SYNOPSIS

The study of convective flows with heat and mass transfer in a porous medium has attracted considerable attention in recent times due to numerous applications in geothermal energy, oil reservoir modeling, building insulation, food processing and grain storage.

Flow through porous media is very prevalent in nature and therefore the study of flow through porous medium has become of principal interest in many scientific and engineering applications. In the theory of flow through a porous medium, the role of momentum equation or free balance is occupied by the numerous experimental observations summarized mathematically as the Darcy’s Law. It is observed that the Darcy’s law is applicable as long as the Reynolds number based on average grain (pore) diameter does not exceed a value between 1 and 10. But in general, the speed of specific discharge increases, the convective forces get developed and the internal stress generated in the fluid due to its viscous nature produces distortions in the velocity field. Saffman (112) employing statistical method derived a general governing equation for the flow in a porous medium which takes into account the viscous stress. Later another modification has been suggested by Brinkmann (14)

\[ \mathbf{O} = -\nabla \mathbf{p} - \frac{\mu}{k} \nabla \mathbf{v} + \mu \nabla^2 \mathbf{v} \]

in which \( \mu \nabla^2 \mathbf{v} \) is intended to account for the distortions of the velocity profiles near the boundary. The same equation was derived analytically by Tam (125) to describe the viscous flow at low Reynolds number past a swarm of small particles. This problem of combined buoyancy driven thermal and mass diffusion has been studied in parallel plate geometries by a few authors in recent times, notably Gebhart
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 reactions. The volumetric heat generation has been assumed to be constant (16, 57, 95, 103) or a function of space variable (28, 47, 49, 55, 75). For example, a hypothetical core – disruptive accident in a liquid metal fast breeder reactor (LMFBR) could result in the setting of fragmented fuel debris on horizontal surfaces below the core. The porous debris could be saturated sodium coolant and heat generation will result from the radioactive decay of the fuel particulate. Keeping this in view, porous medium with internal heat source have been discussed by several authors (17, 53, 103). Another class of problems involving natural convection in porous medium are those related to geothermal energy systems. The heat loss from the geothermal systems in some cases can be treated as if the heat comes from the heat generating source (43a). Vajravelu and Hadjinicolaou [133a] studied the heat transfer characteristics in the laminar boundary layer of a viscous fluid over a stretching sheet with viscous dissipation or frictional heating and internal heat generation. Hossain et al [55a] studied the problem of natural convection flow along a vertical wavy surface with uniform surface temperature in the presence of heat generation or absorption. Alam et al. [8a] studied the problem of free convection heat and mass transfer flow past an inclined semi-infinite heated surface of an electrically conduction and steady viscous incompressible fluid in the presence of a magnetic field and heat generation. Chamkha [26a] investigated unsteady convective heat and mass transfer past a semi-infinite porous moving plate with heat absorption. Hady et al. [49a] studied the problem of free convection flow along a vertical wavy surface.
embedded in electrically conducting fluid saturated porous media in the presence of internal heat generation or absorption effect.

Non-Darcy effects on natural convection in porous media have received a great deal of attention in recent years because of the experiments conducted with several combinations of solids and fluids covering wide ranges of governing parameters which indicate that the experimental data for systems other than glass water at low Rayleigh members do not agree with theoretical predictions based on the Darcy flow model. This divergence in the heat transfer results has been reviewed in detail in Cheng (100) and Prasad et al., (130) among others. Extensive efforts are thus being made to include the inertia and viscous diffusion terms in the flow equations and to examine their effects in order to develop a reasonable accurate mathematical model for convective transport in porous media. The work of Vafai and Tien (62) was one of the early attempts to account for the boundary and inertia effects in the momentum equation for a porous medium. They found that the momentum boundary layer thickness is of order of \( \frac{L}{\sqrt{\tau}} \). Vafai and Thyagaraja (66) presented analytical solutions for the velocity and temperature fields for the interface region using Brinkmann–Forchheimer–extended Darcy equation. Detailed accounts of the recent efforts on non-Darcy convection have been recently reported in Tien and Hong (24), Chang (101), Prasad et al (129) and Kalidas and Prasad (63). Poulikakos and Bejan (32) investigated the inertia effects through the inclusion of Fochhammer’s velocity squared term and presented the boundary layer analysis for tall cavities. They also obtained numerical results for a few cases in order to verify the accuracy of their boundary layer solutions. Later Prasad and Tuntomo (128) reported an extensive numerical work for a wide range of parameters and demonstrated that effects of Prandtl number remain almost unaltered while the dependence on the modified
Grashof number $Gr$ changes significantly with an increase in the Forchheimer number. They also reported a criterion for the Darcy flow limit.

The Brinkmann - Extended Darcy model was considered in Tong and Subramanian (127) and Laurait and Prasad (43) to examine the boundary effects on free convection in a vertical cavity. While Tong and Subramanian performed a Weber - type boundary layer analysis, Laurait and Prasad solved the problem numerically for $A = 1$ and 5. It was shown that for a fixed Rayleigh number $Ra$, the Nusselt number decreases with an increase in the Darcy number, the reduction being larger at higher values of $Ra$. A scale analysis as well as the computational data also showed that the transport term $(v.V)v$, is of low order of magnitude compared to the diffusion plus buoyancy terms (43). A numerical study based on the Forchheimer – Brinkmann – Entended Darcy equation of motion has also been reported recently by Beckermann et al (15). They demonstrated that the inclusion of both the inertia and boundary effects is important for convection in a rectangular packed – sphere cavity.

The application of electromagnetic fields in controlling the heat transfer as in aerodynamic heating leads to the study of magneto hydrodynamic heat transfer. This MHD heat transfer has gained significance owing to recent advancement of space technology. The MHD heat transfer can be divided into two sections. One contains problems in which the heating is an incidental by-product of the electro magnetic fields as in MHD generators pumps etc., and the second consists of problems in which the primary use of electromagnetic fields is to control the heat transfer (91) with the fuel crisis deepening all over the world. There is great concern to utilize the enormous power beneath the earth’s crust in the geothermal region (7). Liquid in the geothermal region is an electrically conducting liquid because of high
temperature. Hence the study of interaction of the geomagnetic field with the fluid in the geothermal region is of great interest, thus leading to interest in the study of MHD convection flows through porous medium.

Bharathi et al. (16.a.) have discussed Non-Darcy Hydro Magnetic Mixed convective Heat and Mass Transfer flow of a viscous fluid in a vertical channel with Heat generating sources. Padmavathi et. al [96] have discussed finite element analysis of Non-Darcy convective Heat and Mass Transfer through a porous medium in a cylindrical annulus with asymmetric wall temperature. Suresh et al. [141] have discussed Non-Darcy Hydromagnetic convective Heat and Mass transfer through a porous medium in a cylindrical annulus with soret effect, radiation and dissipation. Balasubramanyam et al [8.b] have discussed Non Darcy viscous electrically conductive Heat and Mass transfer flow through a porous medium in a vertical channel in the presence of heat generating sources.

Combined heat and mass transfer problems with chemical reaction are importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one of in which electrical energy is extracted directly from a moving conducting fluid. Obviously, the understanding of this transport process is desirable in order to effectively control the overall transport characteristics. The combined effect of thermal and mass diffusion in channel flows
has been studied in the recent times by a few authors (23, 41, 60, 92, 105, 106, 116, 117).

All the above mentioned studies are based on the hypothesis that the effect of dissipation is neglected. This is possible in case of ordinary fluid flow like air and water under gravitational force. But this effect is expected to be relevant for fluids with high values of the dynamic viscosity force. Moreover Gebhart (45), Gebhart and Mollendorf (46) have shown that viscous dissipation heat in the natural convective flow is important when the fluid is of extreme size or is at extremely low temperature or in high gravitational field. On the other hand, Barletta (18) and Zanchini (134,135) pointed out that relevant effects of viscous dissipation on the temperature profiles and the Nusselt number may occur in the fully developed convection in tubes. In view of this, several authors, notably Soundalgekar and Pop (122), Soundalgekar et al., (123), Barletta (18,19) and Zanchini (134,135), Sreevani (118), El Hakein (39), Bulent Yasilata (20) and Barletta and Rissidischio (19) have studied the effect of viscous dissipation on the convective flows past an infinite vertical plate and through vertical channels and ducts.

Raptis (109) analyzed the thermal radiation and free convection flow through a porous medium by using perturbation technique. Bakier and Gorla (21) investigated the effect of thermal radiation on mixed convection from horizontal surfaces in saturated porous media. Satapathy et al., (120) studied the natural convection heat transfer in a darcian porous regime with Rosseland radiative flux effects. With regard to thermal radiation heat transfer flows in porous media, Chamkha (26) studied the solar radiation effects on porous media supported by a vertical plate. Forest fire spread also constitutes an important application of radiative convective heat transfer.
as described by Meroney (89). More recently Chitrapiromsri and Kuznetsov (27) have studied the influence of high-intensity radiation in unsteady thermo fluid transport in porous wet fabrics as a model of fire fighter protective clothing under intensive flash fires. Impulsive flows with thermal radiation effects and in porous media are important in chemical engineering systems, aerodynamic blowing processes and geophysical energy modeling. Such flows are transient and therefore temporal velocity and temperature gradients have to be included in the analysis. Raptis and Singh (107) studied numerically the natural convection boundary layer flow past an impulsively started vertical plate in a Darcian porous medium. The thermal radiation effects on heat transfer in magneto–aerodynamic boundary layers has also received some attention, owing to astronautical re-entry, plasma flows in astrophysics, the planetary magneto-boundary layer and MHD propulsion systems. Mosa (90) discussed one of the first models for combined radiative hydromagnetic heat transfer, considered the case of free convective channel flows with an axial temperature gradient. Nath et al. (94) obtained a set of similarity solutions for radiative–MHD stellar point explosion dynamics using shooting methods. Abd-El-Naby et al. (8) presented a finite difference solution of radiation effects on MHD unsteady free convection flow over a vertical porous plate. Shateyi et al. (121) have analyzed the Thermal Radiation and Buoyancy Effects on Heat and Mass Transfer over a Semi-Infinite Stretching Surface with Suction and Blowing. Dulal Pal et al. (36) have discussed Heat and Mass transfer in MHD non-darcian flow of a micropolar fluid over a stretching sheet embedded in a porous media with non-uniform heat source and thermal radiation. Dulal Pal et al. (37) have analyzed unsteady magneto hydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Ahmed et al
(2a) have analyzed the thermal radiation effect on a transient MHD flow with mass transfer past an impulsively fixed infinite vertical plate. Rajesh et al (104) have considered the radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion, soret & duffer effect. Rawat et al (111) have discussed the finite element study of natural convection heat and mass transfer in a micropolar fluid-saturated porous regime with. Ganesam and Loganathan (40) studied the effect of the radiation and mass transfer effects on flow past a moving vertical cylinder using Rossel and approximation by the Crank – Nicolsan finite difference method. Seddeek.M.A et al (114) have discussed the effects of chemical reaction and variable viscosity on hydro magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation. Devikarani et al. have considered oscillatory mixed convection in horizontal channel with heat sources and radiation effect.

In all above studies the thermal –diffusion effect (Soret effect) has been neglected. This assumption is true when the concentration level is very low. There are, however, exemptions. The Soret effect for instance, has been utilized for isotope separation and in mixtures between gases with very low molecular weight (H2,He) and the medium molecular weight (N2,air), the Soret effect was found to be of a magnitude just it can not be neglected (Eckert and Drake (38)). In view of the importance of this Soret effect, recently Jha and Singh (59) studied the free convection and mass transfer flow in an infinite vertical plate moving impulsively in its own plane, taking into the account of Soret effect. The analytical studies of Jha and Singh and Kafoussias (59, 61) were based on Laplace transform technique. Abdul sattar and Alam (1) have considered an unsteady convection and mass transfer flow of viscous incompressible fluid and electrically conducting fluid past a moving infinite
vertical porous plate taking into the thermal diffusion effect. Similarity equations of momentum, energy and concentration equations are derived by introducing a time dependent length scale. Malshetty et al (81) studied the effect of both soret and duffer effects on the double diffusive convection with compensating horizontal and thermal and solute gradients. Ajay Kumar Singh (3) studied the study free convection and mass transfer flow with Hall Effect, viscous dissipation and joule heating, taking into account the thermal diffusion effect. Sreevani (118) has analyzed the free convective heat and mass transfer flow of a viscous incompressible fluid through a porous medium confined in vertical channel in the presence of constant heat source Q bounded by flat plates. Reddaih et al. [111] have discussed dissipative and soret effect on convective heat and mass transfer through a porous medium in a vertical channel maintained at Non uniform temperature. Sreenivasa Reddy [124] have discussed mixed convective heat and mass transfer through a porous medium in a channel with variable permeability and soret effect. Reddaih [111a] has considered finite element analysis of convective heat and mass transfer through a porous medium in horizontal porous channel with dissipative and soret effects.

In recent years, energy and material saving considerations have prompted an expansion of the efforts at producing efficient heat exchanger equipment through augmentation of heat transfer. It has been established (44) that channels with diverging – converging geometries augment the transportation of heat transfer and momentum. As the fluid flows through a tortuous path viz., the dilated – constricted geometry, there will be more intimate contact between them. The flow takes place both axially (primary) and transversely (secondary) with the secondary velocity being towards the axis in the fluid bulk rather than confining within a thin layer as in straight channels. Hence it is advantageous to go for converging – diverging
geometries for improving the design of heat transfer equipment. Vajravelu and Nayfeh (133) have investigated the influence of the wall waviness on friction and pressure drop of the generated coquette flow. Vajravelu and Sastry (131) have analysed the free convection heat transfer in a viscous, incompressible fluid confined between long vertical wavy walls in the presence of constant heat source. Later Vajravelu and Debnath (132) have extended this study to convective flow in a vertical wavy channel in four different geometrical configurations. This problem has been extended to the case of wavy walls by McMichael and Deutsch (87), Deshikachar et al (33, 34), Rao et al (102) and Sree Ramachandra Murthy (119). Hyan Goo Kwon et al (56) have analyzed that the flow and heat/mass transfer in a wavy duct with various corrugation angles in two dimensional flow regimes. Mahdy et al (79) have studied the mixed convection heat and mass transfer on a vertical wavy plate embedded in a saturated porous media (PST/PSE). Mahdy et al (79) have considered the Heat and mass transfer in MHD free convection along a vertical wavy plate with variable surface heat and mass flux. Comini et al (29) have analyzed the Convective heat and mass transfer in wavy finned-tube exchangers. Jer-Huan Jang et al (58) have analyzed that the Mixed convection heat and mass transfer along a vertical wavy surface

Combined heat and mass transfer problems with chemical reaction are importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one of in which electrical energy is extracted directly from a moving conducting fluid. Obviously, the understanding of this
transport process is desirable in order to effectively control the overall transport characteristics. The combined effect of thermal and mass diffusion in channel flows has been studied in the recent times by a few authors (23,41,60,92,105,106,116,117). The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. A large amount of research work has been reported in this field. In particular the study of heat and mass transfer with chemical reaction is of considerable importance in chemical and hydrometallurgical industries. Chemical reaction can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. Frequently the transformations proceed in a moving fluid, a situation encountered in a number of technological fields. A common area of interest in the field of aerodynamics is the analysis of thermal boundary layer problems for two dimensional steady and incompressible laminar flows passing a wedge. Simultaneous heat and mass transfer from different geometrics embedded in a porous media has many engineering and geophysical application such as geothermal reservoirs, drying of porous solids thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors, and under ground energy transport. A very significant area of research in radiative heat transfer, at the present time is the numerical simulation of combined radiation and convection/conduction transport processes. The effort has arisen largely due to the need to optimize industrial system such as furnaces, ovens and boilers and the interest in our environment and in no conventional energy sources, such as the use of salt-gradient solar ponds for energy collection and storage. In particular, 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 process, solidification of binary alloy and chemical engineering. Kandaswamy et al (64) have discussed the effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in the presence of suction or injection. Mansour et al (83) have studied the coupled heat and mass transfer in darcy free convection from a heated vertical plate embedded in a porous media under the effect of chemical reaction. Kulandaivel et al (68) have considered the chemical reaction on moving vertical plate with constant mass flux in the presence of thermal radiation. Mansour et al (84) have analyzed the effects of chemical reactions and radiation on MHD free convective heat and mass transfer from a horizontal cylinder of elliptic cross section saturated in a porous media with considering suction or injection. Beg et al (10) have considered the chemically-reacting mixed convective heat and mass transfer along inclined and vertical plates with soret and dufour effects: numerical solutions. Mansour et al (85) have studied the effect of chemical reaction and viscous dissipation on MHD natural convection flows saturated in porous media with suction or injection. Nasser S. Elgazery et al (93) have discussed the effects of chemical reaction, Hall and ion-slip currents on MHD flow with temperature dependent viscosity and thermal diffusivity. Sudarshan Reddy [147] has discussed combined influence of sorret and dufour effect on convective heat and mass transfer flow through a porous medium in a cylindrical annulus with heat sources. 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 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.

The effect of radiation on MHD flow and heat transfer problem has become more important industrially. At high operation temperature, radiation effect can be quite significant. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. Bestman [137] examined the natural convection boundary layer with suction and mass transfer in a porous medium. His results confirmed the hypothesis that suction stabilizes the boundary layer and affords the most efficient method in boundary layer control yet known. Abdul Sattar and Hamid Kalim [138] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Mankinde[139] examined the transient free convection interaction with thermal radiation of an absorbing-emitting fluid along moving vertical permeable plate. Recently Ibrihem et al. [140] have studied non classical thermal effects in Stoke's second problem for micropolar fluids by used perturbation method. Keeping the above applications in view we make an attempt to investigate Heat and Mass transfer of viscous incompressible electrically
conducting fluid through a porous medium in planar/circular/rectangular ducts under different conditions. The thesis is divided into six chapters.

The first chapter is introductory in nature. It explains the objective, motive and scope of the thesis. It also gives an idea of the survey work done for the thesis. This chapter presents a brief description of the physical properties of viscous, incompressible fluids and their applications, the basic constitutive equations and boundary layer assumptions to derive boundary layer equations for various dimensionless parameters involved.

In the second chapter, we investigate the effect of hall currents on the double diffusion heat transfer flow of a chemically reaction fluid past a stretching sheet in the presence of constant heat sources. The equations governing the flow heat and mass transfer are solved by employing a Galerkin finite element analysis with three nodded line segments. The velocity, temperature, and concentration are solved for different variations of governing parameters $G$, $M$, $m$, $N$, $Sc$, $\alpha$, $\gamma$. The rate of heat and mass transfer are numerically evaluated for different variations of parameters.

In the third chapter, we investigate the combined influence of thermal radiation and chemical reaction on mixed convective heat and mass transfer flow of a viscous fluid through a porous medium in a rectangular cavity with non-linear density temperature variation in the presence of constant heat sources. The equations governing flow, heat and mass transfer are solved by Galerkin finite element analysis with linear triangular elements. The velocity, temperature, and concentration are discussed for different variations of different horizontal and vertical levels. The rate of Heat and Mass transfer are discussed for different variations of parameters $Ra$, $Sc$, $G$, $D_1^1$, $N$, $N_1$, $\alpha$ and $\gamma$. 

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In the fourth chapter, we consider the effect of radiation and chemical reaction on convective heat and mass transfer flow of a viscous fluid through a porous medium in a vertical channel on whose walls an oscillatory temperature and concentration is prescribed. Assuming the solution to consists of steady and transient past. The equations governing the flow, heat and mass transfer are solved. The effect of thermal radiation and chemical reaction on all flow characteristics are discussed in detail.

In the fifth chapter, we discussed the effect of thermo-diffusion on the Non-Darcy mixed convective Heat and Mass transfer flow of a viscous fluid through a porous medium in a vertical channel bounded by the flat walls in the presence of heat generating sources. The governing equations are solved by perturbation technique with a porous parameter $\delta$ as a perturbation parameter. The velocity, Temperature and concentration, the rate of Heat and Mass transfer are discussed for a different variations of $G$, $D^{-1}$, $N, N_1, Sc, So, \alpha$. The influence of various flow forces on flow characteristics are discussed in detail.

In the last chapter, we analysis the influence of thermal diffusion and radiation effects on the unsteady mixed convective heat transfer flow of a viscous fluid in a vertical wavy cylinder which is maintained at traveling thermal waves. Taking the aspect ratio $\delta$ to be small, we solve the equations governing flow Heat and Mass transfer by a perturbation Technique with $\delta$ as a perturbation parameter. The effect of thermo diffusion and radiation on all the flows characteristics are discussed in detail.
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