Thermal Radiation and Heat Absorption on Transient MHD free Convection flow Embedded in a Porous Medium with Exponentially Decaying Wall Temperature

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Abstract - In this paper we investigated the effects of thermal radiation and heat absorption effects on transient MHD natural convection flow of an electrically conducting fluid past a vertical porous plate with variable temperature. It is assumed that the temperature of the plate decays exponentially with time. Exact solutions to the coupled linear partial differential equations representing the flow problem are obtained using perturbation technique. Effects of different physical parameters involved in the temperature and velocity profiles are shown graphically and discussed in detail. It is inferred from the graphs there is a considerable effect of decay parameter *q* on the velocity. The fluid temperature can be reduced by increased the radiation parameter F, decay parameter *q* and heat source parameter *Q*. Further skin friction and Nusselt number are also derived and their variations with respect to the parameters are investigated through tables.

Key words: Vertical Plate, Free Convection, Thermal Radiation, Porous Medium, Heat Source.

I. INTRODUCTION

MHD flow through porous media is a branch of research undergoing rapid growth in fluid mechanics and heat transfer, because of its important applications in environmental, geophysical and energy related engineering problems. Prominent applications are the utilization of geothermal energy, the control of pollutant spread in groundwater, the design of nuclear reactors, compact heat exchangers, solar power collectors, heat transfer associated with the deep storage of nuclear waste and high performance insulations for buildings, as well as the heat transfer from stored agricultural products that release energy as a result of metabolism of the products. MHD heat transfer has gained significance owning to recent advancement of space technology. The MHD heat transfer can be divided into two sections. One contains problems in which heating is an incidental bi-product of the electromagnetic fields as in MHD generators, pumps etc. The second consists of problems in which the primary use of electromagnetic fields is to control heat transfer. Liquid in the geothermal region is an electrically conducting liquid because of high temperature. Hence the study of the interaction of the geomagnetic field with the fluid in the geothermal region is of great interest, thus leading to the study of MHD convection flow through a porous medium. When the radiative heat transfer takes place, the fluid involved can be electrically conducting in the sense that it is ionized owing to the high operating temperature. Accordingly, it is of interest to examine the effect of the magnetic field on the flow. Studying such an effect has a great importance in the application fields where thermal radiation and MHD are correlative. The process of fusing of metals in an electrical furnace by applying a magnetic field and the process of cooling of the first wall inside a nuclear reactor containment vessel where the hot plasma is isolated from the wall by applying a magnetic field are examples of such fields.

Radiation heat transfer is important for systems such as a porous solid fuel bed radiation is shown to be equivalent to a large non-linear diffusion term. The modeling of thermal radiation continues to represent a significant challenge to the heat transfer community. Radiation effects on free convection flow are important in the context of space technology and processes involving high temperatures. The inclusion of radiation effects in the energy equation, however, leads to a highly nonlinear partial differential equation. Radiation effect on flow and heat transfer is important in the context of space technology and processes involving high temperature.The issue of global warming has become a particular concern in the world of research. To reduce the effects of global warming it have been developing of green building with the aim of energy saving. Other thermal effects were neglected firstly due to good cooling capabilities of the fiber geometry and secondly by selecting ytterbium doped fibers allowing for low quantum defect which is believed to be the main heating source. Heat sources energy are affected by external and internal heat loads. External heat load is heat caused due to conduction, radiation and convection. Internal heat load is the heat caused by the occupants and electrical devices in the room. External heat load include solar radiation transmitted through the glass, the solar radiation on the walls and roof, conduction in the room with irregularities through the walls, heat conduction and convection through the door and window glass due to the temperature difference, the heat caused by air infiltration due to the opening of the door and through gaps of the window. Internal heat load include heat from occupants, heat from lighting and electrical equipment, heat generated by other equipment.

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Heat transfer in porous media is seen both in natural phenomena and in engineering processes. It is replete with the features that are influences of the thermal properties and volume fractions of the materials involved. These features are seen of course as responses to the causes that force the process in to action. For instance many biological materials, whose outermost skin is porous and pervious, saturated or semi saturated with fluids give out and take in heat from their surroundings. Das et al. [1]investigated radiation effects on flow past impulsively started vertical plate.Hossain and Takhar [2] examined radiation effects on mixed convection along vertical plate with uniform surface temperature.Chamkha [3] developed a continuum two-phase fluid–particle model accounting for fluid-phase heat absorption and thermal radiation and applied to the problem of heat transfer in a particulate suspension flow over a horizontal heated surface in the presence of a gravity field. Azzam [4] presented the effect of radiation on MHD free convective flow past a semi-infinite moving vertical plate for high temperature differences. Cookey et al. [5] investigated the viscous dissipation and radiation effects on unsteady free convective flow past an infinite vertical plate embedded in a porous medium with time dependent suction. Unsteady MHD free convective flow of a compressible fluid past a moving vertical plate in the presence of heat transfer was analyzed by Ogulu et al., [6]. Mahmoud Mustafa [7] reconnoitered the flow of fluids with variable viscosity past a moving vertical plate with simultaneous effects of transverse magnetic field and radiation.Ibrahim et al. [8] observed the viscous dissipation and radiation influences on unsteady MHD mixed convection flows of micro-polar fluids.Aliakbar et al. [9] investigated an influence of thermal radiation on MHD flow of Maxwellian fluids above stretching sheet. Das et al. [10] analyzed a hydromagnetic convective flow past a vertical porous plate through a porous medium with heat source.

Singh et al. [11] studied the effect of volumetric heat generation/absorption on mixed convection stagnation point flow on an isothermal vertical plate in porous media. Bhattacharya [12] studied the effects of radiation and heat source on the unsteady boundary layer flow and heat transfer past a shrinking sheet with suction/injection. The effect of radiation on the unsteady natural convection flow past an infinite vertical plate wherein the plate temperature is a ramped is studied by RudraKantaDeka and Sankar Kumar Das [13]. Joseph et al. [14] describes experimental data and scaling analysis of convective heat transfer in foams and micro foams under laminar flow.Balamurugan et al. [15] investigated thermal radiation and radiation absorption effects on unsteady MHD double diffusive free convection flow of Kuvshinski fluid past a moving porous plate embedded in a porous medium heat generation. Siva Reddy et al [16] studied a numerical solution of transient hydro magnetic natural convection viscous incompressible fluid, electrically conducting, heat absorbing and radiative heat transfer past an impulsively moving plate with ramped temperature. RudraKantaDeka et al. [17] examined the thermal radiation effects on unsteady MHD natural convection flow of an electrically conducting fluid past a vertical plate with variable temperature. Jhansi Rani and Ramana Murthy [18] has been examined the variation of flow rate with respect to various flow entities in situation of MHD flow over a moving infinite vertical porous plate in the presence of thermal radiation. Abdullah Dawar et al [19] investigated the effect of thermal radiation and heat source on the fluid flow over an unstable oscillatory porous stretching surface.

The present analysis aims to study the effects of thermal radiation and heat absorption on MHD flow past a vertical porous plate with exponentially decaying plate temperature.

II. FORMULATION OF THE PROBLEM

We have considered a laminar MHD free convection flow of a viscous, incompressible fluid past an infinite vertical plate embedded in a porous medium with thermal radiation and heat source. The physical model of the problem is shown in figure 1. The x' - axis is taken along the plate in the vertical upward way direction and the y' - axis is taken normal to the plate.We made the following assumptions:

1. At $t' \le 0$, the plate and the fluid is at the same temperature T'_∞
2. At time t > 0, the plate temperature is raised to $T'_\infty + (T'_w - T'_\infty)\exp(-ct)$.
3. Viscous dissipation is neglected in the energy equation as the motion is due to free convection only.
4. Heat generation/absorption effects are taken into account.
5. A uniform magnetic field B_0 is applied in the transverse direction to the flow.
6. Temperature of the plate decays exponentially with time.

Under these assumptions with usual Boussinesq's approximation the governing boundary layer equations are:

$$\frac{\partial u'}{\partial t'} = g\beta(T' - T'_\infty) - \frac{\sigma B_0^2}{\rho}u' + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\nu}{K'}u' \quad (1)$$

$$\frac{\partial T'}{\partial t'} = (\rho C_p)^{-1}\left(\kappa\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} - Q_0(T' - T'_\infty)\right) \quad (2)$$

with initial and boundary conditions are

$$\begin{aligned} &u' = 0,\quad T' = T'_\infty && \text{for all } y', t' \le 0 \\ &u' = 0,\quad T' = T'_\infty + (T'_w - T'_\infty)e^{-ct'} && \text{at } y' = 0 \\ &u' \to 0,\quad T' \to T'_\infty && \text{as } y' \to 0 \end{aligned} \Bigg\} \; t' > 0 \quad (3)$$

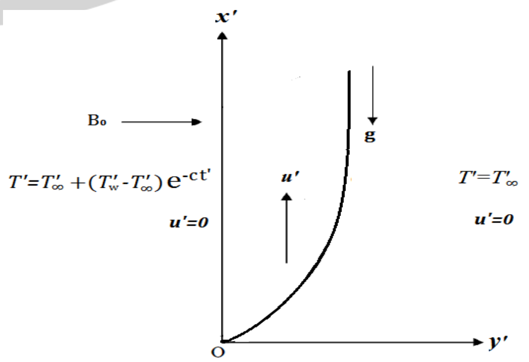

Figure 1: Physical model of the problem

Here u' is the fluid velocity x'– direction, $T'$is the temperature, T_w is temperature at the plate, T_∞ is temperature far away from the plate, B_0 is the magnetic

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field strength, q_r the radiativeflux,Cp the specific heat at constant pressure, t' is the time, c is any constant, σ is the electric conductivity, ρ the density, β is the coefficient of volume extension, g is the acceleration due to gravity, ν is the dynamic consistency and k is the warm conductivity, K' is the permeability parameter, Q_0 is heat source parameter.

The term $\frac{\partial q_r}{\partial y'}$ in equation (2) denotes the variation in the radiative flux with the distance normal to the plate. For an optically thin grey gas, the local radiant is given by,

$$\frac{\partial q_r}{\partial y'} = -4a'\sigma'\left(T_\infty'^4 - T'^4\right) \quad (4)$$

Where σ' and a' are the Stefan-Boltzmann constant and the Mean absorption coefficient, respectively. We assume that the temperature differences within the flow are sufficiently small so that T'^4 can be expressed as a linear function of T' after using Taylor's series to expand T'^4 about the free stream temperature T_∞' and neglecting higher-order terms. This results in the following approximation:

$$T'^4 \cong 4T_\infty'^3 T' - 3T_\infty'^4 \quad (5)$$

Using (4) and (5) in (2) we get

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{16a'\sigma'}{\rho C_p} T_\infty'^3 \left(T' - T_\infty'\right) \quad (6)$$

In order to write the governing equations and the boundary conditions in dimensionless from, the following non-dimensional quantities are introduced.

$$u = u'(U_0)^{-1} \;;\quad y = y'U_0(\nu)^{-1} \;;\quad t = t'U_0^2(\nu)^{-1} \;;$$
$$\theta = (T' - T_\infty')(T_w' - T_\infty')^{-1} \;;\quad \Pr = \kappa^{-1}\mu C_p \;;$$
$$Gr = g\beta\nu(T_w' - T_\infty')(U_0^3)^{-1} \;;$$
$$F = 16a'\sigma' T_\infty'^3 \nu^2(\kappa U_0^2)^{-1} \;;\quad q = (U_0)^{-1}\sqrt{c\nu} \;;$$
$$M = (\rho U_0^2)^{-1}\sigma\nu B_0^2 \;;$$

$$Q_0 = \frac{\rho CpQU_0^2\theta(T_w' - T_\infty')}{\nu(T' - T_\infty')} \;;\; K' = \frac{K\nu^2}{U_0^2} \quad (7)$$

Using the transformations (7), the non-dimensional forms of (1) and (6) are

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta - \left(M + \frac{1}{K}\right)u \quad (8)$$

$$\frac{\partial \theta}{\partial t} = (\Pr)^{-1}\left(\frac{\partial^2 \theta}{\partial y^2} - F\theta\right) - Q\theta \quad (9)$$

And the corresponding initial and boundary conditions are,

$$\left.\begin{array}{lll} u = 0, & \theta = 0 & \text{for all } y, t \le 0 \\ u = 0, & \theta = \exp(-qt) & \left.\begin{array}{l}\text{at } y = 0 \\ \text{as } y \to \infty\end{array}\right\} t > 0 \\ u \to 0, & \theta \to 0 & \end{array}\right\} \quad (10)$$

Where u, θ and t are the dimensionless velocity, temperature and time respectively; U_0 is the reference velocity, Pr is the Prandtl number, Gr is the Grashof number, F is the radiation parameter, M is the Hartmann number and q is the decay parameter, Q is heat source parameter, K is permeability parameter.

Definition of parameters:

Prandtl number (*Pr*)

It is defined as the ratio of viscous force to thermal force of a fluid.

Hartmann number or magnetic parameter (*M*)

It is defined as the ratio of magnetic force toviscous force.

Thermal Grashof number (*Gr*)

The thermal Grashof number signifies the relative effect of the thermalbuoyancy force to the viscous hydrodynamic force.

III. SOLUTION OF THE PROBLEM

To solve the equations (8) and (9) subject to initial and boundary conditions (10), we assumed velocity and temperature as:

$$\left.\begin{array}{l} u = F_0(y)\exp(nt) \\ \theta = G_0(y)\exp(nt) \end{array}\right\} \quad (11)$$

Substituting equation (11) in equations (8) (9), we obtain

$$F_0'' - \left(M + \frac{1}{K} + n\right)F_0 = -Gr\,G_0(y) \quad (12)$$

$$G_0'' - (F + (n+Q)\Pr)G_0 = 0 \quad (13)$$

The corresponding boundary conditions can be written as

$$\left.\begin{array}{ll} F_0 = 0, G_0 = 0 & \text{for all } y, t \le 0 \\ F_0 = 0, G_0 = \exp(-(q+n)t) & \left.\begin{array}{l}\text{at } y = 0 \\ \text{as } y \to \infty\end{array}\right\}, t > 0 \\ F_0 \to 0, G_0 \to 0 & \end{array}\right\} \quad (14)$$

The analytical solutions of the equations (12) & (13) with satisfying boundary conditions (14) are given by

$$F_0(y) = B_1(\exp(-A_2 y) - \exp(-A_1 y))\exp(-nt) \quad (15)$$

$$G_0(y) = \exp(-(q+n)t - A_1 y) \quad (16)$$

In view of the above solutions, the velocity and temperature distributions in the boundary layer becomes

$$u(y,t) = B_1(\exp(-A_2 y) - \exp(-A_1 y)) \quad (17)$$

$$\theta(y,t) = \exp(-qt - A_1 y) \quad (18)$$

It is important to study about local wall shear stress or skin-friction and rate of heat transfer or Nusselt number. These are given by

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Shearing stress

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = B_1(A_1 - A_2) \qquad (19)$$

Nusselt Number

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = A_1 \exp(-qt) \qquad (20)$$

IV. RESULTS AND DISCUSSION

In this section we attempt to understanding the problem physically. To make the physical interpretation of the flow characteristics, numerical calculations have been carried out for the non-dimensional velocity and temperatureand are reported graphically in Figures1-9. Skin – friction coefficientand heat transfer coefficients in terms of shearing stress and Nusselt number are also presented in tabular form. The effects of material parameters such as Hartmann number M, permeability parameter K, decay parameter q, radiation parameter F, Grashof number Gr, heat absorption parameter Q are discussed in detail. The values of the physical parameters are fixed as$F$ = 0.5, t = 0.1, Pr = 0.71, q = 0.1, n = 0.1, Gr= 2, M = 0.5, K = 1and Q = 1.

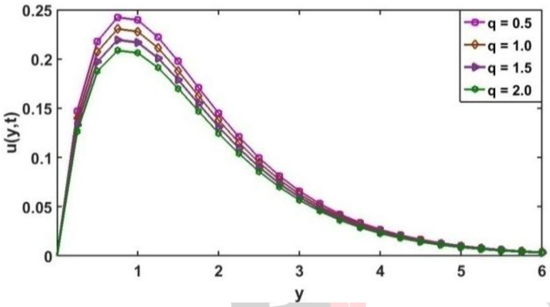

Figure 2: Effect of decay parameter q on velocity profile against y

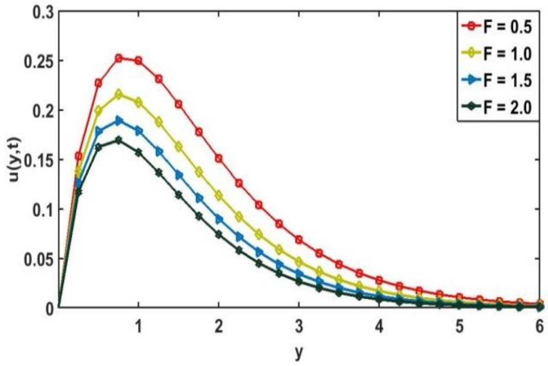

Figure 3: Effect of radiation parameter F on velocity profile against y

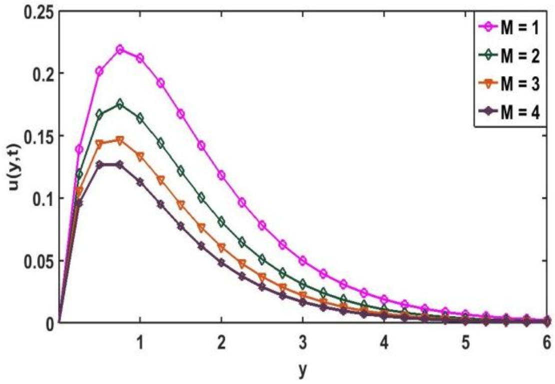

Figure 4: Magnetic field effect M on velocity profile against y

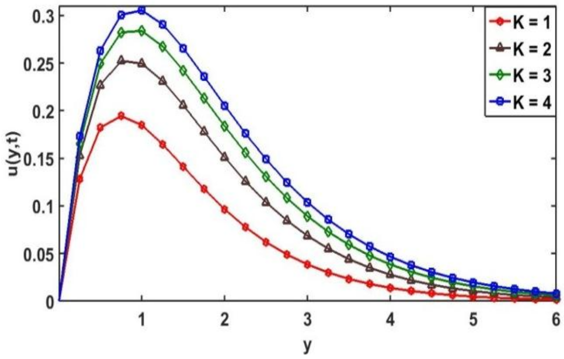

Figure 5: Effect of permeability parameter K on velocity profile against y

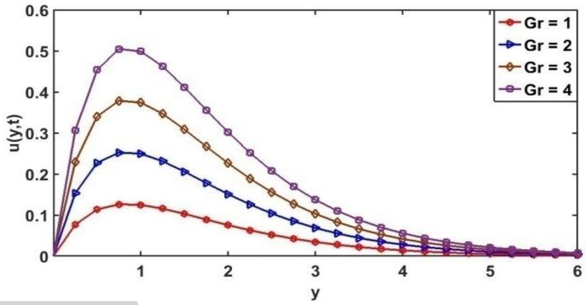

Figure 6: Effect of Grashof number Gron velocity profiles against y

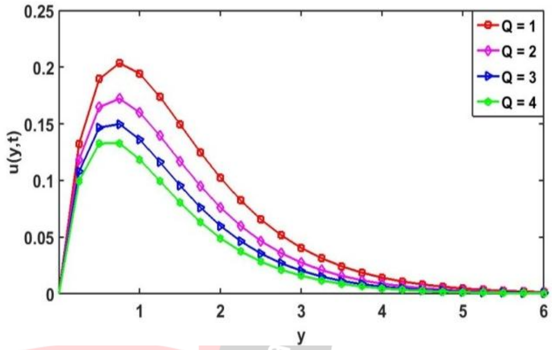

Figure 7: Effect heat source parameter Q on velocityprofiles against y

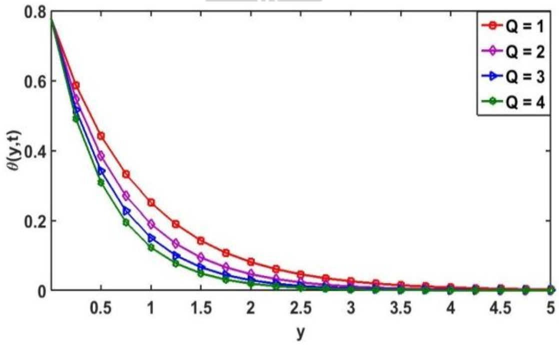

Figure 8: Effect heat source parameter Q on temperature profiles against y

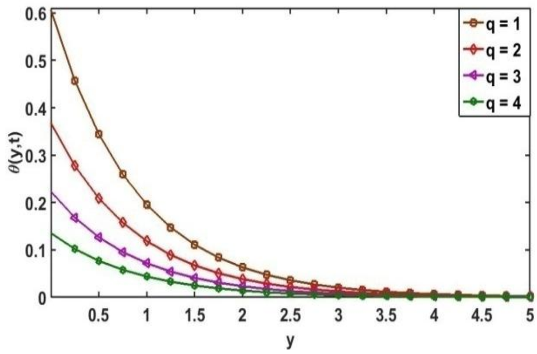

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Figure 9: Effect of decay parameter q on temperature profiles against y

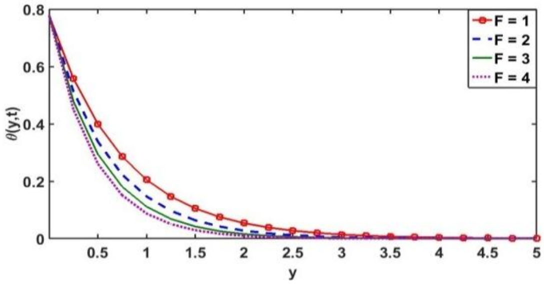

Figure 10: Effect of radiation parameter F on temperature profiles against y

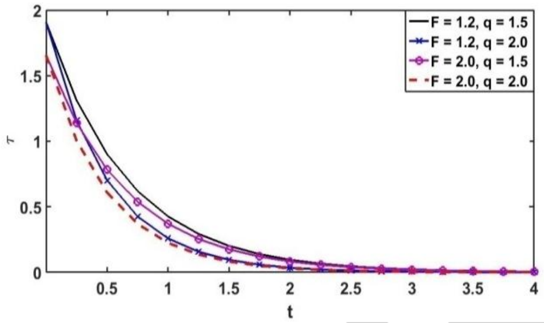

Figure 11: Skin friction profiles with respect to radiation parameter F and decay parameter q when K= 0 and *Q* = 0.

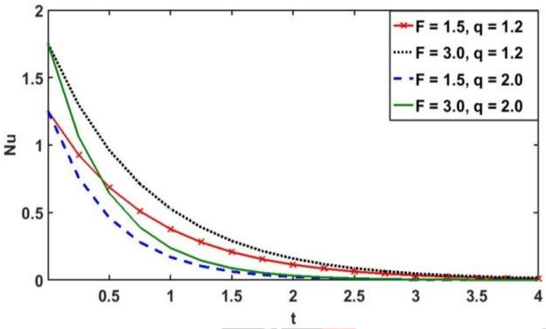

Figure 12: Variations of Nusselt number with respect to radiation parameter F and decay parameter q when K= 0 and Q = 0.

Velocity profiles against *y* for different values of *q* are displayed in Figure2. In the figure it is seen that magnitude of velocity gets declined as q increases. The radiation effects on velocity profiles are shown in Figure 3. It is observed that the velocity profiles decreases with an increases of radiation parameter F. Figure4 shows that the effects of magnetic field parameter M on the velocity profiles. It is obvious that an existence of the magnetic field decreases the velocity field due to Lorentz's force. Figure5shows the velocity profiles for the different values of permeable parameter. It is observed that the increasing values of K the velocity profiles are also increases. Figure 6 exhibits the variation of velocity profiles for different values of Grashof number Gr, in case of corresponding to cooling of the plate (Gr >0). It is observed that the velocity profiles increases with an increases of Gr. The rise in the values of velocity is due to enhancement in buoyancy force. Grashof number is liable for the enrichment of buoyancy force. Buoyancy force increases as magnitude of Gr increases and as such velocity drives up. Velocity and temperature profiles are for various values of Q are displayed in Figures7 and 8. An increase in heat source parameter decreases in both velocity and temperature fields.

Temperature profiles versus *y* for different values of *q* are demonstrated in Figure 9 and it is seen that *q* affects adversely on temperature. The effect of thermal radiation parameter F on the temperature field is illustrated in Figure 10. It is seen that F affects adversely on temperature. It is witnessed that effect of radiation remains quite significant till the fluid mass is far away from the plate. Thus change of radiation creates a long term effect on temperature.

Table 1represents the numerical values of skin-friction coefficient (τ) for variations in radiation parameter *F*,decay parameter *q*, magnetic parameter *M*,Grahsof number *Gr*,porosity parameter *K* and heat source parameter*Q* respectively, corresponding to cooling of the plate. An increase in Gr and K leads to an increase in the value of skin–friction coefficient while in increase in *q*, *F*, *M* and *Q* leads to a decrease in the value of skin–friction coefficient.

Table 2 represents the numerical values of heat transfer coefficient Nu for different values of radiation parameter*F*,decay parameter *q* and heat source parameter*Q*. An increase in F and *Q* leads to an increase in heat transfer coefficient, while an increase in *q* leads to decrease in heat transfer coefficient.

In the absence of porous medium (K= 0) and heat source effect (*Q* = 0), all of the flow and heat transfer solutions reported above are consistent and the results are given good agreement (figures 11 & 12) with those reported earlier byRudraKantaDeka et al [17].

Table 1 Influence of *F*, *q*, *MGr*, K, and *Q*on skin-friction when *t* = 0.1, *Pr* = 0.71, *n* = 0.1

F	*q*	*M*	*Gr*	*K*	*Q*	C_f
0.1	0.1	0.1	2	1	1	0.9735
0.2	0.1	0.1	2	1	1	0.9493
0.3	0.1	0.1	2	1	1	0.9274
0.1	0.2	0.1	2	1	1	0.9638
0.1	0.3	0.1	2	1	1	0.9542
0.1	0.4	0.1	2	1	1	0.9447
0.1	0.1	0.2	2	1	1	0.9525
0.1	0.1	0.3	2	1	1	0.9332
0.1	0.1	0.4	2	1	1	0.9153
0.1	0.1	0.1	3	1	1	1.4602
0.1	0.1	0.1	4	1	1	1.9469
0.1	0.1	0.1	5	1	1	2.4337
0.1	0.1	0.1	2	2	1	1.1154
0.1	0.1	0.1	2	3	1	1.1865
0.1	0.1	0.1	2	4	1	1.2303
0.1	0.1	0.1	2	1	2	0.8402
0.1	0.1	0.1	2	1	3	0.7580
0.1	0.1	0.1	2	1	4	0.6995

Table 2 Influences of *F*, *q*, and *Q*on Nusselt number

F	*q*	*Q*	*Nu*
0.1	**0.1**	**1**	**0.8928**
0.5	0.1	1	1.0766
1.0	0.1	1	1.2695
0.1	**0.5**	1	0.7310
0.1	**1.0**	1	0.5693
0.1	0.1	**2**	1.1998
0.1	0.1	**3**	1.4429

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V. CONCLUSIONS

In this paper we have studied heat source and porous effects on an unsteady MHD free convective heat transfer flow past an infinite vertical plate. From the present investigation the following conclusions are drawn.

- There is a considerable effect of decay parameter *q* on the velocity.
- It is found that, heat source *Q* decreases significantly on velocity profiles.
- Velocity profiles are adversely affected by transversely applied magnetic field as well as radiation.
- Velocity of the fluid increases with the increase in permeability parameter K and Grashof number *Gr*.
- The fluid temperature can be reduced by increased the radiation parameter F, decay parameter *q* and heat source parameter *Q*.
- Skin friction coefficient decelerated due to the increase in the magnetic parameter M, radiation parameter F and heat source parameter *Q*.
- Nusselt number enhanced due to the increase in the radiation parameter F and heat source parameter *Q*.
- Skin friction coefficient and Nusselt number are reduced due to the increase in the decay parameter *q*.

VI. APPENDIX

$$A_1^2 = F + \Pr(Q+n); \quad A_2^2 = M + \frac{1}{K} + n \quad ;$$

$$B_1 = \frac{Gr\, e^{-qt}}{A_1^2 - A_2^2}.$$

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