THERMAL DIFFUSION AND RADIATION EFFECTS ON UNSTEADY MHD FLOW PAST AN EXPONENTIALLY ACCELERATED VERTICAL PLATE WITH VARIABLE TEMPERATURE AND MASS DIFFUSION THROUGH POROUS MEDIUM

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Abstract: The objective of the present study is to investigate thermal diffusion and radiation effects on unsteady MHD flow past an exponentially accelerated vertical plate with variable temperature and mass diffusion through porous medium in the presence of heat source or sink under the influence of applied transverse magnetic field. The fluid considered here is a gray, absorbing/ emitting radiation but a non-scattering medium. At time t>o, the plate is exponentially accelerated with a velocity $u = u_0 \exp(a't')$ in its own plane. And at the same time, the plate temperature and concentration levels near the plate raised linearly with time t. The dimensionless governing equations involved in the present analysis are solved using the Laplace transform technique. The effects of various flow parameters on velocity, temperature, concentration field are studied through graphs and tables

Keywords: MHD, heat and mass transfer, thermal diffusion, exponentially, Accelerated, vertical plate, radiation, Porous medium.

Introduction: MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al. [12]. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate were also studied by Soundalgekar et al. [11]. The dimensionless governing equations were solved using Laplace transform technique. Kumari and nath [8] studied the development of the asymmetric flow of a viscous electrically conducting fluid in the forward stagnation point region of a two-dimensional body and over a stretching surface was set into impulsive motion from the rest. The governing equations were solved using finite difference scheme. The radiative free convection flow of an optically thin gray-gas past semi-infinite vertical plate studied by Soundalgekar and Takhar [13]. Hossain and Takhar have considered radiation effects on mixed convection along an isothermal vertical plate [5]. In all above studies the stationary vertical plate considered. Raptis and Perdikis [10] studied the effects of thermal-radiation and free convection flow past a moving vertical plate. The governing equations were solved analytically. Das et al [4] have considered radiation effects on flow past an impulsively started infinite isothermal vertical plate. The governing equations were solved by the Laplace transform technique. Muthucumaraswamy and Janakiraman [9] have studied MHD and radiation effects on moving isothermal vertical plate with variable mass diffusion.

Mathematical Formulation: An unsteady two-dimensional laminar free convection flow of a viscous, incompressible, electrically conducting, radiating fluid past an impulsively started exponentially accelerated infinite vertical plate with variable temperature and mass diffusion in the presence of transverse applied magnetic field are studied. A temperature dependent heat source (or sink) is assumed to be present in the flow. The plate is taken along x' −-axis in vertically upward direction and y' −axis is taken normal to the plate. Initially it is assumed that the plate and fluid are at the same temperature T'_∞ and concentration level C'_∞ in stationary condition for all the points. At time $t' > 0$, the plate is exponentially accelerated with a velocity $u = u_0 \exp(a't')$ in the vertical upward direction against to the gravitational field. And at the same time the plate temperature is raised linearly with time t and also the mass is diffused from the plate to the fluid is linearly with time. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the direction of flow. The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium. Then under by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.

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

$$\rho c_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} + Q'(T'_\infty - T') \quad (2)$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} + D_1\left(\frac{\partial^2 T'}{\partial y'^2}\right) \quad (3)$$

With the following initial and boundary conditions

$$t' \le 0 : u' = 0, \quad T' = T'_\infty, \quad C' = C'_\infty, \quad for\ all\ y'$$

$$t' > 0: \quad u' = u_0 \exp(a't'), \; T' = T'_\infty + (T'_w - T'_\infty)At', \quad C' = C'_\infty + (C'_w - C'_\infty)At' \quad at \quad y' = 0$$

$$u' = 0, \; T' \to T'_\infty, \; C' \to C'_\infty \; as \; y' \to \infty \quad (4)$$

where $A = \frac{u_0^2}{\nu}$. The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y'} = -4a^*\sigma\left(T'^4_\infty - T'^4\right) \quad (5)$$

It is assumed that the temperature differences within the flow are sufficiently small and that T'^4 may be expressed as a linear function of the temperature. This is obtained by expanding T'^4 in a Taylor series about T'_∞ and neglecting the higher order terms, thus we get

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \quad (6)$$

From equations (5) and (6), equation (2) reduces to

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} + 16a^* \sigma T'^3_\infty (T'_\infty - T') \quad (7)$$

On introducing the following non-dimensional quantities

$$u = \frac{u'}{u_0}, \; t = \frac{t'u_0^2}{\nu}, \; y = \frac{y'u_0}{\nu}, \; \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, \; K = \frac{u_0^2 k'}{\nu^2}$$

$$C = \frac{C' - C'_\infty}{C'_w - C'_\infty}, \; P_r = \frac{\mu C_\rho}{\kappa}, \; S_0 = \frac{D_1 (T'_w - T'_\infty)}{\nu (C'_w - C'_\infty)}$$

$$G_r = \frac{g\beta\nu(T'_w - T'_\infty)}{u_0^3}, \; G_m = \frac{g\beta^\bullet \nu (C'_w - C'_\infty)}{u_0^3},$$

$$S_c = \frac{\nu}{D}, \; M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, \; R = \frac{16a^\bullet \nu^2 \sigma T'^3_\infty}{k u_0^2}, \; H = \frac{Q'\nu^2}{\kappa u_0^2} \quad (8)$$

We get the following governing equations which are dimensionless

$$\frac{\partial u}{\partial t} = G_r\theta + G_m C + \frac{\partial^2 u}{\partial y^2} - Mu - \frac{u}{K} \quad (9)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{1}{\Pr}(R + H)\theta \quad (10)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + S_o \frac{\partial^2 \theta}{\partial y^2} \quad (11)$$

The initial and boundary conditions in dimensionless form as follows:

$$t' \le 0: u = 0, \quad \theta = 0, \quad C = 0 \; for \; all \quad y,$$

$$t > 0: \; u = e^{at}, \; \theta = t, \quad C = t \quad at \quad y = 0,$$

$$u \to 0, \; \theta \to 0, \; C \to 0 \quad as \quad y \to \infty. \quad (12)$$

Solution of the Problem:

The dimensionless governing equations from (9) to (11), subject to the boundary conditions (12) are solved by usual Laplace transform technique and obtained as follows.

$$\theta(y,t) = \left[\begin{array}{l} \left(\frac{t}{2} + \frac{y\Pr}{4\sqrt{S}}\right)\exp\left(y\sqrt{S}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} + \sqrt{\frac{St}{\Pr}}\right) + \\ \left(\frac{t}{2} - \frac{y\Pr}{4\sqrt{S}}\right)\exp\left(-y\sqrt{S}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} - \sqrt{\frac{St}{\Pr}}\right) \end{array}\right] \quad (13)$$

$$C(y,t) = (1+b)\left[\begin{array}{l}\left(t + \frac{y^2 Sc}{2}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right) \\ - y\sqrt{\frac{tSc}{\pi}}\exp\left(-\frac{y^2 Sc}{4t}\right)\end{array}\right] + \left(d - \frac{b}{c}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right)$$

$$-\frac{1}{2}\left(d - \frac{b}{c}\right)\exp(-ct)\left[\begin{array}{l}\exp\left(y\sqrt{-cSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{-ct}\right) \\ + \exp\left(-y\sqrt{-cSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{-ct}\right)\end{array}\right]$$

$$-\frac{1}{2}\left(d - \frac{b}{c}\right)\left[\begin{array}{l}\exp(y\sqrt{S})erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} + \sqrt{\frac{St}{\Pr}}\right) \\ + \exp(-y\sqrt{S})erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} - \sqrt{\frac{St}{\Pr}}\right)\end{array}\right]$$

$$-b\left[\begin{array}{l}\left(\frac{t}{2} + \frac{y\Pr}{4\sqrt{S}}\right)\exp(y\sqrt{S})erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} + \sqrt{\frac{St}{\Pr}}\right) \\ + \left(\frac{t}{2} - \frac{y\Pr}{4\sqrt{S}}\right)\exp(-y\sqrt{S})erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} - \sqrt{\frac{St}{\Pr}}\right)\end{array}\right]$$

$$+\frac{1}{2}\left(d - \frac{b}{c}\right)\exp(-ct)\left[\begin{array}{l}\exp\left(y\sqrt{S - c\Pr}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} + \sqrt{\left(\frac{S}{\Pr} - c\right)t}\right) \\ + \exp\left(-y\sqrt{S - c\Pr}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} - \sqrt{\left(\frac{S}{\Pr} - c\right)t}\right)\end{array}\right]$$

$$u(y,t) = \frac{\exp(at)}{2}\left[\begin{array}{l}\exp\left(y\sqrt{M' + a}\right)erfc\left(\frac{y}{2\sqrt{t}} + \sqrt{(M' + a)t}\right) \\ + \exp\left(-y\sqrt{M' + a}\right)erfc\left(\frac{y}{2\sqrt{t}} - \sqrt{(M' + a)t}\right)\end{array}\right]$$

$$+A_1\left[\begin{array}{l}\left(\frac{t}{2} + \frac{y\Pr}{4\sqrt{S}}\right)\exp\left(y\sqrt{S}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} + \sqrt{\frac{St}{\Pr}}\right) \\ + \left(\frac{t}{2} - \frac{y\Pr}{4\sqrt{S}}\right)\exp\left(-y\sqrt{S}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} - \sqrt{\frac{St}{\Pr}}\right)\end{array}\right]$$

$$+A_2\left[\left(t + \frac{y^2 Sc}{2}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right) - y\sqrt{\frac{tSc}{\pi}}\exp\left(-\frac{y^2 Sc}{4t}\right)\right]$$

$$-(A + A_2)\left[\begin{array}{l}\left(\frac{t}{2} + \frac{y}{4\sqrt{M'}}\right)\exp(y\sqrt{M'})erfc\left(\frac{y}{2\sqrt{t}} + \sqrt{M't}\right) \\ + \left(\frac{t}{2} - \frac{y}{4\sqrt{M'}}\right)\exp(-y\sqrt{M'})erfc\left(\frac{y}{2\sqrt{t}} - \sqrt{M't}\right)\end{array}\right]$$

$$+\frac{A_3}{2}\exp(-ct)\left[\begin{array}{l}\exp\left(y\sqrt{S - c\Pr}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} + \sqrt{\left(\frac{S}{\Pr} - c\right)t}\right) \\ + \exp\left(-y\sqrt{S - c\Pr}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}} - \sqrt{\left(\frac{S}{\Pr} - c\right)t}\right)\end{array}\right]$$

$$+\frac{A_4}{2}\exp(-ct)\left[\begin{array}{l}\exp\left(y\sqrt{-cSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{-ct}\right) \\ + \exp\left(-y\sqrt{-cSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{-ct}\right)\end{array}\right]$$

$$+\frac{A_5}{2}\exp(-lt)\left[\begin{array}{l}\exp\left(y\sqrt{M'-l}\right)erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(M'-l)t}\right)\\+\exp\left(-y\sqrt{M'-l}\right)erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(M'-l)t}\right)\end{array}\right]$$

$$-\frac{A_5}{2}\exp(-lt)\left[\begin{array}{l}\exp\left(y\sqrt{S-l\Pr}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}}+\sqrt{\left(\frac{S}{\Pr}-l\right)t}\right)\\+\exp\left(-y\sqrt{S-l\Pr}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}}-\sqrt{\left(\frac{S}{\Pr}-l\right)t}\right)\end{array}\right]$$

$$-\frac{A_6}{2}\exp(nt)\left[\begin{array}{l}\exp\left(y\sqrt{nSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}+\sqrt{nt}\right)\\+\exp\left(-y\sqrt{nSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}-\sqrt{nt}\right)\end{array}\right]$$

$$+\frac{A_6}{2}\exp(nt)\left[\begin{array}{l}\exp\left(y\sqrt{M'+n}\right)erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(M'+n)t}\right)\\+\exp\left(-y\sqrt{M'+n}\right)erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(M'+n)t}\right)\end{array}\right]$$

$$+\frac{A_7}{2}\left[\begin{array}{l}\exp\left(y\sqrt{S}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}}+\sqrt{\frac{St}{\Pr}}\right)+\\\exp\left(-y\sqrt{S}\right)erfc\left(\frac{y\sqrt{\Pr}}{2\sqrt{t}}-\sqrt{\frac{St}{\Pr}}\right)\end{array}\right]$$

$$+A_8\,erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right)$$

$$-\frac{1}{2}(A_7+A_8)\left[\begin{array}{l}\exp(y\sqrt{M'})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{M't}\right)\\+\exp(y\sqrt{M'})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{M't}\right)\end{array}\right]$$

Heat and Mass Transfer Rates : The rates of Heat and Mass transfer in terms of Nusselt number and Sherwood number are given by

$$Nu=\left[t\sqrt{S}\,erf\sqrt{\frac{St}{\Pr}}+\sqrt{\frac{t\Pr}{\pi}}\exp\left(-\frac{St}{\Pr}\right)+\frac{\Pr}{2\sqrt{S}}erf\sqrt{\frac{St}{\Pr}}\right]$$

$$Sh=2(1+b)\sqrt{\frac{tSc}{\pi}}+\left(d-\frac{b}{c}\right)\sqrt{\frac{Sc}{\pi t}}$$

$$-\left(d-\frac{b}{c}\right)\exp(-ct)\left[\begin{array}{l}\sqrt{\frac{Sc}{\pi t}}\exp(ct)\\+\sqrt{-cSc}\,erf\sqrt{-ct}\end{array}\right]$$

$$-\left(d-\frac{b}{c}\right)\left[\sqrt{\frac{\Pr}{\pi t}}\exp\left(-\frac{St}{\Pr}\right)+\sqrt{S}\,erf\sqrt{\frac{St}{\Pr}}\right]$$

$$+\left(d-\frac{b}{c}\right)\exp(-ct)\left[\begin{array}{l}\sqrt{\frac{\Pr}{\pi t}}\exp\left(-\frac{St}{\Pr}+ct\right)\\+\sqrt{S-c\Pr}\,erf\sqrt{\left(\frac{S}{\Pr}-c\right)t}\end{array}\right]$$

$$-b\left[\begin{array}{l}t\sqrt{S}\,erf\sqrt{\frac{St}{\Pr}}+\sqrt{\frac{t\Pr}{\pi}}\exp\left(-\frac{St}{\Pr}\right)\\+\frac{\Pr}{2\sqrt{S}}erf\sqrt{\frac{St}{\Pr}}\end{array}\right]$$

Graphs and Tables:

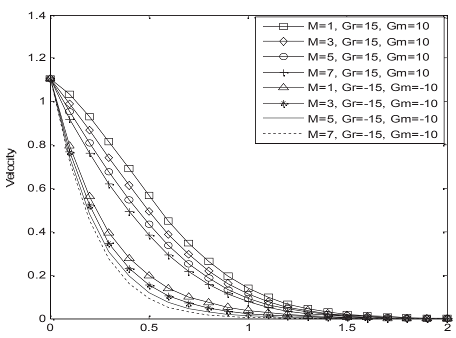

Figure 1: Velocity profiles for different M

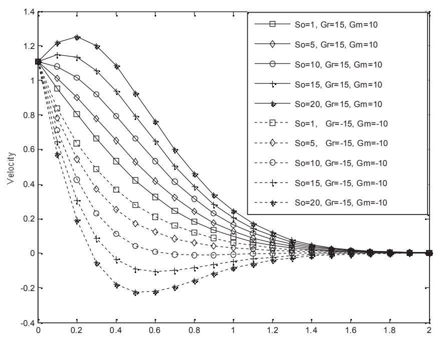

Figure 2: Velocity profiles for different So

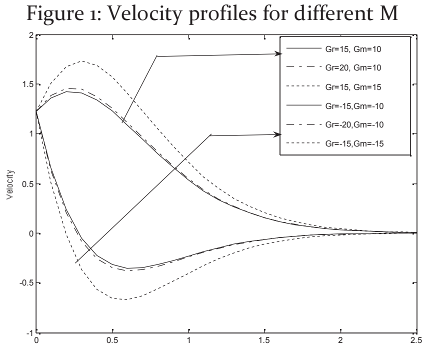

Figure 3: Velocity profiles for different Gr and Gm

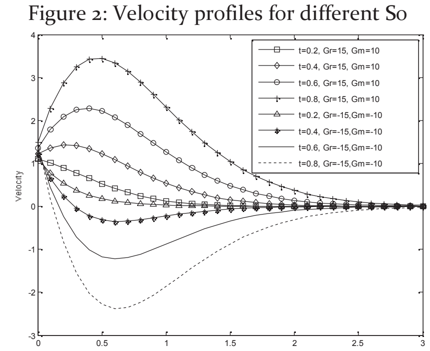

Figure 4: Velocity profiles for different time t

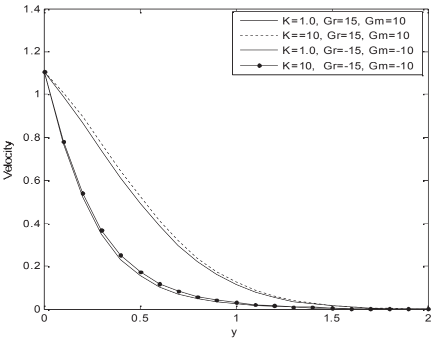

Figure 5: Velocity profiles for different K

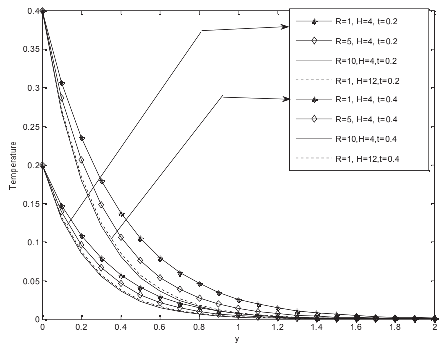

Figure 6: Temperature profiles for ferent R &H

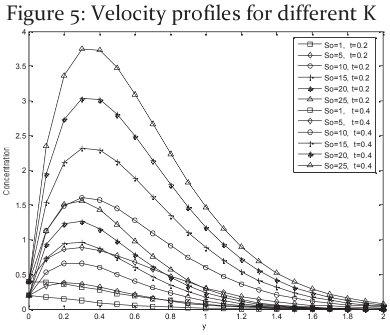

Figure 7: Concentration profiles for different So

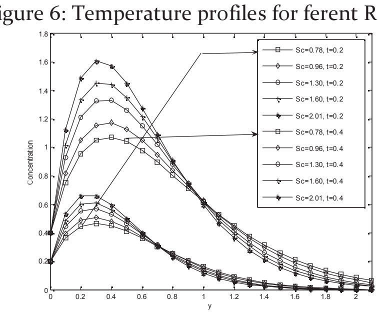

Figure 8: Concentration profiles for different Sc

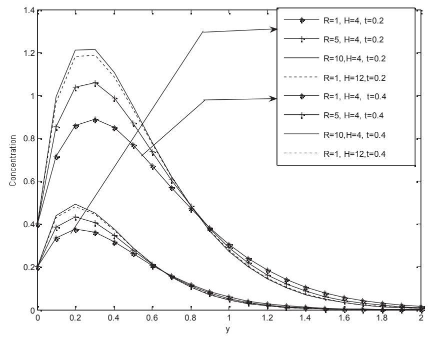

Figure 9: Concentration profiles for different R

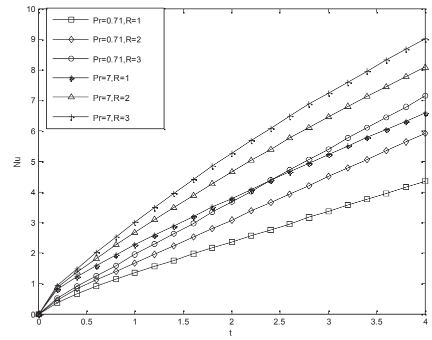

Figure 10: Nusselt Number

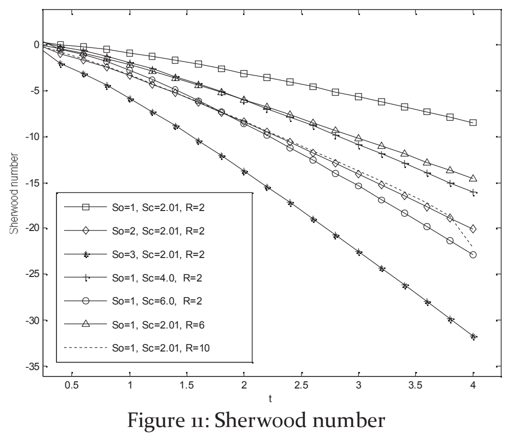

Figure 11: Sherwood number
for different Sc ,So and R

Table 1: Velocity for different R for Gr=15, Gm=10(cooling of the plate)				
y	R=1	R=4	R=8	R=12
0.0	1.1052	1.1052	1.1052	1.1052
0.2	0.8854	0.8905	0.8967	0.9021
0.4	0.6421	0.6449	0.6483	0.6511
0.6	0.4208	0.4194	0.4180	0.4169
0.8	0.2503	0.2467	0.2429	0.2399
1.0	0.1359	0.1322	0.1284	0.1255
1.2	0.0675	0.0648	0.0621	0.0601
1.4	0.0308	0.0292	0.0276	0.0264
1.6	0.0129	0.0121	0.0113	0.0107
1.8	0.0050	0.0046	0.0042	0.0040
2.0	0.0018	0.0016	0.0015	0.0014

Table 2: Velocity for different R for Gr=-15, Gm=-10(Heating of the plate)				
y	R=1	R=4	R=8	R=12
0.0	1.1052	1.1052	1.1052	1.1052
0.2	0.5566	0.5514	0.5452	0.5398
0.4	0.2616	0.2588	0.2555	0.2526
0.6	0.1177	0.1191	0.1205	0.1216
0.8	0.0519	0.0555	0.0593	0.0623
1.0	0.0226	0.0263	0.0301	0.0330
1.2	0.0097	0.0124	0.0151	0.0171
1.4	0.0039	0.0056	0.0072	0.0083
1.6	0.0014	0.0023	0.0031	0.0037
1.8	0.0005	0.0009	0.0012	0.0015
2.0	0.0001	0.0003	0.0004	0.0005

Figure 1 reveals the effect magnetic field parameter on fluid velocity and we observed that an increase in magnetic parameter M the velocity decreases in cases of cooling and heating of the plate for Pr = 0.71. Figure (2) displays the influence of thermal-diffusion parameter (So) on the velocity field in both cases of cooling and heating of the plate. it is found that the fluid velocity increases with increasing values of So in case of cooling of the plate and a reverse effect is observed in the case of heating of the plate From the Figures 3&4, it is found that the velocity u increases as thermal Grashof number Gr or mass Grashof number Gm or time t increases in case of cooling of the plate. And a reverse effect is indentified in case of heating of the plate. It seen that From Figure 5, the velocity increases with increasing values of permeability parameter K in both cases of cooling and heating of the plate. From Tables 1&2 it is observed that with the increase of R the velocity increases up to certain y value and decreases later for the case of cooling of the plate. But the trend is just reversed in case of heating of the plate. From Figure 6, it is observed that as radiation parameter R or heat source parameter H increases the temperature of the flow field decreases at all the points in flow region. From figure 7 it is observed that the concentration increases with an increase in So. Figure 8 and 9 reveal the effect of Sc and R on the concentration distribution of the flow field. The concentration distribution is found to increase faster up to certain y value (distance from the plate) and decreases later as the Schmidt parameter (Sc) or Radiation parameter (R) become heavier.

From Figure 10, the Nusselt number is observed to increase with increase in R for both water and air. From figure 11 it is seen that the Sherwood number decreases with increase in Sc, So and R.

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