करने के लिए समस्त मानव जाति काएक जुट होना जरूरी भी है, परन्तु इस सम्भावना का परंपराओं और संस्कृतियों की विविधता का ह्रास नहीं हैं, आवश्यक है परंपराओं और सांस्कृतियों के सहअस्तित्व का एक नया आधार। समान लक्ष्यों की प्राप्ति के लिए मानव–जाति अवश्य एक हो, परन्तु विश्वव्यापी, सांस्कृतिक एकरूपता न जरूरी है न संभव।

परंपरा के स्वरूप विवेचन में आचार्य 'हजारी प्रसाद द्विवेदी' के इस कथन को देख सकते हैं– "खड़ा पैर, परंपरा है और चलता पैर आधुनिकता, दोनों का पारस्परिक सम्बन्ध खोजना बहुत कठिन नहीं हैं, एक बिना दूसरी की कल्पना ही नहीं की जा सकती। कोई भी आधुनिक विचारक आसमान में पैदा नहीं होता, उसकी जड़ परंपरा

में गहराई तक गयी हैं, सुन्दर से सुन्दर फूल यह दावा नहीं कर सकता है कि वह पेड से भिन्न होने के कारण उससे असम्पृक्त है। कोई भी पेड यह दावा नहीं कर सकता कि वह मिट्टी से भिन्न होने के कारण एकदम उससे विच्छिन्न है। इसी प्रकार कोई आधुनिक विचारक यह दावा नही कर सकता कि वह परंपरा से एकदम कटा हुआ है। परंपरा का क्रम परिवार से जोड़ा जाता है, यह एक पीढी से दुसरी में क्रियाकलापों के माध्यम से स्वतः आ जाती है। उसका अक्षसः पालन समय एवं परिस्थिति के ऊपर निर्भर करता है जो सम्बन्धों को बनाए रखने में सहायक है।

परंपरा का अर्थ अविच्छिनन क्रम चला आता हुआ अटूट शिलशिला है, यह क्रम एक से दूसरे तथा दूसरे से तीसरे की ओर क्रमशः आगे बढ़ता जाता है। यह एक ऐसा अविच्छनन क्रम है, जिसमें कई पीढ़ियॉ सम्मिलित होती है। परंपरा प्रत्यक्ष रूप से हमारे समक्ष उपस्थित नही होती। वह तो वर्तमान में हो रहे प्रयोगों से प्रेरित व संचालित करने का कार्य पृष्ठभूमि से ही करती है। इसी क्रम में जो आज प्रयोग है कल परंपरा होगे और पुनः किन्ही नवीन प्रयोगो से प्रेरित करेगे। परंपरा की इसी गतिशीलता के सन्दर्भ में अज्ञेय ने कहा है कि– जो लोग प्रयोग की निन्दा करने के लिए परंपरा की दुहाई देते है, वे यह भूल जाते है। कि परंपरा ,कम से कम कवि के लिए ऐसी कोई पोटली बॉधकर रखी हुई चीज नही है,जिसे उठाकर सिर पर लादकर चल निकले। परंपरा का कवि के लिए कोई अर्थ नही है, जब तक वह उसे ठोकबजाकर, तोड़मरोड़कर, आत्मसात नही कर लेता, तब वह इतना गहन संस्कार नही बन जाती कि उसका चेष्टा पूर्वक ध्यान रखकर निर्वाह करना आवश्यक हो जाए।[3]

आदिकाल से संचित होती जा रही विरासत को प्रयत्न पूर्वक भी किसी पोटली में बॉधा नही जा सकता। लेकिन फिर भी अपने संस्कार बस हम उससे इस तरह जुड़े होते है कि उसे सहसा उखाड़ फेकना सम्भव होता है। उसकी विच्छिन्नता में बोध आकार ग्रहण करता है, वह सदैव उथला ही रहता है। जड़ों की दृढता व गहराई उसमें नही आ पाती। आचार्य द्विवेदी जी ने परंपरा के सन्दर्भ में सम्प्रदाय का अन्तर स्पष्ट करते हुए परंपरा को गतिशील तथा सन्प्रदाय को स्थिति का संरक्षक माना है। उनके अनुसार "परंपरा सहज है, सम्प्रदाय यत्न सिद्व। आधुनिकता गतिशील प्रक्रिया है। और सम्प्रदाय स्थिति संरक्षक, परन्तु परंपरा से आधुनिकता का वैसा विरोध नही होता। दोनों ही गतिशील प्रक्रियाएं हैं। दोनों में विरोध केवल यह है कि परंपरा यात्रा के बीच पडा हुआ अन्तिम चरण हैं, जबकि आधुनिकता आगे बढ़ा हुआ गतिशील कदम है।"

अतः परंपरा वह प्रकाश स्रोत है जो अतीत से आधुनिक तक की सम्पूर्ण श्रृंखला के क्रम को प्रकाशित करता है। वह आधुनिकता के वर्तमान, समकालीन सन्दर्भ को सम्बल प्रदान करती है तथा भविष्य के प्रति दायित्वपूर्ण बोध के साथ अग्रसर होने क चेतना देती है। आधुनिकता स्वयं वह सम्पूर्ण चेतना होना चाहती है जो अतीत, वर्तमान और भविष्य के नैरन्तर्य का निष्कर्ष हो। ऐसे में परंपरा से उसकी सम्बद्धता के महत्व और कारण दोनों स्पष्ट हो जाते हैं।

परंपरा निश्चित रूप से हमारी अतीत काल से लेकर अब तक की अर्जित उपलब्धियों का सार है। काल के जिस अंश को हम इतिहास कहते हैं, अपने जीवित रूप में परंपरा है और मष्त रूप में रूढ़ि। परंपरा का शाब्दिक अर्थ ही "एक का दूसरे को दूसरे तीसरे को दिया जाने वाला क्रम है। वह अतीत का समानार्थक नहीं है। परंपरा जीवन्त प्रक्रिया है जो अपने परिवेश की संग्रह त्याग की आवश्यकताओं के अनुरूप निरन्तर क्रियाशील रहती है। कभी–2 इसे गलत ढंग से अतीत के सभी आचारों–विचारों का बोधक मान लिया जाता है।[4]

परंपरा प्रत्यक्ष रूप से हमारे सामने उपस्थित तो नहीं होती, लेकिन वर्तमान और नवीन द्वारा वह पुनर्व्याख्यायित होती है और स्वयं वर्तमान को जब अपनी व्याख्या करने की क्षमता देती है, तब उसकी उपस्थिति का अहसास होता है। इससे यह भी स्पष्ट होता है कि परंपरा कभी भी नवीनता या परिवर्तन की शत्रु नही रही चाहे उसका विरोध अवश्य रहा हो। बल्कि नवीनता अक्सर परंपरा को उचित परिप्रेक्ष्य में न समझ पाने के कारण उसका खुले आम तिरस्कार कर देती है। जिस प्रकार गतिशीलता और परिवर्तन आधुनिकता को परिचालित रखता है, उसी प्रकार वह परंपरा को भी जीवित रखता है। आधुनिकता जब परंपरा का पुनर्संस्कार करती है तब उसमें परिवर्तन और विकास का प्रयास करती है तो उसके मूल में भी परंपरा की आत्यान्तिक अवमानना और बहिष्कार नही होता, बल्कि उसके प्रति एक नवीन परिप्रेक्ष्यगत मानसिकता होती है जो परंपरा की पृष्ठभूमि में आगामी परिस्थिति, प्रतिक्रिया या व्यवहार का निर्धारण करती है–"इस दृष्टि से परंपरा से एक नवीनीकृत सम्बन्ध आधुनिकता की एक क्रान्तिकारी सार्थकता का प्रमाण है। आधुनिकता का तात्पर्य ही परंपरा के प्रति एक नयी संवेदना है।"[5]

आधुनिकता देश तथा काल सापेक्ष है। आज जो आधुनिकता है, आगे आने वाले क्रम में वही परंपरा बन सकता है। आज का क्रान्तिकारी चिन्तन आगे आने वाले समय में पुराना पड़ जाता है। श्री विष्णु प्रभाकर ने अपने नाटक "युगे–युगे क्रान्ति" में इसे सुन्दर रूप में निरूपित किया है।

परंपरा का साक्षात्कार संस्कारों से किया जा सकता है। जन्म से मृत्यु तक के संस्कार परंपरा से बंधे है। नारी इन संस्कारों की जननी भी है, तथा वह परंपरा को पीढ़ियों में जीवन्त रखने का कार्य भी कर रही है।

अपने युग को हीन समझना आत्महीनता होगी,
सजग रहो इससे दुर्बलता और दीनता होगी।
जिस युग में हम हुए वहीं तो अपने लिए बड़ा है,
अहा और आगे कितना कर्म-क्षेत्र पड़ा है।

(द्वापर)

श्री जयशंकर प्रसाद की भी मान्यता है कि प्रकृति—पुरातनता की केंचुली को क्षणभर भी सहन नहीं करती। परिवर्तन अवश्यम्भावी है। इसी में आनन्द है—

पुरातनता का यह निर्मोक
सहन करती न प्रकृति पल एक,
नित्य नूतनता का आनन्द
किये है परिवर्तन में टेक। (कामायनी)

परंपराओं के संदर्भ में हम बहुधा भौतिक जगत और वैचारिक जगत और सूक्ष्म जगत में भेद करते है, और उन्हें भिन्न धरातलों का अपने आप में पूर्ण और स्वतंत्र मानते है। यह मान्यता एक भूल है भ्रम है। जैविकीय परंपराओं से मनुष्य अपना विशिष्ट व्यक्तिगत जैविकीय मण्डल पाता है। उसके विचारों और शब्दों का मण्डल अनिवार्य रूप से समान्य जैविकीय परंपराओं से जुड़ा होता है। विचार जगत की जड़े वस्तु जगत में होती है और वह उससे किसी भी तरह अलग नहीं किया जा सकता। मनुष्य का मस्तिष्क उसका अपना होता है, क्योंकि वह उसकी शरीर रचना का अंग है, किन्तु उसकी भाषा सार्वजनिक होती है। विज्ञान की नयी दृष्टि यह मानती है कि भावनाएं और विचार यथार्थ और भौतिक होते है। इस तरह हमें यह मानकर चलना चाहिए कि विचार और उनकी अभिव्यक्ति के माध्यम जैविकीय और भौतिक यथार्थ के विस्तार मात्र है। जिस तरह मनुष्य का शरीर अपने आप में विशिष्ट होकर भी अनुवांशिकता के द्वारा जैविकीय श्रृंखला से जुड़ा होता है। उसी तरह अनेक रूपान्तरों के बाद भी शब्द अपनी ध्वनियों और अर्थों में एक लम्बी परंपरा का इतिहास छिपाए रहते हैं।

साहित्य जगत में अगर परंपरा के प्रति विचार किया जाये तो, साहित्य में मानवीय चेतना की प्रक्रिया और उसका धरातल परिलक्षित होते है। इस तरह साहित्य में एक ओर वर्ग या समुदाय का संकुचित घेरा उसे समाज के सार्वभौम सत्यों से साक्षात्कार नहीं करने देता। साहित्य में परंपरा की अभिव्यक्ति और व्याख्या होती है और उसके माध्यम से इन परंपराओं को स्थायित्व भी मिलता है। साथ ही साहित्य

इन परंपराओं का मूल्यांकन करता हैं और सतत नये अर्थों और प्रयोजनों की खोज भी। ये प्रयत्न स्थितियों की नयी व्याख्या को जन्म देते है। इन व्याख्याओं में होने वाले परिवर्तन मानव की विचार प्रक्रियाओं को नया आधार देते है। इस तरह साहित्य में यदि एक ओर परंपरागत जीवन प्रणाली की अनुकृति देखने को मिलती है तो दूसरी ओर उसमें मानव के विचार जगत के नये आयामों का परिचय मिलता है और उसमें हुई नयी जीवन दृष्टि भी उसमें चित्रित होती है। साहित्य की जड़े समाज में होती हैं वह स्वयं एक सामाजिक उत्पादन है। वह अपनी सामाजिक भूमिका के कारण ही मानवीय परंपरा का अंग बन सका है। साहित्य परंपराओ के प्रेषण का एक प्रमुख माध्यम है। उसके द्वारा परंपराएं एक पीढ़ी से दूसरी पीढ़ी तक पहुंचती है। व्यक्ति समूह और समाज–सम्बन्धी प्रतिमान और परिकल्पनाएं दोनों साहित्य में अभिव्यक्त होते है। जीवन–दृष्टि और मूल्यों के प्रेषण में भी उसका उल्लेखनीय योगदान होता है। इन सब के सम्मिलित प्रभाव से समाज को स्थायित्व देने वाले कारक सशक्त होते है। साथ ही साहित्य में उपलब्ध ज्ञान का संकलन और समन्वय भी होता है जो ज्ञान–विज्ञान और मनन–चिन्तन के क्षितिजों के विस्तार में समाज के सहायक होते है। परंपराएं साहित्य में अभिव्यक्ति मात्र ही नहीं पाती, उनकी व्याख्या भी इस माध्यम से होती है। साहित्य उन पर टीका करता है और उनका मूल्यांकन भी। यह प्रक्रिया परंपराओं को गतिशीलता देती हैं। साहित्य अतीत में विकसित शाश्वत और पावन सत्यों में ही नहीं उलझा रहता। वह उन्हें परम्परागत और नये संदर्भों के परिप्रेक्ष्य में देखने का प्रयास भी करता है और सजग तार्किकता से उनका विश्लेषण भी करता है।

भारतीय संस्कृति में स्वरूपगत रूप से या यूँ कहें कि परंपरा के स्वरूप को विभिन्न कसौटियों के माध्यम से देखा और परखा जा सकता है। 'विश्वकोश' के अनुसार परंपरा की सर्वोत्तम कसौटी उसकी प्रासंगिकता होती है जो परंपरा वर्तमान में व्यवहार्थ नहीं, वह परम्परा हो ही नहीं सकती। रूढ़ि या अन्ध विश्वास हो सकती है। परंपरा अपने स्वस्थ्य रूप में सदा प्रासंगिक और समसामयिक होती है। भारतीय समाज में दाम्पत्य सम्बन्धोत्तर यौन सम्बन्धों के निषेध की परंपरा है, बहुत से लोग इसे तोडकर स्वतंत्र और विवाहेत्तर यौन सम्बन्धों की वकालत करते हुए इसे रूढ़ि कहकर नकारते है। ऐसी स्थिति में प्रासंगिकता के निष्कर्ष पर इस परंपरा का महत्व और औचित्य प्रमाणित होता है। एड्स जैसी घृणित बिमारियों से सर्वोत्तम सुरक्षा के रूप में यह परंपरा सुरक्षा कवच बनकर हमारे समक्ष अपनी प्रासंगिकता प्रमाणित करती है। इससे सिद्ध होता है कि प्रासंगिकता परंपरा की सफल कसौटी है। परंपरा के स्वरूप से सम्बन्धित महत्व की उपादेयता के बारे मे कुछ बिन्दु इस प्रकार हैं। परंपरा

किसी जाति या समाज की अस्मिता का निर्धारण करती है इसलिए उनका महत्व असंदिग्ध है। परंपरा के दर्पण में हम अपना स्वरूप पहचानते हैं। अपनी वैचारिक अवधारणाओं की दिशा निश्चित करते है। अपने विश्वास धारण करते है तथा अपना व्यवहार नियमित करते हैं ये परम्पराएं ही हैं जो हमें ससम्मान जीना सिखाती है और हमें अपने समाज से जोड़कर सामाजिक बनाती है। परंपरा के अभाव में सामाजिक जीवन की कल्पना भी नहीं की जा सकती। परंपत्तएं आशा का प्रकाश देती है और कर्म पथ पर अग्रसर होने को प्रोत्साहित करती हैं। यह राष्ट्रीय हित में बलिदानों की परंपरा ही है। जिसने मध्यकाल की गुलामी से लेकर अंग्रेजी दासता के विरूद्व संघर्ष में हमारा पथ प्रदशंन किया और आज भी विभिन्न विभिषिकाओं और दुर्घटनाओं में हमारी सहायक बनती है। किसी समाज की परंपऱाएं जितनी महान होती है, उसकी जातिय जीवन भी उतना ही गौरवास्पद होता है। परंपरा जातीयता सामूहिकता की आधारशिला है। यह पुरानी पीढ़ी से नयी पीढ़ी को जोड़कर निरन्तरता प्रदान करती है। इससे जीवनधारा अविच्छिन्न बनती है इसलिए डॉ0 राधाकृष्णन ने लिखा हैं– 'परम्परा पीढ़ियों को जोड़ती है– एक से दूसरी को और सभी प्रगति उन्ही विचारों से अनुप्राति होती है, जिनको वह हटाती प्रतीत होती है।"[7]

भारतीय संस्कृति में परंपरा के स्वरूप का महत्व स्वयं सिद्व है। परंपरा के स्वरूप से संदर्भित व्यक्ति का उदान्तिकरण कुछ इस प्रकार स्पष्ट होता हैं– परंपरा मनुष्य को करणीय अकरणीय का भेद बताकर उसके व्यक्तित्व का उदत्तीकरण करती है। मनुष्य का जीवन सीमित है। वह सभी कार्यों को स्वयं सम्पादित करके उनके गुण और दोषों को परख नहीं सकता। इस कार्य में परंपरा उसकी सहायता करती है। परंपरा के दर्पण में वह अपने कर्त्तव्य–अकर्त्तव्य को पहचानता है। इस पहचान से निश्चय ही मानवीय व्यक्तित्व का उदात्तीकरण होता है। वह बहुत से अकर्णीय, निद्य दुष्कर्मों को करने से बच जाता है और सही दिशा में अपनी क्षमताओं का नियोजन कर लेता है। इस अर्थ में परंपरा मनुष्य को दुष्कर्मों से मुक्ति देती है। डॉ0 विद्यानिवास मिश्र ने इस तथ्य को इस प्रकार शब्द दिये हैं– "परंपरा अपने को ही काटकर तोड़कर आगे बढ़ती हैं, इसलिए कि वह निरन्तर मनुष्यों को अनुशासित रखते हुए भी स्वाधीनता के नये–2 आयामों में प्रतिष्ठित करती चलती है। परंपरा बन्धन नहीं है, वह मनुष्य को मुक्ति (अपने लिए ही नही, सबके लिए मुक्ति) कि निरन्तर तलाश है।"[8]

भारतीय संस्कृति में कहने की आवश्यकता नहीं है, मुक्ति व्यक्तित्व के उदात्तीकरण का प्रत्यक्ष हेतु और प्रमाण है। परंपरा मुक्तिप्रदा है, अतः उससे व्यक्तित्व का उदात्तीकरण मानना युक्ति–युक्त है।

शाब्दिक रूप से परंपरा शब्द के स्वरूप में बहुत सारे सामानार्थी शब्द
होते है। जिनमें प्रमुख हैं–"पूर्व प्रथा, पूर्व रिवाज, पूर्व रीति, पूर्व मान्यता ये
प्रायः समानार्थी शब्द है जो परंपरा के अर्थ स्वरूप को स्पष्ट करते हैं, इनमें
रिवाज, प्रथा पूर्वतः प्रथा के अर्थानुसारी है। रीति शब्द पारिभाषिक होने के
काव्यशास्त्र में अवश्य संक्रमित हो जाता है। 'मान्यता' शब्द 'अर्चा' का अर्थ देता है
इसमें 'अर्चना' का भाव अधिक है। स्वरूपगत रूप से परंपरा के भेद गुणात्मक
आधार पर तीन है, पहला उत्कृष्ट परम्परा, मध्यम कोटिक परंपरा तथा तीसरा
परंपरा। गोस्वामी तुलसीदास ने अपने पूर्ववर्ती रामकथाकार से की परंपरा की
किया, अतः उनके द्वारा स्वीकृत परंपरा उत्कृष्ट प्रमाण हैं–

मुनिन्ह प्रथम हरिकीरति गाई।
तेहि मग चलत सुगम मोहि भाई।।

मध्यम कोटिक परंपरा में संशोधन संभव हो जाता है। राम ने अपने
दशरथ द्वारा स्वीकृत परंपरा (एक से अधिक विवाह) का त्यागकर दिया।
परंपरा व्यष्टि तथा समष्टि दोनों के लिए अनर्थकारिणी होती हैं। परंपरा से
उसके स्वरूप को उद्घाटित करने वाली सुभाषित एवं सुक्तियां लोकजगत
प्रकार प्रचलित हैं–'गर्भेश्वर त्वमायभिनव यौवन त्वम प्रतिमरूप।
त्वममानुष शक्ति त्व चेतित महतीयं खल्लवनर्थ।। परंपरा सर्वाकादम्बरी 103
ही ईश्वरत्व स्थायी होना, नवयौवन का होना, अप्रतिम रूप का होना, अमानवीय
का होना, यह सब महान अनर्थ की परंपरा है।)

परंपरा और विद्रोह दोनों का जीवन में अलग–2 स्थान है। परंपरा
डालकर पानी को गहरा बनाती है। विद्रोह घेरों को तोड़कर पानी को चौड़ाई
जाता है। परंपरा रोकती है, विद्रोह आगे बढ़ना चाहता है। इस संघर्ष के बाद
प्रगति होती है, वही समाज की असली प्रगति।[9] 'परंपरा' को स्वीकार करने का
बंधन नहीं, अनुशासन का स्वेच्छा से वरण है।'[10]

'परंपरा की अखण्डता यांत्रिक पुनरूत्पादन नहीं है अपितु यह सर्जनात्मक
रूपान्तरण हैं, सत्य के आदर्श के अधिकाधिक निकट पहुंचता है।'[11]

'जो लोग पहले के मतो से कोई सरोकार न रखकर एक नया मत स्थापित
करना चाहते है, जिस सूत्र में माला गूंधी हुई हैं, उसी को तोड डालना चाहते हैं
शून्य पर नये समाज का गठन करना चाहते हैं, वे बुरी तरह असफल होंगे।'[12]

'जीवित परंपरा आत्महीन नहीं होता, वह समाप्त नहीं होती। उसके
रूपों और प्रारूपों मे लिखते जाने की शक्ति प्रवाहित रहती है।'[13]

'परंपरा इतिहास को विशेष सहयोग प्रदान करती है लेकिन उसकी बातों का सूक्ष्म रूप से निरीक्षण कर तभी हमें उस पर विश्वास करना चाहिए।'[14]

भारतीय संस्कृति में परंपरा की अन्तरनिहित ऊर्जा और क्षमता भी आवश्यक है। परंपरा हमें साधन भी देती है, लक्ष्य भी। निःसन्देह परंपरा और विकास के सम्बन्ध समस्याग्रस्त हैं, उनमें से न एक को छोड़ा जा सकता है, और न दूसरे को। स्वरूपगत रूप से या यूँ कहें कि परंपरा के स्वरूप को विभिन्न कसौटियों के माध्यम से देखा और परखा जा सकता है। 'विश्वकोश' के अनुसार परंपरा की सर्वोत्तम कसौटी उसकी प्रासंगिकता होती है जो परंपरा वर्तमान में व्यवहार्थ नहीं, वह परम्परा हो ही नहीं सकती। रूढ़ि या अन्ध विश्वास हो सकती है। परंपरा अपने स्वस्थ्य रूप में सदा प्रासंगिक और समसामयिक होती है। परंपरा के अभाव में सामाजिक जीवन की कल्पना भी नहीं की जा सकती। परंपराएं आशा का प्रकाश देती है और कर्म पथ पर अग्रसर होने को प्रोत्साहित करती हैं। परंपरा प्रत्यक्ष रूप से हमारे सामने उपस्थित तो नहीं होती, लेकिन वर्तमान और नवीन द्वारा वह पुनर्व्याख्यायित होती है और स्वयं वर्तमान को जब अपनी व्याख्या करने की क्षमता देती है, तब उसकी उपस्थिति का अहसास होता है। इससे यह भी स्पष्ट होता है कि परंपरा कभी भी नवीनता या परिवर्तन की शत्रु नही रही चाहे उससे उसका विरोध अवश्य रहा हो। इस तरह हम कह सकते हैं, परंपराओं की प्रासंगिकता और उनका महत्व असंदिग्ध है, पर उन्हें एक सीमा से अधिक महिमा मण्डित करना भी उचित नहीं है। परंपरा से समाज की पहचान बनती हैं, उसके माध्यम से समुदाय, विचार और व्यवहार का एक स्थिर आधार पाते है, समाज का एक बड़ा भाग परंपराओं को सहज भाषा स्वीकार करता हैं, क्योंकि उनके कोई विकल्प उसके सामने नहीं होते हैं। निर्माणकारी परम्पराओं से ही संस्कृति का निर्माण होता आया है । समाज या समुदाय की निर्माणिक शक्ति भी संस्कृति में ही निहित होती है। माना की वर्तमान परिवेश में अगर परम्पराएँ अपनी निर्माणिक शक्ति खो चुकी हो तो भी हमारी संस्कृति ही उस भयावहता से हमें आगाह करती है।भारतीय संस्कृति की यही विशेषता है। अतः हम कह सकते हैं कि भारतीय संस्कृति निर्माणकारी परम्पराओं से विलग नहीं हैं ।

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