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Effect of mass Transfer on unsteady MHD Oscillatory Flow through a Porous Medium with Slip flow region and heat radiation

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Abstract: In this paper, the effects of slip flow region, transverse magnetic field, mass transfer and heat transfer to unsteady flow of a conducting optically thin fluid through a channel filled with porous medium has been discussed. Exact solutions of the governing equations for fully developed flow are obtained in closed form. Detailed computations of the influence of the Grashof number, modified Grashof number, Hartmann number, slip parameter, porosity parameter and radiation parameter are discussed with the help of tables and graphs.

Keywords: Radiative heat, oscillatory flow, porous medium, slipflow region, MHD, mass transfer.

1. Introduction

In recent years, considerable interest has been developed in the study of flow past of a porous medium due to its natural occurrence and importance in both geophysical and engineering environments. Research on thermal interaction between heat generating porous bed and over lying fluid layer was largely motivated by the researchers to avoid severe accidental problems in nuclear reactors. Raptis et al [3] studied the unsteady free convective flow through a porous medium bounded by an infinite vertical plate. Free convection effect on flow past a vertical surface studied by Vajnvelu et al [2]. Ram and Mishra [1] analyzed unsteady flow through MHD porous media. MHD unsteady free convection Walter's memory flow with constant suction and heat sink was studies by Ramana et al [6].

The phenomenon of slip-flow regime has attracted the attention of a large number of scholars due to its wide ranging application. The problem of the slip flow regime is very important in this era of modern science, technology and vast ranging industrialization. In practical applications, the particle adjacent to a solid surface no longer takes the velocity of the surface. The particle at the surface has a finite tangential velocity and it slips along the surface. The flow regime is called the slip flow regime and its effect cannot be neglected. The fluid slippage phenomenon at the solid boundaries appears in many applications such as micro channels or nano channels. The effect of slip conditions on the MHD steady flow in a channel with permeable boundaries has been discussed by Makinde and Osalusi[4]. Khaled and Vafai[5] obtained the closed form solutions for steady periodic and transient velocity field under slip condition.

The demands from the practical field have necessitated handling MHD problems involving mass transfer phenomenon. The study of stellar structure on solar surface is connected with mass transfer phenomena. Its origin is attributed to difference in temperature caused by the non-homogeneous production of heat which in many cases can rest not only in the formation of convective currents but also in violent explosions. Mass transfer certainly occurs within the mantle and cores of planets of the size of or larger than the earth. Senapati and Dhal[8] have discussed themagnetic effect on mass and heat transfer of a hydrodynamic flow past a vertical oscillating plate in presence of chemical reaction. Senapati et.al [10] have studied the mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink. Unsteady Heat Transfer to MHD Oscillatory Flow through a Porous Medium under Slip Condition have been studied by Usmanet.al [9].

This paper deals with the study of Effect of mass Transfer on unsteady MHD Oscillatory Flow through a Porous Medium with Slip flow region and heat radiation.

2. Mathematical Formulation

Consider the flow of a conducting optically thin fluid between two parallel plates having a distance apart from each other in which one is slip condition and other is stationary filled with saturated porous medium under the influence of an externally applied homogeneous magnetic field and radiative heat transfer. It is assumed that the fluid has a small electrical conductivity and the electromagnetic force produced is very small. Take a Cartesian coordinate system (x', y'), where x' lies along the center of the channel, y' is the distance measured in the normal section. Then, assuming a Boussinesq incompressible fluid model, the equations governing the motion are given as:

$$\frac{\partial u'}{\partial t'} = -\frac{1}{\rho}\frac{\partial P'}{\partial x'} + g\beta(T' - T_0') + g\beta_c(C' - C_0') + \nu\frac{\partial^2 u'}{\partial^2 u'^2} - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K'}u' \qquad (1)$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q'}{\partial y'} \qquad (2)$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} \qquad (3)$$

with boundary conditions

$$\left.\begin{aligned} &u' = \gamma'\frac{\partial u'}{\partial y'},\ T' = T_w',\ C' = C_w' \quad \text{at} \quad y' = 0 \\ &u' = 0, T' = T_0' + (T_w' - T_0')\cos\omega' t',\ C' = C_0' + (C_w' - C_0')\cos w' t' \quad at \quad y' = a \end{aligned}\right\} \qquad (4)$$

It is assumed that the fluid is optically thin with a relatively low density and the radiative heat flux is given by

$$\frac{\partial q'}{\partial y'} = 4\alpha^2(T_0' - T') \qquad (5)$$

where u' is the axial velocity, t' is the time, ω' is the frequency of the oscillation, T' the fluid temperature, P' the pressure, g the gravitational force, C_p the specific heat at constant pressure, k the thermal conductivity, q' the radiative heat flux, β the coefficient of thermal expansion, β_C the coefficient of expansion of mass concentration, K' the porous medium permeability coefficient, B_0 the electromagnetic induction, σ_e the conductivity of the fluid, ρ the density of the fluid, v is the kinematics viscosity coefficient. It is assumed that walls temperature T_w' and T_0', are high enough to induce radiative heat transfer, and γ' is the dimensionless slip parameter.

Let us introduce the following non dimensional parameters

$$\left.\begin{aligned}&Re=\frac{Ua}{\nu},x=\frac{x'}{a},y=\frac{y'}{a},u=\frac{u'}{U},\theta=\frac{T'-T'_0}{T'_w-T'_0}\ ,C=\frac{C'-C'_0}{C'_w-C'_0}\\&H^2=\frac{a^2\sigma_e B_0^2}{\rho\nu}\ ,\omega=\frac{a\omega'}{u}t=\frac{t'U}{a},P=\frac{aP'}{\rho\nu U},\frac{1}{S^2}=\frac{K'}{a^2},Gr=\frac{g\beta(T'_w-T'_0)a^2}{\nu U}\\&Sc=\frac{\nu}{D},Gm=\frac{g\beta_c(C'_w-C'_0)a^2}{\nu U}\ ,Pe=\frac{Ua\rho C_p}{k}\ ,N^2=\frac{4\alpha^2a^2}{k},h=\frac{\gamma'}{a}\end{aligned}\right\} \tag{6}$$

Then using equation (6) to (7), equations (1) to (3) with boundary condition (4), reduce to

$$Re\frac{\partial u}{\partial t}=-\frac{\partial P}{\partial x}+\frac{\partial^2 u}{\partial y^2}-(S^2+H^2)u+Gr\theta+GmC \tag{7}$$

$$Pe\frac{\partial \theta}{\partial t}=\frac{\partial^2\theta}{\partial y^2}+N^2\theta \tag{8}$$

$$Re\,Sc\frac{\partial C}{\partial t}=\frac{\partial^2 C}{\partial y^2} \tag{9}$$

With boundary conditions

$$\left.\begin{aligned}&u=h\frac{\partial u}{\partial y}\ ,\theta=0\ ,C=0\ \text{ at }\ y=0\\&u=0\ ,\theta=\cos\omega t,\ C=\cos\omega t\ \text{ at }\ y=1\end{aligned}\right\} \tag{10}$$

where *Gr* is the thermal Grashof number, *Gm* is modified Grashof Number, *H* is the Hartmann number, *N* is the radiation parameter, *Pe* is the Peclet number, *Re* is the Reynolds number, *D* is the Darcy number, *Sc* is the Schmidt number, *h* is the slip parameter and *S* is the porous medium shape factor.

3. Method of Solution

In order to solve equations (7) to (9) for purely oscillatory flow, let the pressure gradient, fluid velocity, temperature and mass concentration be as below:

$$-\frac{\partial P}{\partial x}=\lambda(e^{i\omega t}+e^{-i\omega t}) \tag{11}$$

$$u=u_0(y)e^{i\omega t}+u_1(y)e^{-i\omega t} \tag{12}$$

$$\theta = \theta_0(y)e^{i\omega t} + \theta_1(y)e^{-i\omega t} \tag{13}$$

$$C = C_0(y)e^{i\omega t} + C_1(y)e^{-i\omega t} \tag{14}$$

where $\lambda < 0$ as the pressure gradient parameter.

By Substituting the above in equation (7) – (9), we get

$$\frac{\partial^2 u_0}{\partial y^2} - (S^2 + H^2 + Re\omega i)u_0 = -(\lambda + Gr\theta_0 + GmC_0) \tag{15}$$

$$\frac{\partial^2 u_1}{\partial y^2} - (S^2 - H^2 - Re\omega i)u_1 = -(\lambda + Gr\theta_1 + GmC_1) \tag{16}$$

$$\frac{\partial^2 \theta_0}{\partial y^2} + (N_2 - Pe\omega i)\theta_0 = 0 \tag{17}$$

$$\frac{\partial^2 \theta_1}{\partial y^2} + (N^2 + Pe\omega i)\theta_1 = 0 \tag{18}$$

$$\frac{\partial^2 C_0}{\partial y^2} - Re\,Sc\omega i\,C_0 = 0 \tag{19}$$

$$\frac{\partial^2 C_1}{\partial y^2} + Re\,Sc\omega i\,C_1 = 0 \tag{20}$$

with the following boundary conditions

$$\left.\begin{array}{l} u_0 = h\dfrac{\partial u_0}{\partial y}\ ,\ u_1 = h\dfrac{\partial u_1}{\partial y}\ ,\ \theta_0 = 0\ ,\ \theta_1 = 0\ , C_0 = 0, C_1 = 0 \ \text{ at } \ y = 0 \\ u_0 = 0, u_1 = 0, \theta_0 = \dfrac{1}{2}\ , \theta_1 = \dfrac{1}{2}, C_0 = \dfrac{1}{2}\ ,\ C_1 = \dfrac{1}{2} \ \text{ at } \ y = 1 \end{array}\right\} \tag{21}$$

By solving equation (15) to (20) using boundary conditions (21), we get

$$\begin{aligned} u = &\Big(B_4\, e^{(A_4 + A_5 i)y} + B_5\, e^{-(A_4 + A_5 i)y} + \lambda B_1 + B_2 \sin h\,((A_2 + A_3 i)y) \\ &+ B_3 \sin h\,(A_1(1+i)y)\Big)e^{i\omega t} + \Big(B_9\, e^{(A_4 + A_5 i)y} + B_{10}\, e^{-(A_4 + A_5 i)y} + \lambda B_6 \\ &+ B_7 \sin h((A_3 + A_2 i)\,y) + + B_8 \sin h\,(A_1(1-i)\,y)\Big)\, e^{-i\omega t} \end{aligned} \tag{22}$$

$$\theta=\left(\frac{\sin h(A_2+A_3 i)y)}{2\sin h(A_2+A_3 i)}\right)e^{i\omega t}+\left(\frac{\sin h(A_3+A_2 i)y)}{2\sin h(A_3+A_2 i)}\right)e^{-i\omega t}, \tag{23}$$

$$C=\left(\frac{\sin h(A_1(1+i)y)}{2\sin h(A_1(1+i))}\right)e^{i\omega t}+\left(\frac{\sin h(A_1(1-i)y)}{2\sin h(A_1(1-i))}\right)e^{-i\omega t}, \tag{24}$$

The non-dimensional shearing stress at the plate having slip condition is

$$\tau_1=\left(\frac{\partial u}{\partial y}\right)_{y=0}=\big((A_4+A_5 i)B_4-(A_4+A_5 i)B_5+(A_2+A_3 i)B_2+A_1(1+i)B_3\big)e^{i\omega t}$$
$$+\big((A_4+A_5 i)B_9-(A_4+A_5 i)B_{10}+(A_3+A_2 i)B_7+A_1(1-i)B_8\big)e^{-i\omega t} \tag{25}$$

The non-dimensional shearing stress at stationary plate is

$$\tau_1=\left(\frac{\partial u}{\partial y}\right)_{y=1}=\Big((A_4+A_5 i)B_4 e^{(A_4+A_5 i)}-(A_4+A_5 i)B_5 e^{-(A_4+A_5 i)}$$
$$+(A_2+A_3 i)B_2\cos h((A_2+A_3 i))+A_1(1+i)B_3\cos h(A_1(1+i))\Big)e^{i\omega t}$$
$$+\Big((A_4+A_5 i)B_9 e^{(A_4+A_5 i)}-(A_4+A_5 i)B_{10}e^{-(A_4+A_5 i)}$$
$$+(A_3+A_2 i)B_7\cos h((A_3+A_2 i))+A_1(1-i)B_8\cos h(A_1(1-i))\Big)e^{i\omega t} \tag{26}$$

The dimensional rate of heat transfer/ Nusselt Number, at the plate having slip condition is

$$Nu_1=-\left(\frac{\partial\theta}{\partial y}\right)_{y=0}=-\left(\frac{1}{2\sin h(A_2+A_3 i))}\right)e^{i\omega t}-\left(\frac{1}{2\sin h(A_3+A_2 i))}\right)e^{-i\omega t}$$

The dimensional rate of heat transfer/ Nusselt Number, at the stationary plate is

$$Nu_2=-\left(\frac{\partial\theta}{\partial y}\right)_{y=0}=-\left(\frac{\cos h(A_2+A_3 i))}{2\sin h(A_2+A_3 i))}\right)e^{i\omega t}-\left(\frac{\cos h(A_3+A_2 i))}{2\sin h(A_3+A_2 i))}\right)e^{-i\omega t}$$

The dimensionless rate of mass transfer/ Sherwood Number at the plate having slip condition is

$$Sh_1 = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = -\left(\frac{1}{2\sin h(A_1(1+i))}\right)e^{i\omega t} - \left(\frac{1}{2\sin h(A_1(1-i))}\right)e^{-i\omega t}$$

The dimensionless rate of mass transfer/ Sherwood Number at the stationary plate is

$$Sh_2 = -\left(\frac{\partial C}{\partial y}\right)_{y=1} = -\left(\frac{\cos h(A_1(1+i))}{2\sin h(A_1(1+i))}\right)e^{i\omega t} - \left(\frac{\cos h(A_1(1-i))}{2\sin h(A_1(1-i))}\right)e^{-i\omega t}$$

where

$$A_1 = \sqrt{\frac{ReSc\omega}{2}}\ ,\ A_2 = \left(\frac{-N^2 + \sqrt{N^4 + (Pe\omega)^2}}{2}\right)^{\frac{1}{2}}\ ,\ A_3 = \left(\frac{N^2 + \sqrt{N^4 + (Pe\omega)^2}}{2}\right)^{\frac{1}{2}}$$

$$A_4 = \left(\frac{(S^2 + H^2) + \sqrt{(S^2 + H^2)^2 + (Re\omega)^2}}{2}\right)^{\frac{1}{2}}\ ,$$

$$A_5 = \left(\frac{-(S^2 + H^2) + \sqrt{(S^2 + H^2)^2 + (Re\omega)^2}}{2}\right)^{\frac{1}{2}}\ ,$$

$$B_1 = \frac{1}{H^2 + S^2 + Re\omega i}\ ,\ B_2 = \frac{-Gr}{2\sin h(A_2 + A_3 i)\left((A_2 + A_3 i)^2 - (H^2 + S^2 + Re\omega i)\right)}\ ,$$

$$B_3 = \frac{-Gm}{2\sin h(A_1(1+i))\left((A_1(1+i))^2 - (H^2 + S^2 + Re\omega i)\right)}$$

$$B_4 = \frac{e^{-(A_4+A_5 i)}(\lambda B_1 - hB_2(A_2 + A_3 i) - hB_3 A_1(1+i)) - (h(A_4 + A_5 i) + 1(\lambda B_1 + B_2 \sin h((A_2 + A_3 i)) + B_3 \sin h(A_1(1+i)))}{(h(A_4 + A_5 i) + 1)e^{(A_4+A_5 i)} + e^{-(A_4+A_5 i)}(h(A_4 + A_5 i) - 1)}\ ,$$

$$B_5 = \frac{e^{-(A_4+A_5 i)}(\lambda B_1 - hB_2(A_2 + A_3 i) - hB_3 A_1(1+i)) - (h(A_4 + A_5 i) - 1(\lambda B_1 + B_2 \sin h((A_2 + A_3 i)) + B_3 \sin h(A_1(1+i)))}{(h(A_4 + A_5 i) + 1)e^{(A_4+A_5 i)} + e^{-(A_4+A_5 i)}(h(A_4 + A_5 i) - 1)}\ ,$$

$$B_6 = \frac{1}{H^2 + S^2 - Re\omega i}\ ,\ B_7 = \frac{-Gr}{2\sin h(A_2 + A_3 i)\left((A_3 + A_2 i)^2 - (H^2 + S^2 - Re\omega i)\right)}$$

$$B_8 = \frac{-Gm}{2\sin h(A_1(1-i))\left((A_1(1-i))^2 - (H^2 + S^2 - Re\omega i)\right)}$$

$$B_9 = \frac{e^{-(A_4+A_5 i)}(\lambda B_6 - hB_7(A_3 + A_2 i) - hB_8 A_1(1-i)) - (h(A_4 + A_5 i)+1)(\lambda B_6 + B_7 \sin h((A_3 + A_2 i)) + B_8 \sin h(A_1(1-i)))}{(h(A_4 + A_5 i)+1)e^{(A_4+A_5 i)} + e^{-(A_4+A_5 i)}(h(A_4 + A_5 i)-1)},$$

$$B_{10} = \frac{e^{-(A_4+A_5 i)}(\lambda B_6 - hB_7(A_3 + A_2 i) - hB_8 A_1(1-i)) - (h(A_4 + A_5 i)-1)(\lambda B_6 + B_7 \sin h((A_3 + A_2 i)) + B_8 \sin h(A_1(1+i)))}{(h(A_4 + A_5 i)+1)e^{(A_4+A_5 i)} + e^{-(A_4+A_5 i)}(h(A_4 + A_5 i)-1)},$$

4. Graphical Results and Discussion

In this paper, I have studied the Effect of mass Transfer on unsteady MHD Oscillatory Flow through a Porous Medium with Slip flow region and heat radiation. The effect of the parameters *Gr*, *Gm*, *H*, *N*, *S*, *Re*, *Pe*, λ, *h* and *Sc* on flow characteristics have been studied and shown by means of graphs and tables. In order to have physical correlations, we choose suitable values of flow parameters. The graphs of velocities, heat and mass concentration are taken w.r.t *y*. Shearing Stress, Nusselt number and Sherwood Number at walls are obtained in the tables for different parameters.

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Velocity profiles:

The velocity profiles are depicted in Figs 1-3. Figure 1 shows the effect of the parameters *H*, *Sc* and *S* on velocity at any point of the fluid, when *Gr*=1, *Gm*=1, *h*=1, *N*=2, *Re*=1, *Pe*=1, λ= -0.5 and *h*=1. It is noticed that the velocity decreases with the increase of Hartmann number(*H*) and porous medium shape factor (*S*), whereas increases with the increase of Schmidt number (*Sc*).

Figure 2 shows the effect of the parameters *Gm*, *Gr* and *h* on velocity at any point of the fluid, when *H*=1, *S*=1, *h*=1, *N*=2, *Re*=1, *Pe*=1, λ=-0.5 and *Sc*=1. It is noticed that the velocity increases with the increase of slip parameter (*h*), Grashoff number (*Gr*) and modified Grashoff number (*Gm*).

Figure 3 shows the effect of the parameters *N*, *Pe*, *Sc* and λ on velocity at any point of the fluid, when *Gr*=1, *Gm*=1, *h*=1, *H*=1, *S*=1, *Sc*=1 and *h*=1. It is noticed that the velocity increases with the increase of radiation parameter (*N*), Peclet number (*Pe*) and pressure gradient parameter (λ), whereas decrease in the increase of Reynolds number (*Re*).

Mass concentration profile:

Figure 4 shows the effect of the parameters *Sc* and *Re* on mass concentration profile at any point of the fluid when ω = 0.5, *t*=1 in the absence of other parameters. It is noticed that the mass concentration increases with the increase of Schmidt number (*Sc*) and Reynolds number (*Re*).

Temperature profile:

Figure 5 shows the effect of the parameters *Pe*, and *N* on Temperature profile at any point of the fluid when ω=0.5, *t*=1 in the absence of other parameters. It is noticed that the temperature rises in the increase of Peclet number (*Pe*) and Radiation parameter (*N*).

Table 1 shows the effects of different parameters on Shearing stress at both the plates. It is noticed that shearing stress increases in the increase of Grashoff number (*Gr*), slip parameter (*h*) and modified Grashoff number (*Gm*) at both the plates, decreases in the increase of Schmidt number (*Sc*) at both the plates and only decreases in plate one in the increase of Hartmann number (*H*) and porous medium shape factor (*S*). But for increase in radiation parameter (*N*) it increases at plate one and decreases at plate two.

Table 2 shows the effects of *N*, *Pe* and ω on Nusselt number at both plates. It is noticed that Nusselt number increases in the increase of frequency of oscillation (ω) Peclet number (*Pe*) and Radiation parameter (*N*).

Table 3 shows the effects of *Sc*, *Re* and ω on Sherwood Number at both plates. It is noticed that Sherwood Number increases in the increase of Schmidt number (Sc), frequency of oscillation (ω) and Reynolds number (*Re*) at the plate one, whereas fluctuates at plate two.

Table 1. Effect of different parameters on shearing stress

Gr	***Gm***	***Sc***	***H***	***S***	***N***	***Re***	***h***	**shearing stress at plate having slip condition**	**shearing stress at stationary plate**
1	1	1	1	1	1	1	1	2.6943	0.2718
3								4.4747	1.0989
5								6.2567	1.9202
1	3							4.1680	0.6494
	5							5.6459	1.0431
	1	2						2.5892	0.2215
		3						2.5033	0.1874
		1	2					1.5044	0.0066
			4					0.8181	0.0135
			1	2				1.5094	0.0066
				3				1.0599	0.0181
				1	2			2.1043	0.1393
					3			2.4536	0.0502
					1	2		2.6805	0.1865
						3		3.7396	0.7448
						1	1.5	2.7869	0.4729
							2	2.8439	0.5980

Table 2: Effect of different parameters on rate of heat transfer/ Nusselt Number

N	**Pe**	ω	**Nusselt Number(Nu_1)**	**Nusselt Number(Nu_2)**
1	1	0.5	0.9099	1.0653
2			1.9102	6.7903
3			4.9802	50.5731
	2		1.1115	1.3040
	3		1.3069	1.6222
		1	1.1115	1.3043
		1.5	1.3069	1.6222

Table 3. Effect of different parameters on rate of mass transfer/ Sherwood Number

Sc	**Re**	ω	**Sherwood Number (Sh_1)**	**Sherwood Number (Sh_2)**
1	1	0.5	0.4573	0.3175
2			0.5835	0.1509
3			0.6339	0.2198
	2		0.5835	0.1509
	4		0.6350	0.7547
		1	0.5335	0.1509
		1.5	0.6339	0.2198

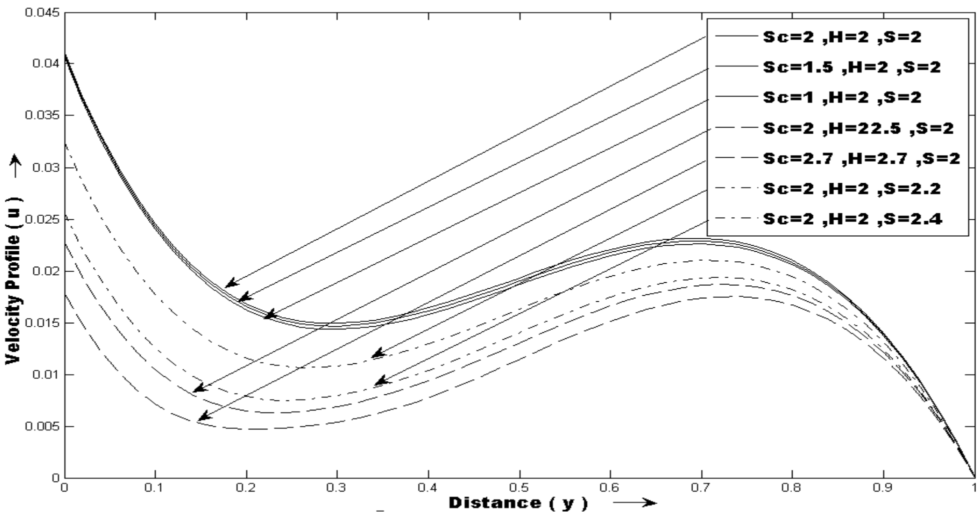

Fig. 1: Effect of H, S and Sc on velocity profile, when Gr=1, Gm=1, h=1, N=2, Re=1, Pe=1, λ=-0.5 and h=1

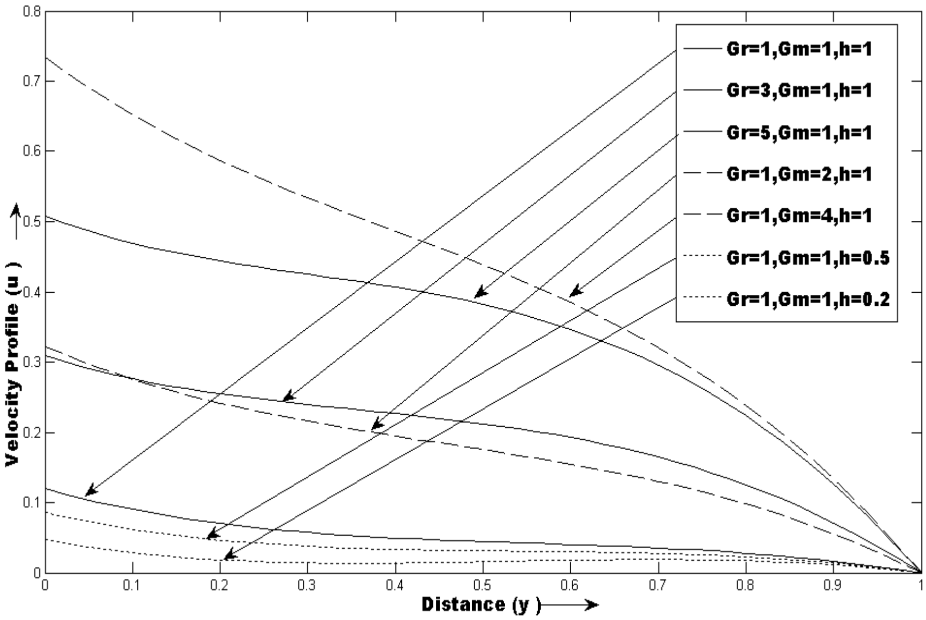

Fig 2: Effect of Gm, Gr and h on velocity profile, when H=1, S=1, h=1, N=2, Re=1, Pe=1, λ= -0.5 and Sc=1

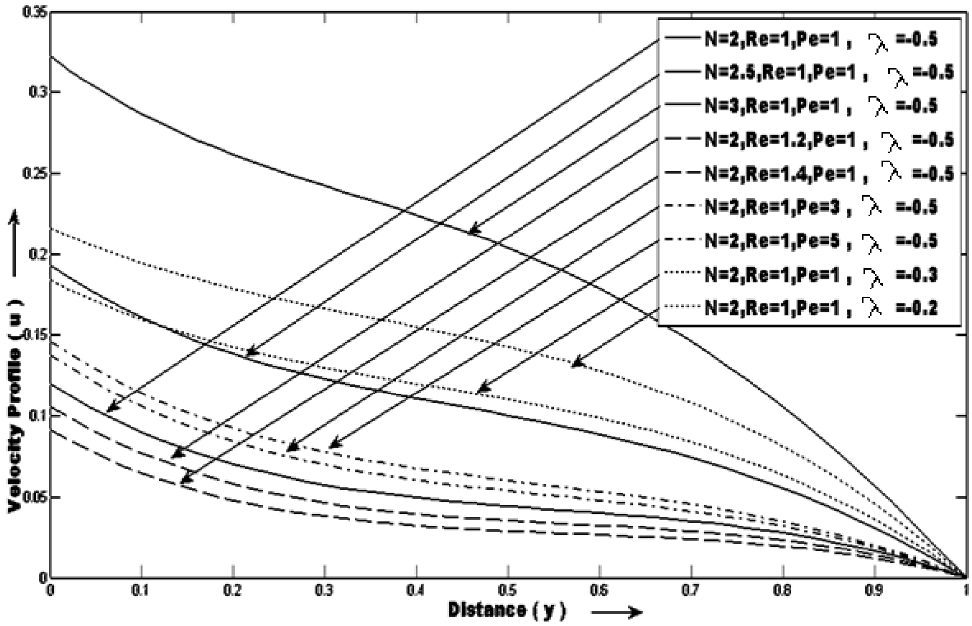

Fig 3: Effect of N, Pe, Sc and λ on velocity profile, when Gr=1, Gm=1, h=1, H=1, S=1, Sc=1 and h=1

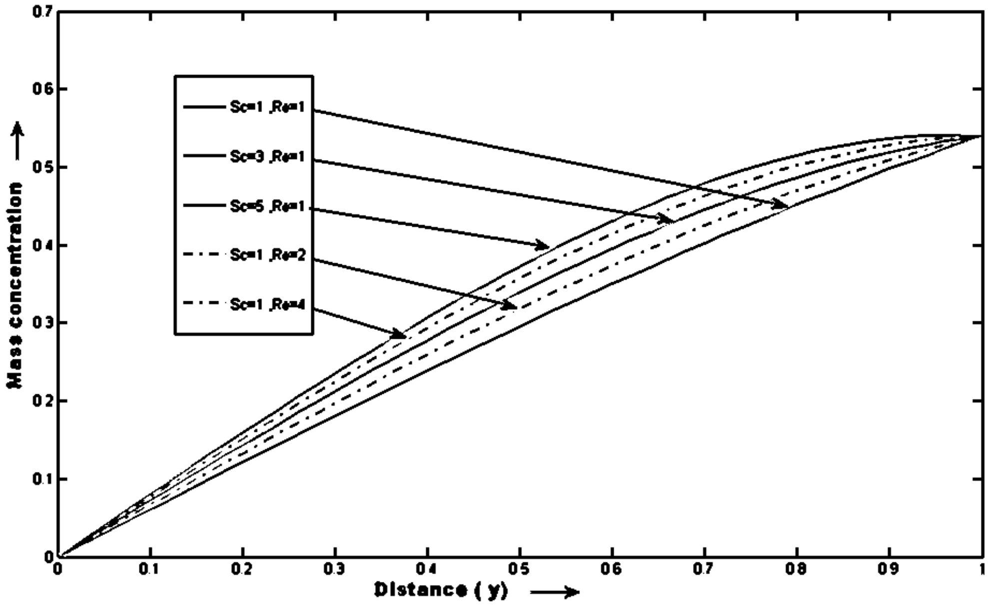

Fig 4: Effect of Sc and Re on Mass concentration profile, when ω=0.5 and t=1 in the absence of other parameter.

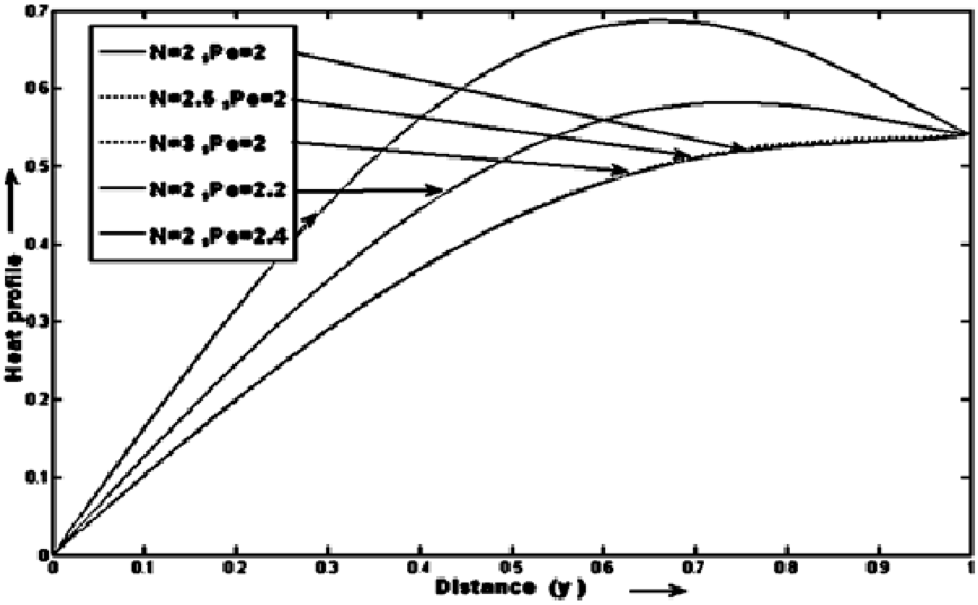

Fig. 5: Effect of N and Pe on Heat profile, when ω=0.5 and t=1 in the absence of other parameter.

5. Conclusions

The following conclusions are drawn from the discussion of the paper:

(i) It is observed that the temperature rises with increasing radiation parameter and Peclet number.

(ii) It is observed that the velocity increases with increase of all parameters except Reynolds number, Hartmann number and porous medium shape factor.

(iii) It is observed that the mass concentration increase with increasing radiation parameter and Reynolds number.

(iv) Nusselt number and Sherwood Number both increase at plate one for all parameters, but only Sherwood Number fluctuates at plate two for all parameters.

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