CHAPTER 1

INTRODUCTION

1.1 HEAT TRANSFER

Heat transfer is defined as the transit of energy due to a temperature difference or gradient. Whenever there exists a temperature difference in a medium or between media, heat transfer must occur. The basic requirement for heat transfer is the presence of temperature difference. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction.

The mechanism of heat transfer is the passage of thermal energy from a hot to a cold body as per the second law of thermodynamics. When a physical body is at a different temperature than its surroundings or another body, transfer of thermal energy between them is also known as heat transfer. It occurs in such a way that the body and the surroundings reach thermal equilibrium.

Many metallurgical and industrial mechanisms or operations like extracting metals involve the study of heat transfer. Considerable knowledge of heat transfer is necessary in the controlling or solving or lessening the environmental problems. To develop better variety of seeds, breeders have to deal with heat transfer problems. Construction of dams and other large multistoried buildings need the study of heat transfer. To develop better variety of seeds, breeders have to deal with heat transfer problems. Food processing needs lot of knowledge of heat transfer.

Several material properties serve to modulate the heat transferred between two regions at differing temperatures. Examples include thermal conductivities, specific heats, material densities, fluid velocities, fluid viscosities, surface emissivities and more. Taken together, these properties serve to make the solution of many heat transfer problems an involved process.

The three basic modes of heat transfer are conduction, convection and radiation.

1.1.1 Conduction

Conduction is a process by which transfer of heat takes place occurs across the medium. Medium man be solid or a fluid. The heat transfer takes place from one molecule to another through a substance from higher temperature to lower temperature by kinetic motion whether the body is at rest or in motion. Not all substances conduct heat at the same speed. Metals and stone are considered good conductors since they can speedily transfer heat, but wood, paper, air, and cloth are poor heat conductors. A simple example is when one side of a stone is heated over a flame and the other side, gradually gets heated up due to the heat that is being conducted along the stone. The energy is transferred by conduction and that the heat transfer rate per unit area is proportional to the normal temperature gradient. Heat conduction is due to the property of matter which allows the passage of heat energy even if a physical body is impermeable to any kind of reaction.

1.1.2 Convection

Convection is the process by which heat transfer that will occur between a surface and a moving fluid when they are at different temperatures, that is heat transmitted from one place to another by the movement of heated particles of a fluid (gas or liquid). As liquids and gases gain thermal energy, they expand and decrease in density.

Internal and external flow can also classify convection. Internal flow occurs when the fluid is enclosed by a solid boundary such as a flow through a pipe. An external flow occurs when the field extends indefinitely without encountering a solid surface. Both these convection's either natural or forced, can be internal or external as they are independent of each other.

Convection is a mechanism in which heat flows or transferred between a fluid and a solid surface because of motion of fluid particles relative to the solid surface when there exists a temperature gradient. The convective mode of heat transfer is generally divided into two basic processes, forced convection and free convection. If the fluid motion is induced by some external agent such as by a fan, a pump, atmospheric winds, fluid machinery, blower, creating an artificially induced convection current then the process is called forced convection. As an example, consider the use of a fan to provide forced convection air cooling of hot electrical components on a stack of printed circuit boards.

Fluid motion is caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid the process is called free or natural convection. Heat transfer that occurs from hot components on a vertical array of circuit boards in air is an example of free convection. In general, a free convection heat transfer is usually much smaller compared to a forced convection heat transfer. It is therefore important only when there is no external flow exists. The density difference is due to the temperature difference and it can be characterized by their volumetric thermal expansion coefficient.

Free convection occurs not only due to temperature differences, but also due to concentration differences or combination of these two, example in atmospheric flows, there exists differences in the H_2O concentration and hence the flow is affected by such concentration difference.

Natural flows occur in nuclear reactor cooling systems, electronic machinery, atmospheric and oceanic circulation and so on. Flow in bodies of water is driven through the comparable effects upon density of temperature, concentration of dissolved materials and suspended particulate matter. Study of convection and both heat and mass transfer is very useful in fields such as industry, agriculture and oceanography. Convective mass transfer plays an important role in pollution of environment, moisture over agricultural fields, drying process, design of chemical processing equipments.

1.1.3 Radiation

Heat transfer by conduction and convection requires the presence of a temperature gradient in some form of matter, but radiation does not require matter to transfer thermal energy. Radiation is the transfer of energy by electromagnetic waves. Radiation is the only mode of heat transfer that can happen in a vacuum. If the temperature of the surrounding fluid is rather high, radiation effects play an important role and this situation does exist in space technology.

Thermal radiation is energy emitted by matter that is at a nonzero temperature. Energy can move by radiation in air like the heat from electric stove top, or in the vacuum of space the way the sun heats the earth. In radiation, the energy does not have to transfer through mass particles.

Radiative convective flows are encountered in countless industrial and environment processes e.g. space vehicles heating and cooling chambers, fossil fuel combustion energy processes, evaporation from large open water reservoirs, astrophysical flows and solar power technology, nuclear power plants, gas turbines and various propulsion device for aircraft, missiles, satellites and space vehicle re entry are examples of such engineering applications. Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment.

1.2 NATURAL CONVECTION

The fluid motion occurs due to change in density differences, caused by temperature variations in the presence of body force such as gravitational force is called Natural Convection or Free Convection.

Natural convection induced by the simultaneous action of buoyancy forces resulting from thermal and mass diffusion is of considerable interest in nature and in many industrial applications such as geophysics, oceanography, drying processes, solidification of binary alloy and chemical engineering. In free convection, fluid surrounding a heat source receives heat, becomes less dense and rises. The surrounding cooler fluid then moves to replace it. This cooler fluid is then heated and the process continues, forming convection current.

Natural convection flow processes involving the combined mechanisms are also encountered in many natural processes such as condensation, agricultural drying and in many industrial applications. It is important in temperature distributions within buildings and in determining heat losses or heat loads for heating, ventilating and air conditioning systems. Natural convection distributes the poisonous products of combustion during fires and is relevant to the environmental sciences, where it drive oceanic and atmospheric motions, as well as the related heat transfer and mass transfer processes. Free convection strongly influences the operating temperatures of power generating and electronic devices. In some heat transfer systems, both natural and forced convection contribute significantly to the rate of heat transfer.

Transient free convective flows have wide application in many industrial and technological processes, for example heating and cooling chambers, astrophysical flows, solar power technology, space vehicle re-entry etc. Hence, many researchers studied this flows under different physical conditions. The laminar free convection in the vicinity of a doubly infinite vertical plate having a step change in wall temperature was first studied by Illingworth (1950) and he derived the solutions in closed form. Siegel (1958) applied momentum integral method to study unsteady free convection flow past a semi-infinite isothermal vertical plate.

Soundalgekar (1979) presented effects of mass transfer and free convection currents on the flow past impulsively started vertical plate. The governing equations were solved by Laplace-transform technique. It was observed that the velocity increases due to the presence of the foreign mass. Greater cooling of the plate causes a rise in the skin-friction and greater heating of the plate causes a fall in the skin friction. Free convection effect on a flow past an impulsively started or oscillating infinite vertical plate was studied by Revankar (2000). Free convection on a vertical plate with uniform and constant heat flux in a thermally stratified micropolar fluid was presented by Chang & Lee (2008).

Natural convection on flow past an linearly accelerated vertical plate in the presence of viscous dissipative heat using perturbation method examined by Gupta et al (1979). Free convection effects on flow past an exponentially accelerated vertical plate was studied by Singh & Naveen Kumar (1984). Free convection and mass transfer effects on the flow past a vertical plate was analyzed by Perdikis (1986). Numerical calculations have been carried out for the velocity, the temperature, the skin friction and the Nusselt number. We observed that when Sc increases the Nusselt number increases, while when Gc increases the Nusselt number decreases.

For a viscous Newtonian fluid Schetz & Eichhorn (1962) studied transient free convective flow past an infinite isothermal vertical plate. In modern technology, many new fluids such as polymer fluids are discovered which exhibits elastic properties also. Hence, Deka et al (1995) studied transient free convective flow past an infinite vertical plate of an elastico-viscous fluid. The effect of heat and mass transfer in elastico-viscous fluid past an impulsively started infinite vertical plate with hall effect has been investigated by Chaudhary & Jha (2008). Very recently, Singh et al (2010) studied analytically the effect of free convection on the visco-elastic fluid flow past an accelerated infinite vertical plate with constant heat flux.

Transient, laminar free convection along a vertical, isothermal flat plate arising from buoyancy forces created by both temperature and concentration gradients was investigated by Callahan & Marner (1976). Here it is discussed about non-dimensionalization of the governing boundary layer equations results in the following parameters: (i) N, the buoyancy ratio parameter, (ii) Pr, the Prandtl number, and (iii) Sc, the Schmidt number. The coupled nonlinear partial differential equations were solved numerically using an explicit finite difference procedure. Results are obtained for $Pr = 1$ and a realistic range of Sc and positive N. It is found that the transient velocity, temperature, and concentration profiles all reach maximum values before decreasing slightly to their respective steady state values. Owing to this overshoot phenomenon in the temperature and concentration profiles, a temporal minimum is observed in both the Nusselt and Sherwood numbers. For mass transfer aiding the flow, the results show that the Nusselt and Sherwood numbers are higher than those for pure thermal convection.

Chamkha et al (2001) studied the effects of steady laminar free convection flow of air past a semi-infinite vertical plate in the presence of chemical species concentration and thermal radiation. The governing dimensionless equations were transformed into a non-similar form and were solved numerically using implicit finite-difference method. It is found that velocity and temperature decreased as the distance from the plates leading edge were increased.

The problems of free convection flows are usually modeled under the assumption of constant surface temperature, ramped wall temperature, or constant surface heat flux. However, in many practical situations where the heat transfer from the surface is taken to be proportional to the local surface temperature, the above assumptions fail to work. Such types of flows are termed as conjugate convective flows, and the proportionally condition of the heat transfer to the local surface temperature is termed as Newtonian heating. Arpita Jain (2014) analyzed the effect of heat and mass transfer chemically reactive flow past an accelerated vertical plate with Newtonian heating in the presence of radiation. Closed form analytic solutions are obtained for temperature, concentration, velocity by Laplace Transform technique.

Narahari & Dutta (2009) presented a theoretical solution to the free convection flow of a viscous incompressible fluid past an infinite vertical moving plate subject to a ramped surface temperature with simultaneous mass transfer using the Laplace transform technique.

1.3 MASS TRANSFER

The driving force for mass transfer is a difference in concentration; the random motion of molecules causes a net transfer of mass from an area of high concentration to an area of low concentration. The amount of mass transfer can be quantified through the calculation and application of mass transfer coefficients. Mass transfer is the net movement of mass from one location (stream, phase, fraction or component) to another. The different modes of mass transfer are diffusion and convective mass transfer.

1.3.1 Diffusion mass transfer

Diffusion is the movement of mass from region of high concentration to low concentration. In diffusion mass transfer the transfer of matter occurs by the movement of molecules or species or particles of one component to another. Diffusion mass transfer may occur either due to concentration gradient or temperature gradient or pressure gradient. In diffusion mass transfer, the bulk velocity is insignificant.

1.3.2 Convective mass transfer

The convective mass transfer mechanism is analogous to convective heat transfer. Convective mass transfer is mechanism in which mass is transferred between the fluid and the solid surface as a result of movement of matter from the fluid to the solid surface or fluid. Convection mass transfer is again classified into (i) Natural or free convective mass transfer (ii) Forced convection mass transfer. In natural convection mass transfer, the transfer of mass occurs by the motion of species due to the density differences resulting from temperature or concentration differences or mixture of varying composition. In forced convection mass transfer, mass is transferred due to forced circulation of species by some external agency. The two modes of mass transfer may occur simultaneously. The mass transfer rates in the bulk liquid will depend on level of mixing and the viscosity and density of the bulk liquid.

Mass transfer is the phrase commonly used in engineering for physical processes that involve molecular and convective transport of atoms and molecules within physical systems. It includes both fluid flow and separation unit operations. In molecular transport, heat or mass there are many similarities. Newtons law for momentum transfer, Fouriers law for heat transfer, and Ficks law for mass transfer are very similar. Therefore there are many analogies among these three molecular transport processes.

Mass transfer often takes place in a thin boundary layer near a surface where the fluid is in laminar flow. Mass transfer occurs in many processes as absorption, evaporation, adsorption, drying, precipitation, membrane filtration and distillation and also applicable in astrophysics, chemical engineering. Diffusion occurs at microscopic or molecular level which deals with the transport of one constituent of a fluid solution or gas mixture from a region of higher concentration to a lower concentration.

Mass transfer finds extensive application in chemical engineering problems, where material balance on components is performed. A great deal of effort has been devoted in the literature for developing analogies among these three transport processes for laminar flow so as to allow prediction of one from any of the others. Mass transfer is one of the most commonly encountered phenomena in chemical industry as well as in physical and biological sciences. Gas-liquid mass transfer is extremely important in bio processing because many processes are aerobic, oxygen must first be transferred from gas bulk through a series of steps onto the surfaces of cells before it can be utilized.

Mass transfer effects on the flow past an uniformaly accelerated vertical plate was studied by Soundalgekar (1982). Also, Effects of mass transfer on the flow past an oscillatory infinite vertical plate with constant heat flux analyzed by Soundalgekar (1994). Basant Kumar et al (1991) have analyzed mass transfer effects on exponentially accelerated infinite vertical plate with constant heat flux and uniform mass diffusion. Mass transfer effects on flow past an accelerated vertical plate with uniform heat flux was analyzed by Singh & Singh (1983). The dimensionless governing equations were solved using the Laplacetransform technique. We observed that a close study of the table indicates that as the Schmidt number increases the skin friction decreases. Thus the skin-friction is greater in the case of hydrogen than in the case of water vapor and oxygen.

Muthucumaraswamy & Visalaskhi (2010) have examined mass transfer effects on exponentially accelerated isothermal vertical plate in the presence of thermal radiation.

Soundalgekar & Hiremath (1983) have studied finite difference analysis of mass transfer effects on flow past an impulsively started infinite isothermal vertical plate in dissipative fluid. The non-linear coupled equations governing the problem are solved by explicit finite difference methods. The presence of different gases like H_2O, CO_2, etc in air are considered. As increase in Sc leads to a decrease in the velocity, the temperature, the skin friction and the rate of heat transfer and an increase in G leads to a rise in the velocity, temperature and the rate of heat transfer, but the skin-friction increases with increasing G at small values of time t, it decreases with increasing G it leads to a separation. Basant kumar Jha & Ravindra Prasad (1990) have analyzed mass transfer effects on the flow past an accelerated infinite vertical plate with heat sources.

Muthucumaraswamy et al (2008) have studied mass transfer effects on exponentially accelerated isothermal vertical plate. Theoretical study of unsteady flow past an exponentially accelerated infinite isothermal vertical plate has been presented in the presence of variable mass diffusion. It is observed that the velocity increases with increasing values of a or t. Muthucumaraswamy et al (2009) have presented the unsteady flow past an accelerated infinite vertical plate with variable temperature and uniform mass diffusion.

The effect on the flow past a vertical oscillating plate due to a combination of concentration and temperature differences was studied extensively by Soundalgekar & Akolkar (1983). Gebhart & Pera (1971) studied the effects of mass transfer on a steady free convection flow past a semi-infinite vertical plate by the similarity method, and it was assumed that the concentration level of the diffusing species in the fluid medium was very low. This assumption enabled them to neglect the diffusion-thermo and the thermo-diffusion effects, as well as the interfacial velocity at the wall due to species diffusion.

1.4 EFFECTS OF HEAT AND MASS TRANSFER

Combined heat and mass transfer with chemical reaction is of importance in chemical industries, hydrometallurgical industries and many processes therefore, has 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 occurs simultaneously.

Natural convection induced by the simultaneous action of buoyancy forces from thermal and mass diffusion is of considerable interest in many industrial applications such as geophysics, oceanography, drying processes and solidification of binary alloy. Free convection flow involving coupled heat and mass transfer occurs frequently in nature and in industrial processes. A few representative fields of interest in which combined heat and mass transfer plays an important role are designing chemical processing equipment, formation and dispersion of fog, distribution of temperature and moisture over agricultural fields and groves of fruit trees, crop damage due to freezing, and environmental pollution.

A lot of authors studied heat and mass transfer in non-Newtonian fluid of different type, most especially in power law and higher order fluids. Recently, various researchers have shown interests in the study of non-Newtonian fluids due to its importance in industrial processes. The development of the theory of non- Newtonian fluid mechanics arose from the inadequacy of the theory of Newtonian fluids in predicting the behaviours of many fluids especially those of high molecular weight. Uwanta & Sani (2013) have investigated the heat and mass transfer flow past an infinite vertical plate with variable thermal conductivity. The governing equations for the model are formulated with appropriate boundary conditions. The equations are simplified, non-dimensionalized and then solved numerically with the aid of MAPLE package. The flow phenomenon are characterized by the flow parameters such as Prandtl number (Pr), Schmidt number (Sc) , Eckert number (Ec), magnetic field (M), porosity (K), thermal Grashof number (Gr), mass Grashof number (Gc), radiation (N), suction (α), thermal conductivity (τ), chemical reaction (Kr) and reaction order (n) which are studied for velocity field, temperature field and concentration distribution. It is noted that The velocity increase with increase in the thermal Grashof number, mass Grashof number, thermal conductivity parameter, porosity parameter and time. Whereas the velocity decrease with increasing Prandtl number, Schmidt number, magnetic field parameter, radiation parameter, suction parameter and chemical reaction parameter. Also the temperature increase with increase in thermal conductivity parameter and time. But, the temperature decrease with increasing Prandtl number and suction parameter. Further, the concentration increase with increasing reaction order parameter and time while the concentration decrease with increase in Schmidt number, suction parameter and chemical reaction parameter. Muthucumaraswamy & Ganesan (1998) have analyzed the unsteady flow past an impulsively started vertical plate with heat and mass transfer.

The phenomenon of heat and mass transfer, also referred to as double diffusive convection, has attracted extensive research interest due to its many applications in science, engineering and technology. Heat and mass transfer processes are also observed in buoyancy induced motions in the atmosphere and in bodies of water. Atmospheric flows are driven appreciably by both temperature and concentration gradients while flows in bodies of water are driven by equally important effects of temperature, concentration of dissolved materials and concentration of suspended particulate matter. Convective heat transfer is one of the major modes of heat and mass transfer in fluids. Mixed convection flow finds application in several industrial and technological processes such as cooling of nuclear reactors, thermal pollution, dispersion of pollutants, cooling of electronic devices by electric fans and the use of heat exchange devices. Considerable research has been carried out to investigate the transfer of heat and mass in the last three decades. The phenomenon of combined heat and mass transfer was studied by Hossain & Rees (1999) when they considered natural convection flow over a vertical wavy surface.

The phenomenon of heat and mass transfer has been the object of extensive research due to its applications in Science and Technology. Such phenomena are observed in buoyancy induced motions in the atmosphere, in bodies of water, quasi solid bodies such as earth and so on. Mangwiro Magodora et al (2013) have considered the double diffusive heat and mass transfer processes over a permeable vertical plate in the presence of wall suction and chemical reaction. The equations of flow were derived from the basic principles of mass conservation, energy conservation, heat and mass diffusion. The equations were non-dimensionalised by use of appropriate approximations and the resulting non-linear differential equations then solved by means of asymptotic expansions in the limit of large buoyancy. The variation of buoyancy with velocity, temperature, concentration, skin friction, rates of heat and mass transfer were analyzed. Results obtained showed that in the vicinity of the plate wall, an increase in buoyancy causes an increase in the velocity of the fluid. Furthermore, the results indicate that the skin friction, heat and mass transfer rates are enhanced by an increase of buoyancy. Profiles obtained also indicated that an increase buoyancy is accompanied by a decrease in fluid temperature as well as fluid concentration. It was also noticed that the concentration and thermal boundary layers are reduced as a consequence of increasing the buoyancy. Results showed that even though an increase in buoyancy leads to a linear increase in skin friction, it was noted that an increase in buoyancy causes a sharp decrease in the rates of heat and mass transfer for very small values of the buoyancy parameter. However as the buoyancy parameter becomes larger, the rates of heat and mass transfer increase proportionally with the buoyancy.

Abid Hussanan et al (2013) have presented an exact analysis of heat and mass transfer past an oscillating vertical plate with Newtonian heating. Equations are modelled and solved for velocity, temperature, and concentration using Laplace transforms. The obtained solutions satisfy governing equations and conditions. Expressions of skin friction, Nusselt number, and Sherwood number are obtained and presented in tabular forms. The results show that increasing the Newtonian heating parameter leads to increase velocity and temperature distributions whereas skin friction decreases and rate of heat transfer increases.

1.5 UNIFORM HEAT AND MASS FLUX

In the study of transport phenomena (heat transfer, mass transfer and fluid dynamics) flux is defined as the amount that flows through a unit area per unit time. Flux in this definition is a vector. The heat transfer per unit area is called heat flux. If q is the amount of heat transfer and A is the area normal to the direction of the heat flow, then the heat flux is

$$Q = \frac{q}{A}$$

The amount of mass transfer per unit area of the flow is called mass flux. If m is the amount of mass flow and A is the area normal to the direction of mass flow, then the mass flux is

$$G = \frac{m}{A}$$

In the field of electro-magnetism and mathematics, flux is usually the integral of a vector quantity over a finite surface. It is an integral operator and acts on a vector field as do the gradient, divergence and curl found in vector analysis. The result of this integration is a scalar quantity. The magnetic flux is thus the integral of the magnetic vector field B over a surface and the electric flux is defined similarly. Using this definition, the flux of the pointing vector over a specified surface is the rate at which electromagnetic energy flows through that surface.

Flux is surface bombardment rate. There are many fluxes used in the study of transport phenomena. Each type of flux has its own distinct unit of measurement along with distinct physical constants. Six of the most common forms of flux from the transport literature that is momentum flux, heat flux, chemical flux, volumetric flux, mass flux and radiative flux. Muthucumaraswamy & Kulandaivel (2003) have investigated chemical reaction effects on moving infinite vertical plate with uniform heat flux and variable mass diffusion.

Das et al (1994) have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started vertical plate with uniform heat flux and mass transfer. The dimensionless governing equations were solved using the Laplace-transform technique. We observed that due to the presence of first order chemical reaction, the velocity decreases but the skin-friction being positive at large values of the chemical reaction parameter, there may not occur separation of the flow near the plate. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction studied by Das et al (1999). The dimensionless governing equations were solved by the usual Laplace Transform technique.

Das et al (1996b) presented mass transfer effects on flow past an impulsively started infinite vertical plate with constant mass flux an exact solution. Solutions were desired using Laplace-transform technique. We observed that transient velocity decreases with increases the Schmidt number and increase with increasing the Grashof number or modified Grashof number, Grashof number or modified Grashof number leads to a decrease in the skin-friction, rate of heat transfer increases with Prandtl number and an increase in Schmidt number leads to a fall in the concentration and a rise in the Sherwood number. Chandrakala & Bhaskar (2011) have studied the effects of heat transfer on flow past an exponentially accelerated vertical plate with uniform heat flux.

Soundalgekar & Patil (1980) studied stokes problem for infinite vertical plate with constant heat flux. The dimensionless governing equations were solved by Laplace-transform technique. It has been observed that the velocity of the fluid increases with increasing time or Grashof number. Mass transfer effects on the flow past an impulsively started infinite vertical plate with variable temperature or constant heat flux was analyzed by Soundalgekar et al (1984). The solutions were solved by Laplacetransform technique. It was observed that an increase in the Schmidt numbers leads to an increase in the skin friction. Chandrakala (2010) considered analytically thermal radiation effects on moving infinite vertical plate with uniform heat flux.

Basant kumar Jha (1991) performed an analytical study to examine the effects of mass transfer on the free convection flow of an incompressible viscous fluid past an exponentially accelerated infinite vertical plate under the action of constant heat flux. The numerical computations for different values of Gr, Gm, Sc, t, a, and Pr are carried out. Muthucumaraswamy et al (2010) studied the heat transfer effects on accelerated vertical plate with variable temperature and mass flux. Patrick & Paul (2010) observed the effect of natural convective heat transfer from a narrow vertical flat plate with a uniform surface heat flux and with different plate edge condition.

Chandrakala & Bhaskar (2013) have examined thermal radiation effects on flow past an impulsively started infinite vertical oscillating plate with uniform heat and mass flux. The fluid considered here is a gray, absorbing-emitting radiation but a nonscattering medium. The dimensionless governing equations are solved using the Laplace-transform technique. The velocity, temperature and concentration are studied for different physical parameters such as the radiation parameter, phase angle, Schmidt number and time. It is noted that the presence of radiation causes a fall in the velocity and temperature. Also, as time increases, it is found that there is a rise in velocity.

1.6 EFFECTS OF THERMAL RADIATION

The radiation effect on convective flow and heat transfer problems has become more important industrial applications. Many processes in engineering areas occur at high temperatures and knowledge of radiation heat transfer becomes very important to many industrial heating, cooling, drying processes, the design of pertinent equipment, nuclear power plants, energy conversion methods that involve fossil fuel combustion, solar radiation and furnace design, materials processing, energy utilization, temperature measurements, remote sensing for astronomy and space exploration, food processing, cryogenic engineering, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas, as well as numerous agricultural, health and military applications.

Thermophoresis is a phenomenon which causes small particles to be driven away from a hot surface towards a cold one. The effect of radiation on free convection has been drawn forth not only for its fundamental aspects but also for its significance in the contexts of space technology and processes involving high temperature. Electromagnetic energy emitted by matter at a finite temperature and concentrated in the spectral region from approximately 0.1 to 100 μm (Incropera et al 2012).

The basic of convection-radiation interaction may be classified into three categories namely (i)optically thin fluid which is non-absorbing but emitting, (ii) optically thick fluid which is absorbing and emitting, (iii) cold fluid layer which absorbs radiation and does not emit. In the presence of an absorbing and emitting gas, the mathematical formulation of the problem becomes much more complex. Further, complexity is introduced by the inclusion of the non-linear integral terms in the energy equation. Cheng & Ozisik (1972) studied a related problem for an absorbing, emitting and isotropically scattering fluid, and treated the radiation part of the problem exactly with the normal mode expansion technique. Muthucumaraswamy & Visalaskhi (2009) have developed thermal radiation on exponentially accelerated vertical plate with variable temperature and uniform mass flux.

The effect of radiation plays an important role in many engineering fields. Therefore Bhattacharya & Dekab (2013) have presented the effect of radiation and thermal stratification on the flow of an elastico-viscous fluid past an infinite vertical plate. The constitutive equations of Walters liquid B' are used. Solutions for velocity and temperature fields are obtained by Laplace transform technique for unit Prandtl number. Numerical computations for velocity, temperatures are made for different values of the physical parameters and presented in graphs. It is observed that in presence of thermal stratification and radiation both velocity and temperature reaches steady state at smaller time. Observations are also made on other physical phenomenon like skin friction, Nusselt number.

Cess (1966) investigated thermal radiation effects on heated vertical plate using singular perturbation technique. Kafousias & Raptis (1981) extended this problem to include mass transfer effects subjected to variable suction or injection. The dimensionless governing equations were solved by numerical methods. It was observed that the suction or injection on the flow field has been extensively discussed when the plate is being cooled or heated by the free convection currents. The skin friction for accelerated vertical plate has been studied analytically by Hossain & Shayo (1986). Raptis & Perdikis (1999) have studied the effects of thermal radiation and free convection flow past a moving vertical plate. The governing equations were solved analytically. Muthucumaraswamy & Saravanan (2013) have discussed unsteady flow past an oscillating semi-infinite vertical plate of uniform mass flux with thermal radiation using implicit finite difference scheme.

Hossain & Takhar (1996) have analyzed radiation effects on mixed convection along an isothermal vertical plate. Agrawal et al (1998) studied free convection due to thermal and mass diffusion in laminar flow of an accelerated infinite vertical plate in the presence of magnetic field. Agrawal et al (1999) further extended the problem of unsteady free convective flow and mass diffusion of an electrically conducting elasto-viscous fluid past a parabolic starting motion of the infinite vertical plate with transverse magnetic plate. The governing equations are tackled using Laplace transform technique.

The effect of radiation on unsteady free convection flow past an infinite vertical plate with ramped wall temperature analyzed by Rudra & Sankar (2011). The nondimensional forms of the governing equations of the fluid flow are solved by Laplace-transform technique. Chandrakala & Bhaskar (2012) have presented radiation effects on oscillating vertical plate with uniform heat flux and mass diffusion. Buoyancy is also of importance in an environment where differences between land and air temperatures can give rise to complicated flow patterns. Das et al (1996a) have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate.

Heat and mass transfer effects on moving vertical plate in the presence of thermal radiation was analyzed by Muthucumaraswamy & SenthilKumar (2004). The dimensionless governing equations are solved using Laplace transform technique. We observed that the velocity slightly decreases with increasing value of radiation parameter. Radiative heat and mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction was analyzed by Muthucumaraswamy et al (2006). The dimensionless governing equations are solved using the Laplace technique. The velocity and skin-friction are studied for different parameters like the radiation parameter, chemical reaction parameter, Schmidt number, thermal Grashof number, mass Grashof number and time. It was observed that the velocity increases with decreasing radiation parameter or chemical reaction parameter.

Effects of radiation on flow past an impulsively started infinite vertical plate with mass transfer was analyzed by Loganathan & Ganesan (2006). The dimensionless governing equations were solved using the Laplace-transform technique. It was observed that the velocity increases due to the presence of a foreign mass. An increase in Sc ($Sc < 1$) leads to drop in the velocity and for $Sc = 1$, an increase in t and Gc leads to a rise in the velocity. It was also seen that an increase in t and radiation parameter N leads to velocity and temperature decrease. For $Gr = Gc = 2$ and small values of t, Pr and Sc the skin-friction increases with the radiation parameter N. At $Sc = 1$, τ_ω becomes negative. In the absence of radiation, at $Gr = Gc = 2$ and small t and Sc skin-friction is negative too.

Ramachandra Prasad et al (2007) have analyzed the free convection with thermal radiation of a viscous incompressible unsteady flow past an impulsively started vertical plate with heat and mass transfer is The fluid is gray, absorbing-emitting but non-scattering medium and the Rosseland approximation is used to describe the radiative flux in the energy equation. The dimensionless governing equations are solved using an implicit finite-difference method of CrankNicolson type. It is observed that, when the radiation parameter increases, the velocity and temperature decrease in the boundary layer. The local and average skin-friction increases with the increase in radiation parameter. For increasing values of radiation parameter the local as well as average Nusselt number increases.

Arpaci (1968) studied about a non-equilibrium interaction between thermal radiation and laminar convection for all values of the absorption of gas, using a heated semi-infinite vertical plate in a stagnant gas as a vehicle. Here the gas is assumed as perfect and gray. Exponential approximation was used to transform integral equations. The local Nusselt number helped to interpret the gas domain from transparent to opaque or cold to hot.

The influence of thermal radiation on unsteady free convection flow past a moving vertical plate with Newtonian heating was investigated by Narahari & Ishak (2011). Ahmed et al (2014) have investigated the study of unsteady flow of a viscous incompressible fluid past an exponentially accelerated moving vertical plate. The fluid is gray, absorbing-emitting but non scattering medium and Rosseland approximation is used to describe the radiative heat flux in energy equation. The dimensionless governing equations are solved analytically using the Laplace transform technique. The velocity, concentration and temperature fields are studied for different physical parameters like thermal Grashof number, mass Grashof number, Schmidt number and time. Temperature decreases with increased strength of radiation and Prandtl number. It is also observed that the velocity increases with increasing values thermal Grashof or mass Grashof number. Similarly, velocity increases with decreasing values of the Schmidt numbers. The effects of thermal radiation on flow past an oscillating plate with variable temperature were studied by Pathak et al (2006).

Chenna Kesavaiah et al (2013) have studied the theoretical solution of radiative flow past a uniformly accelerated isothermal infinite vertical plate with uniform mass diffusion, in the presence of homogeneous chemical reaction of first order. The dimensionless governing equations were solved by the usual perturbation technique. The effect of different physical parameters like chemical reaction parameter, radiation parameter, thermal Grashof number, mass Grashof number and time are studied graphically. It is observed that the velocity increases with increasing values of Gr,Gc and t . But the trend is just reversed with respect to the chemical reaction parameter or radiation parameter. Muthucumaraswamy (2006) studied thermal radiation effects on vertical oscillating plate in the presence of variable temperature and mass diffusion.

Sivaiah et al (2012) investigated an unsteady flow of a viscous incompressible flow past an infinite isothermal vertical oscillating plate, in the presence of thermal radiation and chemical reaction. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. The plate temperature is arised to T_ω, and the concentration level near the plate is raised linearly with respect to time. An exact solution to the dimensionless governing equations has been obtained by the finite element method, when the plate is oscillating harmonically in its own plane. The effects of velocity, temperature, and concentration are studied for different physical parameters like thermal Grashof number, mass Grashof number, radiation parameter, prandtl number, chemical reaction parameter, Schmidt number, phase angle, and time are studied graphically. The skin-friction coefficient, the Nusselt number, and the Sherwood number at the plate are discussed, and their numerical values for various values of physical parameters are presented through tables. It is seen that the velocity increases with decreasing phase angle ωt and radiation parameter R, the wall concentration increases with decreasing Schmidt number. Also, the velocity as well as concentration decreases with an increase in the chemical reaction parameter.

Muthucumaraswamy et al (2013b) have studied the theoretical solution of flow past a uniformly accelerated infinite isothermal vertical plate in the presence of variable mass diffusion. The dimensionless governing equations are solved by the usual Laplace transform technique. The effect of different parameters like thermal Grashof number, mass Grashof number and t are studied graphically. It is observed that the velocity increases with increasing values of Gr, Gc and t. But the trend is just reversed with respect to the rotation parameter or magnetic field parameter M.

1.7 CHEMICAL REACTION

Chemical reactions usually accompany a large amount of exothermic and endothermic reactions. These characteristics can be easily seen in a lot of industrial processes. The study of heat generation or absorption in moving fluids is important in problems dealing with chemical reactions and those concerned with dissociating fluids. Possible heat generation effects may alter the temperature distribution; consequently the particle deposition rate in nuclear reactors, electronic chips and semiconductor waters. A chemically reactive species which transforms according to a simple reaction involving the concentration is emitted from the plate and diffuses into the fluid. The reaction is assumed to take place entirely in the stream.

The study of heat and mass transfer combined along with chemical reaction play an important role in chemical industries like in food processing, polymer production and heat exchangers that are used for the cooling of electronic circuits, packed bed chemical reactor and also in radioactive waste georepositories. In addition, mass transfer with chemical reaction has special significance in chemical and hydrometallurgical industries. The formation of smog represents a first order homogeneous chemical reaction. For instance, one can take into account the emission of NO_2 from automobiles and other smoke-stacks. Thus, NO_2 reacts chemically in the atmosphere with unburned hydrocarbons and produces peroxyacetylnitrate, which forms a layer of photochemical smog.

The chemical reaction effects depend whether the reaction is homogeneous or heterogeneous. This depends on whether they occur at an interface or as a single phase volume reaction. In well mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In majority cases, a chemical reaction 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 the concentration itself (Cussler 1998). Some examples of first order chemical reactions are decomposition of N_2O_5 in CCl_4 and radioactive disintegration of unstable nuclei.

We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate, when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects.

The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reaction. Due to the fast Growth of electronic technology, effective cooling of electronic equipment has become warranted and cooling of electronic equipment ranges from individual transistors to main frame computers and from energy suppliers to telephone switch boards and thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (hydrogen and helium) and medium molecular weight.

Apelblat (1980) investigated analytical solution for mass transfer with a chemical reaction of the first order. Acrivos (1960) considered the laminar forced convection mass transfer with homogeneous chemical reaction. Chambre & Young (1958) have analyzed a first order chemical reaction in the neighbourhood of a horizontal plate. Das et al (1994) have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started vertical plate with uniform heat flux and mass transfer. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction studied by Das et al (1999). The dimensionless governing equations are solved by the Laplace transform technique.

The chemical reaction effect on heat and mass transfer flow along a semi infinite horizontal plate has been studied by Anjalidevi & Kandaswamy (1999). It has been observed that in the presence of chemical reaction, (i) the velocity and concentration increase with decrease of Schmidt number (ii) Skin friction and the rate of concentration decrease with increases of chemical reaction parameter. Muthucumaraswamy & Ganesan (2002) studied diffusion and first order chemical reaction effects on unsteady flow past on impulsively started infinite vertical plate with variable temperature. A numerical solution of the first-order homogeneous chemical reaction in an unsteady free convective flow past a semi-infinite vertical plate were presented by Palani & Kwang Yong Kim (2011).

Effects of mass transfer on flow past an impulsively started infinite vertical plate with Newtonian heating and chemical reaction was analyzed by Rajesh (2012). Muthucumaraswamy & Meenakshisundaram (2006) have studied theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature. Manivannan et al (2009) have developed radiation and chemical reaction effects on isothermal vertical oscillating plate with variable mass diffusion. Muthucumaraswamy & Ganesan (2001) have presented A finite-difference solution of the transient natural convection flow of an incompressible viscous fluid past an impulsively started semi-infinite plate with uniform heat and mass flux, here taking into account the homogeneous chemical reaction of first order. It is observed that due to the presence of first order chemical reaction the velocity decreases with increasing values of the chemical reaction parameter.

1.8 EFFECTS ON A PARABOLIC MOTION OF A VERTICAL PLATE

The analysis of free convection flow near a vertical plate has been carried out as an important application in many industries. Numerous investigations are performed by using both analytical and numerical methods. The first exact solution of the Navier-Stokes equation was given by Stokes (1851) and explains the motion of a viscous incompressible fluid past an impulsively started infinite horizontal plate in its own plane. This is known as Stokess first problem in the literature.

There are many applications for the parabolic motion such as solar cookers, solar concentrators and parabolic trough solar collector. A parabolic concentrator type solar cooker has a wide range of applications like baking, roasting and distillation due to its unique property of producing a practically higher temperature of nearly $250°C$ and hence it provides inconvenience to the user due to high amount of glare.

Solar concentrators have their applications in increasing the rate of evaporation of waste water, in food processing, for making drinking water from brackish and sea water. It produces a high temperature around $250°C$ and the food gets cooked in less time given by Murty et al (2007). A parabolic trough solar collector system will provide within next decade a significant contribution to efficient, economical, sustainable renewable and clean energy supply with positive effect on environmental activities and it is designed to concentrate sun rays via parabolic curved solar reflectors onto a heat absorber element a receiver located in the optical focal line of the collector.

If the plate is in a vertical direction and gives an impulsive motion in its own plane in a stationary fluid, then the resulting effect of buoyancy force was first studied by Soundalgekar (1977) by Laplace transformation technique and the effects of heating or cooling of the plate by free convection currents were discussed. Agrawal et al (1999) have analyzed study of heat and mass transfer past a parabolic started infinite vertical plate. Neel Armstrong & Muthucumaraswamy (2014) have studied the exact solution of unsteady flow past a parabolic motion of an infinite vertical plate with variable temperature and uniform mass diffusion. The dimensionless governing equations are solved using Laplace transform in which the velocity increases with increasing values of thermal Grashof number or mass Grashof number.

Muthucumaraswamy et al (2013a) have presented the theoretical solution of flow past a uniformly accelerated infinite isothermal vertical plate in the presence of variable mass diffusion and first order chemical reaction parameter. The dimensionless governing equations are solved by the usual Laplace transform technique. The effect of different parameters like thermal Grashof number, mass Grashof number and t are studied graphically. It is observed that the velocity increases with increasing values of Gr, Gc and t. But the trend is just reversed with respect to the rotation parameter.

1.9 GOVERNING EQUATIONS

In natural convection, the motion of the fluid arises solely from the buoyancy forces. The buoyancy effect arises due to the interaction between the density differences and body forces, usually gravitational force. The density differences are due to both the temperature or concentration differences of the diffusing species or the combination of these two. So, both thermal and mass diffusing processes must be considered simultaneously for all aspects of the flow.

The basic equations of the motion of the boundary layer interpret the partial differential equations which are due to conservation of the momentum (Navier-Stokes equation), conservation of energy (energy equation) and molecular species (mass diffusion equation).

To obtain these equations on the physical grounds we assume the following:

- The x-axis is taken along the plate and y-axis is taken normal to the plate.
- The flow is unsteady, laminar and two dimensional.
- Fluid has constant properties excepting in the body force.
- Fluid is incompressible. Due to this fact, the influence of density (ρ) variations with temperature and concentration is considered only in the body force in accordance with Boussinesqs approximation.
- The fluid considered here is gray, absorbing-emitting but non-scattering. The Rosseland approximation is invoked in energy equation to approximate radiant flux.
- Heat due to viscous dissipation in the energy equation is very small and it is neglected, which is possible in the case of ordinary fluid flow like air or water under usual gravitational force.
- The concentration of the diffusing species in the binary mixture is very less in comparison to other chemical species which are present in the fluid and there is first order chemical reaction between the diffusion species and the fluid.

Within the frame work of these assumptions the governing equations of two dimensional laminar, free convective flow past a viscous incompressible fluid past a parabolic started infinite vertical plate, Agrawal et al (1999) are expressed as follows:

Equation of momentum

$$\frac{\partial u}{\partial t'} = g\,\beta(T - T_\infty) + g\,\beta^*(C' - C'_\infty) + \nu\frac{\partial^2 u}{\partial y^2}$$

Energy equation

$$\rho\, C_p\frac{\partial T}{\partial t'} = \kappa\frac{\partial^2 T}{\partial y^2}$$

Energy equation with thermal radiation

$$\rho C_p\frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y}$$

Mass diffusion equation

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y^2}$$

Mass diffusion equation with chemical reaction

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y^2} - K_l\,(C' - C'_\infty)$$

1.10 PHYSICAL MODEL

The physical model of the problem is shown in Figure 1.1.

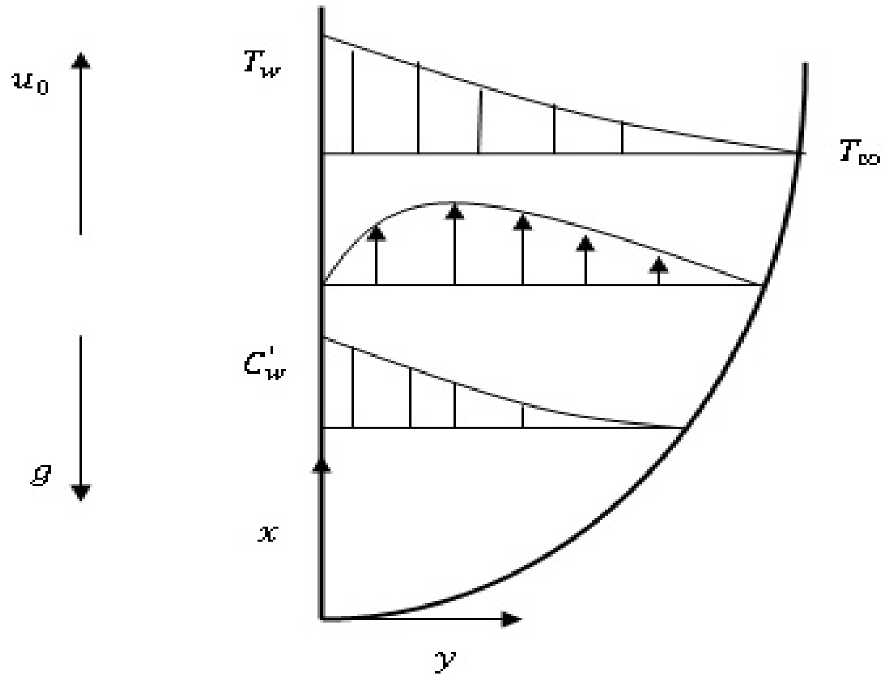

Figure 1.1 Physical model of the problem

1.10.1 Velocity boundary layer

If we have laminar flow of a fluid at high Reynolds number over a smooth solid boundary such as flat plate etc. and if the boundary is at rest, then the fluid in contact with it will also be at rest. As we move upwards along the normal, the velocity of the fluid will gradually increase until eventually the full stream velocity is attained. Strictly speaking this is approached asymptotically, but the greatest rates of change of velocity occur within a thin layer of fluid in contact with the boundary. This is called the velocity boundary layer. Thus if the boundary layer is developed due to the fluid velocity, it is termed as velocity boundary layer.

1.10.2 Thermal boundary layer

The study of heat transfer includes the physical processes whereby thermal energy is transferred as a result of temperature gradient. The heat transfer between a solid body and a liquid or gaseous flow is a problem whose consideration involves the science of fluid motion. In the physical motion of the fluid there is superimposed flow of heat transfer by conduction and convection. In order to determine the temperature distribution it is necessary to combine the equation of motion with those of heat conduction. It is intuitively evident that the temperature distribution around a hot body in a fluid stream with a different level of temperature has the same character as the velocity distribution in boundary layer flow. When a body is heated so that its temperature is maintained above that of the surroundings, then the temperature of the stream will increase only over a thin layer in the immediate neighbourhood of the body and over a narrow wake behind it. The transition from the temperature of the hot body to that of the colder surroundings takes place in a thin layer near the body which in analogy with the flow phenomenon is called thermal boundary layer. Thus, when there is a temperature gradient, the thermal boundary layer develops.

1.10.3 Concentration boundary layer

A concentration boundary layer will develop if the surface concentration and free stream concentration of species are different. we assume a flat plate where the concentration of the species in the fluid at the surface is uniform and is equal to C_w and that in the free stream is uniform and equal to C_∞. It is assumed that the fluid medium has a single chemical species and for $C_w > C_\infty$, the chemical species diffuses from the surface into the fluid and a concentration boundary layer is formed. This diffusion is based on the fact that mass flows from a region of higher concentration to a lower concentration by random molecular motion.

1.11 NON DIMENSIONAL PARAMETERS

The dimensional analysis is a mathematical technique which enables us to obtain the dimensionless quantities of the variables of a physical problem without the knowledge of the governing equations. There are several nondimensional quantities of great significance. The numbers which are relevant to our study are mentioned here.

1.11.1 Prandtl number

The ratio of the Kinematic viscosity to the thermal diffusivity of a fluid is known as the Prandtl number. That is Prandtl Number,

$$Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{\kappa}$$

which is named after the German Scientist Ludwig Prandtl (1857-1953). Here,

$$\alpha = \frac{\kappa}{\rho C_p}$$

is called the thermal diffusivity of a medium or material and it also indicates the heat energy transport through conduction or convection. Here, ν indicates the momentum transport through fluid friction (molecular friction). Thermal diffusivity tells us how fast heat is propagated or it diffuses through a material or medium during changes of temperature with time. In heat transfer problems, the Prandtl number controls the relative thickness of the momentum and thermal boundary layer. Evidently, the Prandtl number is a measure of relative effectiveness of momentum and thermal energy diffusion through a fluid, for a given fluid flow. Clearly, the Prandtl number controls the relation between the velocity and temperature distributions for a fluid flow. It is a material property and varies from fluid to fluid. For air $Pr = 0.71$(approx.) and for water $Pr = 7.0$(approx.). For liquid metal it is very small, e.g. for mercury $Pr = 0.004$(approx.). Again, for highly viscous fluids Prandtl number is very large, e.g. for glycerin $Pr = 7250$.

1.11.2 Schmidt number

The ratio of momentum diffusivity (viscosity) to the mass diffusivity in a fluid medium is known as the Schmidt number which was named after the German engineer Ernst Heinrich Wilhelm Schmidt (1892-1975). Mathematically the Schmidt number Sc is defined as $Sc = \frac{\nu}{D} = \frac{\mu}{\rho D}$, where D is the mass diffusivity of the species. 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 characterizes convective mass transfer in the same manner as the Prandtl number characterizes convective heat transfer. It can also be defined as the ratio of the shear component for diffusivity to the diffusivity for mass transfer. It physically relates the relative thickness of the hydrodynamic layer and mass-transfer boundary layer.

1.11.3 Thermal Grashof number

The ratio of the buoyancy force to the viscous force in the fluid is known as thermal Grashof number. This number is of great significance in natural (free) convection of a fluid caused by a hot body. This dimensionless quantity was named to honour the German Professor Franz Grashof (1826-1893). In natural convection, the flow field is set up by the buoyancy force alone and as such there is no external field present. The Grashof number in free convection plays the same role as the Reynolds number in force convection. For vertical plate the Grashof number is defined as $Gr = \frac{g\beta(T_w - T_\infty)L^3}{\nu^2}$. Some other dimensionless forms of Gr can be easily defined according to the necessities of a given flow problem.

1.11.4 Mass Grashof number

The mass Grashof number defines the ratio of the species buoyancy force to the viscous hydrodynamic force. Mass Grashof number is significant in free convection flows involving mass transfer. The Grashof number for mass transfer is defined as $Gc = \frac{g\beta^* L^3(\Delta C)}{\nu^2}$, where ΔC is some suitable reference molar species concentration difference.

1.12 AIMS AND SCOPE OF THE THESIS

The aim of the thesis is to study the effects of on flow past an infinite vertical plate subjected to parabolic motion with uniform mass and heat flux, in the presence of thermal radiation and chemical reaction parameter. The governing equations of free convection are simplified by invoking the boundary layer and Boussineq's approximation. The dimensionless governing coupled partial differential equations are solved by using Laplace transform technique and exact closed form solutions are presented. The solutions are in terms of complementary error function and exponential function. The solutions are codified in MATLAB and the graphs are plotted for the velocity, the temperature and the concentration profiles for different physical parameters. The present work may be extended to micropolar fluids and nano-fluids. Also the study may be extended by including viscous dissipation effects. Further, the work may be extended to finite difference analysis of parabolic flow past on a semi-infinite vertical plate in the presence of heat and mass transfer.

1.13 ORGANIZATION OF THE THESIS

The layout of the thesis consist of five chapters. The dimensionless governing equations are solved using the Laplace-transform technique. The solutions are in terms of exponential and complementary error function.

Chapter 2 deals with the problem of radiative flow past a parabolic started isothermal vertical plate and uniform mass flux in the presence of thermal radiation parameter. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. The dimensionless governing equations are solved using Laplace-transform technique. The expressions for velocity, temperature and concentration are obtained. The effects of these flow quantities for different physical parameters like thermal radiation parameter (R), thermal Grashof number (Gr), mass Grashof number (Gc), Schmidt number (Sc) and time (t) are discussed with the help of graphs.

In Chapter 3, the problem of unsteady flow of viscous incompressible fluid past a parabolic started infinite vertical plate with variable temperature and uniform mass flux, in the presence of thermal radiation. The plate temperature is raised linearly with time and the mass diffused from the plate to the fluid at a constant rate. The fluid considered here is a gray, absorbing-emitting radiation but a non-scattering medium. The resulting coupled partial differential equations are solved using Laplace-transform technique. The effects of the velocity, the temperature and the concentration for different physical parameters like thermal radiation parameter, thermal Grashof number, mass Grashof number, Schmidt number and time are shown graphically and results are analyzed in detail.

The exact solution of unsteady flow of viscous incompressible fluid past a parabolic started infinite vertical plate with constant heat flux and mass diffusion in the presence of homogeneous chemical reaction of first-order is analyzed in Chapter 4. The plate temperature is raised at a constant rate and the mass is diffused from the plate to the fluid uniformly. Laplace transform method is employed to solve the resulting coupled partial differential equations. The expressions for velocity, temperature and concentration are obtained. The dependence of these flow quantities on thermal Grashof number (Gr), mass Grashof number (Gc), Schmidt number (Sc) , Prandtl number (Pr), time (t) and chemical reaction parameter (K) are sketched graphically and are discussed in detail.

Chapter 5 discusses the theoretical study of unsteady flow of viscous incompressible fluid past a parabolic started infinite vertical plate with uniform heat flux and variable mass diffusion in the presence of homogeneous chemical reaction of first-order. The plate temperature is raised uniformly at a constant rate and the concentration level near the plate is raised linearly with respect to time. The Laplace transform method is used to solve the resulting coupled partial differential equations. The effects of the velocity, temperature and concentration for different physical parameters like chemical reaction parameter, thermal Grashof number, mass Grashof number, Schmidt number, Prandtl number and time are shown graphically and the results are discussed in detail.