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EFFECT OF DISSIPATION AND THERMAL RADIATION ON NON-DARCY MIXED CONVECTIVE HEAT AND MASS TRANSFER FLOW IN A VERTICAL CHANNEL

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Abstract: An attempt has been made to investigate the effect of dissipation and thermal radiation on convective heat and mass transfer in a vertical channel using Galerkin finite element technique. The governing equations of flow heat and mass transfer have been solved to obtain Velocity, Temperature and Concentration. The effects of dissipation and thermal radiation on the flow characteristics have been investigated.

Key Words: Dissipation, Thermal Radiation, Non-Darcy flow, Finite element analysis.

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 influence of electrically conducting the case of fully developed mixed convection between horizontal parallel plates with a linear axial temperature distribution was solved by Gill and Casal [18]. Ostrach [27] solved the problem of fully developed mixed convection between vertical plates with and without heat sources. Cebeci et al [9] performed numerical calculations of developing laminar mixed convection between vertical parallel pates for both cases of buoyancy aiding and opposing conditions. Wirtz and McKinley [41] conducted an experimental study of a opposing mixed convection between vertical parallel plates with one plate heated and the other adiabatic. Al-Nimir and Haddad [2] have described the fully developed free convection in an open-ended vertical channel partially filled with porous material. Greif et al [19] have made an analysis on the laminar convection of a radiating gas in a vertical channel. Gupta and Gupta [20] have studied the radiation effect on a hydro magnetic convective flow in a vertical channel. Datta and Jana [12] have studied the effect of wall conductance on a hydro magnetic convection of a radiation gas in a vertical channel. The combined forced and free convective flow in a vertical channel with viscous dissipation and isothermal –isoflux boundary conditions have been studied by Barletta [4]. Barletta et al [5] have presented a dual mixed convection flow in a vertical channel. Barletta et al [6] have described a buoyancy MHD 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 [11] and Prasad et al. [29] 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 [39] 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 [40] presented analytical solutions for the

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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 [36], Cheng [11] and Kalidas and Prasad [21]. Here, we will restrict our discussion to the vertical cavity only. Poulikakos and Bejan [30] investigated the inertia effects through the inclusion of Forchheimer 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 [28] reported an extensive numerical work for a wide range of parameters, and demonstrated that effects of Prandatl number remain almost unaltered while the dependence on the modified Grashof number, G, 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 [37] and Lauriat and Prasad [23] 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 and5. 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. A numerical study based on the Forchheimer-Brinkman-Extended Darcy equation of motion has also been reported recently by Beckerman et al [7]. They demonstrated that the inclusion of both the inertia and boundary effects is important for convection in a rectangular packed – sphere cavity. Umadevi et al [38] 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 [13] and Kamalakar et al [22] 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

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. Abdul Sattar and Hamid Kalim [1] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Mankinde [24] examined the transient free convection interaction with thermal radiation of an absorbing-emitting fluid along moving vertical permeable plate Raptis [32] analyzed the thermal radiation and free convection flow through a porous medium by using perturbation technique. Bakier and Gorla [3] investigated the effect of thermal radiation on mixed convection from horizontal surfaces in saturated porous media. Chamkha [10] 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. 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 [25] 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 [26] obtained a set of similarity solutions for radiative – MHD stellar point explosion dynamics using shooting methods. Shateyi et al [33] 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 [14] have discussed Heat and Mass transfer in MHD non-Darcian flow of a micropolar fluid over a stretching sheet

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embedded in a porous media with non-uniform heat source and thermal radiation. Dulal Pal et al [15] have analyzed unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Rajesh et al [31] have considered the radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion. .

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 and Mollendorf [17] 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, Zanchini [42] 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, Gebhart [16] have studied the Effects of viscous dissipation in natural convection, Sreevani [34] have studied the effect of viscous dissipation on the convective flows past an infinite vertical plate and through vertical channels and ducts.

Keeping the above application in view we made an attempt has been made to investigate the effect of dissipation and thermal radiation on convective heat and mass transfer in a vertical channel. The Brinkman Forchheimer 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 parameter.

II. FORMULATION OF THE PROBLEM

We consider a fully developed laminar convective heat and mass transfer flow of a viscous 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.

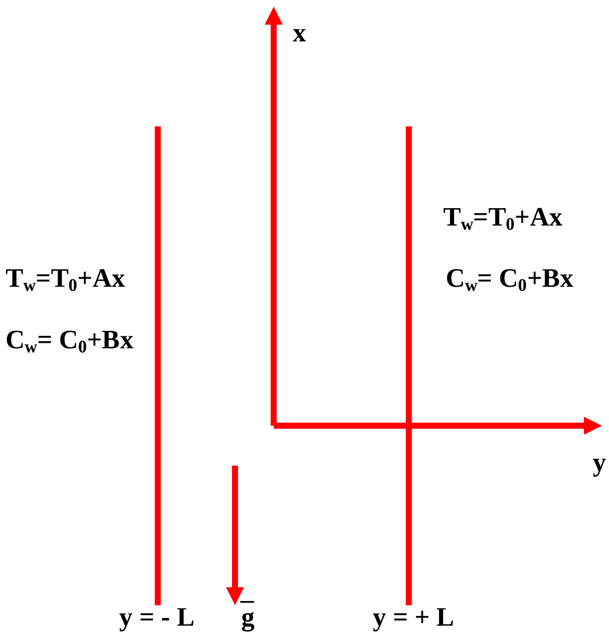

Fig.1: Configuration of the problem

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

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

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

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$$u\frac{\partial C}{\partial x} = D_1\frac{\partial^2 C}{\partial y^2} - k_1 C \qquad (3)$$

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. 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 fluids are considered to be in the thermal equilibrium).

By applying Rosseland approximation (Brewester [8]) the radiative 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 and mean absorption coefficient.

Assuming that the difference in temperature within the flow are such that T'^4 can be expressed as a linear combination of the temperature. We expand T'^4 in Taylor's series about Te as follows

$$T'^4 = T_\infty^4 + 4T_\infty^3(T - T_\infty) + 6T_\infty^2(T - T_\infty) + \ldots\ldots \qquad (6)$$

Neglecting higher order terms beyond the first degree in $(T - T_\infty)$ .we have

$$T'^4 \approx -3T_\infty^4 + 4T_\infty^3 T \qquad (7)$$

Differentiating equation (5) with respect to y and using (7) we get

$$\frac{\partial(q_R)}{\partial y} = -\frac{16\sigma^* T_\infty^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2} \qquad (8)$$

Using (8) equation (2) reduces to

$$\rho_0 C_p u\frac{\partial T}{\partial x} = (k_f + \frac{16\sigma^* T_e^3}{3\beta_R})\frac{\partial^2 T}{\partial y^2} + \mu(\frac{\partial u}{\partial y})^2 \qquad (9)$$

Following Tao [35], 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. 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

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

We define the following non-dimensional variables as

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

$$\theta(\mathrm{y}) = \frac{\mathrm{T}^{\bullet}\text{-}\mathrm{T}_0}{\mathrm{P}_1\mathrm{AL}},\quad \mathrm{C} = \frac{\mathrm{C}^{\bullet}\text{-}\mathrm{C}_0}{\mathrm{P}_1\mathrm{BL}}\ ,\ \ \mathrm{P}_1 = \frac{dp}{dx} \qquad (10)$$

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

$$\frac{d^2 u}{dy^2} = 1 + \delta(D^{-1})u - \delta G(\theta + NC) - \delta^2\Delta u^2 \qquad (11)$$

$$(1 + \frac{4Rd}{3})\frac{d^2\theta}{dy^2} = (P_r)u + Ec\,\Pr(\frac{du}{dy})^2 \qquad (12)$$

$$\frac{d^2 C}{dy^2} - \gamma C = (Sc)u \qquad (13)$$

Where $\Delta = FD^{-1/2}$(Inertia or Forchheimer parameter)

$G = \frac{\beta g A L^3}{\nu^2}$ (Grashof Number)

$$D^{-1} = \frac{L^2}{k} \text{ (Inverse Darcy parameter)}$$

$$Sc = \frac{\nu}{D_1} \text{ (Schmidt number)}$$

$$N = \frac{\beta^{\bullet} B}{\beta A} \text{ (Buoyancy ratio)}$$

$$P_r = \frac{\mu C_p}{k_f} \text{ (Prandtl Number)}$$

$$\gamma = \frac{k_1 L^2}{D_1} \text{ (Chemical reaction parameter)}$$

$$Rd = \frac{4\sigma^* T_e^3}{\beta_r k_f} \text{ (Radiation Parameter)}$$

$$Ec = \frac{\nu^2}{P_1 A L^3 C_p} \text{ (Eckert number)}$$

The corresponding boundary conditions are

$$u = 0 \ , \ \theta = 0 \ , \ C = 0 \quad on \ y = \pm 1 \qquad (14)$$

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

$$E_u^i = \frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - D^{-1}u^i + \delta^2 \mathrm{A}(u^i)^2 - \delta G(\theta^i + NC^i) \quad (15)$$

$$E_c^i = \frac{d}{dy}\left(\frac{dC^i}{dy}\right) - \gamma C^i - Scu^i \qquad (16)$$

$$E_\theta^i = (1+\frac{4Rd}{3})\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - P_r u^i - P_r Ec(\frac{du^i}{dy})^2 \quad (17)$$

Where

$$u^i = \sum_{k=1}^{3} u_k \psi_k \quad C^i = \sum_{k=1}^{3} C_k \psi_k \quad \theta^i = \sum_{k=1}^{3} \theta_k \psi_k \quad (18)$$

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 (15-17) 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

$$\int_{\eta_e}^{\eta_{e+1}} \left(\frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - D^{-1}u^i + \delta^2 \mathrm{A}(u^i)^2 - \delta G(\theta^i + NC^i) \right) \psi_j^i dy = 0 \qquad (19)$$

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{dy}\left(\frac{dC^i}{dy}\right) - \gamma C^i - Scu^i)\psi_j^i dy = 0 \qquad (20)$$

$$\int_{\eta_e}^{\eta_{e+1}} (1+\frac{4Rd}{3})\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - P_r u^i - P_r Ec(\frac{d\theta^i}{dy})^2)\psi_j^i dy = 0 \quad (21)$$

Choosing different Ψ_j^i 's corresponding to each element η_e in the equation (19) - (21) yields a local stiffness matrix of order 3×3 in the form

$$(f_{i,j}^k)(u_i^k) - \delta G(g_{i.j}^k)(\theta_i^k + NC_i^k) + \delta D^{-1}(m_{i.j}^k)(u_i^k) + \delta^2 \mathrm{A}(n_{i.j}^k)(u_i^k) = (Q_{i,j}^k) + (Q_{2,j}^k) \qquad (22)$$

$$((e_{i,J}^k) - \gamma)(C_i^k) - Sc(m_{i.j}^k)(u_i^k) = R_{1J}^k + R_{2J}^k \qquad (23)$$

$$(1+\frac{4Rd}{3})(l_{iJ}^k))(\theta_i^k) - (P_r(1+E_c))t_{iJ}^k)(u_i^k) = S_{1,J}^k + S_{2,J}^k \qquad (24)$$

Where

$\left(f_{i,J}^k\right)$, $\left(g_{i,J}^k\right)$, $\left(m_{i,J}^k\right)$, $\left(n_{i,J}^k\right)$, $\left(e_{i,J}^k\right)$, $\left(t_{iJ}^k\right)$

are3×3 matrices and

$\left(Q_{2,J}^k\right)$, $\left(Q_{1,J}^k\right)$, $\left(R_{2,J}^k\right)$, $\left(R_{1J}^k\right)$, $\left(S_{2J}^k\right)$ and $\left(S_{1J}^k\right)$ are 3×1 column matrices and such stiffness matrices 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((22)-(24)). 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 preassigned percentage.

IV. SHEAR STRESS, NUSSELT NUMBER AND SHERWOOD NUMBER

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

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

In the non-dimensional form is

$$\tau_{y=\pm1} = (\frac{du}{dy})_{y=\pm1}$$

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

$$Nu_{y=\pm i} = (\frac{d\theta}{dy})_{y=\pm1}$$

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

$$Sh_{y=\pm1} = (\frac{dC}{dy})_{y=\pm1}$$

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 spices concentration, skin-friction, Nusselt number and Sherwood number by assigning some specific values i.e., G=2 , M=2, N=1, Sc=1.3, Pr=0.71 to the parameters entering into the problem.

Effects of parameters on velocity profiles:

Fig.2a represents the variation of u with Radiation parameter (Rd). Higher the radiative heat flux smaller the magnitude of the velocity.

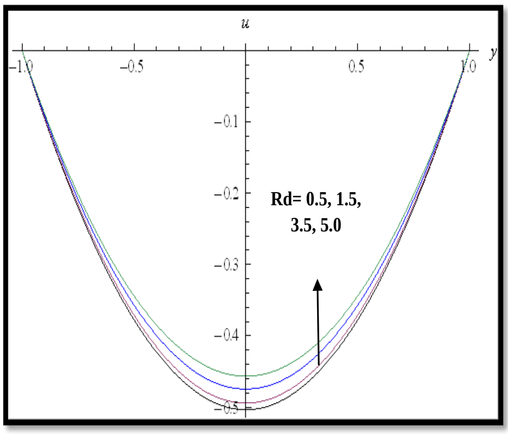

Fig. 2a: Variation of u with Rd
Ec=0.01, γ=0.5, Δ= 2

Fig 3a represents the variation of u with Eckert number (Ec). An increase in the Eckert number (Ec) reduces the axial velocity in the flow region.

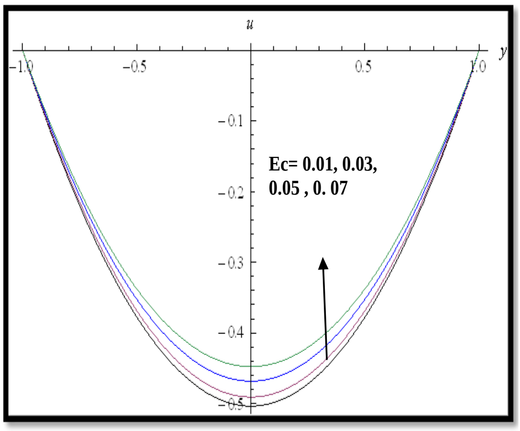

Fig. 3a: Variation of u with Ec
Rd=0.5, γ=0.5, Δ= 2

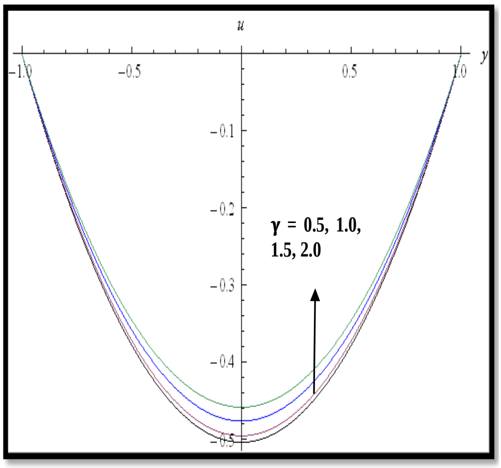

Fig. 4a: Variation of u with γ>0
Rd=0.5, Ec=0.01, Δ=2

The effect of chemical reaction parameter (γ>0) on u is exhibited in Fig.4a. The velocity reduces in the degenerating chemical reaction case.

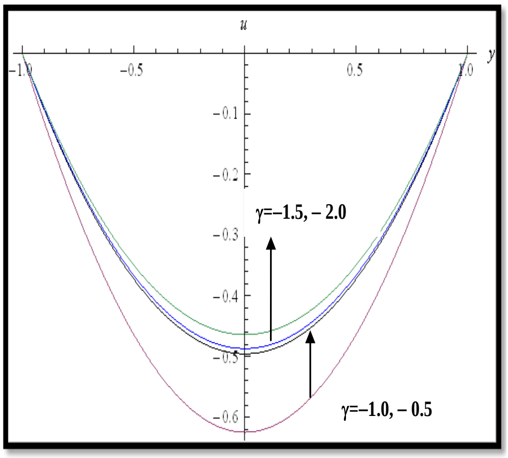

Fig. 5a: Variation of u with γ<0
Rd=0.5, Ec=0.01, Δ=2

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The effect of chemical reaction parameter ($\gamma<0$) on u is exhibited in Fig.5a. The velocity increases with $|\gamma|\leq 1.0$ and higher $|\gamma|\geq 1.5$ in the generating chemical reaction case we notice a depreciation in the magnitude of velocity.

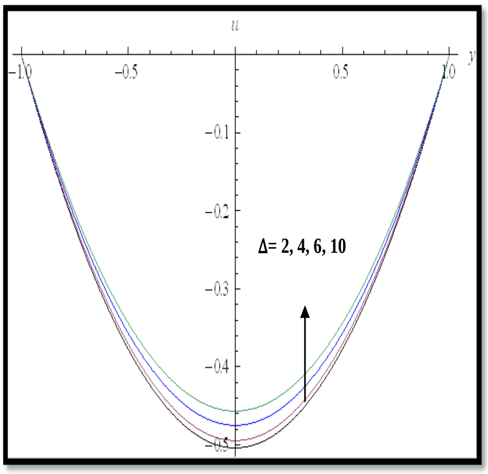

Fig. 6a: Variation of u with Δ
Rd=0.5, Ec=0.01, γ=0.5

Fig.6a represents the variation of u with Forchheimer number (Δ). An increase in the Forchheimer number (Δ) reduces the magnitude of velocity.

Effects of parameters on temperature profiles:

The non-dimensional temperature (θ) is shown in figs.2b-6b 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.

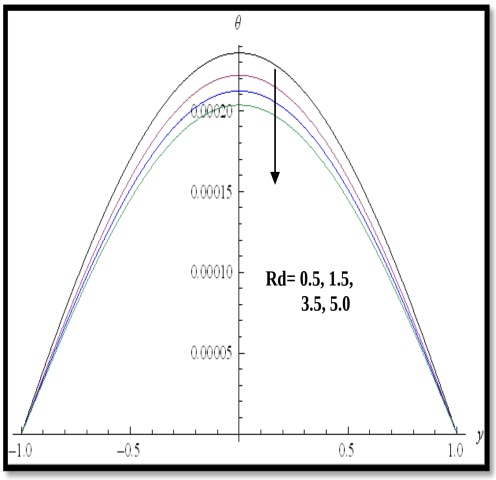

Fig. 2b: Variation of θ with Rd
Ec=0.01, γ=0.5, Δ= 2

Fig.2b exhibits the temperature with Rd. It is found that higher the radiative heat flux smaller the temperature.

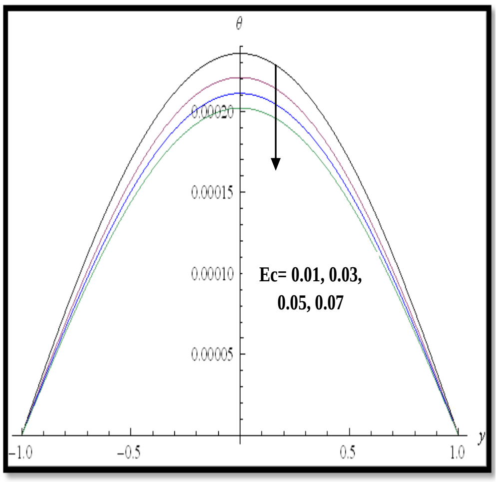

Fig. 3b: Variation of θ with Ec
Rd=0.5, γ=0.5, Δ= 2

Fig 3b represents the variation of θ with Eckert number (Ec). It is observed from the profiles that higher the dissipation smaller the temperature in the entire flow region.

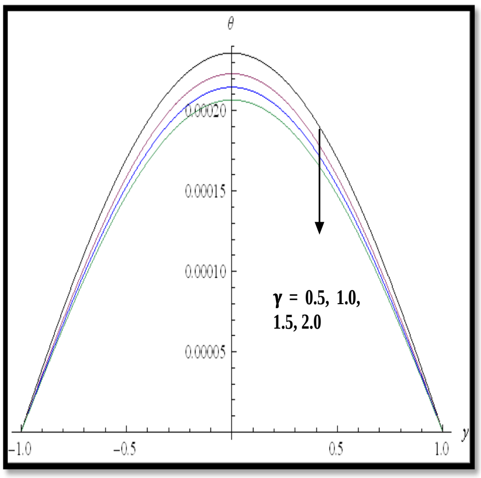

Fig. 4b: Variation of θ with γ>0
Rd=0.5, Ec=0.01, Δ=2

The effect of chemical reaction parameter ($\gamma>0$) on θ is exhibited in Fig.4b. The temperature reduces in the degenerating chemical reaction case.

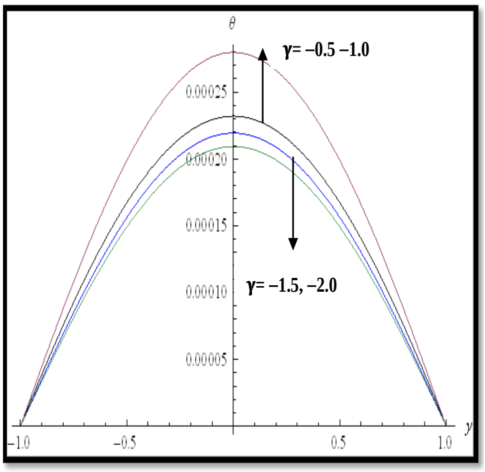

Fig. 5b: Variation of θ with γ<0
Rd=0.5, Ec=0.01, Δ=2

The effect of chemical reaction parameter (γ<0) on θ is exhibited in Fig.5b. The temperature increases with γ||≤1.0 and higher |γ|≥ 1.5 we notice a depreciation in the temperature.

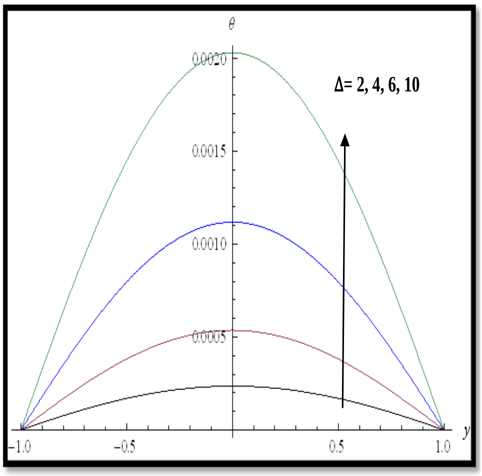

Fig. 6b: Variation of θ with Δ
Rd=0.5, Ec=0.01, γ=0.5

Fig.6b represents the variation of θ with Forchheimer number (Δ). An increase in Δ enhances the temperature in the flow region.

Effects of parameters on concentration profiles:

Fig.2c shows the variation of Concentration with Radiation parameter Rd. It is found that Higher the radiative heat flux smaller the concentration.

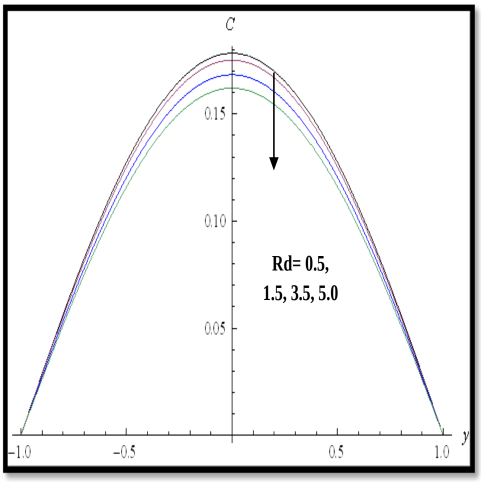

Fig. 2c: Variation of C with Rd
Ec=0.01, γ=0.5, Δ= 2

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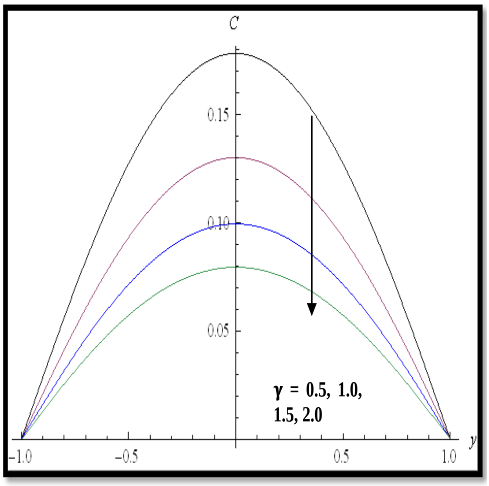

Fig. 4c: Variation of C with γ>0
Rd=0.5, Ec=0.01, Δ=2

The effect of chemical reaction parameter (γ>0) on C is exhibited in Fig.4c.From the profiles we found that the concentration reduces in the degenerating chemical reaction case.

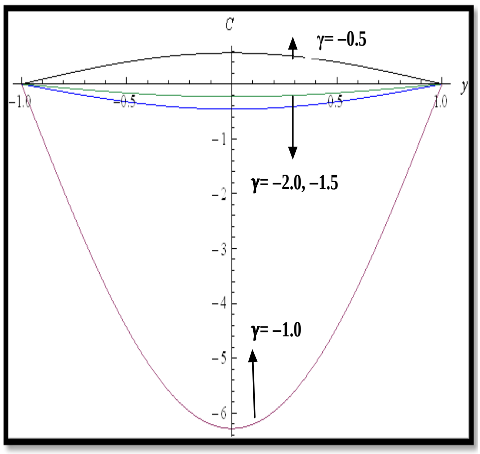

Fig. 5c: Variation of C with γ<0
Rd=0.5, Ec=0.01, Δ=2

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The effect of chemical reaction parameter (γ<0) on C is exhibited in Fig.5c. We found that the actual concentration decreases with |γ|≤1.0 and for higher |γ|≥1.5 we notice an enhancement in the actual concentration.

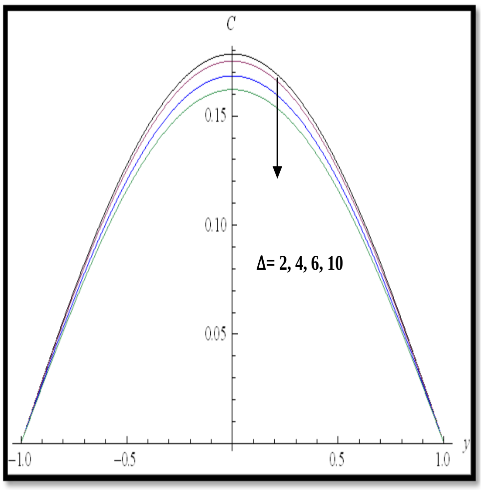

Fig. 6c: Variation of C with Δ
Rd=0.5, Ec=0.01, γ=0.5

Fig.6c. represents the variation of C with Forchheimer number (Δ). An increase in Δ reduces the concentration, thus the inclusion of inertia and boundary effects reduces the velocity and concentration and enhances the temperature in the flow region.

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 Higher the radiative heat flux larger the magnitude of skin friction and smaller the Nusselt number and Sherwood number. Higher the dissipation smaller the magnitude of skin friction, Nusselt number and Sherwood number. The skin friction increases in the degenerating chemical reaction case and reduces in the generating chemical reaction case. The Nusselt number and Sherwood number reduces at the walls in both degenerating (γ>0) and generating (γ<0) chemical reaction cases. An increase in Forchheimer number increases the magnitude of skin friction and Nusselt number and reduces the Sherwood number at both the walls. Thus the inclusion of the inertia and boundary effects enhances the skin friction and Nusselt number and decreases the rate of mass transfer at the walls.

Table –1

		τ(-1)	τ(+1)	Nu(-1)	Nu(+1)	Sh(-1)	Sh(+1)
Rd	**0.5**	**-1.00603**	**1.00603**	**-0.000390218**	**0.000390218**	**-0.287343**	**0.287343**
	1.5	**-1.00623**	**1.00623**	**-0.000355148**	**0.000355148**	**-0.235012**	**0.235012**
	3.5	**-1.00655**	**1.00655**	**-0.000350332**	**0.000350332**	**-0.228738**	**0.228738**
	5.0	**-1.00695**	**1.00695**	**-0.000345723**	**0.000345723**	**-0.208739**	**0.208739**
Ec	**0.01**	**-1.0603**	**1.0603**	**-0.000375218**	**0.000375218**	**-0.287343**	**0.287343**
	0.03	**-1.00702**	**1.00702**	**-0.000345597**	**0.000345597**	**-0.240118**	**0.240118**
	0.05	**-1.00712**	**1.00712**	**-0.000333583**	**0.000333583**	**-0.235383**	**0.235383**
	0.07	**-1.00745**	**1.00745**	**-0.000322583**	**0.000322583**	**-0.223683**	**0.223683**
γ	**0.5**	**-1.00466**	**1.00466**	**-0.000375558**	**0.000375589**	**-0.345577**	**0.345577**
	1.5	**-1.00669**	**1.00669**	**-0.000362954**	**0.000369954**	**-0.275079**	**0.275079**
	-0.5	**-0.89591**	**0.89591**	**-0.000359906**	**0.000359906**	**-0.566442**	**0.566442**
	-1.5	**-0.79972**	**0.79972**	**-0.000347464**	**0.000347464**	**-1.759221**	**1.759221**
Δ	**2.0**	**-1.00603**	**1.00603**	**-0.000399218**	**0.000399218**	**-0.277343**	**0.277343**
	4.0	**-1.00705**	**1.00705**	**-0.000855257**	**0.000855257**	**-0.232751**	**0.232751**
	6.0	**-1.00712**	**1.00712**	**-0.00177461**	**0.001774611**	**-0.295068**	**0.295068**
	10	**-1.00723**	**1.00723**	**-0.00327472**	**0.003257472**	**-0.304627**	**0.304627**

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 important conclusions of the analysis are:

- It is found that higher the radiative heat flux/ Dissipation smaller the velocity and temperature. The actual concentration reduces with increase in Rd. The skin friction enhances the Nusselt number and Sherwood number reduces with increase in Rd. The skin friction, Nusselt number and Sherwood number reduces with increase in Ec.
- The velocity, temperature and concentration reduce in the degenerating chemical reaction case.
- The velocity and temperature reduces, the concentration enhances with increase $|\gamma \leq 1.0$ and for higher $|\gamma| \geq 1.5$ we noticed a reversed effect in the generating chemical reaction case.
- An increase in the Forchheimer number (Δ) enhances the velocity, temperature, skin friction, Nusselt number and reduces the concentration and Sherwood number.

VII. REFERENCES:

[1] Abdual Sattar.M.D, Hamid Kalim.M.D : Unsteady free-convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. J Math Phys Sci; 30:25-37 (1996).

[2] Al-Nimir,M.A,Haddad,O.H, Fully developed free convection in open-ended vertical chasnnels partially filled with porous material,J.Porous Media ,V.2,pp.179-189(1999).

[3] Bakier A.Y and Gorla R.S.R., Thermal radiation effects on mixed convection from horizontal surfaces in porous media Transport in porous media, Vol.23 pp 357-362 (1996).

[4] Barletta,A., Analysis of combined forced and free flow in a vertrical channel with viscous dissipation and isothermal-isoflux boundary conditions, ASME.J.HeatTransfer ,V,121,pp.349-356(1999).

[5] Barletta,A,Magyari,E and Kellaer,B., Dual mixed convection flows in a vertical channel .,INny.J.Heat and Mass Transfer,V.48,pp.4835-4845(2005).

[6] Barletta,A,Celli,M and Magtyari,E and Zanchini,E., Buoyany MHD flows in a vertical channel:the levitation regime.,Heat and Mass Transfer ,V.44,pp.1005-1013(2007).

[7] Beckermann,C.Visakanta,r and.Ramadhyani,S ., A numerical study of non-Darcian natural convection in a vertical enclosure filled with a porous medium., Numerical Heat transfer 10, pp.557-570, (1986).

[8] Brewester,M.Q., Thermal radiative transfer properties.,John Wiley and Sons (1972).

[9] Cebeci,T,Khattab,A.A and LaMont,R., Combined natural and forced convection in a vertical ducts,in:Proc.7th Int. Heat Transfer Conf.,V.3,pp.419-424(1982).

[10] Chamkha A.J., Solar Radiation Assisted natural convection in a uniform porous medium supported by a vertical heat plate, ASME Journal of heat transfer, V.19, pp 89-96 (1997).

[11] Cheng, Heat transfer in geothermal systems. Adv.Heat transfer 14, 1-105(1978).

[12] Datta,N anfd Jana,R.N., Effect of wall conductance on hydromagnetic convection of a radiation gas in a vertical channel., Int.J.Heat Mass Transfer,V.19,pp.1015-1019(1974).

[13] Deepti,J, Prasada Rao,D.R.V., Finite element analysis of chemically reaction effect on Non-Darcy convective heat and mass transfer flow through a porous medium in a vertical channel with constant heat sources.,Int.J.Math.Arch,V.3(11),pp.3885-3897(2012).

[14] Dulal Pal and Sewli Chatterjee., 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, Communications in Nonlinear Science and Numerical Simulation, Volume 15, Issue 7, Pages 1843-1857 (2010).

[15] Dulal Pal and Babulal Talukdar., Perturbation analysis of unsteady magneto hydro dynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction, Communications in Nonlinear Science and Numerical Simulation, Volume 15, Issue 7, July 2010, P.1813-1830 (2010).

[16] Gebhart, B.J., Effects of viscous dissipation in natural convection", fluid Mech, V.14, pp.225 -232 (1962).

[17] Gebhert,B and Mollendorf:J., Viscous dissipation in external natural convection flows Fluid Mech,V.38,pp.97-107(1969).

[18] Gill,W.N and Del Casal,A., A theoretical investigation of natural convection effects in a forced horizontal flows,AIChE J,V.8,pp.513-518(1962).

[19] Greif, R, Habib, I.S and Lin,J.c., Laminar convection of a radiating gas in a vertical channel,J.Fluid.Mech.,V.46,p.513(1971).

[20] Gupta,P.S and Gupta,A.S., Radiation effect on hydromagnetic convection in a vertical channel.,Int.J.heat Mass Transfer,V.127,pp.1437-1442(1973).

International Journal of Advanced Scientific Technologies in Engineering and Management Sciences (IJASTEMS-ISSN: 2454-356X) Volume.2,Special Issue.1Dec.2016

[21] Kalidas.N. and Prasad, V., Benard convection in porous media Effects of Darcy and Pransdtl Numbers, Int. Syms. Convection in porous media, non-Darcy effects, proc.25th Nat. Heat Transfer Conf.V.1, pp.593-604 (1988).

[22] Kamalakar,P.V.S Prasada Rao,D.R.V and Raghavendra Rao,R., Finite element analysis of chemical reaction effect on Non-Darcy convective heat and mass transfer flow through a porous medium in a vertical channel with heat sources., Int.J.Appl.Math and Mech,V,8(13),pp.13-28(2012).

[23] Laurait,G and.Prasad,V. ., Natural convection in a vertical porous cavity a numerical study of Brinkman extended Darcy formulation., J.Heat Transfer.pp.295-320(1987).

[24] Makinde OD., Free convection flow with thermal radiation and mass transfer past moving vertical porous plate. Int Comm Heat Mass Transfer; 32:1411-9 (2005).

[25] Mosa.M.F ., Radiative heat transfer in horizontal MHD channel flow with buoyancy effects and axial temperature gradient, Ph D thesis, Mathematics Dept, Bradford University, England, UK (1979).

[26] Nath.O, Ojha. S.N and Takhar. H.S ., A study of stellar point explosion in a radiative MHD medium Astrophysics and space science, V.183, pp 135-145 (1991).

[27] Ostrach,S., Combined natural and forced convection laminar flow and heat transfer of fluid with and without heat sources in channels with linearly varying wall temperature, NACA TN,3141(1954).

[28] Prasad, V.and Tuntomo, A.., Inertia Effects on Natural Convection in a vertical porous cavity, numerical Heat Transfer, V.11, pp.295-320 (1987).

[29] Prasad.V, F.A,Kulacki and M.Keyhani;" Natural convection in a porous medium" J.Fluid Mech.150p.89-119(`1985).

[30] Poulikakos D., and Bejan, A.., The Departure from Darcy flow in Nat. Convection in a vertical porous layer, physics fluids V.28, pp.3477-3484 (1985).

[31] Rajesh, V and Varma.S.V.K., Radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion, Int.J. of Appl.Math and Mech.6(1).p.39-57 (2010).

[32] Raptis, A.A., Radiation and free convection flow through a porous medium, Int. commun. Heat and mass transfer, Vol. 25, pp 289-295 (1998).

[33] Shatevi, S., Thermal Radiation and Buoyancy Effects on Heat and Mass Transfer over a Semi-Infinite stretching surface with Suction and Blowing , journal of Applied mathematics,v.2008,Article id.414830,12pages (2008).

[34] Sreevani M., Mixed convective heat and mass transfer through a porous medium in channels with dissipative effects, Ph.D thesis, S.K.University, Anantapur, India (2003).

[35] Tao,L.N., On combined and forced convection in channels, ASME J.Heat Transfer,V.82,pp.233-238(1960).

[36] Tien, D., and Hong, J.T., Natural convection in porous media under non-Darcian and non-uniform permeability conditions, hemisphere, Washington. (1985).

[37] Tong, T.L and Subramanian, E., A boundary layer analysis for natural correction in porous enclosures: use of the Brinkman-extended Darcy model, Int.J.Heat Mass Transfer.28, pp.563-571 (1985).

[38] Umadevi,B,Sreenivas,G,Bhuvana vijaya,R and prasada Rao,D.R.V., Finite element analysis of chemical reaction effect on Non-Darcy mixed convective double diffusive heat transfer flow through a porous medium in a vertical channel with constant heat sources., Adv. Appl. Sci. Res. V.3 (5), pp.2924-2939(2012).

[39] Vafai, K., Tien, C.L., Boundary and Inertia effects on flow and Heat Transfer in Porous Media, Int. J. Heat Mass Transfer, V.24. Pp.195-203 (1981).

[40] Vafai, K., Thyagaraju, R., Analysis of flow and heat Transfer at the interface region of a porous medium, Int. J. Heat Mass Trans., V.30pp.1391-1405 (1987).

[41] Wirtz,R.A and McKinley,P., Buoyancy effects on downward laminar convection between parallel plates.Fundamental of forced and mixed convection, ASME HTD,V.42,pp.105-112(1985).

[42] Zanchini E., Effect of viscous dissipation on mixed convection in a vertical channel with boundary conditions of the third kind, Int. J. Heat mass transfer, V.41, pp.3949-3959 (1998).