FINITE ELEMENT ANALYSIS OF NON-DARCY MIXED CONVECTIVE HEAT AND MASS TRANSFER FLOW IN A VERTICAL CHANNEL WITH THERMO-DIFFUSION, CHEMICAL REACTION AND HEAT SOURCES

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Abstract: We made an attempt to study thermo-diffusion and chemical reaction effects on non-Darcy convective heat and Mass transfer flow of a viscous electrically conducting fluid in a vertical channel with heat generating sources. The Brinkman Forchhimer extended Darcy equations which takes into account the boundary and inertia effects are used in the governing linear momentum equation. The effect of density variation is combined to the buoyancy term under Boussineq approximation. The momentum, energy and diffusion equations are coupled equations. In order to obtain a better insight into this complex problem, we make use of Galerkin finite element analysis with Quadratic Polynomial approximations. The Galerkin finite element analysis has two important features. The first is that the approximation solution is written directly as a linear combination of approximation functions with unknown nodal values as coefficients. Secondly, the approximation polynomials are chosen exclusively from the lower order Piecewise polynomials restricted to contiguous elements. The velocity, temperature, concentration, shear stress and rate of Heat and Mass transfer are evaluated numerically for different variations of parameter.

Keywords: Heat and Mass transfer, Vertical Channel, Thermo-Diffusion, Chemical Reaction, Heat Sources.

2.1. 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 Del Casal(15). Ostrach(27)solved the problem of fully developed mixed convection between vertical plates with and without heat sources. Cebeci et al (10) performed numerical calculations of developing laminar mixed convection between vertical parallel pates for both cases of buoyancy aiding and opposing conditions. 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(16) have made an analysis on the laminar convection of a radiating gas in a vertical channel. Gupta and Gupta(17) have studied the radiation effect on a hydromagnetic convective flow in a vertical channel. Datta and Jana(13) have studied the effect of wall conductance on a hydromagnetic 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. Several researchers [Tien and Hong (34), Cheng (11), and Kalidas and Prasad (18), Poulikakos and Bejan (28), Prasad and Tuntomo (29), Beckerman et al (9)] have investigated the boundary intertia effects on flow phenomena. 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. Therefore, so ever, exceptions. The thermal diffusion effects for instance, has 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 (7). In view of the importance of this diffusion – thermo effect, several authors [Jha and Singh (19), Kafousias (20), Jha and Singh(19) and Kafousias (20), Abdul Sattar and Alam (1), Malasetty et al (25), Deepthi et al(14) and Kamalakar et al(22)] have investigated the boundary intertia effects on flow phenomena.

The effects of radiation on MHD flow and heat transfer problem have become more important industrially. 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 various propulsion devices, for aircraft ,missiles , satellites and space vehicles are examples of such engineering areas. Bharathi(7) has studied thermo-diffusion effect on unsteady convective Heat and Mass transfer flow of a viscous fluid through a porous medium in vertical channel. Radiative flow plays a vital role in many industrial and environmental process e.g. heating and cooling chambers , fossil fuel combustion energy process, evaporation form larger open water reservoirs, ,astrophysical flows, solar power technology and space vehicle re-entry. Taneja et al (32) studied the effects of magnetic field on free convective flow through porous medium with radiation and variable permeability in the slip flow regime. Kumar et al (23) studied the effect of MHD free convection flow of viscous fluid past a porous vertical plate through non homogeneous porous medium with radiations and temperature gradient dependent heat source in slip flow regime. The effect of free convection flow with thermal radiation and mass transfer past a moving vertical porous plate was studied by Makinde (24). Ayani et al (3) studied the effect of radiation on the laminar natural convection induced by a line source. Raptis(31) have discussed the effect of radiation and free convection flow through porous medium. MHD oscillating flow on free convection radiation through porous medium with constant suction velocity ws investigated by El.Hakiem(18). Muralidhar(26) has analysed the thermo-diffusion effect of non-Darcy convective heat and mass transfer flow in a vertical channel. Recently, Das et al(12) have studied the mixed convective magnetohydrodynamic flow in a vertical channel filled with nanofluid.

Keeping the above application in view we made an attempt to study thermo-diffusion and chemical reaction effects on non-Darcy convective heat and Mass transfer flow of a viscous electrically conducting fluid in a vertical channel with heat generating sources. The Brinkman Forchhimer extended Darcy equations which takes into account the boundary and inertia effects are used in the governing linear momentum equation. The effect of density variation is combined to the buoyancy term under Boussineq approximation. The momentum, energy and diffusion equations are coupled equations. In order to obtain a better insight into this complex problem, we make use of Galerkin finite element analysis with Quadratic Polynomial approximations. The Galerkin finite element analysis has two important features. The first is that the approximation solution is written directly as a linear combination of approximation functions with unknown nodal values as coefficients. Secondly, the approximation polynomials are chosen exclusively from the lower order Piecewise polynomials restricted to contiguous elements. The velocity, temperature, concentration, shear stress and rate of Heat and Mass transfer are evaluated numerically for different variations of parameter.

2.2. 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.

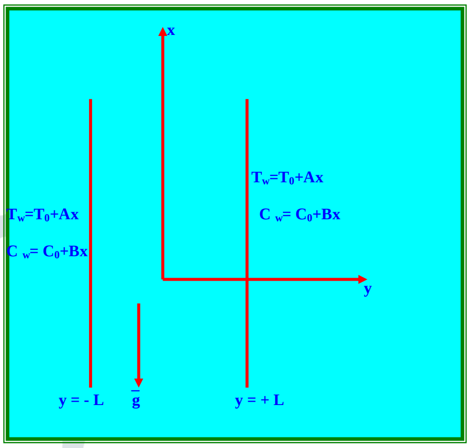

Fig.1 : Configuration of the problem

Since the flow is unidirectional ,the continuity of equation reduces to

$\frac{\partial u}{\partial x} = 0$ where u is the axial velocity implies u = u(y)

The Brinkman-Forchheimer-extended Darcy equation which account for boundary inertia effects in the momentum equation is used to obtain the velocity field. Based on the above assumptions the governing equations are

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

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

$$u\frac{\partial C}{\partial x} = D_1\frac{\partial^2 C}{\partial y^2} - k_1 C + k_{11}\frac{\partial^2 T}{\partial y^2} \qquad (3)$$

The relevant boundary conditions are

$$u = 0, \quad T=T_w, \quad C=C_w \quad \text{at} \quad y=\pm L \qquad (4)$$

where u, T, C, p, ρ, Cp, μ, k, δ, β, k_k, F, β*, k_1, D_1, q_R, k_{11}, Q are velocity, Temperature, Concentration, Pressure, Density, Specific heat and constant pressure, dynamic viscosity, porus permeability, porosity of the medium, coefficient of thermal expansion, coefficient of thermal conductivity, Function depending on Reynolds number and microstructure of porous medium, radiative heat flux, cross diffusivity , heat generating source.

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

We define the following non-dimensional variables as

$$u' = \frac{u}{(\nu/L)},\ (x',y') = (x,y)/L\ ,\quad p' = \frac{p\delta}{(\rho\nu^2/L^2)},\quad \theta(\mathrm{y}) = \frac{\mathrm{T}^{\bullet} - \mathrm{T}_0}{\mathrm{AL}},\quad ,\ \mathrm{C} =,\ \frac{\mathrm{C}^{\bullet} - \mathrm{C}_0}{\mathrm{BL}} \qquad (5)$$

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

$$\frac{d^2u}{dy^2} = \pi + \delta(M_1^2)u - \delta G(\theta + NC) - \delta^2 \Delta u^2 \quad (6)$$

$$\frac{d^2\theta}{dy^2} - \alpha\theta = (P)u \quad (7)$$

$$\frac{d^2C}{dy^2} - \gamma C = (Sc)u - \frac{ScSo}{N}\frac{d^2\theta}{dy^2} \quad (8)$$

where $\Delta = FD^{-1/2}$ (Inertia or Fochhemeir parameter), $G = \frac{\beta g A L^3}{\nu^2}$ (Grashof Number), $M^2 = \frac{\sigma\mu_e^2 H_o^2 L^2}{\nu^2}$ (Hartmann Number), $Sc = \frac{\nu}{D_1}$ (Schmidt number), $N = \frac{\beta^\bullet B}{\beta A}$ (Buoyancy ratio), $P = \frac{\mu C_p}{k_f}$ (Prandtl Number) $\alpha = \frac{QL^2}{k_f}$ (Heat source parameter), $\gamma = \frac{k_1 L^2}{D_1}$ (Chemical reaction parameter), $S_0 = \frac{k_{11}\Delta T}{\nu \Delta T}$ (Soret parameter)

The corresponding boundary conditions are

$$u = 0 \ , \ \theta = 0 \ , \ C = 0 \quad on \ y = \pm 1 \quad (9)$$

2.3. 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

$$E_u^i = \frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - M_1^2 u^i + \delta^2\Delta(u^i)^2 - \delta G(\theta^i + NC^i) \quad (10)$$

$$E_c^i = \frac{d}{dy}\left(\frac{dC^i}{dy}\right) - \gamma C^i + \frac{ScSo}{N}\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - Scu^i \quad (11)$$

$$E_\theta^i = \frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - \alpha\theta^i - Pu^i) \quad (12)$$

where $u^i = \sum_{k=1}^{3} u_k \psi_k$, $C^i = \sum_{k=1}^{3} C_k \psi_k$, $\theta^i = \sum_{k=1}^{3} \theta_k \psi_k$ (13)

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 (10 – 12) 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

$$\int_{\eta_e}^{\eta_{e+1}} E_u^i \psi_j^i dy = 0 \qquad (i = 1,2,3,4,) \quad (14)$$

$$\int_{\eta_e}^{\eta_{e+1}} E_c^i \psi_j^i dy = 0 \qquad (i = 1,2,3,4,) \quad (15)$$

$$\int_{\eta_e}^{\eta_{e+1}} E_\theta^i \psi_j^i dy = 0 \qquad (i = 1,2,3,4,) \quad (16)$$

where

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - M_1^2 u^i + \delta^2\Delta(u^i)^2 - \delta G(\theta^i + NC^i) \ \psi_j^i dy = 0 \quad (17)$$

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

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - \alpha\theta^i - Pu^i)\psi_j^i dy = 0 \quad (19)$$

Following the Galerkin weighted residual method and integration by parts method to the equations (17) – (19) we obtain

$$\int_{\eta_e}^{\eta_{e+1}} \frac{d\Psi_j^i}{dy}\frac{d\psi^i}{dy}dy - \delta M_1^2 \int_{\eta_e}^{\eta_{e+1}} u^i \Psi_j^i dy + \delta^2 \Delta \int_{\eta_e}^{\eta_{e+1}} (u^i)^2 \Psi_j^i dy - \delta G \int_{\eta_e}^{\eta_{e+1}} (\theta^i + NC^i)\Psi_j^i dy = Q_{1,j} + Q_{2,j} \quad (20)$$

where – $Q_{1,j} = \Psi_j(\eta_e)\frac{du^i}{d\eta}(\eta_e)$, $\quad Q_{2,j} = \Psi_j(\eta_{e+1})\frac{du^i}{d\eta}(\eta_{e+1})$

$$\int_{\eta_e}^{\eta_{e+1}} \frac{d\Psi_j^i}{dy}\left(\frac{dC^i}{dy}\right)dy - \gamma \int_{\eta_e}^{\eta_{e+1}} C^i \psi_j^i dy + \frac{ScSo}{N}\int_{\eta_e}^{\eta_{e+1}} \frac{d\Psi_j^i}{dy}\left(\frac{d\theta^i}{dy}\right)\psi_j^i dy - Sc\int_{\eta_e}^{\eta_{e+1}} u^i \psi_j^i dy = R_{1,j} + R_{2,j} \quad (21)$$

where – $R_{1,j} = \Psi_j(\eta_e)\frac{dC^i}{dy}(\eta_e) + \frac{ScSo}{N}\Psi_j(\eta_e)\frac{d\theta^i}{dy}(\eta_e)$

$$R_{2,j} = \Psi_j(\eta_{e+1})(\frac{dC^i}{dy}(\eta_{e+1}) + \frac{ScSo}{N}\frac{d\theta^i}{dy}(\eta_{e+1}))$$

$$\int_{\eta_e}^{\eta_{e+1}} \frac{d\Psi_j^i}{dy}\frac{d\theta^i}{dy}dy - P\int_{\eta_e}^{\eta_{e+1}} u^i \psi_j^i dy - \alpha \int_{\eta_e}^{\eta_{e+1}} \theta^i \psi_j^i dy = S_{1,j} + S_{2,j} \quad (22)$$

where – $S_{1,j} = \Psi_j(\eta_e)\frac{d\theta^i}{dy}(\eta_e) + DuN_2\Psi_j(\eta_e)\frac{dC^i}{dy}(\eta_e)$

$$S_{2,j} = \Psi_j(\eta_{e+1})\frac{d\theta^i}{dy}(\eta_{e+1}) + DuN_2\Psi_j(\eta_{e+1})\frac{dC^i}{dy}(\eta_{e+1})$$

Making use of equations (13) we can write above equations as

$$\sum_{k=1}^{3} u_k \int_{\eta_e}^{\eta_{e+1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy - \sum_{k=1}^{3}\delta M_1^2 u_k \int_{\eta_e}^{\eta_{e+1}} \psi_j^i \psi_k dy - \delta G(\sum_{k=1}^{3}\theta_k \int_{\eta_e}^{\eta_{e+1}} \psi_j^i \psi_k dy + NC_k \sum_{k=1}^{3} \psi_j^i \psi_k dy + \delta^2 \Delta \sum_{k=1}^{3} u_k^2 \int_{\eta_e}^{\eta_{e+1}} \left(\frac{d\psi_k}{d\eta}\right)^2 \psi_j^i dy = Q_{1,j} + Q_{2,j} \quad (23)$$

$$\sum_{k=1}^{3} C_k \int_{\eta_e}^{\eta_{e+1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy - \gamma\sum_{k=1}^{3} C_k \int_{\eta_e}^{\eta_{e+1}} \psi_j^i \psi_k d\eta - Sc\sum_{k=1}^{3} C_k \int_{\eta_e}^{\eta_{e+1}} \psi_j^i \psi_k dy + \frac{ScSo}{N}\sum_{k=1}^{3}\theta_k \int_{\eta_e}^{\eta_{e+1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy = R_{1,j} + R_{2,j} \quad (24)$$

$$\sum_{k=1}^{3} \theta_k \int_{\eta_e}^{\eta_{e+1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy - \alpha\sum_{k=1}^{3}\theta_k \int_{\eta_e}^{\eta_{e+1}} \psi_k \psi_j^i dy - P\sum_{k=1}^{3} u_k \int_{\eta_e}^{\eta_{e+1}} \psi_k \psi_j^i dy = S_{1,j} + S_{2.j} \quad (25)$$

choosing different Ψ_j^i's corresponding to each element η_e in the equation (23) yields a local stiffness matrix of order 3×3 in the form

$$(f_{i,j}^k)(u_i^k) - \delta G(g_{i.j}^k)(\theta_i^k + NC_i^k) + \delta D^{-1}(m_{i.j}^k)(u_i^k) + \delta^2\Delta(n_{i,j}^k)(u_{i,j}^k) = (Q_{i,j}^k) + (Q_{2,j}^k) \quad (26)$$

Likewise the equation (24) & (25) gives rise to stiffness matrices

$$(e_{i,J}^k)(C_i^k) + \frac{ScSo}{N}(t_{iJ}^k)(\theta_i^k) - P(m_{i.j}^k)(u_i^k) = R_{1J}^k + R_{2J}^k \quad (27)$$

$$(l_{iJ}^k)(\theta_i^k) - P_r(t_{iJ}^k)(\theta_i^k) = S_{1,J}^k + S_{2,J}^k \quad (28)$$

where

$(f_{i,J}^k)$, $(g_{i,J}^k)$, $(m_{i,J}^k)$, $(n_{i,J}^k)$, $(e_{i,J}^k)$, (t_{iJ}^k) are 3×3matrices and $(Q_{2,J}^k)$, $(Q_{1,J}^k)$, $(R_{2,J}^k)$, (R_{1J}^k), (S_{2J}^k) and (S_{1J}^k) are 3×1 column matrices and such stiffness matrices (26) – (28) 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 k, θ & C. The ultimate coupled global matrices are solved to determine the unknown global nodal values of the velocity, temperature and concentration in fluid region. In solving these global matrices an iteration procedure has been adopted to include the boundary and effects in the porous region.

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

2.6. COMPARISON:

In this analysis, it should be mentioned that the results obtained herein are compared with the results of Kamalakar et al(22) as shown in Table 1 and the results are found to be in good agreement.

Table. 1 - Comparison of τ,Nu and Sh at y=±1 with Kamalakar et al(22) [with M=0]

Parameters		Kamalakar et al(22)					
S_o	γ	τ(+1)	τ(-1)	Nu(+)	Nu(-1)	Sh(+1)	Sh(-1)
0.50	0.5	0.2775	-0.1423	13.1011	9.6432	12.8323	12.8323
1.0	0.5	0.0206	-0.1962	13.0678	9.6451	13.1010	13.1014
1..5	0.5	0.0198	-0.2109	13.0245	9.6469	13.6515	13.1126
0.5	1.5	0.3022	-0.0374	13.1004	9,6415	13.1005	13.1001
0.5	-0.5	-0.0015	-0.6349	13.1031	9,6562	13.1031	13.1031
0.5	-1.5	-0.0935	-0.0131	13.1011	9,6450	13.1011	13.1011

Parameters		Present results(M=0)					
S_o	γ	τ(+1)	τ(-1)	Nu(+1)	Nu(-1)	Sh(+1)	Sh(-1)
0.50	0.5	0.2779	-0.1421	13.1012	9.6435	12.8324	12.8324
1.0	0.5	0.0208	-0.1965	13.0681	9.6453	13.1012	13.1016
1..5	0.5	0.0199	-0.2110	13.0247	9.6471	13.6517	13.1132
0.5	1.5	0.3025	-0.0375	13.1006	9,6416	13.1009	13.1009
0.5	-0.5	-0.0013	-0.6352	13.1034	9,6564	13.1035	13.1033
0.5	-1.5	-0.0935	-0.0134	13.1012	9,6452	13.1012	13.1019

7. DISCUSSION OF THE NUMERICAL RESULTS

In order to get 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 to the parameters entering into the problem

7.1. Effects of parameters on velocity profiles:

Fig.5 shows the variation of u with Schmidt number(Sc) and Soret parameter (S_0).It is found that the velocity reduces with increases in Sc. This is due to the fact that increasing Sc means reducing molecular diffusivity. Therefore lesser the molecular diffusivity smaller the velocity in the fluid region. The variation of u with Soret parameter S_0 shows that higher the thermo-diffusion effect($S_0\leq 1.5$) larger u in the left region($-1<y\leq 0$) and smaller u in the right region($0.2\leq y\leq 0.8$) and for higher $S_0\geq 2.5$,the velocity u enhances w in the entire flow region except in a narrow region adjacent to the left wall(y=-1). Fig.6 shows the variation of u with heat source parameter (α).It is found that an increase on the strength of the heat generating /absorption source($|\alpha|\leq 4$) larger the velocity in the entire flow region and for higher $|\alpha|\geq 6$,we notice a decrease in the velocity.The effect of chemical reaction parameter (γ) on u is exhibited in fig.7. It is found that the axial velocity enhances with increase in $\gamma\leq 1.5$, and for higher $\gamma\geq 2.5$,the velocity reduces in the entire flow region except in a narrow region adjacent to the left wall in the degenerating chemical reaction case while in the generating chemical reaction case the velocity reduces in the flow region.Fig.8 represent the variation of u with Forchmen parameter (Δ). An increase in $\Delta\leq 4$,reduces the velocity in the left half and enhances in the right half of the channel and for higher $\Delta\geq 6$, the velocity increases u in the left half and decreases in the right half of the channel region. This is due to the fact that increasing Δ reduces the momentum boundary layer in the left half and increases the thickness of the boundary layer in the right half of the channel.

7.2. Effects of parameters on temperature profiles:

Fig.11 represents θ with Sc and S_0. It is found that lesser the molecular diffusivity ($Sc\leq 0.66$)lesser the actual temperature in the entire flow region except in a narrow region adjacent to the left wall y=-1 where it enhances and further lowering of the molecular diffusivity($Sc\geq 1.3$) larger the actual temperature in the flow region. With respect to Soret parameter(S_0) we find that the higher the thermo-diffusion effect($S_0\leq 1.5$) larger the actual temperature and for higher thermo-diffusion effects($S_0\geq 2.5$) lesser the actual temperature in the entire flow region except in a narrow region adjacent to the left wall y=-1. Fig.12 exhibits the variation of θ with heat source parameter(α).It is observed from the profiles that an increase in the strength of the heat generating/absorbing source leads to an enhancement in the actual temperature in the flow region. Fig.13 represents θ with chemical reaction parameter (γ).From the profiles we find that the actual temperature reduces with increase in $\gamma\leq 1.5$ and enhances with higher $\gamma\geq 2.5$ in the degenerating chemical reaction case and it increases in the generating case. Fig.14 shows the variation of θ with Forchment parameter (Δ)As the Δ increases there is a significant reduction in the thermal boundary layer with a fall in the actual temperature throughout the flow region, since enhancement of Δ amounts to reduction of thermal diffusion.

7.3. Effects of parameters on concentration profiles:

Fig.18 shows the variation of C with Sc and S_0. It can be seen from the profiles that the actual concentration enhances with increase in Sc. Also higher the thermo-diffusion effects larger the actual concentration in the flow region except in a narrow region adjacent to the left wall y=-1. Fig.19 shows the variation of C with heat source parameter (α). An increase in $\alpha\leq 4$,the actual concentration increases while for higher α≥6,we notice a depreciation in the actual concentration .In the case of heat absorbing source, the actual concentration enhances with increase in the strength of the heat absorbing heat source. Fig.20 shows the variation of C with Chemical reaction parameter (γ). It can be seen from the profiles that the actual concentration reduces in the degenerating chemical reaction case while in the generating chemical reaction case we notice an enhancement in the actual concentration nin the entire flow region. Fig 21 exhibits the variation of C with Forchment parameter (Δ).As the Δ increases there is a marginal increase in the actual concentration. This is due to the fact the enhancement of Δ amounts to reduction of thermal diffusion.

7.4. 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.2.from the tabular values we find that an increase in Sc or So reduces the skin friction on both the walls. The skin friction reduces on y=+1 with increase in the strength of the heat generating/absorption source, while on y=-1,it reduces with α>0 and enhances with α<0.With reference to the chemical reaction parameter(γ) we find that the skin friction reduces on both the walls in both degenerating/generating chemical reaction cases. As the Prandtl number increases the skin friction enhances on y=±1.

The rate of heat transfer(Nusselt number) enhances with increase in Δ while it reduces with Sc or S_0. The magnitude of Nu reduces on y=±1, with increase in the strength of the heat generating source while an increase in the strength of the heat absorption source enhances Nu on y=+1 and reduces on y=-1.With respect to the chemical reaction parameter (γ)we find that the magnitude of Nu reduces in the degenerating chemical reaction case and enhances in the generating chemical reaction case on both the walls.

The rate of mass transfer (Sherwood number) reduces with increase in So and enhances with Δ on both the walls. An increase in Sc enhances Sh on y=+1 and reduces on y=-1. An increase in α>0 reduces Sh on y=+1 and enhances on y=-1 while a reversed effect is noticed for α<0.With respect to the chemical reaction parameter (γ) we find that the rate of mass transfer reduces on y=+1 in both degenerating and generating chemical reaction cases while on y=-1,it enhances in the degenerating chemical reaction case and reduces in the generating case.

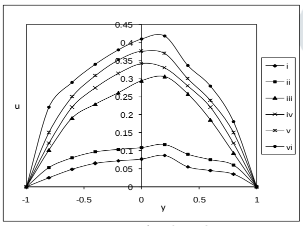

Fig.1 : Variation of u with Sc and S_0

	I	II	III	IV	V	VI
Sc	0.24	0.6	1.3	2.01	1.3	1.3
S_0	0.5	0.5	0.5	0.5	1.5	2.5

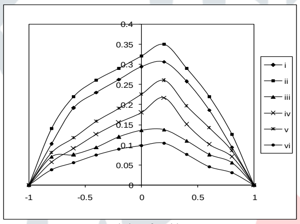

Fig.2 : Variation of u with α

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

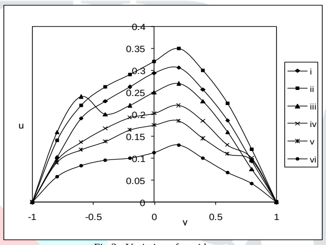

Fig.3 : Variation of u with γ

	I	II	III	IV	V	VI
γ	0.5	1.5	2.5	-0.5	-1.5	-2.5

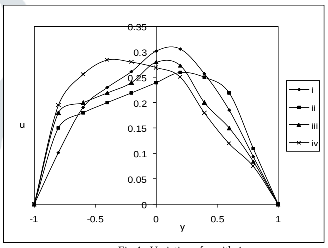

Fig.4 : Variation of u with Δ

	I	II	III	IV
Δ	2	4	6	10

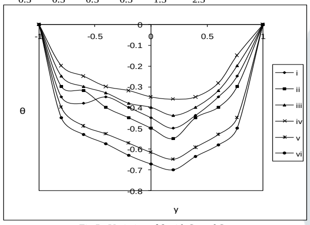

Fig.5 : Variation of θ with Sc and S_0

	I	II	III	IV	V	VI
Sc	0.24	0.6	1.3	2.01	1.3	1.3
S_0	0.5	0.5	0.5	0.5	1.5	2.5

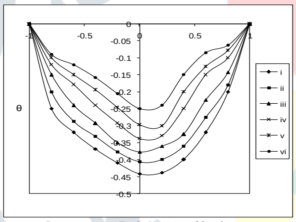

Fig.6 : Variation of θ with α

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

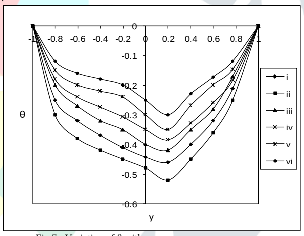

Fig.7 : Variation of θ with γ

	I	II	III	IV	V	VI
γ	0.5	1.5	2.5	-0.5	-1.5	-2.5

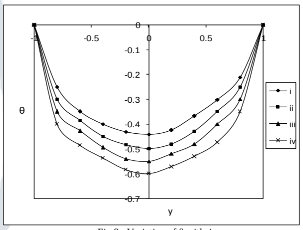

Fig.8 : Variation of θ with Δ

	I	II	III	IV
Δ	2	4	6	10

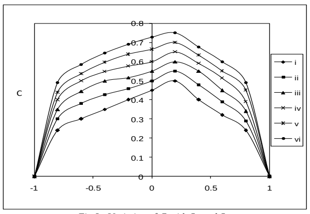

Fig.9 : Variation of C with Sc and S_0

	I	II	III	IV	V	VI
Sc	0.24	0.6	1.3	2.01	1.3	1.3
S_0	0.5	0.5	0.5	0.5	1.5	2.5

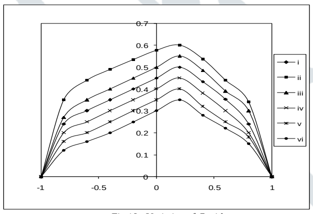

Fig.10 : Variation of C with α

	I	II	III	IV	V	VI
α	2	4	6	-2	-4	-6

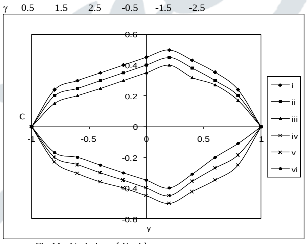

Fig.11 : Variation of C with γ

	I	II	III	IV	V	VI
γ	0.5	1.5	2.5	-0.5	-1.5	-2.5

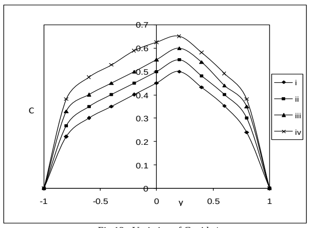

Fig.12 : Variation of C with Δ

	I	II	III	IV
Δ	2	4	6	10

Table -2 : Skin Friction, Nusselt Number and Sherwood Number at y = ±1

Parameter		τ(+1)	τ(-1)	Nu(+1)	Nu(-1)	Sh(+1)	Sh(-1)
α	2	1.06227	-0.9583	-0.2607	-4.0053	0.253339	14.7935
	4	1.05829	-0.95588	-0.13063	-1.9994	0.252809	14.7944
	6	1.05825	-0.95585	-0.08733	-1.3339	0.252926	14.7946
	-2	1.05794	-0.95559	0.255094	4.02685	0.255666	14.7876
	-4	1.05785	-0.95447	-0.67591	2.00876	0.47456	13.6951
Sc	0.24	1.06227	-0.9583	-0.2607	-4.0053	0.253339	14.7935
	0.66	1.05819	-0.95582	-0.25973	-3.9889	0.696339	14.4324
	1.3	1.05792	-0.95558	-0.25966	-3.9880	1.36623	13.8863
S_o	0.5	1.06227	-0.9583	-0.2607	-4.0053	0.253339	14.7935
	1.0	1.05839	-0.95591	-0.25978	-3.9895	0.251604	14.7929
	1.5	1.05834	-0.95635	-0.25979	-3.9885	0.250878	14.7915
γ	0.5	1.06227	-0.9583	-0.26079	-4.0053	0.253339	14.7935
	1.5	1.05844	-0.95601	-0.25979	-3.9898	0.0827635	14.9336
	-0.5	1.05854	-.956091	-0.25982	-3.99	-0.243196	15.2234
	-1.5	1.05852	-0.956087	-0.259813	-3.9901	-0.082195	15.068

8. 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, 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:

1) Lesser the molecular diffusivity($Sc\leq 0.6$) smaller the velocity, temperature and larger the concentration and for further lowering of the molecular diffusivity smaller the velocity, larger the temperature and concentration .The skin friction and the rate of heat transfer reduces with increase in Sc. Also Sherwood number enhances on y=+1 and reduces on y=-1 with increase in Sc.
2) Higher the thermo-diffusion($S_0\leq 1.5$) larger the velocity, temperature and concentration and for higher $S_0\geq 2.5$,the velocity and temperature reduces and the concentration enhances in the flow region. The skin friction, the rate of heat and mass transfer reduces on the walls with increase in S_0.
3) An increase in the strength of the heat generating /absorption heat source($\alpha\leq 4$) enhances the velocity, temperature and concentration and for $\alpha\geq 6$,we notice a reduction in the velocity and concentration ,enhancement in the temperature. The skin friction reduces on y=+1 and enhances on y=-1.The rate of heat transfer reduces on $y=\pm 1$ and Sherwood number reduces on y=+1 and enhances on y=-1with increase in $\alpha>0$.The Nusselt number and Sherwood number enhances on y=+1 and reduces on y=-1 with increase in $\alpha<0$.
4) An increase in the chemical reaction parameter $\gamma\leq 1.5$, enhances the velocity and reduces the temperature and concentration. For higher $\gamma\geq 2.5$,we notice an enhancement in the velocity and temperature and reduces in the concentration in the degenerating chemical reaction case. In the generating chemical reaction case, the velocity reduces while the temperature and concentration enhance in the flow region. The skin friction, the rate of heat and mass transfer reduces on the walls in the degenerating chemical reaction case and a reversed effect is observed in the generating chemical reaction case.
5) The velocity reduces in the left half and enhances in the right half of the channel with $\Delta\leq 4$,enhances with higher $\Delta\geq 6$,we notice a reversed effect in the velocity. Higher Δ smaller the temperature and larger the concentration in the flow region. The skin friction, the rate of heat and mass transfer enhances on the walls with increase in Δ.

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