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Magnetic effect on heat and mass transfer analysis of nanofluid past a vertical plate through a porous medium in the presence of chemical reactive spices

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ABSTRACT

Magnetic effect of Heat and Mass Transfer analysis of Nanofluid past a vertical plate through porous medium in the presence of chemical reaction has been studied. The dimensionless governing equations are solved using Series solution technique. The influences of the various parameters on the flow field, Temperature field, Mass Concentration, Shearing Stress, rate of heat transfer and rate of mass transfer are extensively discussed from graphs and tables.

Keywords: MHD, Heat Transfer, Chemical Reaction, Constant Suction, Mass Transfer, Nano Fluid and Porous Medium

1. INTRODUCTION

Nanofluids have many applications, such as heat exchangers ,photocatalysis,sterilization,electronic cooling system ,biomedicine ,nuclear reactor etc. has attracted considerable attention in the last few years by the researchers in Mechanical engineering .Nanofluids are dilute liquid suspensions of nanoparticles having size less than 100nm.It have been found to possess enhanced thermophysical properties such as thermal conductivity ,thermal diffusion ,viscosity and convective heat transfer co-efficient compared to those of base fluids like oil or water. MHD plays an important role in power generation, space propulsions, cure of diseases, control of thermonuclear reactor, boundary layer control in field of aerodynamic. In past few years several simple flow problems associated with classical hydrodynamics have received new attention within the more general context of hydrodynamics. Based on this motivation, many researchers have considered the porous channel problems with suctions and injection under different physical conditions. Berman [1] derived an exact solution for the channel flow taking into the consideration the uniform suction at the boundary wall of the channel. Mass transfer play avital role in MHD nanofluid. Its application in many process industries like extrusion of plastic in the manufacture of Rayon and Nylon, purification of crude oil, pulp, paper industries, Radio propagation through the ionosphere. The phenomenon of mass transfer is a common theory of stellar structure. The suction with heat and mass transfer on a moving continuous flat surface were analyzed by Eriskon et al.[2]. Mohapatra and Senapati [3] have been analyzed magneto hydrodynamic free convection flow with mass transfer past a vertical plate. Chamkha, A.J. [4] have studied MHD-free convection from a vertical plate embedded in a thermally stratified porous medium with Hall effects. Senapati et. al.[5 6] have studied the effect of chemical reaction on MHD unsteady free convection flow through a porous medium bounded by a linearly accelerated vertical plate. Pop et al. [9] studied the forced convection heat and mass transfer effects in flow of Nanofluid through porous channel with first order chemical reaction. Senapati et.al.[7] studied the effects of chemical reaction on MHD unsteady free convective walter's memory flow with constant suction and heat sink. Heat and mass transfer of a MHD nano fluid with chemical reaction effects have been discussed by Srikanth et al. [10].Hatami et al. [8] has studied the effect forced convection analysis for MHD Al2-O3- water nanofluid flow over a horizontal plate.

In this problem, we try to investigate the magnetic effect of Heat and Mass Transfer analysis of Nanofluid past a vertical plate through porous medium in the presence of chemical reaction.

2. FORMULATION OF PROBLEM

Let us consider a two-dimensional steady flow of an incompressible, electrically conducting viscous Cu-Water nano fluid past along an electrically non-conducting continuously moving of an infinite semi vertical plate with constant suction in the presence of chemical reaction through porous medium. The X –axis is taken along the vertical plate and Y –axis is taken normal to the plate. A magnetic field of uniform strength B_0 acts normal to the plate and magnetic permeability is constant is constant throughout the field.It is assumed that the magnitude of Renold's number is very small ,also .Joulean dissipations ,effect of buoyancy forces and induce magnetic field are neglected. The plate is maintained a constant temperature T_w and the mass concentration is maintained of a value C_w .The temperature of ambient flow isT_∞ and the mass concentration of uniform flow is C_∞ .Then by usual Boussinesq's approximation, the steady flow is governed by the following equations:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2 u}{\rho_{nf}}-\frac{u}{K'} \qquad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{nf}}{(\rho C_p)_{nf}}\frac{\partial^2 T}{\partial y^2}-\frac{Q'}{(\rho C_p)_{nf}}(T-T_\infty) \qquad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-R'(C-C_\infty) \qquad (4)$$

with the following boundary conditions

$$\left.\begin{array}{c} u=U_0, v=V_0(x), T=T_w, C=C_w \ at \ y=0 \\ u=0, v=0, T=T_\infty, C=C_\infty \ as \ y\to\infty \end{array}\right\} \qquad (5)$$

where μ_{nf} is the dynamic viscosity, k_{nf} is the thermal diffusivity, ρ_{nf} is the effective density, $(\rho C_p)_{nf}$ *is* the heat capacity, $(\beta)_{nf}$ *is the* coefficient of volumetric expansion of heat and $(\beta_c)_{nf}$is the coefficient of volumetric expansion of mass of nano fluid are defined by

$$\mu_{nf}=\frac{\mu_f}{(1-\phi)^{2.5}}, \rho_{nf}=(1-\phi)\rho_f+\phi\rho_s, (\rho C_p)_{nf}=(1-\phi)(\rho C_p)_f+\phi(\rho C_p)_s,$$

$$k_{nf}=\left[\frac{k_s+2k_f-2\phi(k_f-k_s)}{k_s+2k_f+2\phi(k_f-k_s)}\right]k_f,$$

σ is the electrical conductivity of the fluid , g is the acceleration due to gravity and ϕ is the volume fraction of nano particles.

Let us introduce the following local similarity variables in the equation

$$\left.\begin{array}{c} `\psi=\sqrt{2\nu_f x U_0}f(\eta), \eta=y\sqrt{\frac{U_0}{2\nu_f x}}, \theta=\frac{T-T_\infty}{T_w-T_\infty}, G=\frac{C-C_\infty}{C_w-C_\infty}, R=\frac{R' 2x\nu_f}{U_0}, \\ , Pr=\frac{\nu_f(\rho C_p)_f}{k_f}, Sc=\frac{\upsilon_f}{D}, M=\frac{2x\sigma B_0^2}{\rho_f U_0}, \frac{1}{K}=\frac{2x}{U_0 K}, S=\frac{2xQ'}{U_0}, f_w=V_0(x)\sqrt{\frac{2x}{\nu_f U_0}} \end{array}\right\} \qquad (6)$$

where D is the mass diffusion, Gr is Grashof number, Gm is modified Grashof number ,K is permeability of porous medium, M is magnetic parameter ,Sc is Schmidt number, Pr is Prandtl number, S is the Source parameter and R is chemical reaction parameter. Substituting equation (6) in the equations (2)- (4) with boundary condition (5), we have

$$f'''+\varphi_1 ff'-\left(M\varphi_0+\frac{\varphi_1}{K}\right)f'=0 \qquad (7)$$

$$\theta''+Pr\varphi_2\theta' f-Pr\varphi_3\theta=0 \qquad (8)$$

$$G''+ScfG'-RScG=0 \qquad (9)$$

with boundary conditions

$$\left.\begin{array}{lll} f=f_w, f'=1 \ \theta=1, G=1 & \text{at} & \eta=0 \\ f=0, \ \theta\to 0, \ G\to 0 & \text{as} & \eta\to\infty \end{array}\right\} \qquad (10)$$

3. METHOD OF SOLUTION

To introduce the new variable ξ in place of η .Let us substitute the following $\xi=\eta f_w$,

$$f(\eta)=f_w X(\xi), \theta(\eta)=f_w^2 Y(\xi), G(\eta)=f_w^2 Z(\xi)$$

In equations (7) to (9) with boundary condition (10), we get

$$X'''^{(\xi)}+\varphi_1 X(\xi)X''^{(\xi)}=\epsilon M_1 X'(\xi) \qquad (11)$$

$$Y''^{(\xi)} Pr\varphi_2 Y'(\xi)X(\xi) = \epsilon Pr\varphi_3 Y(\xi) \qquad (12)$$

$$Z''^{(\xi)} + ScZ'(\xi)X(\xi) = \epsilon ScRZ \qquad (13)$$

With the boundary condition

$$\left.\begin{array}{l} X=1, X'=\epsilon, Y=\epsilon, Z=\epsilon \quad at\ \xi=0 \\ X=0, Y=0, Z=0 \quad as\ \xi\to\infty \end{array}\right\} \qquad (14)$$

Where

$$\epsilon = \frac{1}{f_w^2}\ , M_1 = M\varphi_0 + \frac{\varphi_1}{K}$$

Let us choose the following series satisfying the boundary conditions and substitute in equations (11) to (13) and boundary conditions (14)

$$X = 1 + \epsilon X_1 + \epsilon^2 X_2 + \epsilon^3 X_3 \dots .... \qquad (15)$$

$$Y = \epsilon Y_1 + \epsilon^2 Y_2 + \epsilon^3 Y_3 \dots \dots .. \qquad (16)$$

$$Z = \epsilon Z_1 + \epsilon^2 Z_2 + \epsilon^3 Z_3 \dots \dots .. \qquad (17)$$

Then by comparing the co-efficients of ϵ , ϵ^2 and ϵ^3 ,We get

Equations by comparing $the\ \ co - effecient\ of\ \ \epsilon$

$$\left.\begin{array}{c} X_1''' + X_1'' = 0 \\ Y_1'' + Pr\varphi_2 Y_1' = 0 \\ Z_1'' + ScZ_1' = 0 \end{array}\right\} \qquad (18)$$

With boundary conditions

$$\left.\begin{array}{l} X_1=0, X'_1=1, Y_1=1, Z_1=1\ at\ \xi=0 \\ X_1=0, Y_1=0, Z_1=0 \quad as\ \xi\to\infty \end{array}\right\} (19)$$

Equations by comparing $the\ \ co - effecient\ of\ \ \epsilon^2$

$$\left.\begin{array}{c} X_2''' + X_2'' + X_1'' X_1 = M_1 X_1' \\ Y_2'' + Pr\varphi_2(Y_2' + X_1 Y_1') = Pr\varphi_3 Y_1 \\ Z_2'' + Sc(Z_2' + X_1 Z_1') = ScRZ_1 \end{array}\right\} (20)$$

With the boundary condition

$$\left.\begin{array}{l} X_2=0, X'_2=0, Y_2=0, Z_2=0\ at\ \xi=0 \\ X_2=0, Y_2=0, Z_2=0 \quad as\ \xi\to\infty \end{array}\right\} \qquad (21)$$

Equations by comparing $the\ \ co - effecient\ of\ \ \epsilon^3$

$$\left.\begin{array}{c} X_3''' + X_3'' + X_2'' X_1 + X_2\ X_1'' = M_1 X_2' \\ Y_3'' + Pr\varphi_2(Y_3' + X_1 Y_2' + Y_1' X_2) = Pr\varphi_3 Y_2 \\ Z_3'' + Sc(Z_3' + X_1 Z_2' + Z_1' X_2) = ScRZ_2 \end{array}\right\} (22)$$

With the boundary conditions

$$\left.\begin{array}{l} X_3=0, X'_3=0, Y_3=0, Z_3=0\ at\ \xi=0 \\ X_3=0, Y_3=0, Z_3=0 \quad as\ \xi\to\infty \end{array}\right\} \qquad (23)$$

By solving Equation(18) using boundary condition (19) ,we get

$$\left.\begin{array}{c} X_1 = 1 - e^{-\xi} \\ Y_1 = e^{-b_1\xi} \\ Z_1 = e^{-Sc\xi} \end{array}\right\} (24)$$

By solving equations(20) using boundary condition (21) ,we get

$$\left.\begin{aligned} X_2 &= -\frac{3}{2} + (\xi - 2)e^{-\xi} - \frac{1}{2}e^{-2\xi} \\ Y_2 &= a_1 e^{-b_1\xi} + a_2\xi e^{-b_1\xi} + a_3 e^{-b_2\xi} \\ Z_2 &= a_{12}e^{-Sc\xi} + R\xi e^{-Sc\xi} + Sc\xi e^{-Sc\xi} - Sc^2 e^{-(Sc+1)\xi} \end{aligned}\right\} \quad (25)$$

By solving equations (22) using boundary condition (23), we get

$$\left.\begin{aligned} X_3 &= -\left(M_1 + \tfrac{25}{6}\right) + \left(\tfrac{3}{2} - 3M_1\right)e^{-\xi} + \left(M_1 + \tfrac{5}{3}\right)\xi e^{-\xi} - (M_1 + 1)\tfrac{\xi^2}{2}e^{-\xi} - \left(\tfrac{M_1}{2} + 1\right)e^{-2\xi} + \tfrac{1}{12}e^{-3\xi} + \tfrac{\xi}{2}e^{-2\xi}. \\ Y_3 &= a_{11}e^{-b_1\xi} + a_4\xi e^{-b_1\xi} + a_5\xi^2 e^{-b_1\xi} + a_6 e^{-b_2\xi} + a_7 e^{-(b_1+1)\xi} + a_8\xi e^{-(b_1+1)\xi} + a_9 e^{-(b_2+1)\xi} + a_{10}e^{-(b_2+2)\xi} \\ Z_3 &= (a_{17} + a_{20})e^{-Sc\xi} + (a_{13} + a_{16})\xi e^{-Sc\xi} + (a_{14} + a_{19})e^{-(Sc+1)\xi} + a_{18}\,\xi e^{-(Sc+1)\xi} + +a_{15}e^{-(Sc+2)\xi} \end{aligned}\right\} \quad (26)$$

Using equations (24) to (26), we get

Velocity Distribution

$$u = U_0\, f'(\xi) = U_0\Bigg(e^{-\xi} + \epsilon\left((3 - \xi)e^{-\xi} + e^{-2\xi}\right) + \epsilon^2\left(\left(2M_1 + \frac{1}{3}\right)e^{-\xi} - \left(2M_1 + \frac{8}{3}\right)\xi e^{-\xi} + (M_1 + 1)\frac{\xi^2}{2}e^{-\xi} + 2\left(\frac{M_1}{2} + 1\right)e^{-2\xi} - 4e^{-3\xi} + \frac{\xi}{2}e^{-2\xi}\right)\Bigg) \quad (27)$$

Temperature Distribution

$$\theta = e^{-b_1\xi} + \epsilon\left(a_1 e^{-b_1\xi} + a_2\xi e^{-b_1\xi} + a_3 e^{-b_2\xi}\right) + \epsilon^2\left(a_{11}e^{-b_1\xi} + a_4\xi e^{-b_1\xi} + a_5\xi^2 e^{-b_1\xi} + a_6 e^{-b_2\xi} + a_7 e^{-(b_1+1)\xi} + a_8\xi e^{-(b_1+1)\xi} + a_9 e^{-(b_2+1)\xi} + a_{10}e^{-(b_2+2)\xi}\right) \quad (28)$$

Mass concentration Distribution

$$G = e^{-Sc\xi} + \epsilon\left(a_{12}e^{-Sc\xi} + R\xi e^{-Sc\xi} + Sc\xi e^{-Sc\xi} - Sc^2 e^{-(Sc+1)\xi}\right) + \epsilon^2\left((a_{17} + a_{20})e^{-Sc\xi} + (a_{13} + a_{16})\xi e^{-Sc\xi} + (a_{14} + a_{19})e^{-(Sc+1)\xi} + a_{18}\,\xi e^{-(Sc+1)\xi} + +a_{15}e^{-(Sc+2)\xi}\right) \quad (29)$$

So, the Non dimensional Shearing Stress

$$\tau = U_0\left(1 + \epsilon(-6) + \epsilon^2\left(\tfrac{11}{2} - 6M_1\right)\right) \quad (30)$$

The Dimensionless Nusselt Number

$$Nu = -1 + \epsilon(b_1a_1 - a_2 + b_2a_3) + \epsilon^2\,(b_1a_{11} - a_4 + b_2a_6 + (b_1 + 1)a_7 - a_8 + (b_2 + 1)a_9 + (b_2 + 2)a_{10}) \quad (31)$$

The Dimensionless Sherwood Number

$$Sh = Sc + \epsilon\left(a_{12}Sc - R - Sc - Sc^2(Sc + 1)\right) + \epsilon^2\left((a_{17} + a_{20})Sc - (a_{13} + a_{16}) + (a_{14} + a_{19})(Sc + 1) - a_{18} + +a_{15}(Sc + 2)\right) \quad (32)$$

Where

$$b_1 = Pr\varphi_2\,, b_2 = b_1 + 1, b_4 = Sc + 1, a_1 = \frac{1}{b_1 + 1}\,, a_2 = \frac{\varphi_3}{\varphi_2} + 1\,, a_3 = \frac{b_1}{b_1 + 1}\,,$$

$$a_4 = Pr\left(\varphi_3a_1 + \varphi_2a_1b_1 - \varphi_2a_2 + \varphi_3a_2 + \varphi_2a_2b_2 - \frac{3}{2}\varphi_3\right)$$

$$a_5 = \frac{b_{1Pr}}{2}\left(\varphi_3a_2 + \varphi_2a_2b - 2\frac{3}{2}\varphi_3\right), a_6 = \frac{Pra_3(\varphi_3 + \varphi_2b_2)}{b_2^2 - b_1b_2}, a_7 = \frac{-Pr(a_2a_1b_1 + \varphi_2)}{b_1 + 1} - Pr(b_2 + 2)(\varphi_2a_2b_1 + \varphi_2),$$

$$a_8 = -Pr\varphi_2(b_1+1)(a_2b_1+1), a_9 = -\frac{Pra_2a_3b_2}{(b_2+1)^2 - b_1(b_2+1)}', a_{10} = -\frac{Pr\varphi_2}{(b_2+2)^2 - b_1(b_2+2)},$$

$$a_{11} = -(a_6 + a_7 + a_9 + a_{10}), a_{12} = 1 + Sc^2, a_{13} = Ra_{12} + Sca_{12} - R - 3Sc/2$$

$$a_{14} = \frac{RSc - 4Sc^2 - Sc^3}{(Sc+1)^2 - (Sc+1)}, a_{15} = \frac{Sc^2\left(Sc + \frac{1}{2}\right)}{(Sc+2)^2 - (Sc+2)}, a_{16} = \frac{R + RSc + Sc^2}{Sc^2 + Sc}$$

$$a_{17} = \frac{R + RSc + Sc^2}{(Sc^2 + Sc)^2}, a_{18} = \frac{Sc^2 - RSc^2 - Sc - Sc^3}{(Sc+1)^2 + (Sc+1)}, a_{19} = \frac{(Sc^2 - RSc^2 - Sc - Sc^3)(2Sc+3)}{((Sc+1)^2 + (Sc+1))^2}$$

$$a_{20} = 1 - a_{14} - a_{15} - a_{17} - a_{19}$$

4. RESULTS AND DISCUSSION

In this paper we have studied the magnetic effect on heat and mass transfer analysis of Nanofluid past a vertical plate through porous medium in the presence chemical reactive spices. The effect of the parameters M, K, R, Sc, Pr and $\emptyset$ 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 and the values of Shearing stress, Nusselt Number and Sherwood Number are shown in the table for different values of flow parameters.

Velocity profiles: The velocity profiles are depicted in Figs 1-2. Figure-(1) shows the effect of the parameters M and K on velocity at any point of the fluid, when Sc=2,Pr=2R=2,$\emptyset = 0.05$ It is noticed that the velocity increases with the increase of permeability parameter porous medium (K), whereas decreases with the increase of magnetic parameter(M),physically ,it is justified because the application of transverse magnetic field always results in a restive type force called Lorentz force which is similar to drag force and tends to resist the fluid motion ,finally reducing the velocity. Also by increasing the permeability parameter, drag force decreases and hence velocity increases.

Figure-(2) shows the effect of the parameter $\emptyset$ on velocity at any point of the fluid, when Sc=2, Pr=2,M=2, K=2 and R=2 . It is noticed that the velocity decreases with the increase of volume fractions.

Temperature Profile: The temperature profile is depicted in fig-3, Figure-(3) shows the effect or Pr and $\emptyset$,when all other parameters are absents. It is noticed that temperature rises initially, but decreases later by the increase of Prandtl Number (Pr) and volume fraction ($\emptyset$).

Mass concentration profile: The mass concentration profile is depicted in Fig- 4. Figure-(4) shows the effect of R and Sc on Mass concentration profile, when $\emptyset = 0.05$ .It is noticed that the mass concentration decreases in the increase of Schmidt Number (Sc) , whereas increases in the increase of reaction parameter (R).

Table-(1) shows the effects of different parameters on Shearing stress. It is noticed that shearing stress increases in the increase of permeability parameter porous medium (K), whereas decreases with the increase of Magnetic parameter (M) and volume fraction ($\emptyset$).
Table-(2) shows the effects of different parameters on Nusselt Number. It is noticed that the Nusselt number decreases with the increases of Prandtl Number (Pr),whereas increases with the increase of volume fraction ($\emptyset$).

Table-(3) shows the effects of different parameters on Sherwood Number. It is noticed that Sherwood Number increases in the increase of Schmidt Number (Sc), whereas decreases with the increase of Chemical reaction parameter (R)

Table 1: Effect of Shearing Stress near the plate

M	K	$\emptyset$	Shearing Stress
2	2	0.05	-4.3020
2.5	2	0.05	-6.5153
3	2	0.05	-7.7286
2	2.5	0.05	-4.6593
2	3	0.05	-3.8976
2	2	0.07	-4.7472
2	2	0.09	-5.1221

Table 2: Effect of Nusselt Number near the plate

Pr	$\emptyset$	Nusselt Number (Nu)
2	0.05	-6.46852e+007
3	0.05	-9.7232e+007
4	0.05	-10.3451e+009

2	0.07	-5.2706e+007
2	0.09	-4.3497e+007

Table-(3): Effect of Sherwood Number near the plate

Sc	*R*	Sherwood Number(Sh)
2	2	1.8733
3	2	2.7623
4	2	3.6023
2	4	1.8300
2	6	1.7668

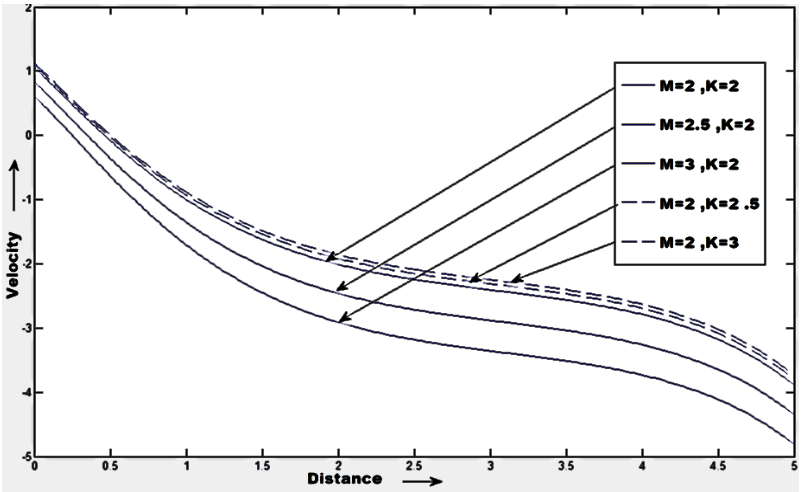

Fig. 1: Effect of M and K on velocity profile, when Sc=2, Pr=2, $\phi = 0.08$ and R=2.

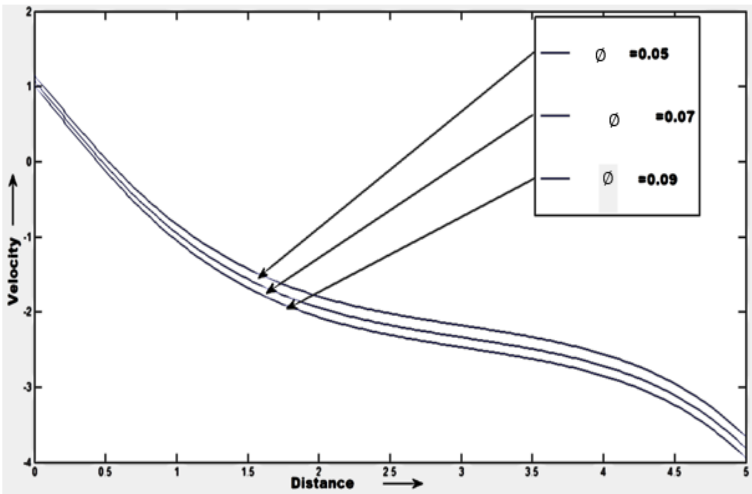

Fig. 2: Effect of ϕ on velocity profile, when Sc=2, Pr=2, $M = 2$, K=2 and R=2.

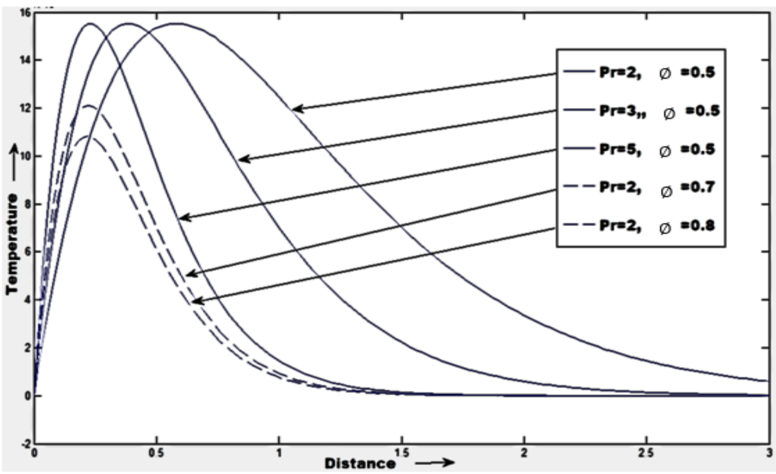

Fig. 3: Effect of Pr and ϕ on Temperature profile in the absence of other parameters.

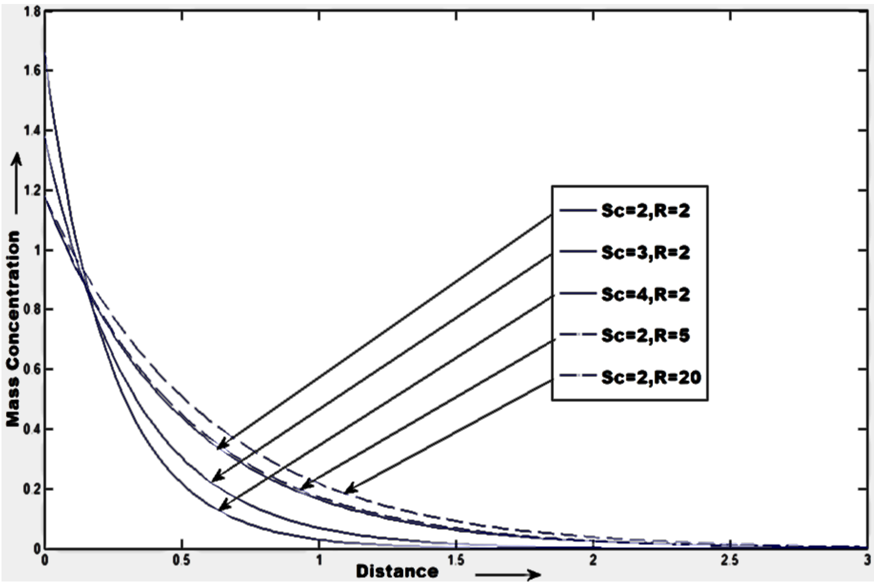

Fig. 4: Effect of Sc and R on Mass Concentration profile ,when $\phi = 0.05$

5. CONCLUSION

In this study of Effect of Chemical reactive spices on Heat and Mass Transfer analysis of MHD Nanofluid past a vertical plate through porous medium, the following points are set out:

1. Permeability parameter porous medium (K) and magnetic parameter (M) both action are opposite to each other. Velocity increases for the increase of K, whereas decrease in the increase of M.So, by increasing the permeability parameter and volume fraction , drag force decreases and hence velocity increases.
2. Mass concentration and Sherwood number are in opposite character by the influence of Sc and R also play the opposite role**.**

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