CHAPTER 1

INTRODUCTION

1.1 HEAT AND MASS TRANSFER

Heat transfer is the fundamental part of thermal engineering. It is the transfer of heat energy due to spatial temperature difference. Heat transfer occurs when the spatial temperature difference is present within a system or between systems in thermal contact with each other.

Several material properties like thermal conductivity, specific heat, density, fluid viscosity, etc., modulate the heat transfer between two regions or systems at differing temperatures. Taken together, these properties serve to make the solution of many heat transfer problems and involved processes.

A porous material may be defined as solid containing holes or voids, connected or not connected, dispersed within it either in a regular or in a random manner. A great variety of natural and artificial materials are porous. Sand, limestone, a tuft of cotton, bread and body lungs are examples of porous materials. In the field of fluid mechanics, the dynamics of fluid flow through a porous material is relatively an old topic extensively used for proper management of an underground water table and the engineering, irrigation systems, The Darcy flow model, which is the foundation of this theory, originated in the nineteenth century in connection with the engineering of the public fountains. However, the convection heat transfer potential of flow through porous medium is a relatively new and rapidly growing branch of fluid mechanics and heat transfer. Porous materials such as sand, crushed rock in the underground are saturated with water, which, under the influence of local pressure gradients, migrate and transport energy through the material. The rapid depletion of the nonrenewable reserves of fossil fuel and their increasing costs with attendant environmental pollution has provided the impetus for the development of the supplementary energy sources. One of the most promising short-term alternatives with acceptable environment impact is geothermal energy. The formation of geothermal reservoir is believed to be associated with the occurrence of recent volcanism or intense tectonic movements. As a result of these activities, magmatic intrusions may occur at shallow depths in the earth's crust. Meteoric water, percolating down to great depths in a permeable formation, is heated directly or indirectly by the intruded magma and is then driven buoyantly upward to the top of the aquifer where it can be tapped by drilling holes. Further examples of convection through porous medium may be found in man-made systems such as fiber and granular insulations, winding structures for high-power density electric machines, the cores of nuclear reactors and grain drying.

In general, three physical mechanisms of heat transfer exist viz. conduction, convection and radiation. Conduction is the mode of heat transfer in which energy transfer occurs from a region of high temperature to that of low temperature by direct molecular interactions and the drift of electrons. Convection is the mode of heat transfer in which the heat energy is transferred by the actual movement of fluid particles due to density variation. Radiation heat transfer is the mode of heat transfer in which the heat energy is transferred through electromagnetic radiation. Unlike for conduction and convection which require a medium, the mode of radiation heat transfer does not require any medium.

Among the various modes of heat transfer, the mode of heat transfer through convection has received considerable attention because of its applications in wide areas of thermal engineering field. Convection is the mode of heat transfer between a solid surface and the moving fluid in contact with it. The faster the fluid motion, greater the convective heat transfer. Convective heat transfer is of three type's viz., forced convection if the fluid is forced to flow over the surface, natural or free convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to variation of temperature in the fluid. The third type of convection known as the mixed convection heat transfer takes place when forced and natural convection act together in a system. Under this process both pressure forces and buoyant forces act together. Donald et al (1989) analysed the mixed convective heat transfer in nuclear reactors and some aspects of electronic cooling.

Mass transfer implies transport of material from the region of high concentration to the region of low concentration. Basically, mass transfer deals with transport of species within the medium or from one medium to another. Broadly, there are two types of mass transfer viz., diffusive mass transfer involves molecular diffusion and convective mass transfer involving moving fluids. In many aspects mass transfer is very much analogous to heat transfer. Similar to heat transfer, which occur from a region of high temperature to a region of low temperature, when there is a temperature gradient, mass transfer occur from a region of high concentration to a region of low concentration when there is a concentration gradient. Just as the heat flux is directly proportional to the temperature gradient, the mass flux is proportional to the concentration gradient. A great similarity of equations related to convective heat transfer and diffusion to those of mass convection and diffusion is noticed by Lienhard IV and Lienhard V (2008) which led to the use of convective mass transfer coefficient like that of heat transfer coefficient. With simple modifications, heat transfer coefficient is analogous to mass transfer co-efficient.

The laws of mass transfer show the relation between the flux of the diffusing substance and the concentration gradient responsible for this mass transfer. Unfortunately, the quantitative description of molecular diffusion is considerably more complex than the analogous descriptions of the molecular transfer of momentum and energy that occur in one component phase.

Mass transfer occurs in many processes such as distillation, absorption, dehumidification, liquid extraction, leaching and drying. Some common examples of mass transfer process are the evaporation of water from pond, purification of blood in kidney and liver and distillation of alcohol. In industry the mass transfer process occurs in the absorbers such as scrubbers, absorbers involving activated carbon beds and liquid-liquid extraction. Mathematical modeling of mass transfer has extensive application in chemical engineering problems.

1.2 FLUID FLOW THROUGH POROUS MEDIUM

The field of fluid flow through a porous medium has got the attention of many researchers because of its applications to thermal engineering, geothermal system, crude oil extraction and energy related engineering problems such as thermal insulation of buildings, recovery of petroleum products, packed bed reactors and sensible heat storage beds etc. By definition, a porous medium consists of a particle medium of very small size with pores between them. The existence of particles in the medium reduces the space available for fluid flow. In the porous medium, the resistance to fluid flow is mainly due to the quantity of particles present i.e., porosity of the medium. Clearly a viscous drag is imminent on the surface of the particles which led to the reduction in the velocity in porous medium. The permeability, which is inverse resistance to fluid flow, depends on the porosity and the surface area per unit volume of the particles within the medium.

The porosity is an isotropic property and hence the interstitial velocity is related to superficial velocity. Clearly the resistance to fluid flow through porous media is related to the density of particles present in the medium termed as porosity.

Porous materials such as sand, rock in the underground are saturated with water or some other fluids. Such fluids flow through the porous medium due to local pressure gradients and transport energy from one region to another. Fast depletion of fossil fuel reserves led to the development of alternative new energy sources. One of the most promising new energy sources is geothermal energy which is very clean and sustainable. The geothermal reservoir is believed to have formed due to the volcanic activities or tectonic movements. As a result, magmatic intrusions may occur at shallow depths in the earth's crust.

A mathematical model consists of a set of equations that have been developed to describe the flow of fluids in a porous medium, together with an appropriate set of boundary and initial conditions. Fluid motion in a porous medium is governed by the conservation of mass, momentum, and energy. In the simulation of flow in the porous medium, the momentum equation is given in the form of Darcy's law. Derived empirically, this law indicates a linear relationship between the fluid velocity and the pressure gradient. Further, the Reynolds number is suitably modified for porous medium and the Darcy's law holds good only for laminar flow for which modified Reynolds number must have a value less than 2.

The rapid depletion of nonrenewable energy sources such as fossil fuel reserves has provided the impetus for the search for new energy sources. Taking the cue from this, the research and development of area of geothermal energy have led to the enormous growth.

1.3 MAGNETO HYDRO DYNAMIC FLUID FLOW

The study of an electrically conducting fluid, which influences many natural and man-made flows, has many applications in engineering problems such as Magneto Hydro Dynamic (MHD) generators, plasma studies, nuclear reactors ,geothermal energy extraction and the boundary layer control in the field of aerodynamics. The process of heat and mass transfer in free convection flow has attracted the attention of a number of researchers due to their application in many branches of science and engineering, viz. in the early stages of melting adjacent to a heated surface, in chemical engineering processes which are classified as a mass transfer process, in a cooling device aeronautics and nuclear reactors. The phenomenon of free convection arises in the fluid when the change of temperature and concentration leads to density variation leading to buoyancy forces acting on the fluid elements. The study of fluid flow is of paramount importance in engineering. For example, the unsteady free convection flow along a vertical plate has been given considerable interest, because of its application in devices which are cooled by natural convection, as in the case of electrical heaters and transformers.

1.4 DARCY’S FLOW MODEL

The fundamental law that governs the flow of fluids through porous media is Darcy’s law. It is analogous to other linear transport laws such as Fick’s law for diffusion of mass and Fourier’s law for heat conduction. The empirical law governing isothermal vertical flow of water through in consolidated sand was first stated by Darcy (1856). The law states that the area averaged fluid velocity through porous medium is directly proportional to the pressure gradient along the column, the permeability of the medium and inversely proportional to the viscosity of the fluid flowing through the medium. Mathematically Darcy's law can be written as

$$u = \frac{K}{\mu}\left[-\frac{dp}{dx}\right] \tag{1.1}$$

where K is the permeability whose dimension is $(\text{Length})^2$. On the length scale the effective pore diameter is taken as $K^{1/2}$. Experimental measurements have shown that Darcy's law is valid as long as O(Re) < 1, where $Re = u\, K^{1/2}/\nu$. If the Reynolds number based $K^{1/2}$ exceeds O(1), then inertial effects come into play. Hence Whitaker (1969) and Hassanizadeh & Gray (1980) developed a set of equations to describe the macroscopic behavior of fluid flow through porous media. Forchheimer (1901) suitably modified the Darcy's equation to include the microscopic inertial effect by incorporating a second order of the velocity term and the equation amounts

$$-\frac{dp}{dx} = \frac{\mu}{K}u + \beta\rho u^2 \tag{1.2}$$

where β is the non-Darcy coefficient and ρ is the fluid density. However in this thesis a simple Darcy model is treated, under the assumption that $O(uK^{1/2}/\nu) < 1$. In the presence of body forces the Darcy law in the vector form is

$$\bar{q} = -\frac{K}{\mu}(\nabla p - \rho g) \tag{1.3}$$

where g is the acceleration due to gravity and $\bar{q}$ = (u,v,w) is the Darcy velocity vector.

In case of flow through fine and medium grain soil, the flow is laminar. However in case of coarse grained soil, the flow is turbulent. Hence the Darcy's law holds well in the former and does not holds well in the later. Darcy's law holds good in the complex porous media like flow in plant roots and tissues, flow of resin in porous molds, flow in ceramics and ceramic foams, unsaturated flow in food drying industry and in paper industry in dewatering of paper pulp.

1.5 ENERGY EQUATION

The following assumptions were made to arrive at the energy equations

i. The Darcy's law holds good in all the systems considered

ii. The porous medium is homogeneous and isotropic, which means that transport properties such as the porosity factor K and thermal conductivity k do not depend on the direction of the experiment from which they are measured.

iii. At any point in the porous medium, the solid matrix is in thermal equilibrium with the fluid filling the pores.

iv. The local Reynolds number based on average velocity and $K^{1/2}$ does not exceed O(1). Then the energy equation can be derived in the form as given by Bejan (1984)

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right] \quad (1.4)$$

where T is the fluid temperature and α is the equivalent thermal diffusivity. In the derivation of the equation the effect of internal heating and viscous dissipation effect have been ignored. In practical problems Equation (1.4) has to be supplemented with the equation of mass conservation and is given for steady flow as

$$\nabla.\bar{q}=0 \tag{1.5}$$

For the buoyancy driven flow the equation of state is required and may be given as

$$\rho=\rho_\infty\left(1-\beta\left(T-T_\infty\right)\right) \tag{1.6}$$

1.6 CONCENTRATION EQUATION

There is a wide range of applications of mass transfer in the fields of engineering and other areas, some of the most prominent are drying, evaporation, respiratory process in living organisms, absorption, adsorption etc., Both similarities and dissimilarities exist between heat and mass transfer mechanisms.

Transfer of energy occurs during heat transfer due to thermal gradient which is similar to transfer of species in mass transfer due to the concentration gradient. Also, many similarities among the momentum transfer which is based on Newton's law, heat transfer which is based on Fourier's law and mass transfer based on Fick's law. The diffusion of mass in mass transfer cannot be compared with diffusion of energy in heat transfer due to conduction and radiation.

It is found that the thermal diffusivity decrease from solids (~ 10^{-4} m^2 /s) to gases (~ 10^{-5} m^2 /s) to liquids (~ 10^{-7} m^2 /s) whereas mass diffusivity decrease from gases (~ 10^{-5} m^2 /s) to liquids (~ 10^{-9} m^2 /s) to solids (~ 10^{-12} m^2 /s).

The following assumptions were made for concentration equation.

i. There is no energy or mass produced within the system.

ii. There is no emission or absorption of radiant energy

iii. There is no viscous dissipation

iv. The velocity profile is not affected by the mass transfer; hence, there is only a low rate of mass transfer.

The concentration is equation given by Fick's Law as,

$$J = -D \frac{\partial \varphi}{\partial x} \tag{1.7}$$

where J is the diffusion flux, φ is the concentration and D is the diffusion coefficient.

1.7 MASS, ENERGY, AND MOMENTUM-TRANSFER ANALOGIES

In the previous analyses of convective mass transfer, we have recognized the similarities in the differential equations for momentum, energy, and mass transfer and in the boundary conditions when the transport gradients were expressed in terms of dimensionless variables. These similarities have permitted us to predict solutions for the similar transfer processes. In this section, we shall consider several analogies among transfer phenomena that have been proposed because of the similarity in their mechanisms. The analogies are useful in understanding the transfer phenomena and as a satisfactory means for predicting behavior of systems for which limited quantitative data are available.

To explore those analogies, it could be understood that the diffusion of mass and conduction of heat obey very similar equations. In particular, diffusion in one dimension is described by the Fick's law as given in Equation (1.7).

Heat conduction is described by Fourier's law as

$$q = -k\frac{dT}{dx} \tag{1.8}$$

where k is the thermal conductivity, T is the temperature and q is the quantity of heat flow

The similar equation describing momentum transfer is given as

$$\tau = -\mu\frac{\partial v}{\partial x} \tag{1.9}$$

where τ is the momentum flux (or shear stress) and μ is the viscosity of fluid.

At this point it has become conventional to draw an analogy among mass, heat and momentum transfer. Each process uses a simple law combined with a mass or energy or momentum balance.

The similarity among the transfer phenomena and accordingly the existence of the analogies require that the following five conditions exist within the system

1. The physical properties are constant as there may be slight changes in the physical properties due to variations in temperature or concentration. This condition can be

approximated by using average concentration and temperature properties.

2. There is no viscous dissipation of energy.
3. The velocity profile is not affected by the mass transfer. This implies there should be a low rate of mass transfer.
4. There is no energy or mass produced within the system
5. There is no emission or absorption of radiant energy from the system.

1.8 OBJECTIVES OF THE RESEARCH

The objectives of this research work are

i. To investigate the different effects of the thermo physical parameters such as the thermal stratification parameter, power law index of the surface temperature, variable viscosity, chemical reaction parameter, magnetic parameter, Eckert number, Prandtl number, Schmidt number, Reynolds number, Gebhart number, permeability parameter, heat generation or absorption parameter, radiation parameter, Grashof number, heat source/sink parameter on the dimensionless velocity, temperature and concentration fields and rate of heat transfer.

ii. To illustrate the skin friction coefficient, Nusselt number and Sherwood number for various values of the major parameters.

iii. To assess the above parameters with quantitative technique.

iv. To develop a computer program for the analysis of velocity, temperature and concentration profiles.

1.9 LITERATURE SURVEY

Salman Haq & Mulligan (1990) analysed the transient, buoyancy-induced flow and heat transfer adjacent to a suddenly heated vertical wall embedded in a porous medium saturated with a non-Newtonian fluid. Results obtained shows that Nusselt number decrease continuously with time and heat transfer coefficient decrease with a decrease in the power law index.

Baoku et al (2013) investigated the influence of third grade, partial slip and other thermo physical parameter on the steady flow, heat and mass transfer of visco-elastic third grade fluid past an infinite vertical insulated plate subject to suction across the boundary layer by the space occupying the fluid in porous media, coupled with non linear governing problem are solved by efficient numerical technique based on midpoint integration scheme with Richardson's extrapolation.

Chung Liu (2004) proposed analytical solution for the flow of heat transfer in a steady laminar boundary layer flow of an electrically conducting fluid of second grade subject to a transverse uniform magnetic field past a semi-infinite stretching sheet with power law surface temperature. Also the effect of viscous dissipation, internal heat generation, work done due to deformation and joule heating in the energy equation are considered. It was reported that the velocity component increases with visco elastic parameter and decreases with magnetic parameter.

Lester et al (2009) applied a novel spectral method to quantity asymptotic scalar transport within Newtonian and non-Newtonian fluid over the control parameter space of a chaotic flow. The results demonstrate the ability of chaotic advection to address difficult transport problems involving non-Newtonian and highly viscous fluid. It has been reported that the prospects for design and construction of low energy transport enhancement devices.

Moraga et al (2010) numerically analysed the transient phase change of a power law non-Newtonian fluid inside an inner thin walled container caused by external mixed convection in a square cavity and the external cooling fluid in air and modified non-Newtonian water as the phase change fluid.

Cimpean & Pop (2012) investigated the problem of the steady fully developed mixed convection flow in an inclined porous channel filled by three types of nano fluids like Cu- water, Al_2O_3- water and T_iO_2- water. The governing equations are solved by analytical method. It has been concluded that the nano fluid greatly increase the heat transfer, even for small additions of nano particles in the base water fluid.

Postelnicu (2012) investigated the heat and mass transfer in boundary layer free convection over an inclined flat plate embedded in a fluid saturated porous medium in the presence of thermophoresis. Thus the governing equations are transformed into differential equation and solved numerically by using local non similarity method. The effect of thermophoretic co efficient and thermophorosis parameter on thermophoretic velocity deposition, Nusselt number and concentration profiles have been analysed for both hot and cold wall conditions.

Kechichian et al (2012) developed a mathematical model for the simulation of the continuous thermal processing of a non-Newtonian liquid food under non- ideal laminar flow in a tabular system and tested on a study case of Sour soup juice processing. The model comprising differential equation for heat and mass transfer is proposed for the simulation of the continuous thermal processing of a non- Newtonian food in a tubular system.

Chung Liu (2005) analysed the flow and heat transfer of a steady laminar boundary layer flow of electrically conducting fluid of second grade in a porous medium subject to a transverse uniform magnetic field past a semi-infinite stretching sheet with power law surface temperature (or) power low surface heat flux.

Sochi (2010) reviewed the single phase flow of non-Newtonian fluid in porous medium. It has been reported that continuum model, bundle of tubes models, numerical methods and pore-scale network modeling are the four main approaches for describing the flow through porous media, since the modeling of non-Newtonian flow is very complex which cannot be explained based on a single model. Further, it has been stated that the actual geometry and topology of the porous region is more complex and hence must be fully considered in modeling the flow through porous media.

Mariano et al (2013) analysed the thermal conductivity, rheological behavior and the high pressure density of several non- Newtonian ethylene glycol based SnO_2 nano fluid. It has been reported that the characteristics of ethylene glycol/Sno_2 nano fluid exhibit shear thinning and rheopecty under non-Newtonian conditions and the elastic behavior is dominant.

Yilmaz et al (2009) experimentally investigated the Newtonian and non- Newtonian fluid flow in porous medium and built experimental setup for future water, gas and chemical core flood experiments. The flow of Newtonian fluid (distilled water) and non-Newtonian fluid (poly acryl amide solution with concentration 5 and 10ppm) through porous medium (Berea sandstone) have been studied. It has been found that Newtonian fluid and the non-Newtonian fluid mentioned above exhibited a linear and non linear flow behavior respectively.

Kairi & Murthy (2011) investigated the influence of viscous dissipation and Soret effect on natural convection heat and mass transfer from vertical cone in a non- Darcy porous media saturated with non- Newtonian fluid. Also the effect of non- Darcy parameter, viscous dissipation parameter have been analysed. It has been reported that increase in dissipation parameter results in increase of temperature distribution inside the boundary layer. Whereas increase in Soret parameter results in decrease of temperature distribution across the boundary layer for all values of power law index. Also it has been reported that the concentration profile increase with increase in Soret parameter but decrease in concentration profile with increase in dissipation factor. It is clearly noted that the temperature and concentration profiles as well as heat and mass transfer coefficients are affected by the power law index parameter, viscous dissipation and Soret effect in the medium.

Mondragon et al (2013) experimentally investigated the thermo physical properties of nano fluids at high temperature conditions for heat transfer applications. Water based nano fluid of Silica, alumina and carbon nano tubes that were characterized in terms of thermal conductivity, specific heat, viscosity and stability were used. Thus the measurements were done up to high temperature (80^{o}C) conditions.

Wang et al (2002) proposed the natural convection of non-Newtonian power law fluids with or without yield stress over the permeable two dimensional or axisymmetric bodies of arbitrary shape in a fluid saturated porous medium. The local non- similarity solution is obtained by using the forth order Runge-Kutta scheme and shooting method.

Bortolozzi & Deiber (2005) investigated the flow of Newtonian fluid through a porous medium for the particular case of natural convection and are produced by hot and cold spot placed in the solid phase. It has been reported that the intensities of thermal spots are negative for cold spot or sink, and positive for hot spot or source is controlling both thermal and momentum boundary layers of a fluid throughout the porous cavity. Also, thermal intensities together with configuration control the fluid movement in porous cavity have been analysed in detail.

Khelifa et al (2012) investigated the onset of motion and the resulting convective motion in a shallow porous cavity filled with a non-Newtonian binary fluid. The problem was solved both by analytical and numerical method and reported a simpler method. Through the present model it is possible to predict the supercritical and subcritical Rayleigh numbers for the onset of motion.

Pawar & Sunnapawar (2013) experimentally investigated isothermal steady state and non-isothermal unsteady state conditions which were carried out in helical coils for Newtonian and non-Newtonian fluids. Water, Glycerol-water mixture as Newtonian fluid and dilute aqueous polymer solution of sodium carboxymethyl cellulose (SCMC), sodium alginate (SA) as Non-Newtonian fluids was used. The result shows the overall heat transfer coefficient and Nusselt number of water are higher than the glycerol-water mixture and Non-Newtonian fluids.

Degan et al (2007) investigated transient free convection boundary layer flow along a vertical surface embedded in an anisotropic porous medium saturated by a non- Newtonian fluid. It has been concluded that both the power law index and the anisotropic properties have a strong influence on the heat transfer rate.

Haddad et al (2004) analytically investigated the local thermal equilibrium assumption in natural convection over a vertical plate embedded in porous medium. It is based on the two phase model using the Brinkman term to cover the flow. It has been reported that more than one dimensionless parameter govern the validity of local equilibrium assumption.

Tai & Char (2010) numerically investigated the combined laminar free convection flow with thermal radiation and mass transfer of non-Newtonian power law fluids along a vertical plate with in a porous medium and analysed the effect of the Dufour number, Soret number, and Power law index and radiation parameters.

Abel et al (2010) studied the boundary layer flow and heat transfer characteristics of a second grade, non- Newtonian fluid through a porous medium. The effect of viscous dissipation, non- uniform heat source on heat transfer are considered. It has been reported that suction parameter, second order fluid parameter, Prandtl number decrease the heat transfer whereas porous parameter increase the heat transfer in the boundary layer region. Further it can be noticed that the viscous dissipation of the fluid increase the wall temperature. Geetha and Moorthy (2011) considered the viscous dissipation effect on steady convection and mass transfer flow past a continuously moving semi infinite plate and reported significant changes in heat and mass transfer co efficient due to viscous dissipation in the medium.

Cheng (2006) investigated the effect of fluid inertia on the natural convection heat and mass transfer near a vertical wavy surface embedded in a non- Darcy fluid saturated porous medium. Thus the boundary layer equations are solved by the cubic spine collocation method. Also the effects of the modified Grashof number, the buoyancy ratio, Lewis number, and amplitude-wave- length ratio, Sherwood and Nusselt number have been studied. It was reported that, when the Lewis number is increased, the local Nusselt number decreases while the local Sherwood number increases. Further, an increase in the buoyancy ratio tends to increase both the local Nusselt number and the local Sherwood number and an increase in the modified Grashof number tends to greatly decrease the heat and mass transfer rates.

Ravikumar et al (2013) studied the thermophoresis particle deposition in mixed convection on a vertical plate embedded in a porous medium. The similarity technique was employed for the transformation of partial differential governing equations into ordinary differential equations. For solving the set of ordinary differential equations implicit finite difference method was employed. After analyzing the results obtained, it has been concluded that the concentration distribution is affected everywhere inside the boundary layer for higher values of thermophoresis parameter. Whereas the concentration distribution is affected in a region away from the leading edge on the plate for low values of thermophoresis parameter. The concentration distribution increases more rapidly in the non Darcy case than in Darcy case. Mass transfer increases with the increase of Lewis number.

Das (2012) investigated the combined effects of thermophoresis and thermal radiation on MHD mixed convective heat and mass transfer flow of an incompressible, electrically conducting second grade fluid past a semi infinite stretching sheet in presence of viscous dissipation and Joule heating. The governing boundary layer equations were transformed in to a set of non linear ordinary differential equations by similarity transformations. The ordinary differential equations have been solved numerically using symbolic MATHEMATICA software. It has been reported that increase in thermophoresis particle deposition leads to the decrease in velocity and concentration of the fluid. Further, increase in thermophoresis parameter, magnetic parameter and second grade parameter leads to decrease in momentum boundary layer thickness.

Kabir & Mahbub (2012) analysed the effect of thermophoresis on unsteady magneto hydrodynamic free convection flow over an inclined porous plate with time dependent suction in presence of magnetic field with heat generation. The equations were integrated using sixth order Runge-Kutta scheme together with Nachtsheim-Swigert shooting technique. The results obtained indicate that velocity profile increase whereas the temperature profile decreases with increase of free convection current. Magnetic field retards the motion of the fluid whereas increase in Darcy number leads to increase in velocity profile. The growth of boundary layer can be controlled using suction.

Chamkha et al (2006a) focused on the study of coupled heat and mass transfer by boundary layer free convection over a vertical plate embedded in a fluid saturated porous medium in the presence of thermophoresis particle deposition and heat generation or absorption effects. The governing partial differential equations are transformed into ordinary differential equations using special transformations. The resulting similarity equations are integrated numerically by an efficient implicit tri diagonal finite difference method. It has been concluded from the comparison with previously published work and after thorough analysis that an increase in heat generation, absorption co-efficient, Lewis number, buoyancy ratio parameter leads to decrease in particle concentration level and concentration boundary layer thickness. However, an increase in heat generation, absorption co-efficient, Lewis number, leads to increase in the fluid temperature and thermal boundary layer thickness and decrease with the increase in buoyancy ratio. The thrermophoretic deposition velocity decreased while there is increase in heat generation, absorption co efficient and Lewis number and increase when the buoyancy ratio was increased.

Kishan & Maripala (2012) investigated the effects of thermophoresis on MHD mixed convection, heat and mass transfer about an isothermal vertical plate embedded in a fluid saturated porous medium in the presence of viscous dissipation. The governing equations of the problem under consideration have been transformed into coupled ordinary differential equations which are solved numerically by finite difference method. It is reported that increase in thermophoretic parameter leads to decrease in velocity profile, whereas increase in mixed convection parameter leads to decrease in velocity profile. The effect of Schmidt number was analysed by choosing the most common diffusing chemical species such as Hydrogen(Sc=0.2), Water vapour (Sc=0.6) and Ammonia(Sc=0.78) in air at 20^{o}C and one atmospheric pressure and it leads to the conclusion that the velocity profile decreases with increase in Schmidt number(Sc), buoyancy parameter and inertia parameter. Further, an increase in viscous dissipation parameter results in an increasing of the velocity profile and increase in magnetic parameter decreases the Hydro magnetic boundary layer which leads to the decrease in fluid velocity.

Mahapatra et al (2007) investigated the steady two dimensional stagnation-point flow of an incompressible visco elastic fluid over a flat deformable surface when the surface is stretched in its own plane with a velocity proportional to the distance from the stagnation-point. It is shown that for a visco-elastic conducting fluid of short memory (obeying Walters' B_ model), a boundary layer is formed when the stretching velocity of the surface is less than the inviscid free-stream velocity and velocity at a point increases with increase in the Hartmann number. However, an inverted boundary layer is formed when the surface stretching velocity exceeds the velocity of the free stream and the velocity decreases with increase in the Hartmann number. A novel result of the analysis is that the flow near the stretching surface is that corresponding to an inviscid stagnation-point flow when the surface stretching velocity is equal to the velocity of the free stream. It is found that in the absence of viscous and Ohmic dissipation and strain energy in the flow, temperature at a point decreases with increase in the Hartmann number.

Bhargava et al (2007) studied the effect of Pulsatile magneto-bio fluid flow and mass transfer in a non-Darcian porous medium channel. A numerical solution for the hydro magnetic Newtonian bio-fluid flow in a porous channel with simultaneous mass transfer has been presented. Both finite element and finite difference numerical methods have been employed. It has been reported that increase in magnetic field reduces the flow velocity whereas the increase in Reynolds number increase the flow velocity across the channel. The mass transfer function increases considerably while there is an increase in Schmidt number for the general magneto hydrodynamic, pulsating, non- Darcian flow.

Chamkha et al (2006b) studied the effect of Marangoni mixed convection boundary layer formed along the interface of two immiscible fluids, in surface driven flows. The governing partial differential equations are transformed into a set of coupled ordinary differential equations by similarity transformation method and solved numerically. The velocity and temperature profiles as well as the interface velocity and heat transfer at the interface are determined and discussed in detail. It is concluded that the Marangoni mixed convection parameter has a substantial effect on the flow and heat transfer characteristics. However, for some values of Prandtl Number this flow model eventually breaks down. More extensive numerical experiments are necessary in an attempt to resolve this situation.

Jayaraj et al (1999) investigated the effect of thermophoresis in natural convection with variable properties like density, viscosity and thermal conductivity with temperature for a laminar flow over a cold vertical flat plate. For a selected fluid, Prandtl number variation with temperature is neglected and the Prandtl number corresponding to film temperature is used for the analysis. Solution is carried out by finite difference method. Variation of wall concentration and wall flux along the length of plate is studied. The effect of thermophoretic coefficient on wall concentration is also studied. For all cases analysed nature of variation of wall concentration is identical. The wall concentration decreases with increase in thermophoretic coefficient whereas it decreases with increase in temperature ratio. With decrease in temperature ratio, wall flux increases.

Hsiao (2010) investigated the effect of heat and mass transfer with radiation effect of a steady laminar boundary-layer flow of a micro polar flow past a nonlinearly stretching sheet. The problems have been analyzed using similarity transformation, finite-difference method and Runge–Kutta method. After analysis of the results obtained, it has been reported that at a particular point of the flow region, heat transfer effect increases, when there is an increase of Prandtl number or radiation parameter. At a particular point of the flow region, the increase of Eckert number or thermophoresis co efficient results in the decrease of heat transfer effect and Heat transfer effect increases in presence/absence of thermal conductivity parameter. It was presented that the increase in Schmidt number results in the increase of concentration effect. It was also observed that increase in Prandtl number or radiation parameter significantly increases the thickness of the thermal boundary layer of the fluid.

Hamad et al (2011) investigated heat and mass transfer over a moving porous plate with hydrodynamic slip and thermal convective boundary conditions and concentration dependent diffusivity. The similarity representation of the system of partial differential equations of the problem is obtained through Lie group analysis. The resulting equations are solved numerically by Maple with Runge–Kutta–Fehlberg fourth– fifth order method. It is noticed that the analytical results are in good agreement with numerical results. The investigation led to the conclusion that Hydrodynamic slip parameter reduces the velocity while it increases the temperature and concentration. The concentration diffusivity parameter increases while Schmidt number reduces concentration and near the plate the concentration gradient decreases with concentration diffusivity parameter.

Ibrahim et al (2013) analyzed the effect of magnetic field on stagnation point flow and heat transfer due to nanofluid towards a stretching sheet. The governing nonlinear boundary-layer equations are transformed in to a set of coupled higher order nonlinear ordinary differential equations by Similarity transformation method. These equations were numerically solved using Runge–Kutta fourth order method together with shooting technique. The obtained results indicate that the skin friction coefficient and local Nusselt number increases with an increase in velocity ratio parameter. The increase in velocity ratio and Lewis number increases the local Sherwood number. It was also reported that the heat transfer rate at the surface increases with the magnetic parameter when the free stream velocity exceeds the stretching velocity. The mass transfer rate at the surface increases with an increase in both Lewis number and velocity ratio.

Gireesha et al (2012) studied the magneto hydrodynamic boundary layer flow and heat transfer characteristics of a dusty fluid over a flat stretching sheet in the presence of viscous dissipation. The governing equations in the form of partial differential equations were transformed to a set of non-linear ordinary differential equations by similarity transformation. The transformed equations are solved numerically by applying Runge Kutta Fehlberg fourth-fifth order method (RKF45 Method). The effects of fluid-particle interaction parameter, Chandrasekhar number, Prandtl number, Eckert number on heat transfer characteristics for two general cases namely, the prescribed surface temperature (PST) case and the prescribed wall heat flux (PHF) case are presented graphically and discussed. It is reported that the increase in Chandrasekhar number increases temperature distribution in the flow region in both PST and PHF cases. The rate of heat transfer decreases with increasing the Prandtl number and fluid-particle interaction parameter whereas it increases with increasing the Eckert number. The effect of Prandtl number is to decrease the thermal boundary layer thickness.

Reddy et al (2013) studied the effects of heat and mass transfer on MHD mixed convection flow of a vertical surface with radiation, heat source/absorption and chemical reaction. The resulting set of coupled non-linear ordinary differential equations is solved by perturbation technique. Approximate solutions have been derived for the velocity, temperature, concentration profiles, skin friction and Nusselt number. The obtained results are discussed with the help of the graphs to observe the effect of various parameters like Grashof number, modified Grashof number, Schmidt number, Prandtl number, Magnetic parameter, Radiation parameter, Chemical reaction, Heat source parameter and Radiation absorption parameter.

Sreenivasulu (2013) discussed a two dimensional hydromagnetic stagnation-point flow of a radiating, chemically reacting nanofluid over a heated porous stretching sheet embedded in a porous medium with internal heat generation/absorption and suction/blowing. The governing partial differential equations are transformed into a set of ordinary differential equations, by Lie group analysis and the resultant equations are then solved numerically. Numerical results for the velocity, temperature, concentration and nanoparticle volume fraction as well as the friction factor, surface heat and mass transfer rates have been computed for the variations of the Magnetic parameter M, radiation parameter Nr, thermophoresis parameter Nt, Brownian motion parameter Nb, Lewis number Le, suction/injection parameter S, permeability parameter *K*, source/sink parameter *l*, Prandtl number *Pr* and chemical reaction parameter *R*.

Poornima et al (2013) analyzed the effects of thermal radiation and chemical reaction on MHD convective heat and mass transfer flow of a viscous incompressible fluid past a semi-infinite vertical permeable plate with time dependent suction. The governing boundary layer equations are solved by a regular perturbation technique. The effect of various thermo-physical parameters like radiation parameter N, Magnetic parameter M, Permeability parameter K, chemical reaction parameter γ, Schmidt number Sc, radiation absorption coefficient Q, heat absorption coefficient φ and time t on the velocity, temperature and concentration as well as the skin friction, rates of heat and mass transfer are obtained numerically and discussed. It is found that the rate of heat transfer at the plate increases with increasing in values of the radiation parameter and the mass transfer rate increases with increasing in values of the chemical reaction parameter.

Eshetu Haile and Shankar (2014) investigated study on boundary layer flow of a nano fluid through a porous medium subjected to a magnetic field, thermal radiation, viscous dissipation and chemical reaction effects. The effects of porosity, thermal radiation, magnetic field, viscous dissipation and chemical reaction to the flow field were thoroughly explained for various values of the governing parameters. Copper and Alumina water nano fluids were considered. The partial differential equations appearing in the governing equations of the problem were transformed into a couple of nonlinear ordinary differential equations with the help of similarity transformations. The transformed equations were solved numerically by the Keller Box method. For selected values of the parameters involved in the governing equations like nanofluid volume fraction, the porous medium parameter, magnetic parameter, Eckert number , Schmidt number, Soret number, thermal radiative parameter and chemical reaction parameter, numerical results of velocity field, temperature distribution, concentration, Skin friction coefficient, Nusselt number and Sherwood number were obtained. The results were analysed and discussed with the help of graphs and tables. Comparisons with previously published works were performed and they are in excellent agreement.

Khanafer (2013) numerically investigated the natural convective flow and heat transfer in a cavity filled with a saturated porous medium using fluid structure interaction for various pertinent parameter such as Rayleigh number, elasticity of the flexible wall, effective thermal conductivity of porous medium and porosity. The result shows that Rayleigh number and elasticity of the flexible wall have a profound impact on the shape and the penetration of the flexible wall and consequently on the heat transfer enhancement.

1.10 PROFILE OF PRESENT WORK

The thesis is devoted to study a few problems on effect of thermo physical parameters on heat and mass transfer in hydro magnetic flow and also on a continuously moving surface.

In Chapter 2, the effects of power law index of the surface temperature variation (exponent), magnetic parameter and variable parameter on a hydro magnetic flow and heat transfer on a continuously moving surface have been studied numerically using the Runge-Kutta Gill method together with the shooting technique.

In Chapter 3, the studies of free convection of heat transfer in flow past a semi-infinite flat plate in transverse magnetic field with heat flux have been examined. The governing equations are solved numerically using the Runge-Kutta method with shooting technique.

In Chapter 4, an analysis is carried out to study free convection and heat transfer flow with the effect of radiation over an exponentially stretching surface with MHD. Using the similarity variable, the partial differential equations are reduced to ordinary differential equations. Furthermore, the similarity equations are solved numerically by using Runge-Kutta Gill method along with shooting technique.

In Chapter 5, approximate numerical solutions for free convective heat and mass transfer flow near a continuous moving plate with variable temperature have been analyzed. The non-linear partial differential equations, governing the flow field under consideration have been transformed into a system of ordinary differential equations and then solved numerically by applying Runge-Kutta Gill method along with shooting technique.

In Chapter 6, the approximate numerical solution is presented to study the effects of thermal radiation, chemical reaction, internal heat generation on chemically reacting MHD boundary layer flow of heat and mass transfer past a moving vertical plate with suction/injection. It investigates numerically the effects of heat and mass transfer in a hydro magnetic boundary layer flow of a moving vertical porous plate with uniform heat generation, chemical reaction, thermal radiation, and magnetic strength field in the presence of suction/injection.

In Chapter 7, the results of the interpretation and analysis of the conclusion of previous chapters are given in detail. The scope for the future work is also enumerated briefly.