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Radiation Effects on Unsteady MHD Free Convective Heat and Mass Transfer Flow Of Past a Vertical Porous Plate Embedded In a Porous Medium with Viscous Dissipation

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ABSTRACT: An analysis of thermal radiation effects on unsteady MHD free convective heat and mass transfer flow past a vertical porous plate immersed in a porous medium with time dependent suction in presence of magnetic field with viscous dissipation has been considered by employing shooting iteration technique along with fourth order Runge-Kutta integration scheme. Resulting non-dimensional velocity, temperature and concentration profiles are then presented graphically for different values of the parameters entering into the problem. Finally, the effects of the pertinent parameters on the skin-friction coefficient, the rate of heat transfer (Nusselt number) and the rate of mass transfer (Sherwood number), which are of physical interest, are exhibited in the tabular form.

KEYWORDS: Free convection Flow; Thermal radiation; MHD; viscous dissipation; Mass transfer; porous medium**.**

I. INTRODUCTION

Free convection flow occurs frequently in nature, flows of fluid through porous media are of main interest now days and have attracted by many research scholars due to their applications in the science and Technology. Study of fluid flow in porous medium is based upon the empirically determined Darcy's law. Such flows are considered to be useful in diminishing the free convection, which would otherwise occur intensely on a vertical heated surface. In addition, recent developments in modern technology have intensified more interest of many researchers in studies of heat and mass transfer in fluids due to its wide applications in geothermal and oil reservoir engineering as well as other geophysical and astrophysical studies. A theoretical and experimental work on this subject can be found in the recent monographs by Ingham and Pop [1] and Nield and Bejan [2]. Suction/blowing on convective heat transfer over a vertical permeable surface embedded in a porous medium was analyzed by Cheng [3]. In that work an application to warm water discharge along the well or fissure to an aquifer of infinite extent is discussed. Kim and Vafai [4] have analyzed the buoyancy driven flow about a vertical plate for constant wall temperature and heat flux. Raptis and Singh [5] studied flow past an impulsively started vertical plate in a porous medium by a finite difference method. Seigel [6] first studied transient free convection flow past a semi-infinite vertical plate by an integral method. Since then many researchers have been published papers on free convection flow past a semi-infinite vertical plate. Soundalgekar et al. [7] studied free convection flow past a vertical porous plate. Yamamoto et al. [8] investigated the acceleration of convection in a porous permeable medium along an arbitrary but smooth surface. Raptis [9] studied free convection in a porous medium bounded by an infinite plate. Raptis and Perdikis [10] studied numerically free convection flow through a porous medium bounded by a semi-infinite vertical porous plate. Sattar [11] studied the same problem and obtained analytical solution by the perturbation technique adopted by Singh and Dikshit [12]. Sattar et al. [13] studied unsteady free convection flow along a vertical porous plate embedded in a porous medium.

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Vol. 3, Issue 11, November 2014

From the technological point of view, MHD free- convection flows have also great significance for the applications in the fields of stellar and planetary magnetospheres, aeronautics, chemical engineering, and electronics. The effects of magnetic field on free convection flow of electrically conducting fluids past through a porous medium has been studied many authors. Ahmed [14] looked the effects of unsteady free convective MHD flow through a porous medium bounded by an infinite vertical porous plate. Chaudhary and Arpita Jain [15] have discussed the MHD heat and mass diffusion flow by natural convection past a surface embedded in a porous medium. Kim [16] studied unsteady MHD convection flow of polar fluids past a semi-infinite vertical-moving porous plate in a porous medium. Soundalgekar [17] obtained approximate solutions for the two-dimensional flow of an incompressible, viscous fluid past an infinite porous vertical plate with constant suction velocity normal to the plate, the difference between the temperature of the plate and the free stream is moderately large causing the free convection currents. Raptis [18] studied mathematically the case of unsteady two-dimensional natural convective heat transfer of an incompressible, electrically conducting viscous fluid via a highly porous medium bound by an infinite vertical porous plate. The effects of magnetic field on free convection flow of electrically conducting fluids past a plate has been studied by many authors such as Soundalgekar [19], Singh et al.[20].

All the above investigations are restricted to MHD flow and heat transfer problems only. However, of late, the radiation effects on MHD flow and heat transfer problems have become more important, industrially. At high operating temperature, radiation effects can be quite significant. Sparrow [21] explained a parameter named Rosseland approximation to describe the radiation heat flux in the energy equation in his book. The radiative flows of an electrically conducting fluid with high temperature, in the presence of a magnetic field, are encountered in electrical power generation, astrophysical flows, solar power technology, space vehicle re-entry, nuclear engineering applications and other industrial areas. The radiation effects on boundary layer flow with and without applying a magnetic field under different situations has been studied by many investigators, for examples: Israel-cookey et al. [22], Mahmoud [23], Hayat et al.[24]. Radiative heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. England and Emery [25] have studied the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Radiation effect on mixed convection along a isothermal vertical plate were studied by Hossain and Takhar [26]. The governing equations were solved analytically. Das et al. [27] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. Prasad *et al.* [28] studied the radiation and mass transfer effects on unsteady MHD free convection flow past a vertical porous plate embedded in porous medium. Mohammed Ibrahim et.al. [29] proposed the radiation and chemical reaction effects on MHD free convection flow past a moving vertical plate.

The viscous dissipative heat effects on the steady or unsteady free convection and on combined free and forced convection flows have been extensively studied by Ostrach[30-34]. V.M.Soundalgekar [35] studied the viscous dissipation effect on unsteady free convection flow past an infinite, vertical porous plate with constant suction. Viscous dissipation effects on the unsteady free convection flow of an elastico-viscous fluid past an infinite vertical plate with constant suction have been studied by V.M.Soundalgekar and G.A.Desai[36].The problem of Dissipation effects on MHD nonlinear flow and heat transfer past a porous surface with prescribed heat flux have been studied by S.P. Anjali Devi and B. Ganga [37]. Abo-Eldahab and El Aziz [38] studied the effect of viscous dissipation and Joule heating on MHD free convection flow past a semi-infinite vertical flate plate in the presence of the combined effect of Hall in which he considered power- law variation of the wall temperature. The viscous and Joules dissipation and internal heat generation was taken into account in the energy equation. Combined effect of conduction and viscous dissipation on magneto hydrodynamics free convection flow along a vertical flat plate were discussed Abdullah et al.[39]. The effect of viscous and joules dissipation on MHD flow, heat and mass transfer past a stretching porous surface embedded in porous medium was studied by Anjai Devi and B. Ganga [40]. Viscous dissipation effects on nonlinear MHD flow in a porous medium over a stretching porous surface have been studied by S.P. Anjali Devi and B.Ganga[41].An analysis of thermal boundary layer in an electrically conducing fluid over a linearly stretching sheet in the presence of a constant suction transverse magnetic field with suction or blowing at the sheet have been studied by Chaim[42]. The effect of the viscous dissipation term along with temperature dependence heat source/ sink on momentum, heat and mass transfer in a visco-elastic fluid flow over an accelerating surface were studied by Sonth et al.[43].

The present paper is the investigation of the thermal radiation effects of an unsteady electrically conducting, viscous, incompressible fluid interaction with viscous dissipation on a free convective flow past a vertical porous flat plate

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International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

embedded in a porous medium with time dependent suction in presence of heat and mass transfer permitted by a transversely applied uniform magnetic field. The similarity solutions are then obtained numerically for various parameters entering into the problem and discussed them from the physical point of view.

II. MATHEMATICAL FORMULATION

Let us consider the problem of an unsteady MHD free convection flow of a viscous, incompressible and electrical conducting fluid along a vertical porous flat plate under the influence of a uniform magnetic field. The flow is assumed to be in the *x* – direction, which is taken along the plate in the upward direction and *y* – axis normal to the plate. Initially it is assumed that the plate and the fluid are at a constant temperature T_∞ in a stationary condition with concentration level C_∞ at all points. At time $t > 0$ the plate is assumed to be moving in the upward direction with the velocity U(t) and there is a suction velocity $v_0(t)$ taken to be a function of time, the temperature of the plate raised to T(t) and the concentration level at the plate is raised to C(t) where $T(t) > T_\infty$ and $C(t) > C_\infty$. The plate is considered to be of infinite length, all derivatives with respect to x vanish and so the physical variables are functions of y and t only.
The fluid is assumed to have constant properties except that the influence of the density variations with temperature and concentration, which are considered only in the body force term, and is considered to be gray, absorbing emitting radiation but non-scattering medium and the Rosseland approximation, is used to describe the radioactive heat flux in the energy equation. A uniform magnetic field of strength B_0 is applied normal to the plate parallel to *y*-direction.

Under the usual boundary layer and Boussinesq approximation and using the Darcy-Forchhemier model, the flow and heat transfer in the presence of radiation are governed by the following equations.
Continuity Equation

$$\frac{\partial v}{\partial y} = 0 \tag{1}$$

Momentum Equation

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\sigma B_0^2}{\rho}u - \frac{\upsilon}{k}u - \frac{b}{k}u^2 \tag{2}$$

Energy Equation

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \frac{\upsilon}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \tag{3}$$

Concentration Equation

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = D_m\frac{\partial^2 C}{\partial y^2} \tag{4}$$

where *u* and *v* are the velocity components along *x*- and *y*- directions respectively, *t* is time, υ is the kinematic viscosity, ρ is the density of the fluid, g is the acceleration due to gravity, β is the coefficient of volume expansion, β^* is the volumetric coefficient of expansion with concentration, α is the thermal diffusivity, σ is the electric conductivity, B_0 is the uniform magnetic field induction, T and T_∞ are the temperature of the fluid within the boundary layer and in the free stream respectively, while C and C_∞ are the corresponding concentrations, c_p is the specific heat at constant pressure, *k* is the permeability of the porous medium, and D_m is the coefficient of mass diffusivity.
Initially (*t = 0*) the fluid and the plate are at rest. Thus the no slip boundary conditions at the surface of the plate for the above problem for t > 0 are:

$$u = U(t), v = v_0(t), T = T_0(t), C = C_0(t) \quad at \text{ y} = 0$$

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International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

$$u = 0, T = T_\infty, C = C_\infty \quad as \ y \to \infty \tag{5}$$

By using Rosseland approximation q_r takes the form

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

where σ^* is the Stefan-Boltzmann constant and k^* is the mean absorption coefficient. It is assumed that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms, thus

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \tag{7}$$

Using (6) and (7) in equation (3) we have

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{4\sigma^* T_\infty^3}{\rho c_p k^*}\frac{\partial^2 T}{\partial y^2} + \frac{\upsilon}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \tag{8}$$

In order to obtain a similarity solution in time of the problem, we introduce a similarity parameter δ as

$$\delta = \delta(t) \tag{9}$$

such that δ is a length scale.

With this similarity parameter, a similarity variable is then introduced as

$$\eta = \frac{y}{\delta} \tag{10}$$

In terms of this length scale, a convenient solution of the equation (1) can be taken as

$$v = v(t) = -\frac{\upsilon}{\delta}v_0 \tag{11}$$

where v_0 is the mass transfer parameter, which is positive for suction and negative for injection. Following Samad and Rahman [44], we see that *U(t), T(t) and C(t)* are now considered to have the following form:

$$U(t) = U_0\delta_1^{2n+2}$$
$$T(t) = T_\infty + (T_0 - T_\infty)\delta_1^{2n} \tag{12}$$
$$C(t) = C_\infty + (C_0 - C_\infty)\delta_1^{2n}$$

where n is a non-negative integer and, U_0, T_0 and C_0 are respectively the free stream velocity, mean temperature and concentration. Here $\delta_1 = \frac{\delta}{\delta_0}$, where δ_0 is the value of δ at $t = t_0$.

Now to make the equations (2), (4) and (8) dimensionless, we introduce the following transformations:

$$u = U(t)f(t) = U_0\delta_1^{2n+2}f(\eta)$$
$$T = T_\infty + (T_0 - T_\infty)\delta_1^{2n}\theta(\eta) \tag{13}$$
$$C = C_\infty + (C_0 - C_\infty)\delta_1^{2n}\phi(\eta)$$

Using equations (9), (10) and (13) the equations (2), (4) and (8) are become (using the analysis of Hashimoto [45], Sattar et al. [46] and Sattar and Maleque [47])

$$f'' + (2\eta + v_0)f' - \left(4n + 4 + M + \frac{1}{M}\right)f + Gr\theta + Gc\phi - \frac{Fs}{Da}f^2 = 0 \tag{14}$$

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

$$\theta'' + (2\eta + v_0)\left(\frac{3R\Pr}{3R+4}\right)\theta' - \left(\frac{12nR\Pr}{3R+4}\right)\theta + \left(\frac{3R\Pr}{3R+4}\right)Ecf'^2 = 0 \tag{15}$$

$$\phi'' + (2\eta + v_0)Sc\phi' - 4nSc\phi = 0 \tag{16}$$

where $Gr = \frac{g\beta(T_0 - T_\infty)\delta_0^2}{\upsilon U_0}$ is the local Grashof number, $Gc = \frac{g\beta^*(C_0 - C_\infty)\delta_0^2}{\upsilon U_0}$ is the modified Grashof number, $M = \frac{\sigma B_0^2\delta^2}{\rho\upsilon}$ is the local magnetic field parameter, $Fs_* = \frac{b}{\delta}$ is the Forchhemier number, $Fs = \frac{b}{\delta}\left(\frac{\delta}{\delta_0}\right)^{2n+2}\mathrm{Re}$ is the modified Forchhemier number, $\mathrm{Re} = \frac{v_0\delta}{\upsilon}$ is the local Reynolds number, $Da = \frac{k}{\delta^2}$ is the Darcy number, $\Pr = \frac{\upsilon}{\alpha}$ is the Prandtl number, $R = \frac{\kappa k^*}{4\sigma^* T_\infty^3}$ is the thermal radiation parameter, (κ is the thermal conductivity), $Ec = \frac{U_0^2}{c_p(T_0 - T_\infty)}$ is the Eckert number and $Sc = \frac{\upsilon}{D_m}$ is the Schmidt number.

The corresponding boundary conditions for t > 0 are given by

$$f = 1, \theta = 1, \phi = 1 \quad \text{at } \eta = 0,$$

$$f = 0, \theta = 0, \phi = 0 \text{ as } \eta \to \infty \tag{17}$$

The parameters of engineering interest for the present problems are the skin-friction coefficient, local Nusselt number and local Sherwood number which indicate physically wall shear stress, rate of heat transfer and rate of mass transfer respectively.

The skin-friction coefficient is given by

$$C_f\left(\frac{\mathrm{Re}_x}{2}\right)^{\frac{1}{2}} = f''(0), \tag{18}$$

the local Nusselt number may be written as

$$Nu_x\left(\frac{\mathrm{Re}_x}{2}\right)^{-\frac{1}{2}} = -\theta'(0) \tag{19}$$

and the local Sherwood number may be written as

$$Sh_x\left(\frac{\mathrm{Re}_x}{2}\right)^{-\frac{1}{2}} = -\phi'(0) \tag{20}$$

Thus the values proportional to the skin-friction coefficient, Nusselt number and Sherwood number are $f''(0), -\theta'(0)$ and $-\phi'(0)$ respectively.

III. NUMERICAL COMPUTATION

The numerical solutions of the nonlinear differential equations (14) – (16) under the boundary conditions (17) have been performed by applying fourth order Runge-Kutta iteration technique along with shooting method. We have chosen a step size of $\Delta\eta = 0.01$ to satisfy the convergence criterion of 10^{-6} in all cases. The value of η_∞ was found to each iteration loop by $\eta_\infty = \eta_\infty + \Delta\eta$. The maximum value of η_∞ to each group of parameters v_0, *Gr*, *Gc*, *M*, *Da*, *Fs*, *n*, *Pr*, *R*, *Ec*, and *Sc* determined when the value of the unknown boundary conditions at $\eta = 0$ not change to successful loop with error less than 10^{-6}. Figs 1-11. Show the velocity, temperature and concentration profiles for different step

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International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

sizes respectively considering $Gr = 10.0, Gc = 6.0, M = 0.5, Da = 0.25, Fs = 1.0, \Pr = 0.71, R = 0.5, Ec = 0.5, Sc = 0.6, n = 1.0$ and $v_0 = 0.5$.

IV. RESULTS AND DISCUSSION

For the purpose of discussing the results, the numerical calculations are presented in the form of non-dimensional velocity temperature and concentration profiles. Numerical computations have been carried out for different values of the Grashof number *Gr*, modified Grashof number *Gc*, magnetic field parameter *M*, Darcy number *Da*, modified Forchhemier number *Fs*, constant parameter *n*, Prandtl number Pr, radiation parameter *R*, the Eckert number *Ec*, Schmidt number *Sc* and suction parameter v_0.

The values of Grashof number *Gr* are taken be large from the physical point of view. The large Grashof number values correspond to free convection problem.

Figures.1 and Figure.2 represent the velocity distribution profiles is drawn against η for different values of Grashof number *Gr* and modified Grashof number *Gc*. It is observe that the velocity distribution is increase with increase in Grashof number *Gr* and modified Grashof number *Gc.*

The effect of magnetic field parameter on the velocity profiles are shown in Figure. 3. It is observed from this figure that the magnetic field has decreasing effect on the velocity field increases. There is no outcome on the temperature and concentration profiles due the distinction of the values of magnetic field parameter *M.*

We choose *Da* = 0.25, 0.5, 1.0, 2.0 to analyze the effect of the Darcy number on the velocity fields shown in Figure 4. expressing that the velocity increases with the increase of *Da* but no effect is shown on the temperature and concentration profiles due the distinction of the values of *Da.*

Here *n = 0.0, 0.5, 1.0, 1.5* are considered to demonstrate the effect of the nonlinearity constant parameter. Figures 5(a) – 5(b) represent the control of the constant parameter *n* to all the profiles. All the profiles decrease with the increase of *n.* The effects of n are very significant and smooth on the distributions.

The effect of the modified Forchhemier number *Fs* on the velocity field is shown on Figure. 6. It is observed from this figure that modified Forchhemier number has slightly decreasing effect on the velocity field.

The influence of the Prandtl number *Pr* on velocity and temperature field are shown in Fig. 7(a) and Fig. 7(b) . It is obvious that both velocity and temperature decrease as Prandtl parameter *Pr* increase.

The effect of radiation parameter *R* on the velocity profiles is shown in Figure 8(a). This figure shows that velocity decreases with the increase of the radiation parameter *R*. Figure 8(b). shows the effect of radiation parameter *R* on the temperature profiles. For large *R*, it is clear that temperature decreases more rapidly with the increase of radiation parameter *R*. therefore using radiation we can control the flow characteristic and temperature distribution.

The effect of the viscous dissipation parameter i.e., the Eckert number *Ec* on the dimensionless velocity component and temperature profiles are shown in Figs. 9(a) and 9(b) respectively. The positive Eckert number implies cooling of the plate i.e., loss of heat from the plate to the fluid. Hence, greater viscous dissipative heat causes a rise in the temperature as well as the velocity, which is evident from Figs. 9(a) and 9(b).

The influence of the Schmidt numbers Sc on the dimensionless velocity and concentration profiles are plotted in Figs. 10(a) and 10(b) respectively. As the Schmidt number *Sc* increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers. These behaviors are clear from Figs. 10(a) and 10(b).

Figures 11(a) – 11(b) display the effects of the suction parameter v_0 on the velocity, temperature and concentration profiles respectively. It is observed that, when suction v_0 increases, all the profiles *i.e.* velocity, temperature and concentration are decrease.

Finally, the effects of various parameters on the skin-friction coefficient C_f , local Nusselt number *Nu* and local Sherwood number *Sh* are shown in Tables 1 – 7.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

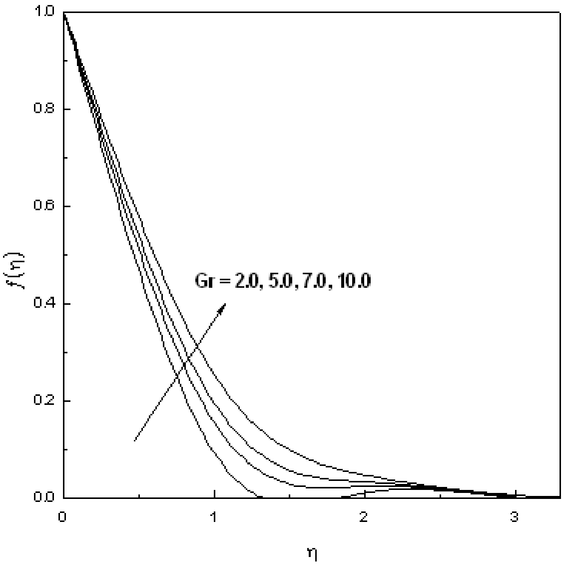

Fig.1. Velocity profiles for different values of *Gr*.

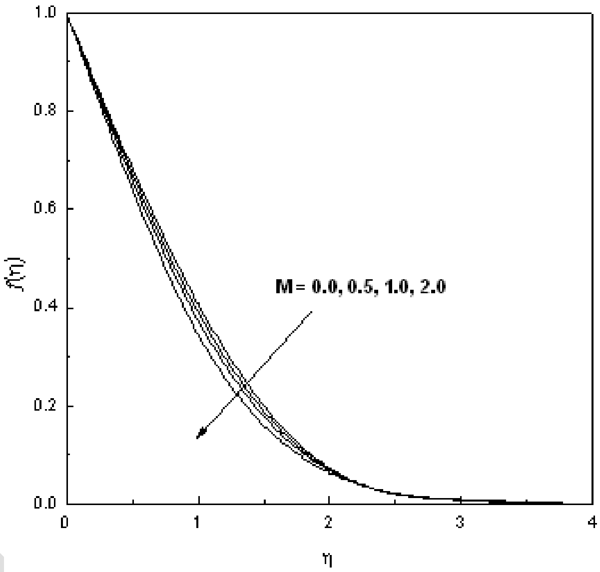

Fig.3. Velocity profiles for different values of *M*

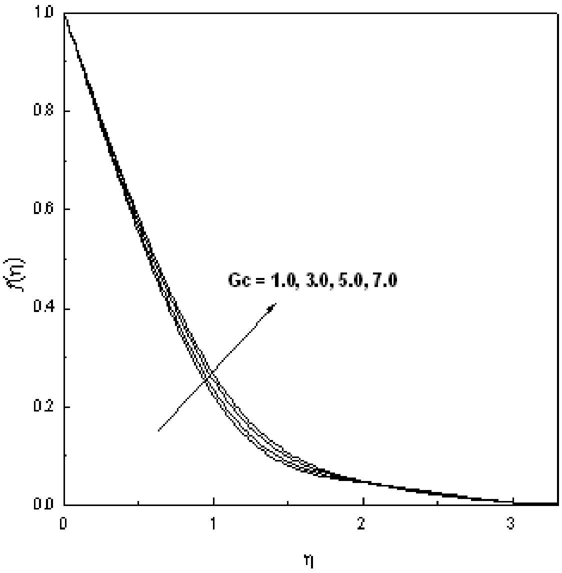

Fig.2. Velocity profiles for different values of *Gc*.

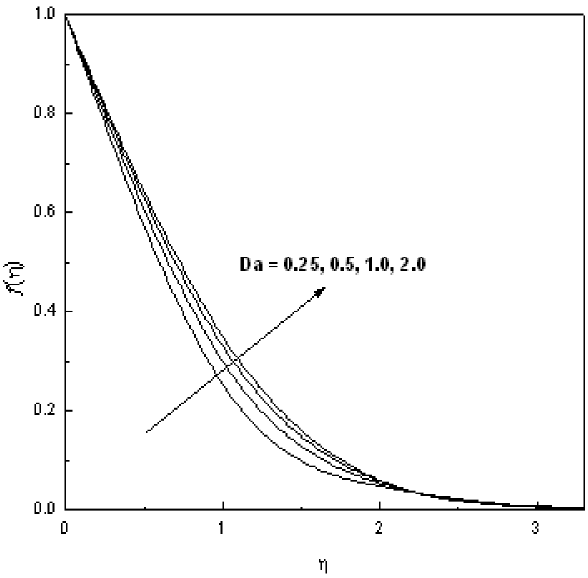

Fig.4. Velocity profiles for different values of Da

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
(An ISO 3297: 2007 Certified Organization)
Vol. 3, Issue 11, November 2014

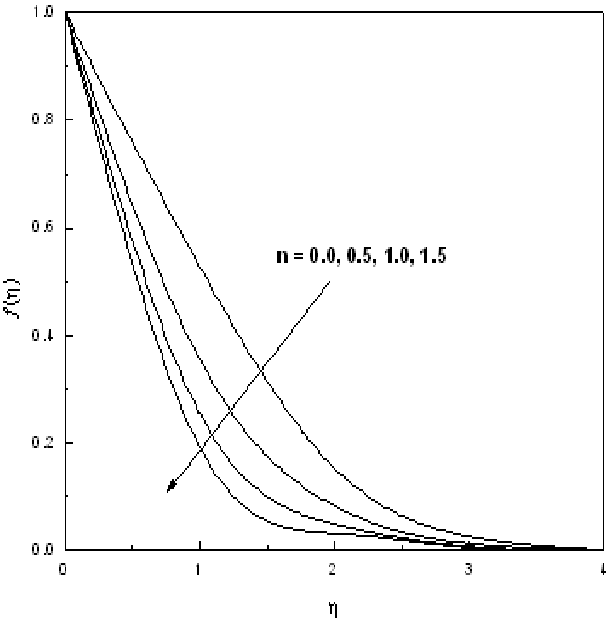

Fig.5(a). Velocity profiles for different values of *n*.

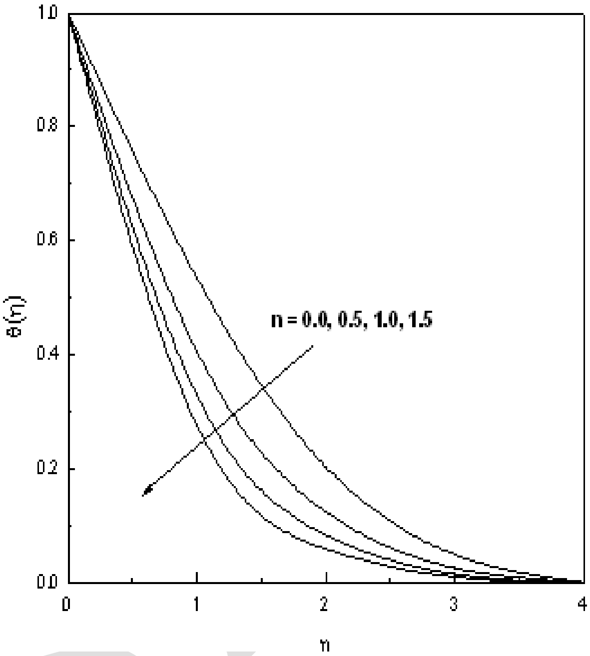

Fig.5(b).Temperature profiles for different values of *n*

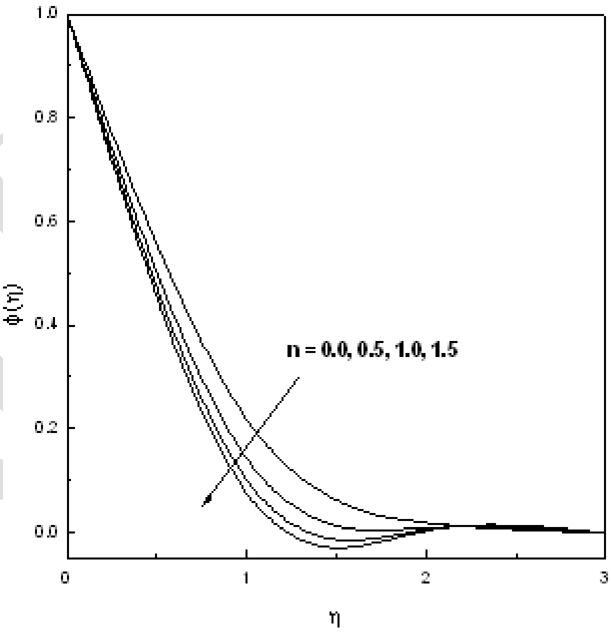

Fig.5(c).Concentration profiles for different values of *n*

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

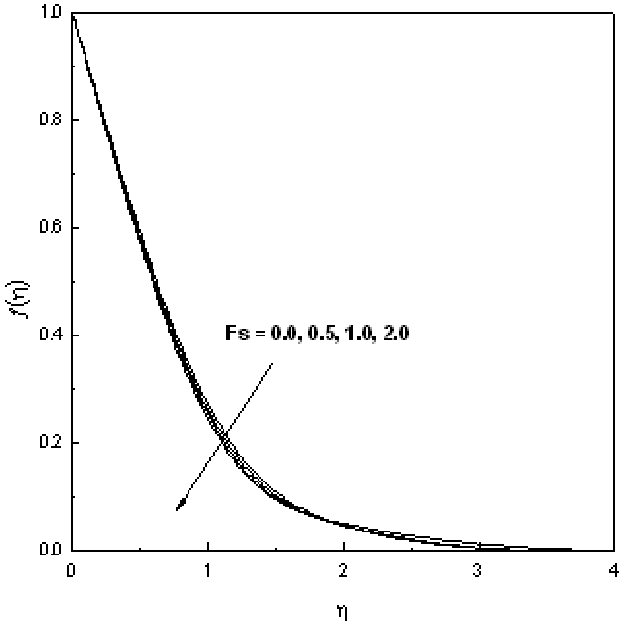

Fig.6. Velocity profiles for different values of *Fs*.

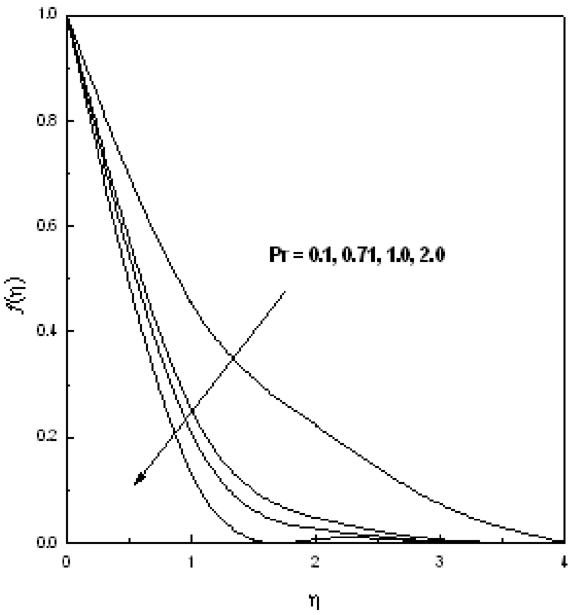

Fig.7(a). Velocity profiles for different values of *Pr*

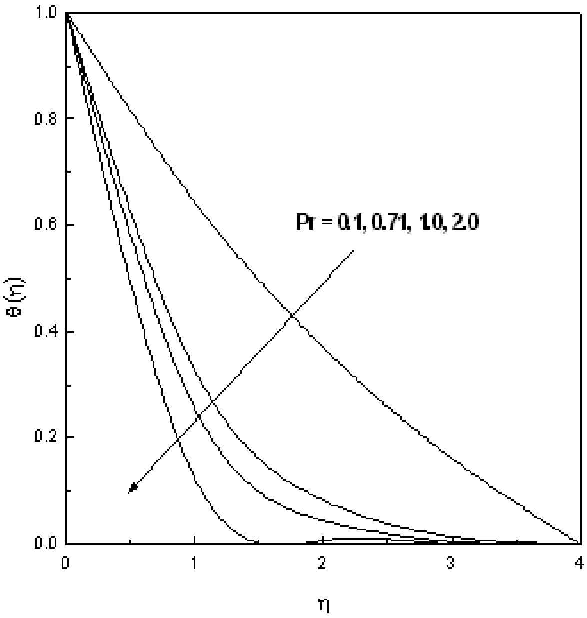

Fig.7(b). Temperature profiles for different values of *Pr*.

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(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

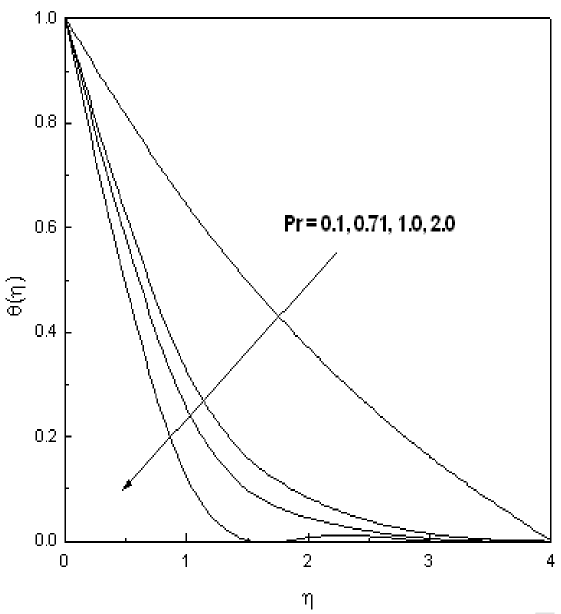

Fig.8(a). Velocity profiles for different values of Pr.

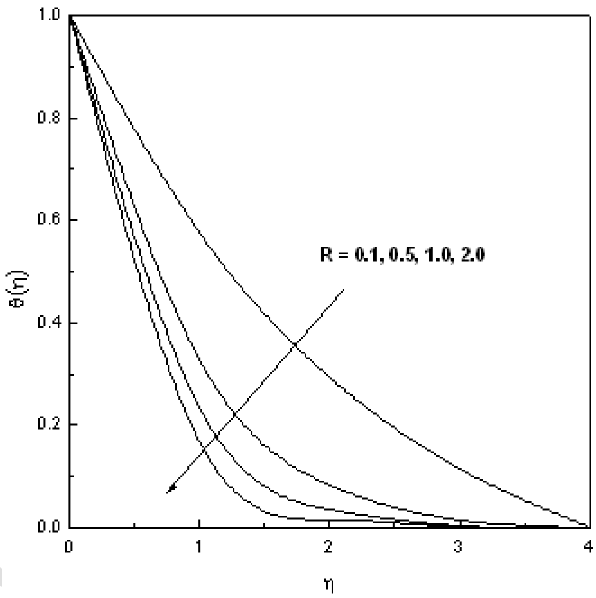

Fig.8(b). Temperature profiles for different values of *R*.

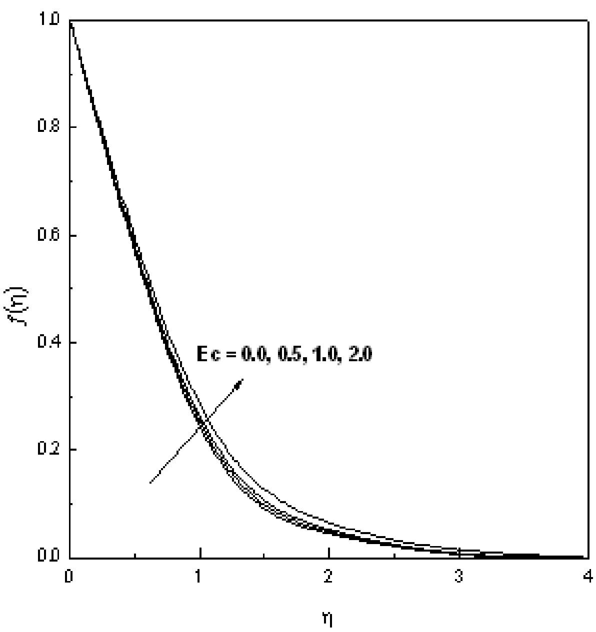

Fig.9 (a). Velocity profiles for different values of *Ec*.

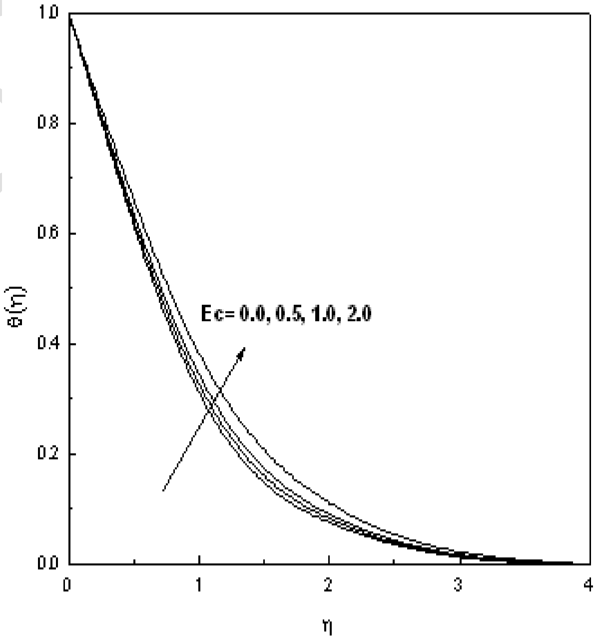

Fig.9 (b).Temperature profiles for different values of *Ec*.

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International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 3, Issue 11, November 2014

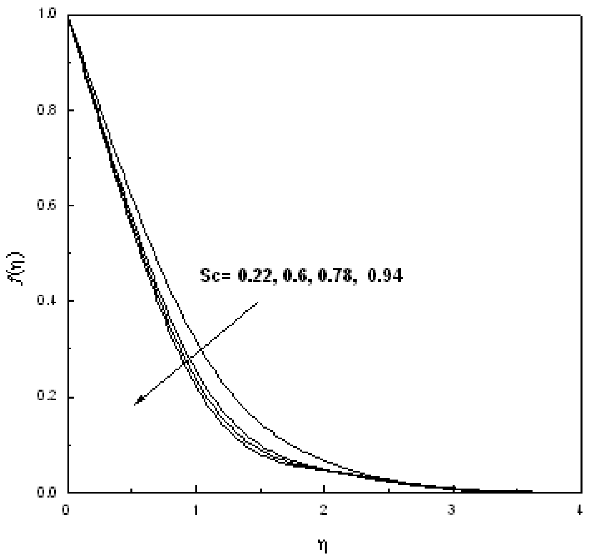

Fig.10(a). Velocity profiles for different values of *Sc*

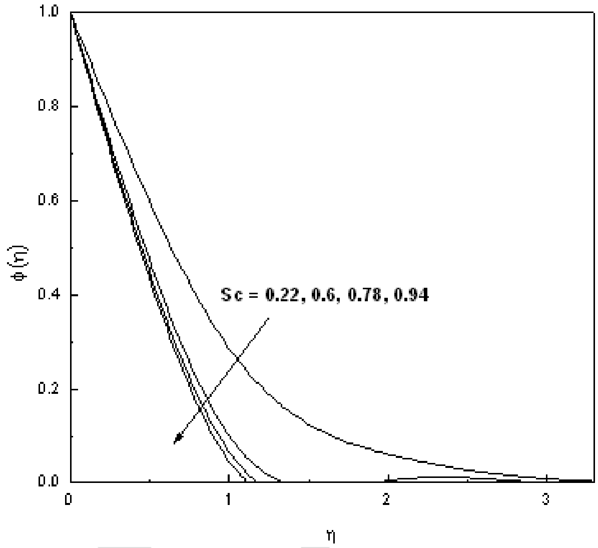

Fig.10(b). Temperature profiles for different valu of *Sc*

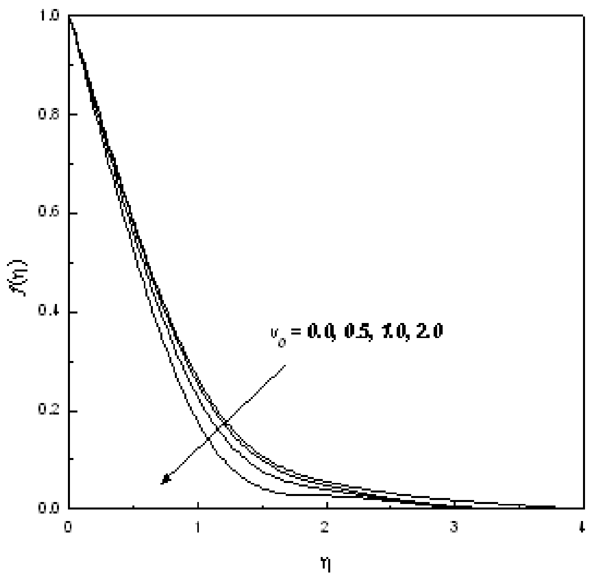

Fig.11 (a). Velocity profiles for different values of V_0.

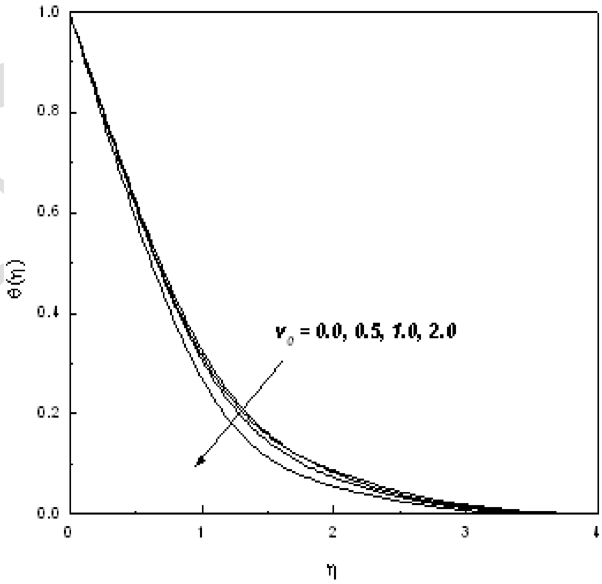

Fig.11 (b). Temperature profiles for different values of V_0.

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(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 11, November 2014

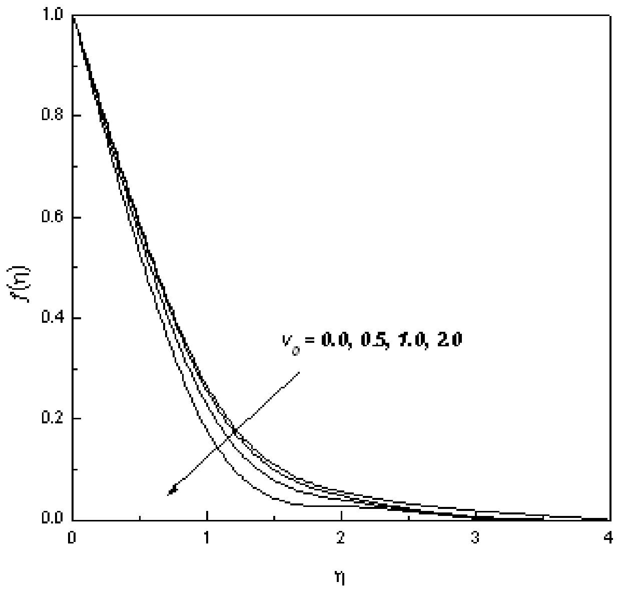

Fig.11(c). Concentration profiles for different values of v_0.

V. Conclusion

In this paper we have investigated the thermal radiation interaction with unsteady MHD free convective heat and mass transfer flow past a vertical porous flat plate embedded in porous medium under the influence of heat source. From the present study we can make the following conclusions:

- The velocity profiles increase with an increase of the free convection current.
- Magnetic field has significant effect on velocity field and retards the motion of the fluid.
- Velocity profiles increase with the increase of Darcy number.
- Using suction boundary layer growth can be controlled. Suction stabilizes the hydrodynamic, thermal as well as concentration boundary layers growth.
- Velocity and temperature profiles increase with increase of Eckert number.
- Radiation has significant effects on the velocity as well as temperature distributions. *i.e.* velocity and temperature profiles reduce with the increase of thermal radiation.
- Flow characteristics strongly depend on the constant parameter.
- The skin-friction coefficient, local Nusselt number and local Sherwood number increase with an increase of suction parameter or constant parameter.
- As radiation increases, the skin-friction coefficient and local Nusselt number are also increase.
- The skin-friction coefficient and local Nusselt number are reduces with an increase of Eckert number.

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