Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2017, 4(9):75-85**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

MHD Mixed Convection Heat and Mass Transfer Flow from Vertical Surfaces in Porous Media with Soret and Dufour Effects

Okedoye A.M.[1]*, Akinrinmade V.A.[2]

[1]Department of Mathematics and Computer Science, Federal University of Petroleum Resources, Effurun, Nigeria

[2]Department of Mathematics and Statistics, osun State College of Technology, Esa-Oke, Osun State, Nigeria

Abstract In this paper MHD Mixed Convection Heat and Mass Transfer Flow from Vertical Surfaces in Porous Media with Soret and Dufour Effects has been considered. Numerical Calculations for non-dimensional velocity, temperature and concentration profiles for different values of governing parameters on the flow were carried out. Attention is focused on positive values of the buoyancy parameters which correspond to the cooling of the plate problem. From the result, it was discovered that the non-dimensional velocity increases with thermal Grashof, Soret and Dufour numbers. Increasing magnetic field strength also decreases the velocity boundary layer, skin-friction, Nusselt and Schmidt numbers. Soret and Dufour numbers as well as magnetic field strength were seen to increases temperature. Effect of other governing parameters were obtained, presented in graphs and table and discussed.

Keywords free convection, porous medium, MHD, Dufour, Soret and finite difference method
Mathematics Subject Classifications: 76W05, 76D05, 80A20

Introduction

Several studies have been found in literature to analyze the influence of the combined heat and mass transfer process by natural convection in a thermal and/or mass stratified porous medium. This is due to its wide applications, such as development of advanced technologies for nuclear waste management, hot dike complexes in volcanic regions for heating of ground water, separation process in chemical engineering, etc. Here stratified porous medium means that the ambient concentration of dissolved constituent and/or ambient temperature is/or not uniform and varies as a linear function of vertical distance from the origin. When heat and mass transfer occur simultaneously in a moving fluid, the relation between the fluxes and the driving potentials are of more intricate nature. It has been found that an energy flux can be generated not only by temperature gradients but by composition gradients as well. The energy flux caused by a composition gradient is called the Dufour or diffusion-thermo effect. On the other hand, mass fluxes can also be created by temperature gradient and this is the Soret or thermal–diffusion effect. These effects are considered as second-order phenomena, on the basis that they are of smaller order of magnitude than the effects described by Fourier's and Fick's laws, but they may become significant in areas such geosciences or hydrology.

Heat and mass transfer by natural convection in a fluid-saturated porous medium is an active area of research due to the numerous area of applications such as oil recovery, geothermal reservoirs, drying of porous solids and cooling of nuclear reactors. Earlier researcher in this area includes but not limited to [1] who made the first contribution in this direction by examining the two-dimensional flow of a fluid near a stagnation point and obtained an exact similarity solution of the governing equations. Thermal effects in such a flow were introduced by [2]. Devi *et al.* [3] presented the unsteady mixed convection in stagnation point flows for arbitrary distribution of surface temperature and concentration or surface heat and mass flux conditions. They found that dual solutions exist for a certain range of the buoyancy parameter when the flow is opposing. The effect of radiation on MHD flow and heat transfer problems has become industrially more important. Many engineering processes occur at high temperatures and hence the knowledge of radiation heat transfer is essential for designing appropriate equipment. In designing some of the complex equipments such as Nuclear power plants, gas turbines and various propulsion devices for aircrafts, the knowledge of radiation heat transfer becomes essential. In view of these, many authors have made contributions to the study of fluid flow with thermal radiation.

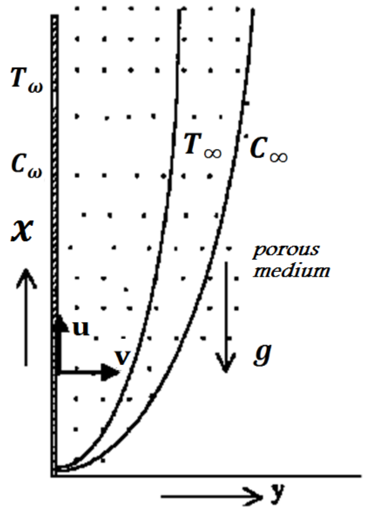

Figure 1: Flow model and physical coordinate system

Simultaneous heat and mass transfer by natural convection in a two dimensional stagnation point flow of a fluid saturated porous medium, using the Darcy–Boussinesq model, including suction/blowing, Soret and Dufour effects are studied by [4]. [5]have analytically studied the problem of the two dimensional stagnation-point flow in a porous medium of a viscous incompressible fluid impinging on a permeable stretching surface with heat generation/absorption. [6] studied thermal-diffusion and diffusion-thermo effects on combined heat and mass transfer on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with a viscoelastic fluid in the presence of magnetic field is investigated. Numerical values of physical quantities, such as the local skin friction coefficient, the local Nusselt number and the local Sherwood number are presented and discussed. [7] extended to work of [8] to include hydro-magnetic mixed convection stagnation point flow with thermal radiation past a vertical plate embedded in a porous medium.

Bhupendra [9] report the Soret and Dufour effects on unsteady MHD mixed convection flow past an infinite radiative vertical porous plate embedded in a porous medium in the presence of chemical reaction. They used Rosseland approximation to describe the radiative heat flux in energy equation. [10] studies the Soret and Dufour effects on the boundary layer flow due to mixed convection heat and mass transfer over a downward-pointing vertical wedge in a porous medium saturated with Newtonian fluids with constant wall temperature and concentration. The effects of the Dufour parameter, Soret parameter, wedge angle parameter, mixed convection variable, and buoyancy ratio on the heat and mass transfer characteristics were presented. The analysis the effects of heat and mass transfer in the presence of thermal radiation, internal heat generation and Dufour effect on an unsteady magneto-hydrodynamic mixed convection stagnation point flow towards a vertical plate embedded in a porous medium was presented by [11]. They report that the temperature increases for increasing values of the internal heat generation, thermal radiation and the Dufour number and hence thermal boundary layer thickness increases. [12] extended the work of [13] on problem of radiative natural convection heat transfer flow past an inclined surface embedded in a porous medium. They have analyzed this problem with the inclusion of internal heat generation and found that both the velocity and temperature increase significantly when the value of the heat generation parameter increases.

Darbhasayanam [14] analyzes the flow, heat and mass transfer characteristics of the mixed convection on a vertical plate in a micropolar fluid in the presence of Soret and Dufour effects. The rate of heat and mass transfer at the plate are presented graphically for various values of coupling number, magnetic parameter, Prandtl number, Schmidt number, Dufour and Soret numbers. Soret and Dufour effects on similarity solution of hydro magnetic heat and mass transfer over a vertical plate with a convective surface boundary condition and chemical reaction are studied by [15].
Babu [16] have analyzed the steady MHD boundary layer flow due to an exponentially stretching sheet with radiation in the presence of mass transfer and heat source or sink. Lie group analysis of natural convection over an inclined semi-infinite plate with variable thermal conductivity is investigated by [17]. They observed that the velocity and temperature for all angles increase when the thermal conductivity parameter increases. An analysis of visco-elastic free convective MHD flow over a vertical porous plate through porous media in presence of radiation and chemical reaction is presented by [18]. Sinha [19] presented a numerical solution on a MHD stagnation-point flow with heat transfer over a shrinking sheet in the presence of magnetic field. The effects of slip velocity and thermal slip on an electrically conducting viscous incompressible fluid are investigated in this paper. Steady two-dimensional stagnation point flow and heat transfer of a nanofluid over a porous stretching sheet with heat generation is investigated analytically by [20]. An investigation of the effects of Hall current and rotation on unsteady hydro-magnetic natural convection flow with heat and mass transfer of an electrically conducting, viscous, incompressible and time dependent heat absorbing fluid past an impulsively moving vertical plate in a porous medium taking thermal and mass diffusions into account is carried out by [21]. Jagadha and Kishan [22]analyze the effects of Soret and Dufour and MHD on Darcy-Forchheimer mixed convection flow with heat and mass transfer from a vertical flat plate embedded in a saturated porous medium taking into the influence thermophoresis, viscous dissipation and radiation. Other relevant work to this paper could be found in [23].
Motivated by the above studies, we investigate MHD Mixed Convection Heat and Mass Transfer Flow from Vertical Surfaces in Porous Media with Soret and Dufour Effects has been considered. Numerical Calculations for non-dimensional velocity, temperature and concentration profiles for different values of governing parameters on the flow were carried out. Attention is focused on positive values of the buoyancy parameters which correspond to the cooling of the plate problem.

Problem Formulation

Consider the natural convection in a porous medium saturated with a Newtonian fluid on a vertical flat plate. The x-coordinateis measured along the surface and the y-coordinate normal to it (see Fig. 1).The temperature of theambient medium is T_∞ and the wall temperature is T_w. The flow along the vertical flat plate contains a species Aslightly soluble in the fluid B, the concentration at the plate surface is C_w and the solubility of A in B far away fromthe plate isC_∞.
Several assumptions are used in the present paper viz:

- the fluid and the porous medium are in local thermodynamic equilibrium;
- the flow is laminar, steady-state and two-dimensional;
- the porous medium is isotropic and homogeneous;
- the properties of the fluid and porous medium are constant;
- the Boussinesq approximation is valid and the boundary layer approximation is applicable;
- the concentration of dissolved A is small enough.

In-line with these assumptions, the governing equations describing the conservation of mass, momentum, energy and concentration can be written as follows

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial x}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}-\frac{\sigma\beta_0^2}{\rho}u+\frac{g\beta}{\rho}[(T-T_\infty)+(C-C_\infty)] \tag{2}$$

$$\rho c_p\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=K\frac{\partial^2 T}{\partial y^2}+\frac{D_m K_T}{c_s}\frac{\partial^2 C}{\partial y^2} \tag{3}$$

$$\rho\left(u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}\right)=D_m\frac{\partial^2 T}{\partial y^2}+\frac{D_m K_T}{T_m}\frac{\partial^2 C}{\partial y^2}+A(C-C_\infty) \quad (4)$$

Where all quantities are defined in the list of symbols.

The boundary conditions of the problem are

$$\left.\begin{aligned} y=0: v=0, T=T_w, C=C_w \\ y\to\infty: u\to 0, T\to T_\infty, C\to C_\infty \end{aligned}\right\} \quad (5)$$

WhereT_w, C_w, T_∞andC_∞have constant values.

Equations 1, 2, 3, 4, 5 are now nondimensionalized using the following quantities:

$$\psi=\sqrt{vU_0}x^{3/4}f(\eta), \eta=\sqrt{\frac{U_0}{v}}x^{-1/4}y, \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}, \emptyset(\eta)=\frac{C-C_\infty}{C_w-C_\infty}$$

Where the stream function ψsatisfied continuity equation (1)

The governing equations become

$$f'''+\frac{3}{4}ff''-\frac{1}{2}f'^2-Mf'+Gr(\theta+N\emptyset)=0 \quad (6)$$

$$\theta''+\frac{3}{4}Prf\theta'+Du\emptyset''=0 \quad (7)$$

$$\emptyset''+\frac{3}{4}Scf\emptyset'+Du\theta''=0 \quad (8)$$

The boundary conditions becomes

$$\left.\begin{aligned} \eta=0: f'(\eta)=\theta(\eta)=\phi(\eta)=1 \\ \eta\to\infty: f'(\eta)\to 0, \theta(\eta)\to 0\to, \phi(\eta)\to 0 \end{aligned}\right\} \quad (9)$$

where

$$M=\frac{\beta_0^2}{U_0}\frac{\sigma}{\rho}, Gr=\frac{g\beta_\tau(T_w-T_\infty)}{\rho U_0^2}, N=\frac{\beta_c(C_w-C_\infty)}{\beta_\tau(T_w-T_\infty)}$$

$$P_r=\frac{\mu c_p}{k}, Sc=\frac{\mu}{Dm}, Du=\frac{D_m(C_w-C_\infty)}{c_s(T_w-T_\infty)}, Sr=\frac{K_T(T_w-T_\infty)}{T_m(C_w-C_\infty)}$$

We notice that N is positive for thermally assisting flows, negative for thermally opposing flows and zero forthermal-driven flows.

The parameters of engineering interest for the present problem are the local Skin-Friction, local Nusselt number and local Sherwood number, which are given by the expressions.

Skin-Friction: We now study skin-friction from velocity field. It is given by

$$c_f=\frac{T_f}{\rho u_\infty v_\infty}=\frac{d^2}{dy^2}u(y,t)\bigg|_{y=0}$$

Therefore

$$\tau=-\frac{df(\eta)}{d\eta}\bigg|_{\eta=0}$$

Nusselt Number: In non-dimensional form, the rate of heat transfer at the wall is computed from Fourier's law and is given by

$$Nu=\frac{q_w v}{(T_w-T_\infty)kv_w}=-\frac{d}{dy}\theta(y,t)\bigg|_{y=0}, q_w=-k\frac{dT}{dy}\bigg|_{y=0}$$

Therefore,

$$Nu=-\frac{d\theta(\eta)}{d\eta}\bigg|_{\eta=0}$$

Sherwood Number: The rate of mass transfer at the wall which is the ratio of length scale to the diffusive boundary layer thickness is given by

$$Sh=\frac{J_w v}{(C_w-C_\infty)Dv_w}=\frac{d}{dy}\phi(y,t)\bigg|_{y=0}, J_w=-D\frac{d\phi}{dy}\bigg|_{y=0}$$

Which implies

$$Sh = -\left.\frac{d\phi(\eta)}{d\eta}\right|_{\eta=0}$$

Methodology and Solution of the Problem

Our method of solution depends on the application of trapezoid methods that use Richardson extrapolation enhancement or deferred correction enhancement**.** Numerical solution to the transformed set of non-linear ordinary differential equations (6)–(8) with boundary conditions in (9) were obtained, using a seventh-eighth order continuous Runge-Kutta method along with boundary value problem sub method 'trapezoid methods (traprich)' that use Richardson extrapolation enhancement [24]. Because of end-point singularities, midpoint (middefer) methods with deferred correction enhancement are coupled together to handle harmless end-point singularities, with Sr, Du, M, N, γ and$v_0$as prescribed parameters.

Grid-independence studies show that the computational domain $0 < \eta < \eta_\infty$ can be divided into intervals each of uniform step size which equals 0.02. This reduces the number of points between $0 < \eta < \eta_\infty$ without sacrificing accuracy. The value $\eta_\infty = 6$ was found to be adequate for all the ranges of parameters studied here.

Results and Discussion

Numerical Calculations were carried out for non-dimensional velocity profiles f', temperature profiles θ, and concentration profiles ϕ different values of Du , Sr , M, $Gr$and N, for the purpose of discussing the effect of governing parameters on the flow. Attention is focused on positive values of the buoyancy parameters that is, thermal Grashof number $Gr > 0$, which corresponds to the cooling of the plate problem. In order to point out the effects of these parameters on flow characteristic, to be realistic, the value of Prandtl number is chosen to be $Pr = 0.71$ and $Sc = 0.62$ which represents air at temperature 25^oC and one atmospheric pressure. All parameters are primarily chosen as follows: $Sr = 0.5, Du = 0.5, Gr = 2.0, M = 0.2,$ and $N = 0.5$ unless otherwise stated. It worth mention that $N < 1$ implies that thermal buoyancy is dominant and $N > 1$ means mass buoyancy is dominant.

In fig. 1.1, the effect of fluid type on transient velocities is presented for different values of Pr. The non-dimensional velocity f' decreases with an increase in Prandtl number. This will be so because fluids with higher Prandtl number have higher density and thus less volatile. In fact, the higher the Prandtl number, the more the fluid transit to solid state. Velocity increases with thermal Grashof, Soret and Dufour numbers as seen in fig. 1.2, 1.3 and 1.4 respectively. The effect of increasing the magnetic field strength is seen to decrease the velocity boundary layer. It is a well-established fact that magnetic field present a damping force on the velocity as a result of induced Lorentz force with opposes the motion. Thus increase in Hartmann number decreases the velocity as seen in fig. 1.5. Fig. 1.6 displays the effect of buoyancy ratio on the flow velocity. It could be seen that velocity increases with the increasing of N. The presence of peaks in the velocity profiles indicates that the maximum velocity occur in the body of the fluid close to the surface. However, we observed that at lower thermal Grashof number or when thermal Grashof number is zero, the maximum velocity is the velocity at the surface. Higher magnetic field strength may remove the maximum velocity from the body to the surface. From figures 2.1 – 2.5 show that the temperature profiles for different flow parameters. In Fig. 2.1 Temperature profile is seen to increase with a decrease in thermal Grashof number. Soret and Dufour numbers as well as magnetic field strength are seen to increases the floe temperature as shown in fig. 2.2 – 2.4 respectively. In fig. 2.5, increase in buoyance force is shown to decrease the temperature field. In addition, the maximum temperature is at the surface. The concentration profiles are displayed in Figures 3.1 to 3.5. From these figures, we observed that an increase in thermal Grashof or Dufour numbers and magnetic field strength decreases the concentration boundary layers as shown in figures 3.1, 3.3 and 3.5 respectively. The concentration is seen from fig. 3.2 to increase with an increase in Soret number. Higher values of Soret number is seen to shift the maximum velocity to the body of the fluid close to the surface. In fig 3.4, the concentration profile plotted for different buoyancy ratio. From this figure we observed that the concentration profile decreases with the increase in buoyancy ratio.

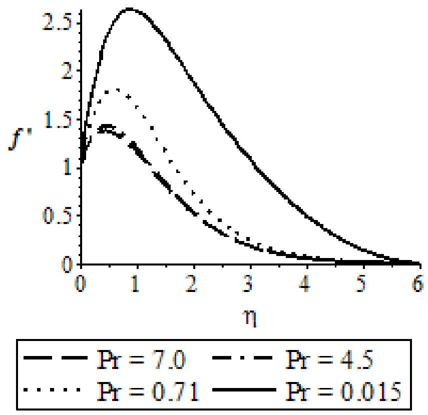

Figure 1.1: Effect of fluid type on the flow velocity field

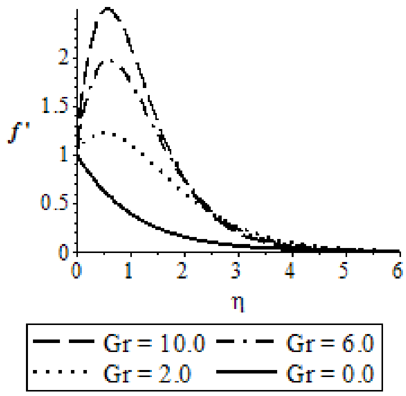

Figure 1.2: Effect of Grashof number on the flow velocity

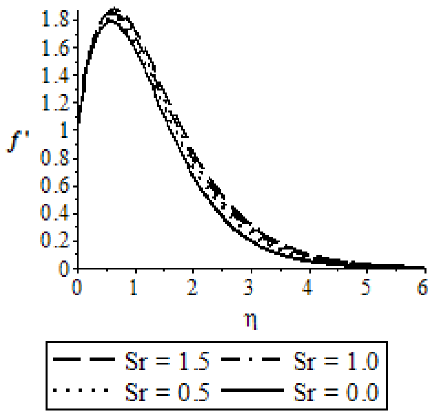

Figure 1.3: Effect of Soret number on the flow velocity

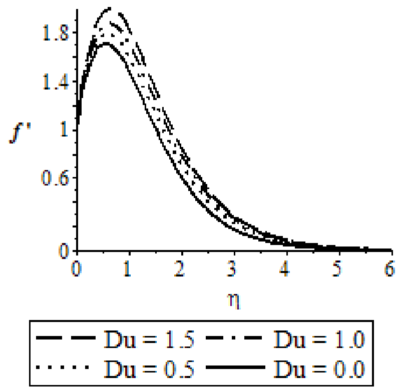

Figure 1.4: Effect of Dufour number on the flow velocity

The effect of flow governing parameters of interest on Skin-friction, rate of heat transfer and mass transfer rate at the wall are shown in Table 1. From this table it could be seen that increase in Prandtl number brings about increase in skin-friction and Schmidt number and decreases Nusselt number. It is also observed from the table that thermal Grashof number and buoyancy ratio brings about increase in $\tau, Nu$and Sh. Increase in Soret number is seen to result in increase in skin-friction and Schmidt number and, decrease Nusselt number. While, increase in Dufour number is seen to increase both skin-friction and rate of heat transfer at the wall, but decreases mass transfer rate at the wall. It is also seen from the table that, increase in magnetic field strength result in decrease skin-friction, Nusselt and Schmidt numbers.

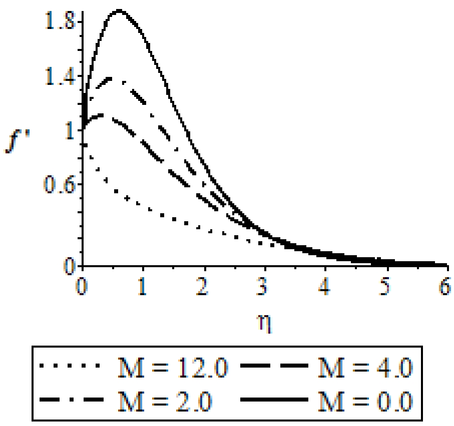

Figure 1.5: Effect of Hartmann number on the flow velocity

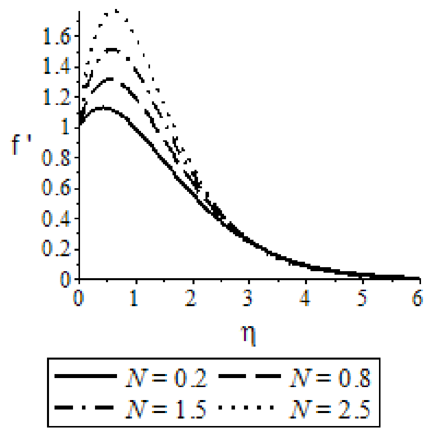

Figure 1.6: Effect of buoyancy ratio on the flow velocity

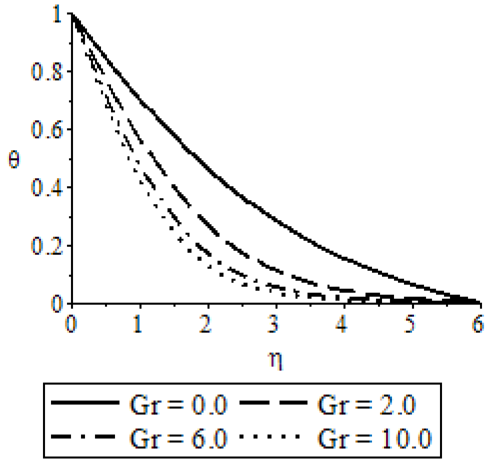

Figure 2.1: Effect of Grashof number on temperature distribution

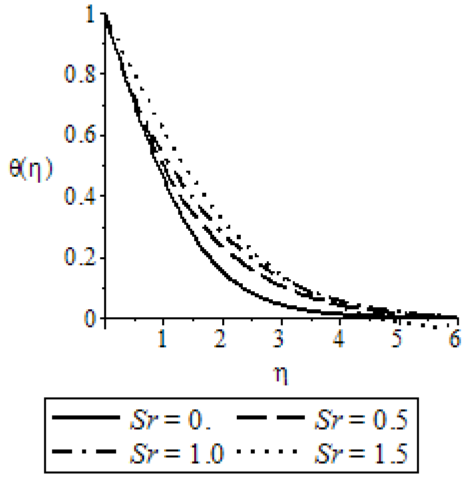

Figure 2.2: Effect of Soret number on temperature distribution

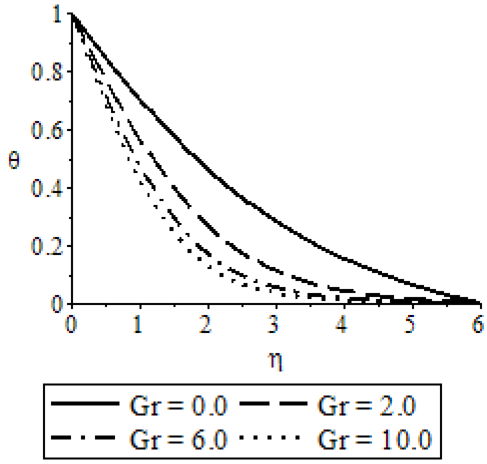

Figure 2.3: Effect of Dufour number on temperature distribution

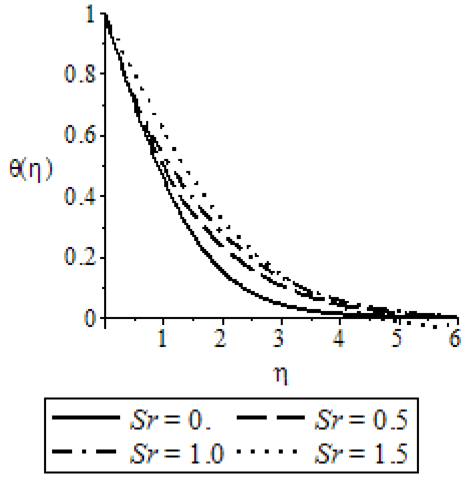

Figure 2.4: Effect of Hartmann number on temperature distribution

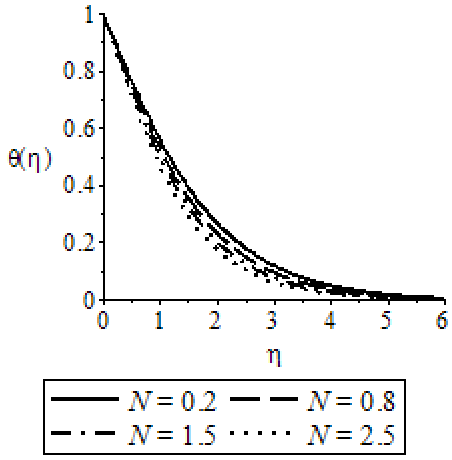

Figure 2.5: Effect of Hartmann number on temperature distribution

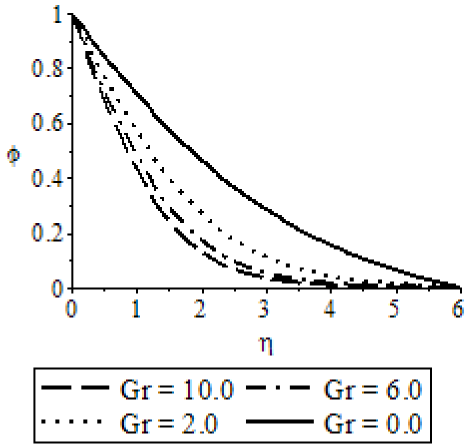

Figure 3.1: Effect of Grashof number on concentration field

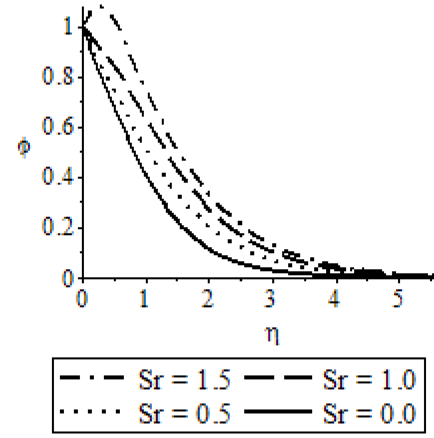

Figure 3.2: Effect of Soret number on concentration field.

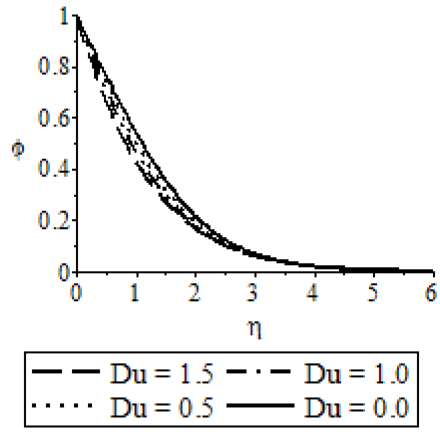

Figure 3.3: Effect of Dufour number on concentration field

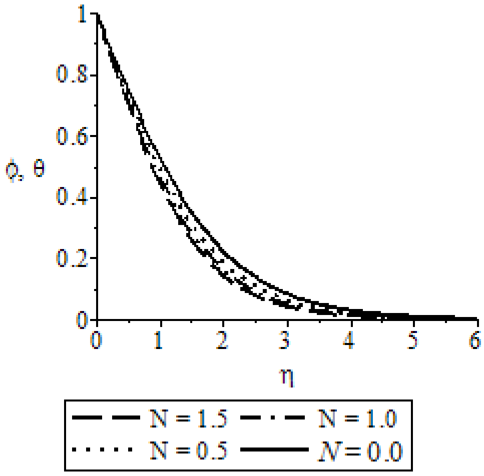

Figure 3.4: Effect of sustentation parameter on concentration field

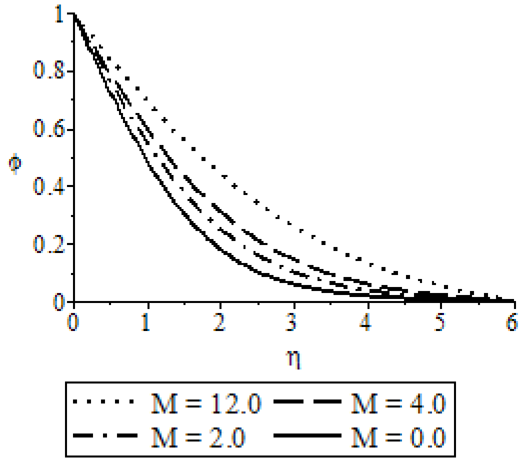

Figure 3.5: Effect of Hartmann number on concentration field

Table 1: Effect of flow parameter on skin friction and, temperature and concentration at the wall

Pr	Gr	Sr	Du	N	M	τ	Nu	Sh
0.015	5.0	0.4	0.6	0.5	0.2	4.308378015	0.876271337	0.232188568
0.71	5.0	0.4	0.6	0.5	0.2	3.023209331	0.54626583	0.547561807
4.50	5.0	0.4	0.6	0.5	0.2	2.142128992	0.051225542	1.743144643
7.00	5.0	0.4	0.6	0.5	0.2	1.977681471	0.012726051	2.189227541
0.71	0.0	0.4	0.6	0.5	0.2	-0.889537101	0.308837554	0.309698536
0.71	2.0	0.4	0.6	0.5	0.2	0.942009538	0.458590796	0.459736935
0.71	6.0	0.4	0.6	0.5	0.2	3.649606010	0.566990864	0.568323073
0.71	10.0	0.4	0.6	0.5	0.2	5.965936870	0.631442189	0.632889269
0.71	5.0	0.0	0.6	0.5	0.2	2.987743071	0.653656903	0.495901185
0.71	5.0	0.5	0.6	0.5	0.2	3.032246461	0.513749768	0.563201165
0.71	5.0	1.0	0.6	0.5	0.2	3.078595310	0.284262958	0.676256397
0.71	5.0	1.5	0.6	0.5	0.2	3.124524545	0.424608411	1.059622715
0.71	5.0	0.4	0.0	0.5	0.2	2.830790151	0.479720686	0.687707316
0.71	5.0	0.4	0.5	0.5	0.2	2.989903184	0.534383789	0.574672783

0.71	5.0	0.4	1.0	0.5	0.2	3.163809985	0.599984236	0.417854755
0.71	5.0	0.4	1.5	0.5	0.2	3.409980039	0.718591228	0.111104822
0.71	5.0	0.4	0.6	0.0	0.2	1.914196293	0.504136786	0.505360208
0.71	5.0	0.4	0.6	0.5	0.2	3.023209331	0.54626583	0.547561807
0.71	5.0	0.4	0.6	1.0	0.2	4.055119696	0.579530541	0.580884812
0.71	5.0	0.4	0.6	1.5	0.2	5.032196390	0.607374306	0.60877806
0.71	5.0	0.4	0.6	0.5	0.0	3.204306921	0.555168186	0.556475947
0.71	5.0	0.4	0.6	0.5	2.0	1.712654129	0.478203091	0.479402813
0.71	5.0	0.4	0.6	0.5	4.0	0.701745798	0.424174816	0.425282689
0.71	5.0	0.4	0.6	0.5	12.0	-1.604923490	0.318584531	0.319420867

Conclusion

In this paper MHD Mixed Convection Heat and Mass Transfer Flow from Vertical Surfaces in Porous Media with Soret and Dufour Effects has been considered. Numerical Calculations for non-dimensional velocity, temperature and concentration profiles for different values of governing parameters on the flow were carried out. Attention is focused on positive values of the buoyancy parameters which correspond to the cooling of the plate problem. From this study, the following conclusions were drawn:

- the non-dimensional velocity decreases with an increase in Prandtl number
- velocity increases with thermal Grashof, Soret and Dufour numbers
- increasing magnetic field strength decrease the velocity boundary layer, skin-friction, Nusselt and Schmidt numbers
- velocity increases with the increasing of N
- maximum velocity occur in the body of the fluid close to the surface
- temperature increase with a decrease in thermal Grashof number
- Soret and Dufour numbers as well as magnetic field strength increases temperature
- increase in buoyance force decrease the temperature field
- increase in thermal Grashof or Dufour numbers and magnetic field strength decreases the concentration boundary layers
- concentration increases with an increase in Soret number and deccrease in buoyancy ratio
- increase in Prandtl number brings about increase in skin-friction and Schmidt number and decreases Nusselt number
- thermal Grashof number and buoyancy ratio brings about increase in τ, Nu and Sh
- increase in Soret number increase in skin-friction and Schmidt number and, decrease Nusselt number

Nomenclature

Sr Soret number	θ Dimensionless temperature
T Temperature	ρ Density
K Thermal diffusivity	ψ Stream function
T Coefficient of thermal expansion	N sustentation parameter
C Coefficient of concentration expansion	**Subscripts**
x, y Cartesian co-ordinates along and normal to the surface, respectively	W Condition at wall
Dimensionless group	∞ Condition at infinity
ϕ Dimensionless concentration	**Superscript**
η Similarity variable	$'$ Differentiation with respect to η
υ Kinematic viscosity	

References

[1]. Hiemenz, K. (1911). The boundary layer at a constant flow stream in the uniform flow stream cylinder. Die Grenzschicht an einem in den gleichformigenflussigkeitsstromeingetacuhtengeradenkrebzylinder. *Journal of Dingl. Polytech.*326, 321-410.

[2]. Eckert, E. R. G. (1942). Die Berechnung des Wärmeubergangs in der laminaren Grenzschichtumstromter Körper. *VDI Forschungsheft* 416, 1-23.

[3]. Devi, C. D. S., H. S. Takhar and G. Nath (1991). Unsteady mixed convection flow in stagnation region adjacent to a vertical surface. *W¨armeund Stoff¨ubertragung*, 26(2), 71-79.

[4]. Postelnicu, A. (2010). Heat and mass transfer by natural convection at a stagnation point in a porous medium considering Soret and Dufour effects. *Heat Mass Transfer* 46,831-840.

[5]. Kazem, S., M. Shaban and S. Abbasbandy (2011). Improved analytical solutions to a stagnation point flow past a porous stretching sheet with heat generation, *Journal of the Franklin Institute* 348, 2044-2058.

[6]. Gbadeyan, J.A., Idowu, A.S., Ogunsola, A.W., Agboola, O.O., Olanrewaju, P.O. (2011). Heat and mass transfer for Soret and Dufour's effect on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with a viscoelastic fluid in the presence of magnetic field. *Global Journal of Science Frontier Research.* Vol 11 Issue 8 Version 1.0 November 2011.

[7]. Makinde, O. D. (2012). Heat and mass transfer by MHD mixed convection stagnation point flow toward a vertical plate embedded in a highly porous medium with radiation and internal heat generation. *Meccanica* 47, 1173-1184.

[8]. Singh, G., P. R. Sharma and A. J. Chamkha (2010). Effect of volumetric heat generation /absorption on mixed convection stagnation point flow on an isothermal vertical plate in porous media. *International Journal of Industrial Mathematics* 2(2), 59-71.

[9]. Bhupendra K. Sharma, Kailash Yadav, Nidhish K. Mishra, R. C. Chaudhary (2012). Soret and Dufour Effects on Unsteady MHD Mixed Convection Flow past a Radiative Vertical Porous Plate Embedded in a Porous Medium with Chemical Reaction. *Applied Mathematics*, Vol. 3 No. 7 (2012) , DOI:10.4236/am.2012.37105

[10]. Cheng, CY. (2012). Soret and Dufour Effects on Mixed Convection Heat and Mass Transfer from a Vertical Wedge in a Porous Medium with Constant Wall Temperature and Concentration. *Transport Porous Medium*, 94:123–132 DOI 10.1007/s11242-012-9992-1.

[11]. Karthikeyan, S., M. Bhuvaneswari, S. Rajan and S. Sivasankaran (2013). Thermal radiation effects on MHD convective flow over a plate in a porous medium by perturbation technique. *Applied Mathematics and Computation. Intel*. 2(1), 75-83.

[12]. Bhuvaneswari, M., S. Sivasankaran and Y. J. Kim (2012).Lie group analysis of radiation natural convection flow over an inclined surface in a porous medium with internal heat generation. *Journal of Porous Media* 15(12), 1155-1164.

[13]. Lee, J., P. Kandaswamy, M. Bhuvaneswari and S. Sivasankaran (2008). Lie group analysis of radiation natural convection heat transfer past an inclined porous surface. *Journal of Mechanical Science and Technology* 22, 1779- 1784.

[14]. Darbhasayanam S. (2013) Soret and dufour effects on MHD mixed convection heat and mass transfer in a micropolar fluid. *Open Engineering*, 2391-5439, DOI: https://doi.org/10.2478/s13531-013-0131-8

[15]. Gangadhar, K. (2013). Soret and Dufour effects on hydro magnetic heat and mass transfer over a vertical plate with a convective surface boundary condition and chemical reaction. *Journal of Applied Fluid Mechanics* 6(1), 95- 105.

[16]. Babu, P. R., J. A. Rao and S. Sheri (2014). Radiation effect on MHD heat and mass transfer flow over a shrinking sheet with mass suction. *Journal of Applied Fluid Mechanics* 7(4), 641-650.

[17]. Bhuvaneswari, M. and S. Sivasankaran (2014). Free convection flow in an inclined plate with variable thermal conductivity by scaling group transformations. *AIP Conf. Proc*. 1605, 440- 445.

[18]. Choudhury, R. and S. Kumar Das (2014). Viscoelastic MHD free convective flow through porous media in presence of radiation and chemical reaction with heat and mass transfer. *Journal of Applied Fluid Mechanics* 7(4), 603- 609.

[19]. Sinha, A. (2014). Steady stagnation point flow and heat transfer over a shrinking sheet with induced magnetic field. *Journal of Applied Fluid Mechanics* 7(4), 703-710.

[20]. Malvandi, A, F. Hedayati and M. R. H. Nobari (2014). An HAM analysis of stagnation-point flow of a nanofluid over a porous stretching sheet with heat generation. *Journal of Applied Fluid Mechanics* 7(1), 135-145.

[21]. Seth, G. S., S. Sarkar, S. M. Hussain and G. K. Mahato (2015). Effects of Hall current and rotation on hydromagnetic natural convection flow with heat and mass transfer of a heat absorbing fluid past an impulsively moving vertical plate with ramped temperature. *Journal of Applied Fluid Mechanics* 8(1), 159- 171.

[22]. Jagadha S. and Kishan N. (2015). Soret and Dufour effects on MHD mixed convective heat and mass transfer flow with thermophoresis past a vertical flat plate embedded in a saturated porous medium in the presence of radiation and viscous dissipation. *Advances in Applied Science Research*, 2015, 6(8):67-81 ISSN: 0976-8610 CODEN (USA).

[23]. S. Karthikeyan , M. Bhuvaneswari , S. Sivasankaran and S. Rajan (2016) Soret and Dufour Effects on MHD Mixed Convection Heat and Mass Transfer of a Stagnation Point Flow towards a Vertical Plate in a Porous Medium with Chemical Reaction, Radiation and Heat Generation. Journal of Applied Fluid Mechanics, Vol. 9, No. 3, pp. 1447-1455, 2016. Available online at www.jafmonline.net, ISSN 1735-3572, EISSN 1735-3645

[24]. Ascher, U., and Petzold, L. *"Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations."*SIAM, Philadelphia. 1998.