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HEAT AND MASS TRANSFER FOR SORET, DUFOUR'S AND MAGNETCI EFFECTS IN TRANSIENT FLOW OF CONDUCTING FLUID OVER A STRETCHING SHEET EMBEDDED IN A POROUS MEDIUM WITH CHEMICALLY REACTIVE SPICES

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Abstract- An investigation is made to carry out to study the thermal-diffusion and diffusion thermo-effects in hydro-magnetic transient flow by a mixed convection boundary layer past an impermeable vertical stretching sheet embedded in a conducting fluid-saturated porous medium in the presence of a chemical reaction effect. The velocity of stretching surface, the surface temperature and the concentration are directly proportional to the distance along the surface. The flow is impulsively set into motion rest, and both the temperature and concentration at the surface are also suddenly changed from that of the ambient fluid. An external magnetic field of strength is applied perpendicular to the stretching sheet. Introducing non- dimensional parameters, the governing set of partial differential equation are transformed into the self-similar unsteady boundary layer equations. These equations are solved by Runge-kutta integration scheme with shooting method for the whole transient flow from initial state($\xi = 0$) to final steady state flow ($\xi = 1$). Numerical results for the velocity, temperature, and Concentration profiles are presented graphically for different existing flow parameter. A special case of our results is in good agreement with an earlier published work.

Key words: Heat and mass transfer, boundary layer flow, porous media, magnetic field Soret number and Dufour's number.

I. INTRODUCTION

During recent years of studies, the effect of magnetic field on the flow of viscous fluid with heat and mass transfer through a uniform porous media has become the subject of great interest due to wide application in the fast growing field of science and technology. Numerous publications has been appeared in the leading journal in developed country. It appears that knowledge of the effect of an applied magnetic field on flow, mass and heat transfer is useful for cooling processes in the presence of an electrolytic bath. In some metallurgical processes, such as drawing, annealing and those that involve the cooling of continuous strips of filament by drawing tinning of copper wires etc, the properties in quiescent fluid of the final product depend to a great extent on the rate of cooling. The rate of cooling can be controlled by drawing such strips in an electrically conducting fluid subject to a magnetic field, and the final product of desired characteristic can be achieved.

The recent studies of physics of fluid flow through porous media has become basic for science and technology and of great interest in present days due to their engineering application. One may refer the branches of application as aquifer systems in studies of ground water hydrology, chemical engineering soil mechanics, water purification, industrial filtration etc.

The coupled heat and mass transfer phenomenon in porous media has drawn the attention of galaxy scholars/authors due to it interesting and tremendous application. The processes involving heat and mass transfer in porous media are often encountered in the chemical industry, in reservoir engineering in connection with thermal recovery processes, and in the study of dynamics of hot and salty spring of sea, underground spreading of chemical waste and other pollutants, gain storage, evaporation cooling, and solidification are a few other application area where combined thermosolutal convection in porous media is observed. The exhaustive volume of work devoted to this area by the most recent books by Nield and Bejan(1999), Vafai(2000). Furthermore, the presence of a foreign mass in air or water causes some kind of chemical reaction. During a chemical reaction between two spices, heat is also generated. Duffusion and chemical in an isothermal laminar flow along a soluble flat plate was discussed by Fairbanks and wike(1950). Das et.al. (1994) discussed the effects of mass transfer on the flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction. The flow of mass diffusion of a chemical spices with first order and {(Pop and Ingham (2001) and Ingham and Pop (1998-2002)} higher order reactions over a linearly stretching surface was investigated by Andersson et.al.(1994). The mixed convective heat and mass transfer over a horizontal moving plate with a chemical reaction effect was studied by Fan et.al.(1998). Anjalidevi and Kandasamy (1999) studied the steady laminar flow along a semi-infinite horizontal plate in the presence of a spices concentration and chemical reaction. The flow and mass diffusion of a chemical spices with first order and higher order reactions over a continuously stretching sheet with an applied magnetic field was studied by Tahkar et.al.(2000). Muthucumaraswamy (2002) investigated the effects of a chemical reaction on a moving isothermal vertical infinitely long surface with suction. Chamkha et.al.(2004) studied the double-diffusive convective flow of a micro-polar fluid over a vertical plate embedded in a porous medium with a chemical reaction. The combined effects of the free convective heat and mass transfer on the unsteady boundary layer flow over a stretching surface in the presence of a species concentration and chemical reaction was investigated by Aboeldahab and Azam(2006). Postelnicu (2007) analysed numerically the heat and mass transfer characteristics of natural convection about a vertical surface embedded in a saturated porous medium subjected to a chemical reaction. Rashad and El-kabeir(2010) recently investigated the heat and mass transfer in transient flow by mixed convection boundary layer over a stretching sheet embedded in a porous medium with chemically reactive spices. Sallam.N(2010) analysed the thermal-diffusion and diffusion-Thermo effects on mixed convection heat and transfer in a porous medium.

The purpose of the present paper is to study the simultaneous heat and mass transfer by an unsteady mixed convection boundary layer past an impermeable vertical stretching sheet embedded in a conducting fluid saturated porous medium with chemically reactive species in the presence of magnetic field.

II. FORMULATION OF THE PROBLEM

We consider a unsteady two-dimensional laminar heat and mass transfer by a mixed convection boundary layer flow of viscous, incompressible, Newtonian conducting fluid past an impermeable vertical plate stretching in the direction with a positive velocity $U_e\left(x\right)=ax$ of a saturated porous medium in the presence of a magnetic field of uniform strength B_0 which is perpendicular to the direction of flow. The chemical reaction is taking place in the flow over the porous medium with effective mass diffusivity D_e and the rate of chemical reaction K_1 throughout the fluid. The magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field can be neglected. In addition, Joule heating is neglected but Soret and Dufour's effects are examined.

For the mathematical modeling, we take Cartesian coordinates (x, y) as shown in fig.1, where the positive x-axis is extended along the sheet in the upward direction while the y-axis is normal to the surface of the sheet and is positive in the direction from the sheet to the fluid. The stationary co-ordinate system has its origin located in the center of the sheet. The sheet is maintained a temperature $T_w(x)=T_\infty+bx$ and concentration $C_w(x)=C_\infty+bx,$ and the ambient medium temperature and concentration far away from the surface of the sheet T_∞ and C_∞ are assumed to be uniform. For $T_w>T_\infty$ and $C_w(x)=C_\infty+ax,$ an upward (assisting)flow is induced as a result of the thermal and concentration buoyancy effects. Initially (t<0), the ambient fluid –saturated porous medium is quiescent and has temperature T_∞ and concentration C_∞ respectively. At t=>0, the fluid is impulsively started in motion with the velocity $U(x),$ and both the temperature and the concentration at the sheet suddenly changed to constant values $T_w>T_\infty$ and $C_w(x)=C_\infty+ax,$ respectively. The fluid is assumed to have constant properties, except for the influence of the density and chemical reaction variations with temperature and concentration which are considered in the body force term. Under the preceding assumption, the physical variables are functions of *y* and *t* only and the governing boundary layer equations of mass, momentum, energy and diffusion under Boussinesq approximation could be written as follows

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta_T(T_w-T_\infty)+g\beta_C(C_w-C_\infty)-\frac{\upsilon}{K}u-\frac{\sigma B_0^2}{\rho}u, \tag{2}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_eK_T}{C_sC_p}\frac{\partial^2 C}{\partial y^2}, \tag{3}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_e\frac{\partial^2 C}{\partial y^2}-K_1(C_w-C_\infty)+\frac{D_eK_T}{T_m}\frac{\partial^2 T}{\partial y^2}, \tag{4}$$

The initial and boundary conditions of equations (1)-(4) are

$$t<0:\ u(x,y,t)=0,\ v(x,y,t)=0,\ T(x,y,t)=T_{\infty,}\ C(x,y,t)=C_{\infty,} \tag{5a}$$

$$\left.\begin{array}{l} t\geq 0:\ u(x,0,t)=U_e(x)=ax,\ v(x,0,t)=0,\ T(x,0,t)=T_w=T_\infty+bx \\ C(x,0,t)=C_w=C_\infty+bx,\quad u(x,\infty,t)=0,\ T(x,\infty,t)=T_{\infty,}\ C(x,\infty,t)=C_{\infty,} \end{array}\right\} \tag{5b}$$

Where u and v are the velocity components along the x-axis and y-axis respectively; T and C are the temperature and concentration of the conducting fluid, σ is the electrical conductivity, B_0 is the intensity of the uniform magnetic field, ρ is the density, υ is the kinematic viscosity, α is the thermal diffusivity, β_T is the thermal expansion co-efficient, β_C is the concentration expansion co-efficient, K is the permeability of the porous medium, K_1 is the dimensional chemical reaction parameter and $a, b(>0)$ are constant.

Introducing the flowing change of variables as Rasad and El Kabeir(2010) and Ishak et.al.(2006)

$$\tau = at,\ \eta = \sqrt{\frac{a}{\upsilon}}\ \xi^{-\frac{1}{2}} y,\quad \xi = 1 - e^{-\tau},\ \psi = \sqrt{a\upsilon}\ x\xi^{\frac{1}{2}} f(\xi,\tau),\quad \theta = \frac{T - T_\infty}{T_w - T_\infty},\ \phi = \frac{C - C_\infty}{C_w - C_\infty}, \qquad (6)$$

Where ψ is the stream function which is defined as

$$u = \frac{\partial \psi}{\partial y} \quad \text{and} \quad v = -\frac{\partial \psi}{\partial x}. \qquad (7)$$

The equation of continuity (1) is identically satisfied which can be easily verified. It is convenient for one to select the time scale ξ so that the region of time integration $0 \le \tau < \infty$ occur $0 \le \xi \le 1$. Using (6) and (7) , the equation (2), (3) and (4) converts to

$$f''' + \frac{1}{2}(1-\xi)\eta f'' + \xi f f'' - \xi(\frac{1}{D_a} + f')f' + \lambda\xi(\theta + N\phi) - \xi M f' = \xi(1-\xi)\frac{\partial f'}{\partial \xi}, \qquad (8)$$

$$\frac{1}{P_r}\theta'' + \frac{1}{2}(1-\xi)\eta\theta' + \xi f\theta' - \xi f'\theta + D_f\phi'' = \xi(1-\xi)\frac{\partial \theta}{\partial \xi}, \qquad (9)$$

$$\frac{1}{S_c}\phi'' + \frac{1}{2}(1-\xi)\eta\phi' + \xi f\phi' - (\xi f' + \gamma)\phi + S_r\theta'' = \xi(1-\xi)\frac{\partial \phi}{\partial \xi}, \qquad (10)$$

Where prime denotes differentiations with respect to η only, and the suffix ξ denotes the partial derivatives with respect to ξ, λ is the mixed convection parameter, N is the ratio of buoyancy force due to mass diffusion to the buoyancy force due to thermal diffusion, D_a is the Darcy number, M is the hydro-magnetic parameter which is the ratio of Lorentz force to the viscous force, P_r is the Prandtl number, D_f is the Dufour's number, S_c is the Schmidt number for porous medium, γ is the dimensionless parameter of chemical and S_r is the Soret number which are defined, respectively as

$$\left.\begin{aligned} &D_a = \frac{Ka}{\upsilon},\quad N = \frac{\beta_C(C_w - C_\infty)}{\beta_T(T_w - T_\infty)},\quad \lambda = \frac{\dfrac{g\beta_T(T_w - T_\infty)x}{\upsilon^2}}{\left(\dfrac{U_e(x)}{\upsilon}\right)^2} = \frac{Gr_x}{\mathrm{Re}_x^2},\quad P_r = \frac{\upsilon}{\alpha},\quad S_c = \frac{\upsilon}{D}, \\ &D_f = \frac{(C_w - C_\infty)D_e K_T}{C_s C_p \gamma (T_w - T_\infty)} = \frac{D_e K_T \Delta C}{C_s C_p \gamma \Delta T},\quad \gamma = \frac{K_1}{a},\quad S_r = \frac{D_e K_T (T_w - T_\infty)}{\gamma T_m (C_w - C_\infty)} = \frac{D_e K_T \Delta T}{\gamma T_m \Delta C}, \end{aligned}\right\} \qquad (11)$$

Where D_e is the effective mass diffusivity , T_m is the mean fluid density, β_C is the concentration expansion co-efficient, β_T is the thermal expansion co-efficient, K_T is the thermal diffusion ratio, D is the fluid mass diffusivity , Gr_x is the local grashof number, Re_x is the local Reynolds number.

It is observed that when λ is positive, i.e. $\lambda > 0,$ it corresponds to the (aiding flow) assisting flow case. When λ is negative i.e. $\lambda < 0,$ then it corresponds to the opposing flow case. The boundary condition 5(a) and 5(b) in view of (6) are reduced to

$$\left.\begin{aligned} &f(\xi,0) = 0,\quad f'(\xi,0) = 1,\quad \theta(\xi,0) = 1,\quad \phi(\xi,0) = 1, \\ &f'(\xi,\infty) = 0,\quad \theta(\xi,\infty) = 0,\quad \phi(\xi,\infty) = 0 \end{aligned}\right\}. \qquad (12)$$

It is noted that the equation (8)-(11) for $M = 0,\ D_f = 0,\ S_r = 0$ reduce to those of Rashad and El-Kabeir (2010). Furthermore, for $M = 0, D_f = 0, S_r = 0, D_a = 0, N = 0,\ \gamma = 0$ reduce to those of Ishak et.al, (2006)

III. NUMERICAL SOLUTION

The equation (8)-(10) together with boundary condition(12) are the parabolic partial differential equations. Instead of solving these partial differential equation directly, we look for the particular case of the problem which are the system of ordinary differential equations with a set of constraints at the boundary and can be easily solved by the shooting method. The solution procedure for the entire time domain $0 \le \xi \le 1$ is explained in the following part.

A. Unsteady solution at initial stage (state) when $\xi = 0$

When time scale $\xi = 0$, i.e. for initial unsteady flow, it corresponds to $\tau = 0,$, the equation (7)-(9) converts to

$$f''' + \frac{1}{2}\eta f'' = 0, \quad (12)$$

$$\frac{1}{P_r}\theta'' + \frac{1}{2}\eta\theta' + D_f\phi'' = 0, \quad (13)$$

$$\frac{1}{S_c}\phi'' + \frac{1}{2}\eta\phi' - \gamma\phi + S_r\theta'' = 0, \quad (14)$$

Subject to the boundary conditions

$$\left.\begin{aligned} &f(0) = 0, \quad f'(0) = 1, \quad \theta(0) = 1, \quad \phi(0) = 1, \\ &f'(\infty) = 0, \quad \theta(\infty) = 0, \quad \phi(\infty) = 0 \end{aligned}\right\}. \quad (15)$$

3.2. Solution for steady state when $\xi = 1$, i.e. final steady flow.

When $\xi = 1$, corresponding to $\tau \to \infty$, equations(8)-(10) becomes

$$f''' + ff'' - (\frac{1}{D_a} + f')f' + \lambda(\theta + N\phi) - Mf' = 0, \quad (16)$$

$$\frac{1}{P_r}\theta'' + f\theta' - f'\theta + D_f\phi'' = 0, \quad (17)$$

$$\frac{1}{S_c}\phi'' + f\phi' - (\gamma + f)\phi + S_r\theta'' = 0, \quad (18)$$

Subject to the boundary conditions

$$\left.\begin{aligned} &f(1,0) = 0, \quad f'(1,0) = 1, \quad \theta(1,0) = 1, \quad \phi(1,0) = 1, \\ &f'(1,\infty) = 0, \quad \theta(1,\infty) = 0, \quad \phi(1,\infty) = 0 \end{aligned}\right\}. \quad (19)$$

3.3. Solution for small ξ (or τ)

The approximate solutions of equation (8)-(10) subject to the boundary condition (12), which are valid for the region $\xi \le 1$, equivalent to the small time $\tau << 1$ solution, can be expressed as

$$f(\xi,\eta) = f_0(\eta) + \xi f_1(\eta) + \xi^2 f_2(\eta) + ----------- \quad (20)$$

$$\theta(\xi,\eta) = \theta_0(\eta) + \xi\theta_1(\eta) + \xi^2\theta_2(\eta) + ----------- \quad (21)$$

$$\phi(\xi,\eta) = \phi_0(\eta) + \xi\phi_1(\eta) + \xi^2\phi_2(\eta) + ----------- \quad (22)$$

Where

$$f_0''' + \frac{1}{2}\eta f_0'' = 0, \quad (23)$$

$$\frac{1}{P_r}\theta_0'' + \frac{1}{2}\eta\theta_0' + D_f\phi_0'' = 0, \quad (24)$$

$$\frac{1}{S_c}\phi_0'' + \frac{1}{2}\eta\phi_0' - \gamma\phi_0 + S_r\theta_0'' = 0, \quad (25)$$

Subject to the boundary conditions

$$\left.\begin{aligned} &f_0(0) = 0, \quad f_0'(0) = 1, \quad \theta_0(0) = 1, \quad \phi_0(0) = 1, \\ &f_0'(\infty) = 0, \quad \theta_0(\infty) = 0, \quad \phi_0(\infty) = 0, \end{aligned}\right\}, \quad (26)$$

$$f_1''' + \frac{1}{2}(f_1'' - f_0'')\eta + f_0 f_0'' - f_0'^2 + \lambda(\theta_0 + N\phi_0) - \frac{1}{D_a} f_0' - M f_0' - f_1' = 0, \qquad (27)$$

$$\frac{1}{P_r}\theta_1'' + \frac{1}{2}\eta(\theta_1' - \theta_0') + f_0\theta_0' - f_0'\theta_0 - \theta_1 + D_f\phi_1'' = 0, \qquad (28)$$

$$\frac{1}{S_c}\phi_1'' + \frac{1}{2}\eta(\phi_1' - \phi_0') + f_0\phi_0' - f_0'\phi_0 - \phi_1 - \gamma\phi_1 + S_r\theta_1'' = 0, \qquad (29)$$

Subject to the boundary conditions

$$\left.\begin{array}{l} f_1(0)=0, \quad f_1'(0)=0, \quad \theta_1(0)=0, \quad \phi_1(0)=0, \\ f_1'(\infty)=0, \quad \theta_1(\infty)=0, \quad \phi_1(\infty)=0 \end{array}\right\}, \qquad (30)$$

And

$$f_2''' + \frac{1}{2}(f_2'' - f_1'')\eta + f_0 f_1'' + f_1 f_0'' - 2 f_0' f_1' + \lambda(\theta_1 + N\phi_1) - \frac{1}{D_a} f_1' - M f_1' + f_1' - 2 f_2' = 0, \qquad (31)$$

$$\frac{1}{P_r}\theta_2'' + \frac{1}{2}\eta(\theta_2' - \theta_1') + f_0\theta_1' + f_1\theta_0' - f_0'\theta_1 - \theta_0 f_1' - 2\theta_2 + \theta_1 + D_f\phi_2'' = 0, \qquad (32)$$

$$\frac{1}{S_c}\phi_2'' + \frac{1}{2}\eta(\phi_2' - \phi_1') + f_0\phi_1' + f_1\phi_0' - f_0'\phi_1 - \phi_0 f_1' - 2\phi_2 + \phi_1 - \gamma\phi_2 + S_r\theta_2'' = 0, \qquad (33)$$

Subject to the boundary conditions

$$\left.\begin{array}{l} f_2(0)=0, \quad f_2'(0)=0, \quad \theta_2(0)=0, \quad \phi_2(0)=0, \\ f_2'(\infty)=0, \quad \theta_2(\infty)=0, \quad \phi_2(\infty)=0 \end{array}\right\}, \qquad (34)$$

IV. NUMERICAL SOLUTION

The numerical solution to the boundary value problem of ordinary differential equations is obtained by the Runge kutta method in association with the shooting technique. It may be noted that the source of error in the simulation may come from the prescribed boundary conditions at the infinity. The reason is that the physical domain under consideration is unbounded whereas the computational domain is finite. In fact, the far field boundary condition usually depends on the physical parameters of the problem, and its value needs to be adjusted as the value of the parameters change. In practice, the computational domain is chosen to be sufficiently large, so that the numerical solution closely approximates the terminal boundary conditions at infinity. Here boundary condition at the far end has been fixsed to 10 and is suitably less than 10 depending on the choice of the parameters.

V. RESULTS AND DISCUSSION

A representative graphical results of velocity profiles, temperature profiles and concentration profiles are presented in Figs. 2—13 for various existing flow parameters across the boundary layer of the conducting fluid. These Figs1-3. Demonstrate the advancement of Velocity, temperature and concentrtaion profiles from initial to final steady state when $D_f = 0,\ S_r = 0,$ $P_r = 0.7,\ S_c = 0.22,\ D_a = 2,\ N = 1,\ \lambda = 2,\ \gamma = 1,\ M = 0$. From figs 2 & 3, it is clear that the variations of velocities and temperature are observed to be rise more from initial state ($\xi = 0$)to final steady state ($\xi = 1$) respectively where as the results presented in the fig.4 for the concentration of the fluid, are observed to be decline from initial state ($\xi = 0$) to final steady state ($\xi = 1$). The variation of velocity profiles f' vs η for various magnetic parameter M for fixed $D_f = 0.5,\ S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22, D_a = 5,$ $N = 1,\ \lambda = 8,\ \gamma = 1$ are shown in Fig.5.The effects of magnetic field are seen to decrease the velocity f' across the boundary layer of the conducting fluid as the Lorentz force retards the motion of the conducting fluid throughout the boundary layer. The variation of temperature profiles θ vs η for various magnetic parameter M for fixed $D_f = 0.5,\ S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22, D_a = 5,$ $N = 1,\ \lambda = 8,\ \gamma = 1$ are shown in Fig.6. The effects of magnetic field are seen to increase the temperature θ across the boundary layer of the conducting fluid. The concentration profiles ϕ vs η for various magnetic parameter M for fixed $D_f = 0.5,\ S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22, D_a = 5,$ $N = 1,\ \lambda = 8,\ \gamma = 1,$ are plotted in Fig.7. The effects of magnetic field are seen to decrease the concentration ϕ across the boundary layer of the conducting fluid as the Lorentz force retards the motion of the conducting fluid across the boundary layer. Variations of velocity profiles f' vs η and temperature profile θ vs η for various Dafour number D_f for fixed parameter $S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,$ $D_a = 5,\ N = 1,\ \lambda = 10,\ \gamma = 1, M = 1$, are plotted in Figs.8 and Fig.9 respectively. The effects of Dafour number are seen to increase the velocity and temperature of the conducting fluid across the boundary layer. The variations of Concentration profiles ϕ vs η for various Dafour number D_f for fixed parameter $S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,$ $D_a = 5,\ N = 1,\ \lambda = 10,\ \gamma = 1, M = 1$, are plotted in Figs.10. The concentration are seen to increase with the increase of Dafour number D_f. Variations of velocity profiles f', temperature profile θ and Concentration profiles ϕ, vs η for various Soret number S_r for fixed parameter $D_f = 0.5,\ P_r = 0.7,\ S_c = 0.22,$ $D_a = 5,\ N = 1,\ \lambda = 8,\ \gamma = 1, M = 1$ are plotted in Figs.11, 12 & 13 respectively. It is observed form Fig.11 that the velocity distributions f', increases with the increases of Soret number S_r across the boundary layer of the conducting fluid. Fig.12 shows that the temperature distributions θ increases with the increases of Soret number S_r across the boundary layer of the conducting fluid. The effects of Soret number S_r are seen to increase the Concentration profile ϕ across the boundary layer which are shown in Fig.13.

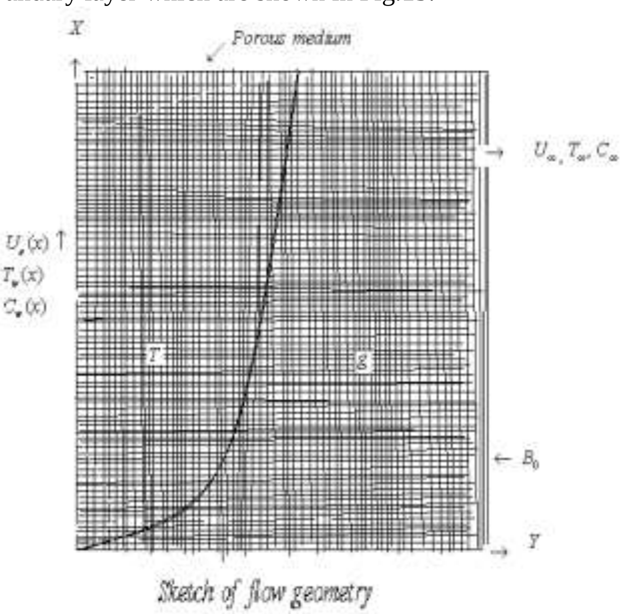

Fig.1 Sketch of flow geometry

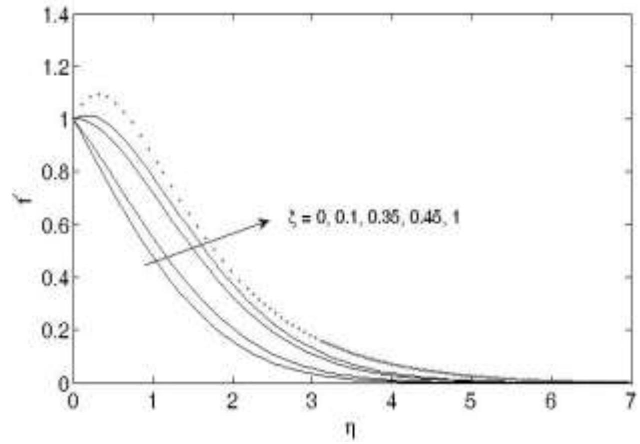

Fig.2 Variations of velocity profiles f' from initial ($\xi = 0$) to final steady state ($\xi = 1$)

When $D_f = 0, S_r = 0,\ P_r = 0.7, S_c = 0.22,\ D_a = 2, N = 1, \lambda = 2, \gamma = 1, M = 0$.

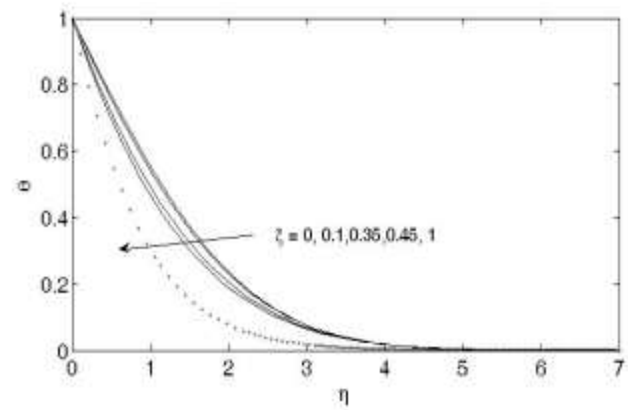

Fig.3 Variations of temperature profiles θ from initial ($\xi = 0$) to final steady state ($\xi = 1$) when

$D_f = 0,\ S_r = 0,\ P_r = 0.7,\ S_c = 0.22,\ D_a = 2,\ N = 1,\ \lambda = 2,\ \gamma = 1,\ M = 0$

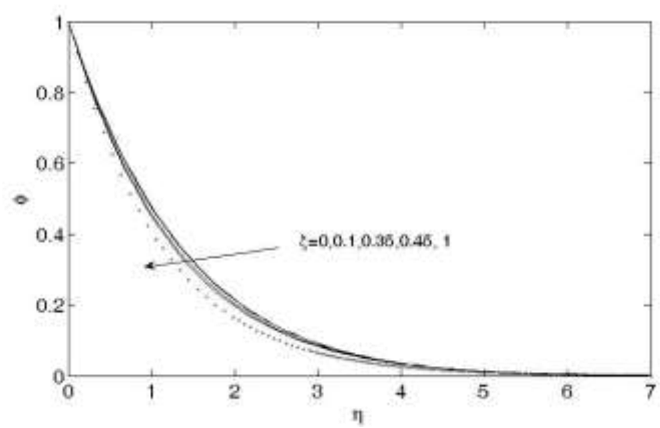

Fig.4 Variations of Concentration profiles ϕ from initial ($\xi = 0$) to final steady state ($\xi = 1$) when

$D_f = 0,\ S_r = 0,\ P_r = 0.7,\ S_c = 0.22,\ D_a = 2,\ N = 1,\ \lambda = 2,\ \gamma = 1,\ M = 0$

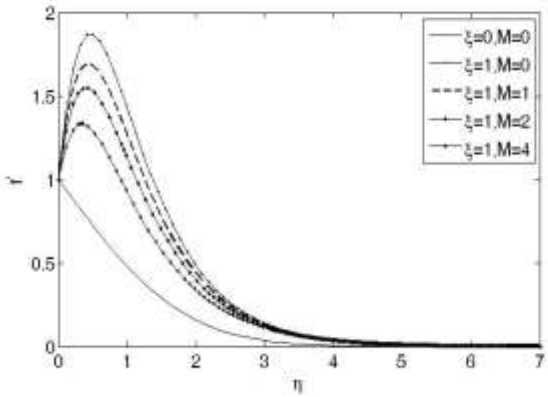

Fig.5 Variations of velocities profiles f' from initial ($\xi = 0$) to final steady state ($\xi = 1$) for various magnetic parameter M when $D_f = 0.5,\ S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,$ $D_a = 5,\ N = 1,\ \lambda = 8,\ \gamma = 1,$

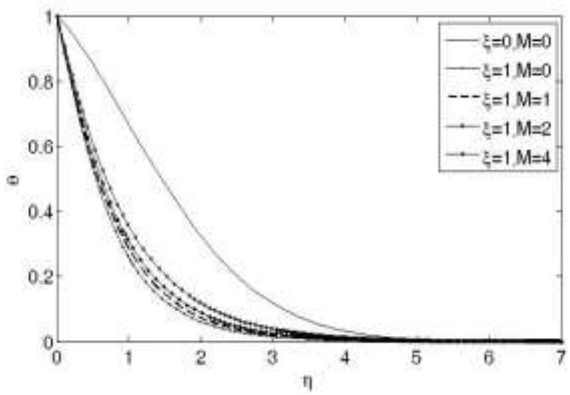

Fig.6 Variations of temperature profiles θ from initial ($\xi = 0$)to final steady state ($\xi = 1$) for various magnetic parameter M when $D_f = 0.5,\ S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,$ $D_a = 5,\ N = 1,\ \lambda = 8,\ \gamma = 1,$

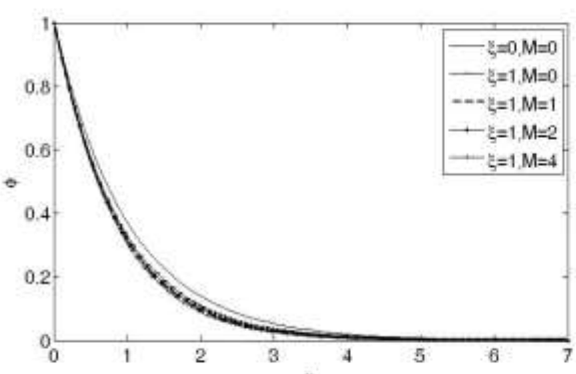

Fig.7 Variations of Concentration profiles ϕ from initial ($\xi = 0$)to final steady state ($\xi = 1$) for various magnetic parameter M when
$D_f = 0.5,\ S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,\ D_a = 5,\ N = 1,\ \lambda = 8,\ \gamma = 1,$

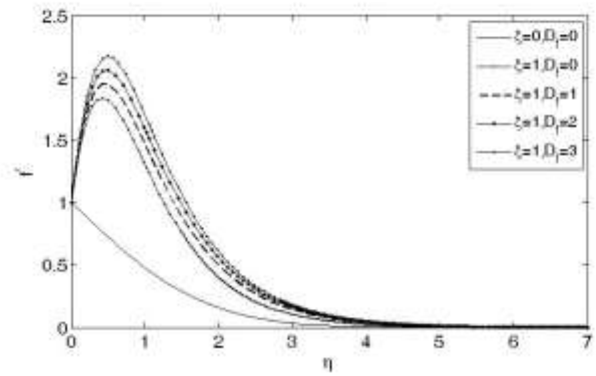

Fig.8 Variations of velocities profiles f' from initial ($\xi = 0$)to final steady state ($\xi = 1$) for various Dafour number D_f for fixed parameter $S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,$ $D_a = 5,\ N = 1,\ \lambda = 10,\ \gamma = 1, M = 1$.

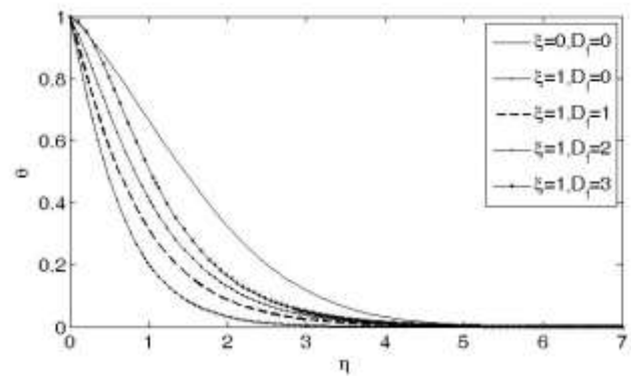

Fig.9 Variations of temperature profiles θ from initial ($\xi = 0$) to final steady state ($\xi = 1$) for various Dafour number D_f for fixed parameter
$S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,\ \ D_a = 5,\ N = 1,\ \lambda = 10,\ \gamma = 1, M = 1$.

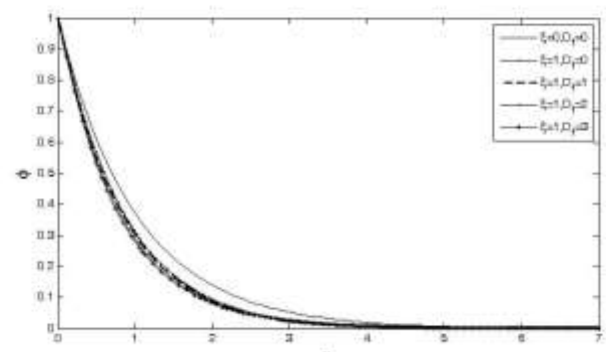

Fig.10 Variations of Concentration profiles ϕ from initial ($\xi = 0$)to final steady state ($\xi = 1$) for various Dafour number D_f for fixed parameter
$S_r = 0.5,\ P_r = 0.7,\ S_c = 0.22,\ \ D_a = 5,\ N = 1,\ \lambda = 10,\ \gamma = 1, M = 1$.

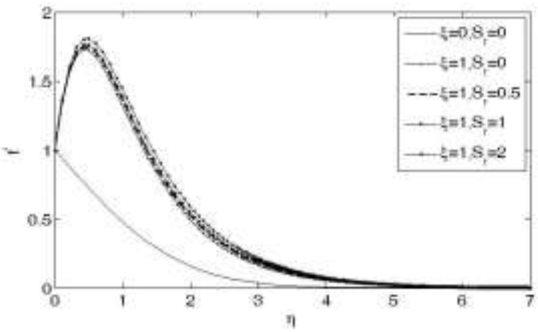

Fig.11 Variations of velocities profiles f' from initial ($\xi=0$)to final steady state ($\xi=1$) for various Soret number S_r for fixed parameter

$D_f=0.5,\ P_r=0.7,\ S_c=0.22,\ \ D_a=5,\ N=1,\ \lambda=8,\ \gamma=1, M=1.$

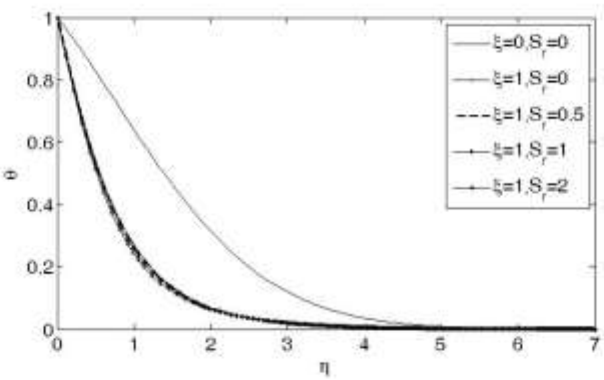

Fig.12 Variations of temperature profiles θ from initial ($\xi=0$)to final steady state ($\xi=1$) for various Soret number S_r for fixed parameter

$D_f=0.5,\ P_r=0.7,\ S_c=0.22,\ \ D_a=5,\ N=1,\ \lambda=8,\ \gamma=1, M=1.$

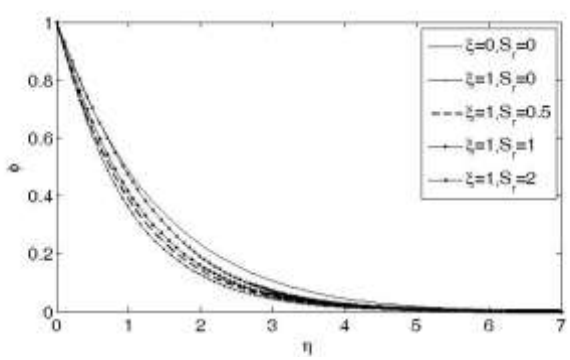

Fig.13 Variations of Concentration profiles ϕ from initial ($\xi=0$)to final steady state ($\xi=1$) for various Soret number S_r for fixed parameter $D_f=0.5,\ P_r=0.7,\ S_c=0.22,$

$D_a=5,\ N=1,\ \lambda=8,\ \gamma=1, M=1.$

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