Chapter - I

Introduction
CHAPTER I
INTRODUCTION

1.1. FLUID DYNAMICS

Fluid Mechanics is the study of fluids either in motion or at rest and the subsequent effects of the fluid upon the boundaries which may be either solid surfaces or interfaces with other fluids. Fluid Mechanics is an important branch of applied mathematics and engineering. This branch of science deals with the static, kinematic and dynamic aspects of fluids. The fluid is considered to be static if all the particles of the fluid are at rest with respect to a reference coordinate system. The study of fluids in motion, where pressure forces are not considered is called fluid kinematics and if the pressure forces are also considered for the fluids in motion then that branch of science is called fluid dynamics.

The fluid state is commonly divided into liquid, gaseous and plasma. The study of former two states comes under fluid dynamics and the study of latter one comes under plasma dynamics. Again, the two corresponding branches of fluid dynamics are called hydrodynamics and aerodynamics, the former relating to water as well as other liquids and the latter to air and other gases.

Fluid dynamics is an important and rich branch of science and engineering, as any living being in the universe cannot exist without fluid. The development of the fluid dynamics started in quite early age of civilization. Archimedes (250 B.C.) formulated the basic principles of fluid dynamics which are true till day. Some applications of fluid dynamics are flow in pipes and channels, irrigation and in the design of water supply system, dam spillways, ships, submarines, air crafts, rockets, wind mills, turbines, missiles, ice bergs, engines, filters, jets etc.,

The study of Magneto hydrodynamics with heat and mass transfer in the presence of radiation and diffusion has attracted the attention of a large number of scholars due to diverse applications. Magneto Hydrodynamics (MHD) is the branch of continuum mechanics which deals with the flow of electrically conducting fluids in the electric and magnetic fields. The word magneto hydrodynamics is comprised of words. Magneto meaning magnetic hydro meaning water and dynamics referring to the movement of an object by forces. The
The fundamental concept behind MHD is that magnetic fields can induce currents in a moving conductive fluid, which in turn creates forces on the fluid and also the magnetic field itself. The presence of transverse magnetic field produces a resistive force on the fluid flow this force is called the Lorentz force.

In nature, there exists flows which are caused not only by the temperature differences but also by the concentration differences. These mass transfer differences do effect the rate of heat transfer. In Industries, many transport processes exist in which heat and mass transfer takes place simultaneously as a result of combined buoyancy effect in the presence of thermal radiation. If the temperature of surrounding fluid is rather high, the radiation effects play an important role and this situation does exist in space technology. In such cases, one has to take into account the combined effect of the thermal radiation and mass diffusion. Diffusion is the process by which the molecules ions or other small particles spontaneously mix moving from regions of relatively high concentration into relatively lower concentration. Soret effect (Thermo-diffusion), the diffusion of material in an unevenly heated mixture of gases or a solution caused by the presence of a temperature gradient in the system. The effect is named for the Swiss scientist J. Soret, who was the first to study thermo diffusion (1879). Dufour effect (diffusion-thermo), it is the inverse phenomenon of thermal diffusion. If two chemically different non reacting gases or liquids, which are initially at the same temperature are allowed to diffuse into each other thus there arises a difference of temperatures in the system. The difference in temperatures is retained if a concentration gradient is maintained. The effect was first observed by Swiss physicist L. Dufour in 1873.

1.2. CLASSIFICATION OF FLUIDS

Matter exists in two states, solid state and fluid (liquid, gaseous and plasma) state. If matter has a definite shape in the absence of external forces and thermodynamic conditions then, such matter is called a solid. A material substance, which can be take deformation, increases continuously without the limit under the action of forces, is called a fluid. The tendency of fluids to flow due to the continuous deformation under the action of forces. Every material whether it is a solid or liquid is made up of small particles. These small particles are known as molecules. A liquid has intermolecular forces, which holds it together so that it possesses volume but not definite shape. Where as in gases the molecules which are in
motion, collide with each other tending to disperse it so that the gases has no definite volume or shape. The intermolecular forces are extremely small in gases.

The fluids can be classified as (i) Ideal fluids and (ii) Real fluids. A fluid, which is incompressible, irrotational and non-viscous is known as an ideal fluid. The ideal fluids are also known as in viscid fluids or perfect fluids or frictionless fluids. In true sense, no such fluids exists in nature. The assumption of ideal fluids helps in simplifying the mathematical analysis. However fluids which have low viscosities such as water and air can be treated as ideal fluids under certain conditions. A fluid, which has viscosity, surface tension and compressibility in addition to the density is known as a real fluid. It is also known as viscous fluid. In a viscous fluid internal friction plays an important role during the motion of the fluid. One of the important characteristics of viscous fluid is that it offers internal resistance to flow. Viscosity, being the characteristic of the real fluids, exhibits a certain resistance to alteration of the form also. Again viscous or real fluids are classified into two categories (i) Newtonian fluid and (ii) Non Newtonian fluid. The Newton’s law of viscosity, which states that the shear stress \( \tau \) on a fluid element layer is directly proportional to the rate of shear strain and is expressed as,

\[
\tau = \mu \frac{du}{dy}
\]

where, \( \mu \) is the co-efficient of viscosity in N s m\(^{-2}\) or Pascal sec (Pa s) and \( \frac{du}{dy} \) is the shear strain in s\(^{-1}\).

Fluids which obey the above relation are known as Newtonian fluids and the fluids which do not obey the above relation are called non-Newtonian fluids.

1.3. TYPES OF FLUID FLOW: The fluid flow is classified as,

i. Steady and unsteady flow: Steady flow is defined as that type of flow, in which the fluid characteristics like velocity, pressure, density etc., at a point do not change with time. Steady state flow refers to the condition where the fluid properties are at a point in the system do not change over time. Where as in unsteady flow the velocity, pressure, density, etc., at a point changes with respect to time.
ii. **Uniform and Non uniform flow:** Uniform flow is defined as that type of flow in which the velocity at any given time does not change with respect to space non uniform flow is that type of flow in which the velocity at any given time changes with respect to space.

iii. **Laminar and Turbulent flow:** Laminar flow is defined as that type of flow in which the fluid particles move along well defined paths or stream lines and all stream lines are straight and parallel. The particles move in laminar or layers gliding called stream line flow or viscous flow. Turbulent flow is that type of flow in which the fluid particles move in a zig-zag way, due to this movement, the eddies formation takes place which are responsible for high energy loss.

iv. **Compressible and incompressible flow:** Compressible flow is that type of flow in which the density of fluid changes from point to point or in other words the density is not constant for the fluid. Incompressible is that type of flow in which the density is constant for fluid flow liquids are generally incompressible while gases are compressible

1.4. HEAT TRANSFER

Heat transfer is an important phenomena in nature and is applicable to all branches of Science and Technology. The science of heat transfer is concerned with the analysis of the rate of heat transfer taking place in a system. In studying the heat transfer, knowledge of the temperature distribution in a system is essential. Heat flow takes place wherever there is a temperature gradient in a system. Once the temperature distribution is known, the heat flux, which is the amount of heat transfer per unit area, per unit time is determined from the law relating the heat flows to the temperature gradient. The fundamental modes of heat transfer are:

i) **Conduction:**
   The transfer of energy between objects that are in physical contact.

ii) **Convection:**
    The transfer of energy between an object and its environment, due to fluid motion.

iii) **Radiation:**
     The transfer of energy to or from a body by means of the emission or absorption of electromagnetic radiation.

iv) **Advection:**
    The transfer of energy from one location to another as a side effect of physically moving an object containing that energy.
I. CONDUCTION

On a microscopic scale, heat conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighbouring atoms and molecules, transferring some of their energy (heat) to these neighbouring particles. In other words, heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Fluids, especially gases, are less conductive. Thermal contact conductance is the study of heat conduction between solid bodies in contact.

Steady state conduction is a form of conduction that happens when the temperature difference driving the conduction is constant, so that after an equilibration time, the spatial distribution of temperatures in the conducting object does not change any further. In steady state conduction, the amount of heat entering a section is equal to amount of heat coming out.

Transient conduction occurs when the temperature within an object changes as a function of time. Analysis of transient systems is more complex and often calls for the application of approximation theories or numerical analysis by computer.

II. CONVECTION

Convective heat transfer, or convection, is the transfer of heat from one place to another by the movement of fluids, a process that is essentially the transfer of heat via mass transfer. Bulk motion of fluid enhances heat transfer in many physical situations, such as (for example) between a solid surface and the fluid. Convection is usually the dominant form of heat transfer in liquids and gases. Although sometimes discussed as a third method of heat transfer, convection is usually used to describe the combined effects of heat conduction within the fluid (diffusion) and heat transference by bulk fluid flow streaming. The process of transport by fluid streaming is known as advection, but pure advection is a term that is generally associated only with mass transport in fluids, such as advection of pebbles in a river. In the case of heat transfer in fluids, where transport by advection in a fluid is always also accompanied by transport via heat diffusion (also known as heat conduction) the process of heat convection is understood to refer to the sum of heat transport by advection and diffusion/conduction.
Free, or natural, convection occurs when bulk fluid motions (steams and currents) are caused by buoyancy forces that result from density variations due to variations of temperature in the fluid. Forced convection is a term used when the streams and currents in the fluid are induced by external means such as fans, stirrers, and pumps creating an artificially induced convection current.

Convective heating or cooling in some circumstances may be described by Newton's law of cooling: "The rate of heat loss of a body is proportional to the difference in temperatures between the body and its surroundings." However, by definition, the validity of Newton's law of a temperature gradient.

Convection heat transfer may be classified into two ways, forced convection heat transfer and free or natural convection heat transfer.

If the heat transfer between the fluid and the solid surface occurs by fluid motion induced by external agencies or forces then the mode of heat transfer is termed as “Forced convection”, in all types of heat exchangers, nuclear reactors, air conditioning apparatus are by force convection.

A free convection flow field is a self-sustained flow driven by the presence of a temperature gradient (as opposed to a forced convection flow where external means are used to provide the flow), as a result of the temperature difference, the density of the field is not uniform. Buoyancy will induce a flow current due to the gravitational field and the variation in the density field. In general, a free convection heat transfer is usually much smaller compared to a force convection heat transfer. It is therefore important only when there is no external flow.

III. RADIATION

Thermal radiation is energy emitted by matter as electromagnetic waves, due to the pool of thermal energy in all matter with a temperature above absolute zero. Thermal radiation propagates without the presence of matter through the vacuum of space.

Thermal radiation is a direct result of the random movements of atoms and molecules in matter. Since these atoms and molecules are composed of charged particles (protons and electrons), their movement results in the emission of electromagnetic radiation, which carries
energy away from the surface. Red-hot iron object, transferring heat to the surrounding environment primarily through thermal radiation

Unlike conductive and convective forms of heat transfer, thermal radiation can be concentrated in a small spot by using reflecting mirrors, which is exploited in concentrating solar power generation.

**IV. ADVECTION**

By transferring matter, energy including thermal energy is moved by the physical transfer of a hot or cold object from one place to another. This can be as simple as placing hot water in a bottle and heating a bed, or the movement of an iceberg in changing ocean currents. A practical example for this is thermal hydraulics. This can be described by the formula

$$Q = \rho \cdot C_p \cdot \Delta T \cdot v$$

(1.2)

where, $Q$ is heat flux in Wm$^{-2}$, $\rho$ is density in kgm$^{-3}$, $C_p$ is heat capacity at constant pressure Jkg$^{-1}$K$^{-1}$, $\Delta T$ is the change in temperature in K and $v$ is the velocity in ms$^{-1}$.

**1.5. MASS TRANSFER**

Mass transfer is defined as the transfer of matter by virtue of species concentration difference in a system. The difference in concentration provides a driving force for the transfer of mass and it always occur in the direction of redacting concentration gradient.

The phenomena of mass transfer are very common in the theory of stellar structure and observable effects are detectable at least on the solar surface. The involvement and application of mass transfer process goes to greater lengths in numerous fields of Science, Engineering and Technology. Mass transfer operation quite often occurs in the fields of Electric Engineering, Civil Engineering, Aeronautics, Metallurgy, Environmental Engineering, Refrigeration, and Air conditioning, Biological and industrial process. The study of Geophysics, Astronomy, Meteorology, Agricultural, Oceanography and Food processing demands the knowledge of heat and mass transfer. Mass transfer flows are highly significant for their varied practical importance; many examples of mass transfer applications can be cited from the environment. Mass transfer broadly occurs in Biological, Chemical, Physical and Engineering fields. It involves in biological functions or process like respiratory mechanisms, oxygenation or purification of blood, kidney function, osmosis and assimilation of food and drugs. Evaporation of clouds, smoke formation, dispersion of fog, distribution
temperature and moisture over agricultural fields and grooves of fruit trees, damages of crops due to freezing and pollution of the environment are some of the mass transfer phenomena found in nature. Mass transfer finds its place in ablative coding transpiration and film cooling of rocket and jet engines. Mass transfer applications are widely found in chemical engineering process like distillation, absorption of gases, interaction of solids and liquids from the mixtures and chromatography processes like, Air humidification, cooling of water, ion exchange involve mass transfer.

1.6. POROUS MEDIUM

A Porous medium can be defined as a material consisting of solid matrix with an interconnected void. The interconnected pores are very important because they are the ones that affect the flow. The definition of the porosity of the porous medium can be given as the ratio of pore volume to the total volume of a given sample of material. Daray’s law is used for flow in porous media and works with variables averaged over several pore widths. In recent years, the investigation of flow of fluids through porous media has become an important topic due to the recovery of crude oil from the pores of reservoir rocks. Also the flow through porous media is of interest in Chemical engineering (absorption, filtration), Petroleum engineering, Hydrology, Soil physics, Bio-physics and Geophysics. With the growing importance of non-Newtonian fluids in modern technology and industries, the thermal instability, thermal solution instability and Rayleigh-Taylor instability, problems of Walter fluid and couple stress fluid are desirable.

Permeability of the porous medium is a measure of ease with which fluids pass through porous material. The intrinsic permeability is an important property of the solid material and it is independent of the density and viscosity of the fluid. The permeability \( k \) can be defined as,

\[
k = \frac{-Q}{A} \frac{\mu}{\rho g} \left( \frac{\partial h}{\partial s} \right)^{-1}
\]

where, \( A \) is the cross sectional area of the fluid in m\(^2\), \( Q \) is the total discharge of the fluid, \( \mu \) is the viscosity of the fluid in Pa.s, \( \rho \) is the density of the fluid in kg.m\(^{-3}\), \( g \) is the acceleration due to gravity ms\(^{-1}\), and \( \frac{\partial h}{\partial s} \) is the hydraulic gradient in Wm\(^{-3}\)K\(^{-1}\).
1.7. NEWTONIAN HEATING

Newton's law of heating, which describes the change in temperature in an object whose surroundings are hotter than it is. If the temperature at a time $t$ is $T(t)$, then Newton's law of heating is

$$T(0) = \alpha (T_s - T) , \quad T(0) = T_0$$

(1.3)

where $T_s$ and $T_0$ are the constants representing the temperature of the surroundings and the initial temperature of the object respectively.

The differential equation in (1.3) simply states that the rate of change of the temperature is proportional to the difference between the temperatures of the surroundings and the object. This type of heating is also called Newtonian heating. The solution of the equation (1.3) is

$$T(t) = T_s - (T_s - T_0) e^{-\alpha t}$$

(1.4)

where, $\alpha$ is a constant in s$^{-1}$

1.8. MAXWELL'S ELECTROMAGNETIC EQUATIONS IN THE VECTOR FORM

The most common force on a fluid flow is gravitational force due to gravitational field. Sometimes electromagnetic fields dominant in case of conducting fluids. Maxwell's equations combine the fundamental laws of electricity and magnetism and are profound importance in the analysis of MHD flow problems. Maxwell's equations are derived from Ampere's law, Faraday’s law and Gauss law which are listed below,

<table>
<thead>
<tr>
<th>Maxwell's law</th>
<th>Vector differential equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>First law: Based on Gauss law of electrostatics</td>
<td>$\nabla \cdot \vec{D} = \rho$</td>
</tr>
<tr>
<td>Second law: Based on Gauss law of magnetostatics</td>
<td>$\nabla \cdot \vec{B} = 0$</td>
</tr>
<tr>
<td>Third law: Based on Faraday's law of electromagnetism</td>
<td>$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$</td>
</tr>
<tr>
<td>Fourth law: Based on the Amperer's law</td>
<td>$\nabla \times \vec{H} = \sigma \vec{E} + \frac{\partial \vec{D}}{\partial t}$</td>
</tr>
</tbody>
</table>
where,
\[ \vec{D} = \text{electric displacement vector in } \text{C m}^{-2}, \ \rho = \text{volume charge density in } \text{C m}^{-3} \]
\[ \vec{B} = \text{magnetic induction in } \text{Wb m}^{-2}, \ \vec{E} = \text{electric field intensity in } \text{V m}^{-1} \]
\[ \vec{H} = \text{magnetic field intensity in } \text{A m}^{-1}, \ \sigma = \text{electrical conductivity in } \text{S m}^{-1} \]
and the current density \[ \vec{J} = \sigma \vec{E} + \frac{\partial \vec{D}}{\partial t} \quad (1.5) \]

1.9. BASIC EQUATIONS IN THE VECTOR FORM

The investigation of any liquid motion involves solving a set of non-linear partial
differential equations called the Fundamental equations of fluid dynamics. The fundamental
equations governing any flow phenomena are stated below:

i). Conservation of mass (Equation of continuity): Mass can neither be created nor be
destroyed.
\[ \frac{\partial \rho}{\partial t} + \nabla . (\rho \vec{q}) = 0 \quad (1.6) \]
where, \( \vec{q} \) is the velocity vector of the fluid, \( \frac{\partial \rho}{\partial t} \) is the rate of increase of the density in the
control volume, \( \nabla . (\rho \vec{q}) \) is the rate of mass flux passing out of the control surface per
unit volume.

ii). Conservation of momentum (Equation of momentum): According to Newton’s law of
motion, the total force acting on a fluid mass enclosed in an arbitrary volume fixed in space is
equal to the time rate of change of linear momentum.
\[ \frac{\partial \vec{q}}{\partial t} + (\vec{q} \cdot \nabla) \vec{q} = -\vec{g} - \frac{\nabla p}{\rho} + \nu \nabla^2 \vec{q} - \frac{\mu}{\kappa} \frac{\vec{J} \times \vec{B}}{\rho} \quad (1.7) \]
where, \( \vec{B} \) is a magnetic field vector, \( \vec{g} \) is an acceleration due to gravity,
\( \vec{j} \) is the Current density vector, \( \vec{j} \times \vec{B} \) is the Lorentz force,
\( p \) is the pressure of the liquid, \( \vec{q} \) is the velocity vector of the fluid,
\[
\frac{\partial \tilde{q}}{\partial t} \text{ is an unsteady acceleration, } (\tilde{q} \nabla) \tilde{q} \text{ is the convective acceleration, } \\
\frac{\partial \tilde{q}}{\partial t} + (\tilde{q} \nabla) \tilde{q} \text{ is the inertia force, } \left(\nabla \frac{p}{\rho}\right) \text{ is the pressure gradient, } \\
\nu \nabla^2 \tilde{q} \text{ is the viscous force. }
\]

This momentum equation is called as the **Navier-Stokes equation**.

**iii). Conservation of energy (Equation of energy):** According to the first law of thermodynamics the energy added to a closed system increases the internal energy per unit mass of the fluid.

\[
\frac{\partial \tilde{T}}{\partial t} + (\tilde{q} \nabla) \tilde{T} = \frac{K}{\rho c_p} \nabla^2 \tilde{T} + \phi + \frac{j^2}{\sigma}
\]

where, \( \tilde{j} \) is the Current density, \( \tilde{T} \) is the temperature of the fluid, \( \phi \) is the viscous energy dissipation, \( \frac{j^2}{\sigma} \) is the ohmic dissipation function.

**iv). Equation of species diffusion:**

\[
\frac{\partial \tilde{C}}{\partial t} + (\tilde{q} \nabla) \tilde{C} = D \nabla^2 \tilde{C},
\]

where, \( \tilde{C} \) is the Species diffusion, \( \tilde{q} \) is the the velocity vector of the fluid, \( D \) is the Species diffusion coefficient.

The above four equations are the fundamental equations of the fluid dynamics. Now, we shall consider the mathematical formulation which forms the basis for the specific problems investigated in the thesis.

**1.10. NON-DIMENSIONAL PARAMETERS**

Non dimensional parameters help us to understand the physical significance of a particular phenomenon associated with the problem. The basic equations are made dimensionless using certain dependent and independent characteristic values. Some of the dimensionless parameters used in thesis are explained below.
i) Thermal Grashof number \((G_r)\)

It plays a significant role in free convection heat and mass transfer. The ratio of the product of the internal force and the buoyancy force to the square of viscous force in the convection flow system is interpreted as Grashof number. Grashof number in free convection is analogous to Reynolds number in forced convection.

\[
G_r = \frac{\rho g \beta \nu^2 (T_w - T_\infty)}{V_0^3 \mu} \tag{1.10}
\]

where, \(\beta\) is volumetric coefficient of thermal expansion, \(\gamma\) is kinematic viscosity
\(u_o\) is velocity of the plate \(T_w\) and \(T_\infty\) two representative temperatures

ii) Prandtl number \((P_r)\)

It is an important dimensional parameter dealing with the properties of a fluid. It is defined as ratio of fluid velocity boundary layer thickness to the fluid temperature boundary layer thickness

\[
P_r = \frac{\mu c_p}{\kappa} \tag{1.11}
\]

Where \(c_p\) is specific heat at a constant pressure, \(\mu\) is coefficient of viscosity,
\(\kappa\) is thermal conductivity of the fluid,

iii) Schmidt number \((S_c)\)

The ratio of molecular diffusivity or momentum to the mass molecular diffusivity is given by Schmidt number it plays a major role in convective mass transfer.

\[
S_c = \frac{\nu}{D} \tag{1.12}
\]

where, \(\nu\) is kinematic viscosity, \(D\) is species diffusion coefficient.

iv) Sherwood Number \((S_h)\)

The ratio of convective to diffusive mass transport is called the Sherwood number

\[
S_h = \frac{\kappa L}{D} \tag{1.13}
\]

where, \(\kappa\) is thermal conductivity, \(D\) is mass diffusivity,
\(L\) is dimension less wavelength of wavy wall.
v) **Eckert number** \((E_C)\)

This is defined as two times of the ratio of the dynamic temperature \(t_d\), and to the heat transfer temperature difference \((t_0 - t_\infty)\). It is equal to the kinetic energy of the flow relative to the boundary layer enthalpy difference.

\[
E_C = 2 \left( \frac{t_d}{t_0 - t_\infty} \right) = \frac{U^2}{c_p \Delta T}
\]

vi) **Nusselt number** \((N_u)\)

The ratio of the conductive thermal resistance to the convective thermal resistance of the fluid is called Nusselt number.

\[
N_u = \frac{hL}{\kappa}
\]

Where, \(h\) is conductive thermal resistance where, \(\kappa\) is thermal conductivity

\(L\) is dimensionless wavelength of the wavy wall

**1.11. REVIEW OF THE PREVIOUS WORK**

Hydro magnetic incompressible viscous flows have many important engineering applications such as magneto hydrodynamic power generators and the cooling of reactors also its applications to problems occurred in geophysics, astrophysics and engineering etc. The first exact solution of the Navier-Stokes equation was given by Stokes (1851) which is connected with the flow of a viscous incompressible fluid past an infinite horizontal plate oscillating in its own plane in an infinite mass of stationary fluid. This is also known as Rayleigh’s problem in the literature. Instead of horizontal plate, if an infinite isothermal vertical plate is given an impulsive motion how the flow is affected by the free convection currents which exists due to temperature difference between the plate temperature and that of fluid far away from the plate, this was first studied by Soundalgekar (1977) who presented an exact solution for free convection effects on the Stokes problem for an infinite vertical plate. The influence of magnetic field in flow past an impulsively started vertical plate was investigated by Raptis et al (1983) and Murty (1991). On the other hand, the study of heat generation or absorption in moving fluids is important in problems dealings with chemical reactions of dissociating fluids. Possible heat generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electronic chips
and semi-conductor wafers. Since some fluids can also emit and absorb thermal radiation, it is of interest to study the effects of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and absorbing radiation. Hence, heat transfer by thermal radiation is becoming of greater importance when we concerned with space applications and higher operating temperatures.

Greif at al (1971) obtained an exact solution for the problem of laminar convective flow in a vertical heated channel in the optically thin limit. In the optically thin limit, the fluid does not absorb its own emitted radiation which means that there is no self absorption but the fluid does absorb radiation emitted by the boundaries. Later Gupta and Gupta (1974) studied radiation effects on the combined free and forced convection of an electrically conducting fluid inside an open-ended vertical channel in the presence of uniform transverse magnetic field. They found that radiation tends to increase the rate of heat transfer to the fluid there by reducing the effect of natural convection. Soundalgekar and Takhar (1992) first, studied the effect of radiation on the natural convection flow of a gas past a semi-infinite plate using Cogly-Vincente- Gilles equilibrium model. For the same gas Takhar et al (1996) investigated the effects of radiation on the MHD free convection flow past a semi-infinite vertical plate while, Hossain et al (1999) studied the effect of radiation on free convection from porous vertical plates. Recently, Muthucumaraswamy and Senthil kumar (2004) analyzed the thermal radiation effects on moving infinite vertical plate in the presence of variable temperature.

The study of Magneto hydro-dynamics with heat and mass transfer in the presence of radiation and diffusion has attracted the attention of a large number of scholars due to diverse applications. In astrophysics and geophysics, it is applied to study the stellar and solar structures, radio propagation through the ionosphere etc. In engineering it has vast applications like in MHD pumps, MHD bearings, etc. The phenomenon of mass transfer is also very common in the theory of stellar structure and observable effects are detectable on the solar surface. In free convection flow the study of effects of magnetic field play a major role in liquid metals, electrolytes and ionized gases. In power engineering, the thermal physics of hydro magnetic problems with mass transfer have enormous applications. Radiative flows are encountered in many industrial and environment processes. e.g. heating and cooling
chambers, fossil fuel combustion energy processes, evaporation from large open water reservoirs, astrophysical flows, solar power technology and space vehicle re-entry

Boundary layer flow on moving horizontal surfaces was studied by Sakiadis (1961). The effects of transversely applied magnetic field on the flow of an electrically conducting fluid past an impulsively started isothermal vertical plate were studied by Soundalgekar et al. (1979). MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse applied magnetic field were studied by Soundalgekar et al. (1981). The dimensionless governing equations were solved using Laplace transform technique. Kumari and Nath (1999) studied the development of the asymmetric flow of a viscous electrically conducting fluid in the forward stagnation point of a two-dimensional body and over a stretching surface with an applied magnetic field. The governing equations were solved using Laplace transform technique.

In nature, there exists flows which are caused not only by the temperature differences but also by the concentration differences. These mass transfer differences do effect the rate of heat transfer. In Industries, many transport processes exist in which heat and mass transfer takes place simultaneously as a result of combined buoyancy effect in the presence of thermal radiation. Hence radiative heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling nuclear power plants, gas turbines, various propulsion device 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. England and Emery (1969) have studied the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Soundalgekar and Takhar (1993) have considered radiative free convective flow of an optically thin gray-gas past a semi-infinite vertical plate. Radiation effects on mixed convection along an isothermal vertical plate were studied by Hossain and Takhar (1996). Raptis and Perdikis (1999) studied the effects of thermal radiation and free convection flow past a moving vertical plate and the governing equations were solved analytically. Dass et al. (1996) analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate and the governing equations were solved by the Laplace transform technique. Muthucumaraswamy and Janakiraman (2006) studied MHD and radiation effects on moving isothermal vertical plate with variable mass diffusion. Rajesh and
Varma (2009) studied radiation and mass transfer effects on MHD free convection flow past an exponentially accelerated vertical plate with variable temperature. Again, Rajesh and Varma (2010) analyzed radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion.

Free convection flows that occur in nature and in engineering practice is very large and has been extensively considered by many authors. When heat and mass transfer occurs simultaneously between the fluxes the driving potentials are more intricate in nature. An energy flux is generated not only by temperature gradients but by composition gradients as well. Temperature gradients can also create mass fluxes and this is the Soret or thermal-diffusion effect. Generally, the thermal-diffusion and diffusion-thermo effects of smaller order magnitude than the effects prescribed by Fourier’s or Fick’s laws and are often neglected in heat and mass transfer processes. Due to the importance of thermal-diffusion and diffusion-thermo 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 and the contributors such as Eckert and Drake (1972), Dursunkaya and Worek (1992), Anghel et.al (2000), Postenlnicu (2004) are worth mentioning. Alam and Rahman (2005) studied the Dufour and Soret effects on steady MHD free convective heat and mass transfer flow past a vertical porous plate embedded in a porous medium. The governing non-linear partial differential equations were solved by applying Nachtsheim-Swigert shooting iteration technique together with sixth-order Runge-Kutta integration technique. They found that suction stabilizes the hydrodynamic, thermal and concentration boundary layers growth.

Alam et al (2005) investigated the Dufour and Soret effects on unsteady free convection and mass transfer flow past an impulsively started infinite vertical plate embedded in a porous medium under the influence of transverse magnetic field. They observed that large Darcy number leads to the increase of the velocity and decrease of the temperature and as well as concentration of the flow fluid with in the boundary layer. Alam and Rahman (2006) examined Dufour and Soret effects on mixed free-forced convective and mass transfer flow of a viscous incompressible fluid over an isothermal semi-infinite vertical porous flat plate embedded in a porous medium. They found in their study interestingly, the flow field is appreciably influenced by the Dufour and Soret effects. Again Alam et al. (2006) studied Dufour and Soret effects on steady/unsteady free convective heat and mass transfer flow past
a semi-infinite vertical porous plate in a porous medium. The governing non-linear partial
differential equations were solved numerically by applying Nachtsheim-Swigert shooting
iteration technique together with sixth-order Runge-Kutta integration technique. They
examined that velocity profiles decrease with the increase of permeability parameter while it
increases with increase of free convection currents.

In view of many applications, in this thesis an attempt has been made to study heat and mass transfer effects on MHD boundary layer flows past an infinite surface through porous or non-porous media. The thesis is divided in to six chapters including the introduction chapter. In the first two chapters, the governing equations are solved using an implicit finite difference method of the Crank-Nicolson type for a numerical solution. In the last three chapters, the governing equations are solved using Laplace transform technique.
1.12. REFERENCES


Text book References:


