IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 9, Issue 5 Ver. IV (Sep. - Oct. 2017), PP 53-63
www.iosrjournals.org

Effect Of Thermo Difussion On Hydro Magnetic Mixed Convective Non-Darcy Flow In A Vertical Channel In The Presence Of Temperature Gradiant Dependent Heat Source

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Abstract: *An attempt has been made to investigate the effect of thermo diffusion on hydro magnetic mixed convective Non-Darcy flow in a vertical channel with temperature gradient dependent heat source using Galerkin finite element technique .The governing equations of flow, heat and mass transfer have been solved to obtain velocity, temperature , concentration, shear stress and rate of Heat and Mass transfer numerically for different values of Q,D^{-1},Sr,F and Pr.*

Keywords: *Thermo diffusion, Non-Darcy flow, finite element analysis, temperature gradient dependent heat source.*

Date of Submission: 26-10-2017 Date of acceptance: 07-11-2017

I. Introduction

The vertical channel is a frequently encountered configuration in thermal engineering equipment, for example, collectors of solar energy, cooling devices of electronic and micro-electronic equipments etc. The problem of fully developed mixed convection between vertical plates with and without heat sources was solved by Ostrach [1]. An experimental study of an opposing mixed convection between vertical parallel plates with one plate heated and the other an adiabatic one was conducted by Wirtz and McKinley [2]. The fully developed free convection in an open-ended vertical channel partially filled with porous material has been described by Al-Nimir and Haddad [3]. The radiation effect on a hydro magnetic convective flow in a vertical channel has been studied by Gupta and Gupta[4]. The effect of wall conductance on a hydro magnetic convection of a radiation gas in a vertical channel has been studied by Datta and Jana[5]. The combined forced and free convective flow in a vertical channel with viscous dissipation and isothermal – iso flux boundary conditions have been studied by Barletta[6].Barletta et al[7] have presented a dual mixed convection flow in a vertical channel.

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 numbers, 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 [8] and Prasad et al. [9] among others. Extensive effects 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 [10] 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 $\sqrt{\frac{k}{\varepsilon}}$ Vafai and Thiyagaraja [11] presented analytical solutions for the velocity and temperature fields for the interface region using the Brinkman Forchheimer –extended Darcy equation. Detailed accounts of the recent efforts on non-Darcy convection have been recently reported in Tien and Hong [12], Cheng], and Kalidas and Prasad [13]. Here, we will restrict our discussion to the vertical cavity only. Poulikakos and Bejan [14] investigated the inertia effects through the inclusion of Forchheimer'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 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 [15] reported an extensive numerical work for a wide range of parameters, and demonstrated that effects of Prandtal number remain almost unaltered while the dependence on the modified Grashof number, Gr, changes significantly with an increase in the Forchheimer number. This result in reversal of flow regimes from boundary layer to asymptotic to conduction as the contribution of the inertia term increases in comparison with that of the boundary term. They also reported a criterion for the Darcy flow limit.

The Brinkman – Extended – Darcy modal was considered in Tong and Subramanian [16], to examine the boundary effects on free convection in a vertical cavity. While Tong and Subramanian performed a Weber – type boundary layer analysis, Lauriat and Prasad solved the problem numerically for A=1 and 5. It was shown that for a fixed modified Rayleigh number, Ra, the Nusselt number; decrease 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 $(v.\nabla)v$, is of low order of magnitude compared to the diffusion plus buoyancy terms. 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. Mankinde [17] examined the transient free convection interaction with thermal radiation of an absorbing-emitting fluid along moving vertical permeable plate. Raptis [18] analyzed the thermal radiation and free convection flow through a porous medium by using perturbation technique. Chitraphiromsri and Kuznetsov [19] 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 [20] 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 astronautically re-entry, plasma flows in astrophysics, the planetary magneto-boundary layer and MHD propulsion systems. Shateyi et al [21] 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 [22] have discussed Heat and Mass transfer in MHD non-Darcian flow of a micro polar fluid over a stretching sheet embedded in a porous media with non-uniform heat source and thermal radiation. Dulal Pal et al [23] 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. Seddeek. et al [24] 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[25] have considered oscillatory mixed convection in horizontal channel with heat sources and radiation effect. Madhusudhana rao et al[26] have studied MHD transient free convection and chemically reactive flow past a porous vertical plate with radiation and temperature gradient dependent heat source in slip, flow regime.

Also in all the above studies the thermal diffusion effect (known as Soret effect) has been neglected. This assumption is true when the concentration level is very low. The thermal diffusion effects for instance have been utilized for isotropic separation and in mixtures between gases with very light molecular weight (H_2.He) and the medium molecular weight (N_2, air) the diffusion – thermo effects was found to be of a magnitude just it cannot be neglected. In view of the importance of this diffusion – thermo effect, recently, Abdul Sattar and Alam [27] have considered an unsteady convection and mass transfer flow of viscous incompressible and electrically conducting fluid past a moving infinite vertical porous plate taking into the thermal diffusion effects. Similarity equations of the momentum energy and concentration equations are derived by introducing a time dependent length scale. Malasetty et al [28] have studied the effect of both the soret coefficient and Dufour coefficient on the double diffusive convective with compensating horizontal thermal and solutal gradients. Umadevi et al[29] have studied the chemical reaction effect on Non-Darcy convective heat and mass transfer flow through a porous medium in a vertical channel with heat sources. Deepthi et al [30] and Kamalakar et al [31] have discussed the numerical study of non-Darcy convective heat and mass transfer flow in a vertical channel with constant heat sources under different conditions. Recently, Ravindra et al [32] investigated the effect of dissipation and thermal radiation on non-Darcy mixed convective heat and mass transfer flow in a vertical channel.

In this chapter we investigate combined influence of thermal radiation and thermo-diffusion on non-Darcy mixed hydromantic convective heat and Mass transfer flow of a viscous, electrically conducting fluid in a vertical channel with temperature gradient dependent heat sources. The Brinkman Forchhimer extended Darcy equations which take into account the boundary and inertia effects are used in the governing linear momentum equation. In order to obtain a better insight into this complex problem, we make use of Galerkin finite element analysis with Quadratic Polynomial approximations. The velocity, temperature, concentration, shear stress and rate of Heat and Mass transfer are evaluated numerically for different variations of parameters.

II. Formulation Of The Problem

We consider a fully developed laminar convective heat and mass transfer flow of a viscous, electrically conducting fluid through a porous medium confined in a vertical channel bounded by flat walls. We choose a Cartesian co-ordinate system O(x, y, z) with x- axis in the vertical direction and y-axis normal to the walls. The walls are taken at y= $\pm$ L. The walls are maintained at constant temperature and concentration. The temperature gradient in the flow field is sufficient to cause natural convection in the flow field .A constant axial pressure gradient is also imposed so that this resultant flow is a mixed convection flow. The porous medium is assumed to be isotropic and homogeneous with constant porosity and effective thermal diffusivity. The thermo physical properties of porous matrix are also assumed to be constant and Boussinesq approximation is invoked by confining the density variation to the buoyancy term. In the absence of any extraneous force flow is unidirectional along the x-axis which is assumed to be infinite.

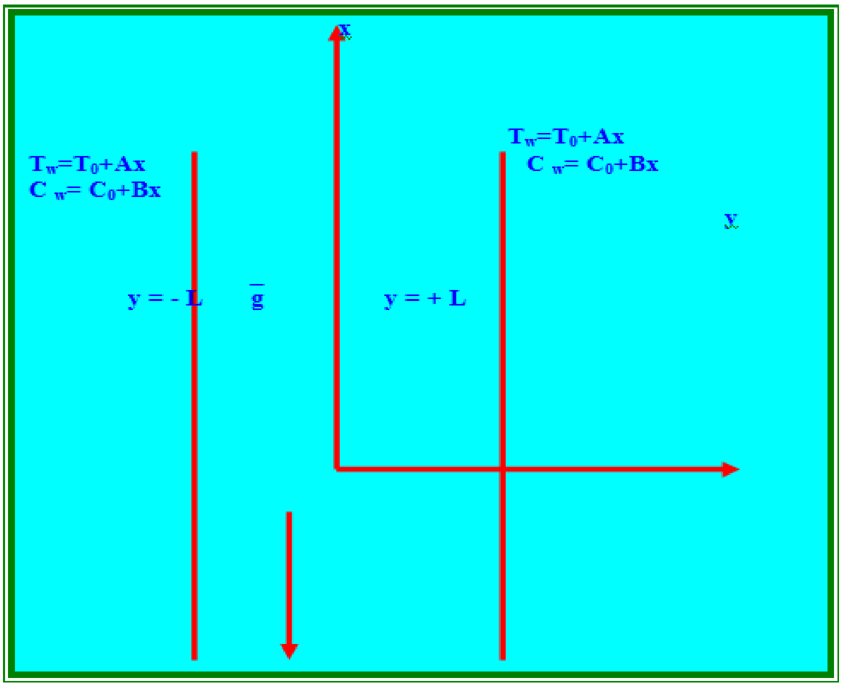

Fig.1 : Configuration of the problem

The momentum, energy and diffusion equations in the scalar form are

$$-\frac{\partial p}{\partial x}+(\frac{\mu}{\delta})\frac{\partial^2 u}{\partial y^2}-(\frac{\sigma\mu_e^2 H_o^2}{\rho_o})u-\frac{\rho\delta F}{\sqrt{k}}u^2-\rho g=0 \qquad (1)$$

$$\rho_0 C_p u\frac{\partial T}{\partial x}=k_f\frac{\partial^2 T}{\partial y^2}+Q\frac{dT}{dy}-\frac{\partial(q_R)}{\partial y} \qquad (2)$$

$$u\frac{\partial C}{\partial x}=D_m\frac{\partial^2 C}{\partial y^2}-k_1 C+\frac{D_m k_t}{T_m}\frac{\partial^2 T}{\partial y^2} \qquad (3)$$

The relevant boundary conditions are

$u=0$, $T=T_w$, $C=C_w$ at $y=\pm L$ (4)

where u, T, C are the velocity, temperature and Concentration, p is the pressure ,ρ is the density of the fluid ,Cp is the specific heat at constant pressure, μ is the coefficient of viscosity, k is the permeability of the porous medium, δ is the porosity of the medium,β is the coefficient of thermal expansion, k_f is the coefficient of thermal conductivity ,F is a function that depends on the Reynolds number and the microstructure of porous medium, $\beta^{\bullet}$ is the volumetric coefficient of expansion with mass fraction concentration, k_1 is the chemical reaction coefficient and D_1 is the chemical molecular diffusivity, q_R is the radiative heat flux,$k_{11}$is the cross diffusivity, q_R is the radiative heat flux and Q is the strength of the heat generating source. Here, the thermo physical properties of the solid and fluid have been assumed to be constant except for the density variation in the body force term (Boussinesq approximation) and the solid particles and the fluid are considered to be in the thermal equilibrium.

By applying Rosseland approximation (Brewester (3)) the radioactive heat flux q_r is given by

$$q_r = -\left(\frac{4\sigma^*}{3\beta_R}\right)\frac{\partial}{\partial y}\left[T'^4\right] \qquad (5)$$

Where σ* is the Stephan – Boltzmann constant

β_R is the mean absorption coefficient.

Expanding T'^4 about T_e in Taylor Series we get

$$T'^4 = 4T_e^3 T - 3T_e^4 . \qquad (6)$$

Substituting (5) & (6) in (2),we obtain

$$\rho_0 C_p u \frac{\partial T}{\partial x} = k_f \frac{\partial^2 T}{\partial y^2} + Q\frac{dT}{dy} + \frac{16\sigma^* T_e^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2} \qquad (7)$$

Following Tao [33], we assume that the temperature and concentration of the both walls is $T_w = T_0 + Ax$, $C_w = C_0 + Bx$ where A and B are the vertical temperature and concentration gradients which are positive for buoyancy –aided flow and negative for buoyancy –opposed flow, respectively, T_0 and C_0 are the upstream reference wall temperature and concentration respectively. For the fully developed laminar flow in the presences of radial magnetic field, the velocity depend only on the radial coordinate and all the other physical variables except temperature, concentration and pressure are functions of y and x, x being the vertical co-ordinate

The temperature and concentration inside the fluid can be written as

$$T = T^{\bullet}(y) + Ax \qquad , \qquad C = C^{\bullet}(y) + Bx$$

We define the following non-dimensional variables as

$$u' = \frac{u}{(\nu / L)},\ (x', y') = (x, y)/L\ ,\ \ p' = \frac{p\delta}{(\rho\nu^2 / L^2)}$$

$$\theta(\mathrm{y}) = \frac{\mathrm{T}^{\bullet}\text{-}\mathrm{T}_0}{\mathrm{P}_1\mathrm{AL}}, \quad , \quad \mathrm{C} = , \quad \frac{\mathrm{C}^{\bullet}\text{-}\mathrm{C}_0}{\mathrm{P}_1\mathrm{BL}}\ ,\mathrm{P}_1 = \frac{dp}{dx} \qquad (8)$$

Introducing these non-dimensional variables the governing equations in the dimensionless form reduce to (on dropping the dashes)

$$\frac{d^2u}{dy^2} = 1 + \delta(D^{-1})u - \delta\, G(\theta + NC) - \delta^2 \Delta u^2 \qquad (9)$$

$$(1 + \frac{4F}{3})\frac{d^2\theta}{dy^2} + \alpha\frac{d\theta}{dy} = (P_r)u \qquad (10)$$

$$\frac{d^2C}{dy^2} - \gamma\, C = (Sc)u + ScSr\frac{d^2\theta}{dy^2} \qquad (11)$$

where $\Delta = FD^{-1/2}$ (Inertia or Fochhemeir parameter) $G = \frac{\beta g A L^3}{\nu^2}$ (Grashof Number)

$D^{-1} = \frac{L^2}{k}$ (Inverse Darcy parameter) $F = \frac{4\sigma^* T_e^3}{\beta_R k_f}$ (Radiation parameter)

$Sc = \frac{\nu}{D_1}$ (Schmidt number) $Sr = \frac{D_m K_T A}{T_m B}$ (Soret parameter)

$N = \frac{\beta^{\bullet} B}{\beta A}$ (Buoyancy ratio) $P = \frac{\mu C_p}{k_f}$ (Prandtl Number)

$\alpha = \dfrac{QL}{k_f}$ (Heat source parameter) $\gamma = \dfrac{k_1 L^2}{D_m}$ (Chemical reaction parameter)

The corresponding boundary conditions are

$$u = 0 \;\; , \;\; \theta = 0 \;\; , \;\; C = 0 \quad on \;\; y = \pm 1 \tag{12}$$

III. Finite Element Analysis

To solve these differential equations with the corresponding boundary conditions, we assume if u^i, θ^i, c^i are the approximations of u, θ and C we define the errors (residual) E_u^i, E_θ^i, E_c^i as

$$E_u^i = \frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - D^{-1}u^i + \delta^2 \mathrm{A}(u^i)^2 - \delta G(\theta^i + NC^i) \tag{13}$$

$$E_c^i = \frac{d}{dy}\left(\frac{dC^i}{dy}\right) - \gamma C^i - Scu^i + ScSr\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) \tag{14}$$

$$E_\theta^i = (1 + \frac{4F}{3})\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) + \alpha\frac{d\theta^i}{dy} - P_r u^i \tag{15}$$

Where

$$\left.\begin{aligned} u^i &= \sum_{k=1}^{3} u_k \psi_k \\ C^i &= \sum_{k=1}^{3} C_k \psi_k \\ \theta^i &= \sum_{k=1}^{3} \theta_k \psi_k \end{aligned}\right\} \tag{16}$$

These errors are orthogonal to the weight function over the domain of e^i under Galerkin finite element technique we choose the approximation functions as the weight function. Multiply both sides of the equations (13 – 15) by the weight function i.e. each of the approximation function ψ_j^i and integrate over the typical three nodded linear element (η_e, η_{e+1}) we obtain
where

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - D^{-1}u^i + \delta^2 \mathrm{A}(u^i)^2 - \delta G(\theta^i + NC^i)\; \psi_j^i dy = 0 \tag{17}$$

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{dy}\left(\frac{dC^i}{dy}\right) - \gamma\, C^i - Scu^i + ScSr\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right))\psi_j^i dy = 0 \tag{18}$$

$$\int_{\eta_e}^{\eta_{e+1}} ((1 + \frac{4F}{3})\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) + \alpha\left(\frac{d\theta^i}{dy}\right) - P_r u^i)\psi_j^i dy = 0 \tag{19}$$

Choosing different Ψ_j^i's corresponding to each element η_e in the equation (17)-(19) yields a local stiffness matrix of order 3×3 in the form

$$(f_{i,j}^k)(u_i^k) - \delta G(g_{i.j}^k)(\theta_i^k + NC_i^k) + \delta D^{-1}(m_{i.j}^k)(u_i^k) + \delta^2 \mathrm{A}(n_{i.j}^k)(u_i^k) = (Q_{i,j}^k) + (Q_{2,j}^k)$$

(20)

$$((e^{k}_{i,J})-\gamma)(C^{k}_{i})-Sc(m^{k}_{i.j})(u^{k}_{i})+ScSr(p^{k}_{i.j})=R^{k}_{1J}+R^{k}_{2J} \tag{21}$$

$$((1+\frac{4F}{3})(l^{k}_{iJ})-\alpha)(\theta^{k}_{i})-P_{r}(t^{k}_{iJ})(u^{k}_{i})=S^{k}_{1,J}+S^{k}_{2,J} \tag{22}$$

where

$\left(f^{k}_{i,J}\right), \left(g^{k}_{i,J}\right), \left(m^{k}_{i,J}\right), \left(n^{k}_{i,J}\right), \left(e^{k}_{i,J}\right), \left(t^{k}_{iJ}\right), \left(p^{k}_{iJ}\right)$ are 3×3matrices and $\left(Q^{k}_{2,J}\right), \left(Q^{k}_{1,J}\right), \left(R^{k}_{2,J}\right), \left(R^{k}_{1J}\right), \left(S^{k}_{2J}\right)$ and $\left(S^{k}_{1J}\right)$ are 3×1 column matrices and such stiffness matrices (20) – (22) in terms of local nodes in each element are assembled using inter element continuity and equilibrium conditions to obtain the coupled global matrices in terms of the global nodal values of u, θ & C. The resulting coupled stiffness matrices are solved by iteration process. This procedure is repeated till the consecutive values of u_i's, θ_i's and C_i's differ by a pre assigned percentage

IV. Shear Stress, Nusselt Number And Sherwood Number

The shear stress on the boundaries $y=\pm 1$ is given by

$$\tau_{y=\pm L}=\mu(\frac{du}{dy})_{y=\pm L}$$

which in the non-dimensional form is

$$\tau_{\;y=\pm 1}=(\frac{du}{dy})_{y=\pm 1}$$

The rate of heat transfer (Nusselt Number) is given by

$$Nu_{y=\pm i}=(\frac{d\theta}{dy})_{y=\pm 1}$$

The rate of mass transfer (Sherwood Number) is given by

$$Sh_{y=\pm 1}=(\frac{dC}{dy})_{y=\pm 1}$$

V. Discussion Of The Numerical Results

In order to gets physical Insight into the problem we have carried out numerical calculations for non-dimensional velocity, temperature and concentration, Nusselt number and Sherwood number by assigning some specific values to the parameters entering into the problem

Effects of parameters on velocity profiles:

Fig.1 represents u with the inverse Darcy parameter (D^{-1}).The axial velocity reduces with increase in D^{-1}.The presence of the porous medium enhances the resistance to the flow resulting in the reduction of the velocity field. Fig.2 shows that the variation of u with Radiation parameter F. It can be seen from the profiles that higher the radiative heat flux (F≤1.5) and for higher F≥3.5, we notice a reduction in u in the entire flow region. Fig.3 shows the variation of u with temperature gradient heat source parameter (Q). It is found that an increase on the strength of the temperature gradient dependent heat source larger the velocity in the entire flow region.

The effect of thermo-diffusion (Sr) on u is exhibited in fig.4.It is observed from the profiles that higher the thermo-diffusion effects larger the magnitude of u in the flow region. Fig.5 represents the variation of u with Prandtl number (Pr). An increase in Pr decreases the velocity in the flow region. This is due to the fact that increasing Pr decreases the thickness of the momentum boundary layer which in turn reduces the velocity in the flow region.

Effects of parameters on temperature profiles:

The non-dimensional temperature (θ) is shown in figs.6-10 for different parametric representation. We follow the convention that the non-dimensional temperature (θ) is positive/negative according as the actual temperature $(T^{\bullet})$ is greater/lesser than the reference temperature T_0. With reference to D^{-1} we find that the actual temperature increases with increasing values of D^{-1}. This is due to the fact that the thickness of the boundary layer increases owing to the Darcy drag developed by the porous medium (Fig.6).Fig.7 represents θ with radiation parameter F. It is found that higher the radiative heat flux smaller the actual temperature in the flow region. Fig.8 exhibits the variation of θ with temperature gradient heat source parameter(Q).It is observed that the profiles that an increase in the strength of the heat source leads to an enhancement in the actual temperature in the flow region. Fig.9 shows the variation of θ with Soret parameter Sr. It can be seen from the profiles that higher the thermo-diffusion effects larger the actual temperature. Fig.10 shows the variation of θ with Prandtl number (Pr).As the Prandtl number increases there is a significant enhancement in the thermal boundary layer with a rise in the actual temperature throughout the flow region, since enhancement of Pr amounts to reduction of thermal diffusion.

Effects of parameters on concentration profiles:

The non-dimensional concentration (C) is shown in figs.11-15 for different parametric variations. We follow the convention that the non-dimensional concentration (C) is positive/negative according as the actual concentration ($C^{\bullet}$) is greater/lesser than the reference concentration. Fig.11 represents C with D^{-1}. We find that lesser the permeability of the porous medium smaller the actual concentration in the entire flow region. The variation of C with radiation parameter F is shown in fig.12. It is found that higher the radiative heat flux F≤1.5 smaller the actual concentration while for higher F≥3.5, we notice an enhancement in it. Fig.13 shows the variation of C with temperature gradient heat source parameter (Q). An increase in the strength of the heat source leads to a reduction in the actual concentration .The effect of thermo-diffusion(Sr) on C is exhibited in fig.14. It can be seen from the profiles that higher the thermo-diffusion effect smaller the actual concentration. Fig.15exhibits the variation of C with Prandtl number (Pr), as the Prandtl number increases there is a marginal decrease in the actual concentration. This is due to the fact the enhancement of Prandtl number amounts to reduction of thermal diffusion.

Effects of parameters on Skin friction, Nusselt number and Sherwood number:

The Skin friction, the rate of heat and mass transfer at the boundaries y=±1 is exhibited in table.1. From the tabular values we find that an increase in the strength of the temperature dependent heat source reduces the skin friction, Nusselt number and Sherwood number on y=±1. Higher the thermo- diffusion effects larger the skin friction, the rate of heat transfer and lesser the Shewood number at the walls, As the Prandtl number increases the skin friction, Sherwood number reduces on y=±1 and enhance the Nusselt number on the both the walls .The rate of heat transfer (Nusselt number) enhances with increase in D^{-1}

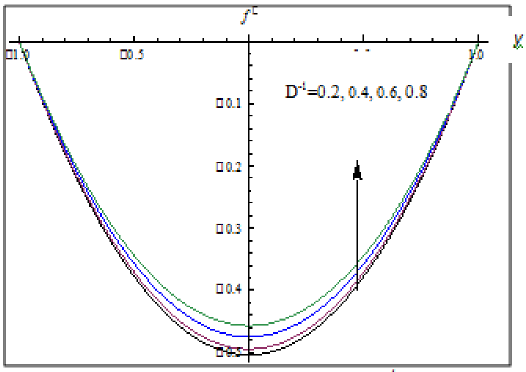

Fig.1: Variation of *u* with D^{-1}
G=10, M=0.5, N=1, F=0.5, γ=0.5,
Q=2, Sc=1.3, Sr=0.5, Pr=0.71

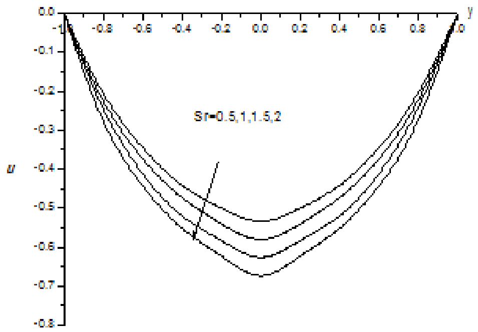

Fig.4: Variation of u with Sr
G=10,M=0.5,D-1=0.2, N=1, F=0.5γ=0.5,
Q=2, Sc=1.3, Pr=0.71

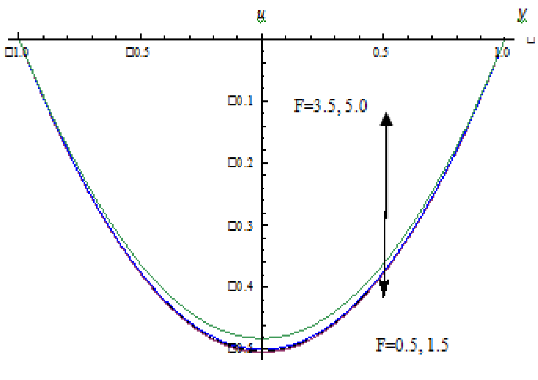

Fig.2: Variation of *u* with F
G=10, M=0.5, D^{-1}=0.2, N=1, γ=0.5,

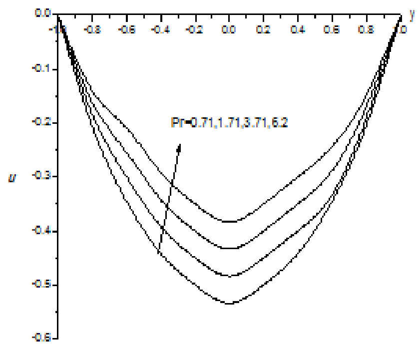

Fig.5: Variation of *u* with Pr
G=10, M=0.5, D^{-1}=0.2, N=1, F=0.5, γ=0.5,
Q=2, Sc=1.3, Sr
Q=2, Sc=1.3, Sr=0.5, Pr=0.71

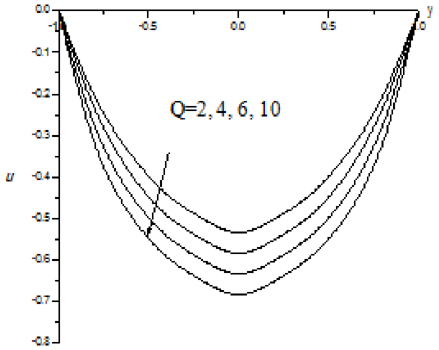

Fig.3 : Variation of *u* with Q > 0
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5 γ=0.5,
Q=2, Sc=1.3, Pr=0.71

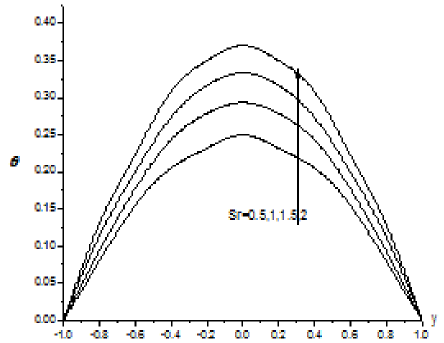

Fig.9 : Variation of θ with Sr
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5, γ=0.5,
Q=2, Sc=1.3, Pr=0.71

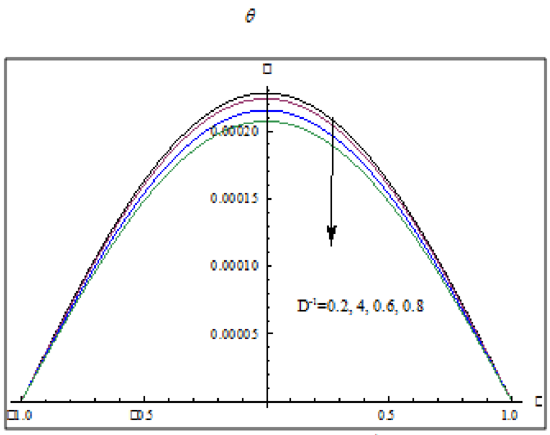

Fig. 6 : Variation of θ with D^{-1}
G=10,M=0.5, N=1, F=0.5, γ=0.5 Q=2
Sc=1.3, Sr=0.5, Pr=0.71

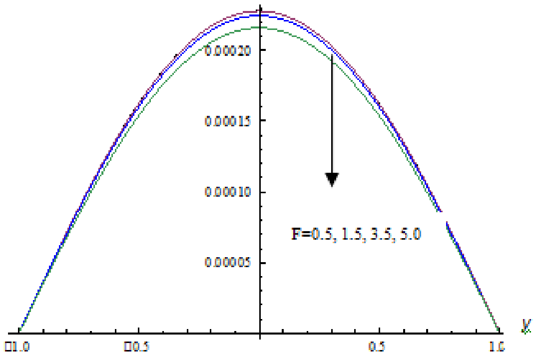

Fig. 7 : Variation of θ with F
G=10,M=0.5,D^{-1}=0.2, N=1, γ=0.5,
Q=2, Sc=1.3, Sr=0.5, Pr=0.71

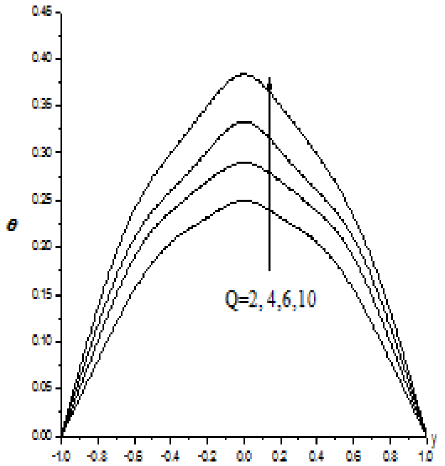

Fig. 8 : Variation of θ with Q >0
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5, γ=0.5,
Sc=1.3, Sr=0.5, Pr=0.71

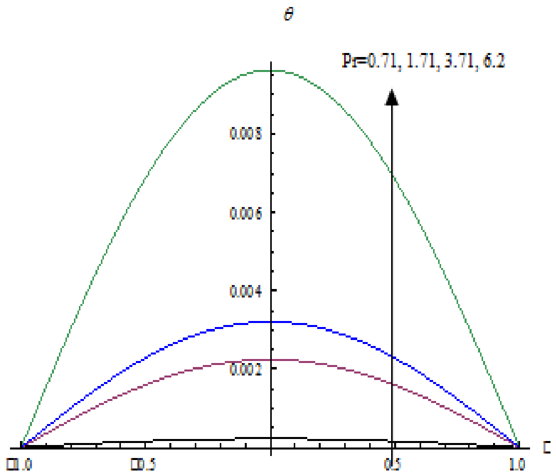

Fig. 10 : Variation of θ with Pr
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5, γ=0.5,
Q=2, Sc=1.3, Sr=0.5

Sc=1.3, Sr=0.5, Pr=0.71

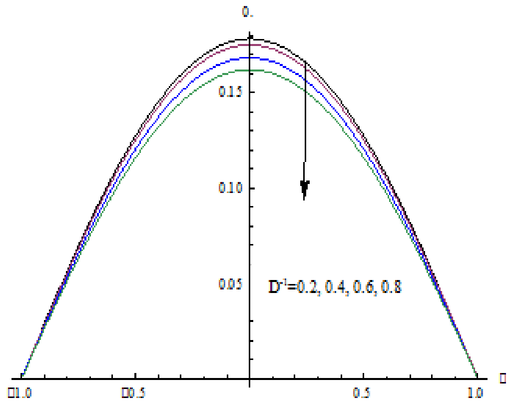

Fig11 : Variation of C with D^{-1}
G=10,M=0.5, N=1, F=0.5, γ=0.5,
Q=2, Sc=1.3, Sr=0.5, Pr=0.71

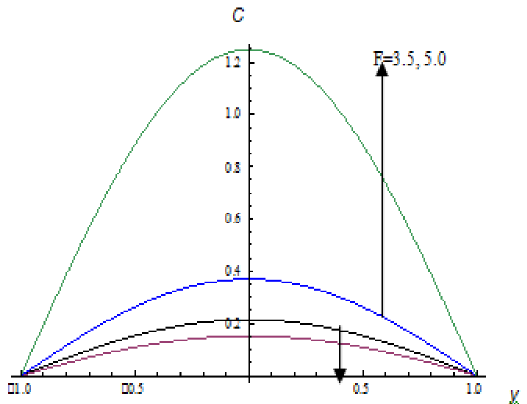

Fig.14 : Variation of C with F
G=10,M=0.5,D^{-1}=0.2, N=1, γ=0.5,
Q=2, Sc=1.3, Sr=0.5, Pr=0.71

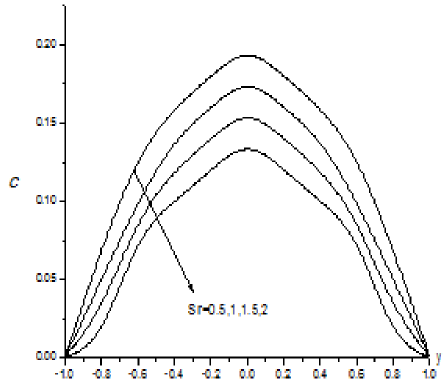

Fig. 13 : Variation of C with Sr
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5γ=0.5,
Q=2, Sc=1.3, Pr=0.71

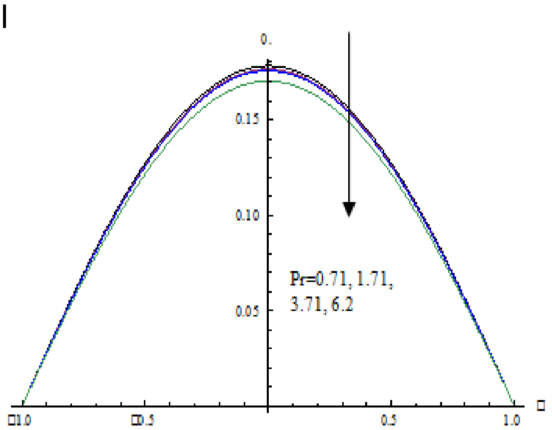

Fig. 15 : Variation of C with Pr
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5, γ=0.5,
Q=2, Sc=1.3, Sr=0.5

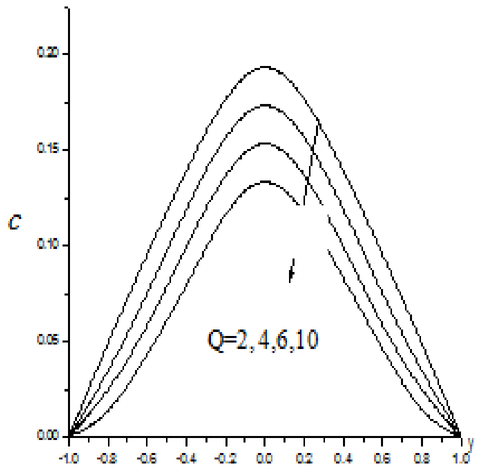

Fig. 12 : Variation of C with Q >0
G=10,M=0.5,D^{-1}=0.2, N=1, F=0.5, γ=0.5,

Table- Variation of Skin Friction, Nusselt Number, Sherwood Number at y = ± 1

Parameter		Skin Friction		Nusselt Number		Sherwood Numl	
		τ (-1)	τ (1)	Nu (-1)	Nu (1)	Sh (-1)	Sh (1)
D^{-1}	0.2	-1.00603	1.00603	-000036703	0.000362569	-0.28737	0.287383
	0.4	-1.00266	1.00266	-000036556	0.000361114	-0.28623	0.286237
	0.6	-0.99932	0.99932	-0.00036413	0.000359671	-0.28509	0.2851
	0.8	-0.99606	0.99606	-0.00036265	0.00035824	-0.28396	0.283971
Q	2	-1.06438	1.06438	-.000390409	0.000389453	-0.30706	0.30706
	4	-1.06425	1.06425	-000039088	0.000388975	-0.30709	0.30709
	6	-1.06411	1.06411	-0.00039136	0.000388497	-0.30712	0.307012
	10	-1.06399	1.06399	-0.00039184	0.000388019	-0.30716	0.307016
Sr	0.5	-1.06438	1.06438	-0.00039040	0.000389453	-0.30706	0.30707
	1.0	-1.06445	1.06445	-0.00039042	0.000389484	-0.30675	0.306761
	1.5	-1.06452	1.06452	-0.00039047	0.000389516	-0.30644	0.306452
	2.0	-1.06459	1.06459	-0.00039050	0.000389547	-0.30613	0.306143
F	0.5	-1.06438	1.06438	-0.00039040	0.000389453	-0.30706	0.30707
	1.5	-1.06399	1.06399	-0.00038937 -	0.000388423	-0.30707	0.307071
	3.5	-1.05999	1.05999	0.00038732	0.00038638	-0.30708	0.307073
	5.0	-1.05577	1.05577	-0.00038579	0.000384862	-0.30710	0.307074
Pr	0.71	-1.06438	1.06438	-0.00039040	0.000389455	-0.30706	0.30707
	1.71	-1.06436	1.06436	0.000940261 -	0.000937959	-0.30659	0.306594
	3.71	-1.06433	1.06433	0.002039	0.00203491	-0.30563	0.305643
	7.0	-1.06427	1.06427	-0.0038486	0.0038392	-0.30406	0.304078

VI. Conclusions

The non-linear coupled equations governing the flow, heat and mass transfer have been solved by employing Galerkin finite element technique. The velocity, temperature, concentration, skin friction and the rate of heat and mass transfer on the walls have been discussed for different variations of the parameters. The significant conclusions of the analysis are:

1) An increase in the strength of the temperature gradient heat source (Q) enhances the velocity, temperature and concentration. The skin friction and nusselt number reduces on the walls with Q>o .An increase in the strength of the temperature gradient heat source larger the Sherwood number at the walls.
2) Higher the thermo-diffusion larger the velocity, temperature , and the rate of heat transfer smaller the concentration and the Sherwood number .the skin friction enhances on both the walls with increasing soret parameter.

3) Lesser the permeability of the porus medium smaller the velocity , concentration , temperature and larger the skin friction, rate of heat and mass transfer on the walls.

4). Higher the radiative heat flux (F≤1.5) smaller the velocity , temperature and concentration and for higher F≥3.5,the velocity and temperature reduces and the concentration enhances in the flow region. Higher the radiative heat flux lesser the skin friction and Nusselt number on both walls.

5). An increase in prandtl number reduces the velocity, actual temperature, the skin friction and the rate of mass transfer. As the prandtl number increase there is a significant enhancement in the temperature and the rate of heat transfer.

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IOSR Journal of Applied Physics (IOSR-JAP) is UGC approved Journal with Sl. No. 5010, Journal no. 49054.

Ch. Neeraja Effect Of Thermo Difussion On Hydro Magnetic Mixed Convective Non-Darcy Flow In A Vertical Channel In The Presence Of Temperature Gradiant Dependent Heat Source." IOSR Journal of Applied Physics (IOSR-JAP) , vol. 9, no. 5, 2017, pp. 53-63.