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Radiative heat and mass transfer effects on MHD free convective flow past an inclined plate with variable temperature and mass diffusion through porous medium

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Abstract

An analytical study is performed to investigate radiative heat and mass transfer effects on unsteady MHD free convective fluid flow past an inclined plate with variable temperature and mass diffusion through porous medium in the presence of transverse applied magnetic field. The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium. At time $t > 0$, the plate temperature and concentration levels near the plate are raised linearly with time t. The governing equations are solved in closed form by the Laplace transform technique. The velocity, temperature, concentration, the rate of heat transfer and the rate of mass transfer are studied through graphs while the numerical values of skin-friction is presented in tabular form for different physical parameters like radiation parameter (R), magnetic field parameter (M), Schmidt parameter (Sc), Prandtl number (Pr), thermal Grashof number (Gr), mass Grashof number (Gm), accelerated parameter (a), inclination parameter (α) and time (t).

Key words : MHD, exponential, Accelerated, inclined plate, thermal radiation, Porous medium.

Nomenclature :

a^* Absorption coefficient
a Accelerated parameter
B_0 External magnetic field
C' Species concentration
C'_w Concentration of the plate
C'_∞ Concentration of the fluid far away from the plate

C Dimensionless concentration
C_P Specific heat at constant pressure
g Acceleration due to gravity
G_r Thermal Grashof number
G_m Mass Grashof number
M Magnetic field parameter
Nu Nusselt number
P_r Prandtl number
q_r Radiative heat flux in the y-direction
R Radiative parameter
α inclination parameter
k permeability parameter
S_c Schmidt number
T' Temperature of the fluid near the plate
T'_w Temperature of the plate
T'_∞ Temperature of the fluid far away from the plate
t' Time
t Dimensionless time
u' Velocity of the fluid in the -direction
u_0 Velocity of the plate
u Dimensionless velocity
y' Co-ordinate axis normal to the plate
y Dimensionless co-ordinate axis normal to the plate

Greek symbols :

κ Thermal conductivity of the fluid
α Thermal diffusivity
β Volumetric coefficient of thermal expansion
β^* Volumetric coefficient of expansion with concentration
μ Coefficient of viscosity
ν Kinematic viscosity
ρ Density of the fluid
σ Electric conductivity
θ Dimensionless temperature

erf Error function
erfc Complementary error function

Subscripts :

w Conditions on the wall
∞ Free stream conditions

Introduction

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 device for aircraft, missiles, satellites, combustion and furnace design, materials processing, energy utilization, temperature measurements, remote sensing for astronomy and space exploration, food processing and cryogenic engineering, as well as numerous agricultural, health and military applications. If the temperature of surrounding fluid is rather high, radiation effects play an important role and this situation does exist in space technology. In such cases, one has to take into account the combined effect of thermal radiation and mass diffusion. Umemure and Law[1] developed a generalized formulation for the natural convection boundary layer flow over a flat plate with arbitrary inclination. They found that the flow characteristics depend not only on the extent of inclination but also on the distance from the leading edge. Hossain *et al.*[2] studied the free convection flow form an isothermal plate inclined at a small angle to the horizontal. Anghel *et al*.[3] presented a numerical solution of free convection flow past an inclined surface. Chen[4] performed an analysis to study the natural convection flow over a permeable inclined surface with variable wall temperature and concentration. They observed that increasing the angle of inclination decreases the effect of buoyancy force.

M.S. Alam *et al*.[5] investigated heat and mass transfer effects on MHD free convective fluid flow past an inclined plate with heat generation. Rajesh kumar *et al*.[6] presented a numerical solution of transient MHD free convection flow of dusty viscous fluid along an inclined plate with ohmic dissipation. England and Emery[7] studied the thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate. Soundalgekar and Takhar[8] considered the radiation free convection flow of an optically thin gray gas past a semi-infinite vertical plate. Radiation effects on mixed convection along isothermal vertical plate were studied by Hossain and Takhar[9]. In all above studies, the stationary vertical plate is 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*.[11] analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. The governing equations were solved by the Laplace transform technique. Recently, Muthucumaraswamy *et. al*.[12] and Rajesh *et. al*.[13] studied radiation and mass transfer effects on exponentially accelerated isothermal vertical plate. Very recently, Vijaya kumar and Varma[14] studied thermal radiation and mass transfer effects on unsteady MHD flow past an exponentially accelerated vertical plate with variable temperature and mass diffusion.

The aim of the present work is to study the MHD free convective heat and mass transfer fluid flow past an inclined surface of an electrically conducting, radiating and unsteady viscous incompressible fluid in the presence of applied transverse magnetic field. The dimensionless governing equations are solved in closed form by Laplace transform technique. The solutions are derived in terms of exponential and complementary error functions.

Mathematical formulation :

In this problem we consider an unsteady hydro magnetic free convective flow of a viscous incompressible, electrically conducting, radiating fluid past an infinite inclined plate with an acute angle (α) to the vertical. The flow is assumed to be in the x'- direction, which is taken along the infinite inclined plate and y' -axis normal to it. Initially, it is assumed that the plate and fluid are at the same temperature T'_∞ in the stationary condition with concentration level C'_∞ at all the points. At time $t' > 0$, the plate is exponentially accelerated with a velocity $u_0 \exp(a't')$ in its own plane. At the same time, the plate temperature is raised linearly with time t and also mass is diffused from the plate linearly with time. A magnetic field of uniform strength B_0 is introduced normal to the direction of the flow. In this analysis, It assumed that the magnetic Reynolds number is much less than unity so that the induced magnetic field is neglected in comparison to the applied magnetic field. It is also assumed that all the fluid properties are constant except the influence of the density variation with temperature and concentration in the body force term.

$$\frac{\partial u'}{\partial t'} = g\beta(T' - T'_\infty)cos\alpha + \ g\beta^*(C' - C'_\infty)cos\alpha$$
$$+v\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma\beta_0^2 u'}{\rho} - v\frac{u'}{k} \quad (1)$$

$$\rho C_p\frac{\partial T'}{\partial t'} = \kappa\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} \quad (2)$$

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

With the following initial and boundary conditions

$$t' \leq 0: \ u' = 0, T' = T'_\infty, C' = C'_\infty \ for \ \ all \ \ y'$$
$$t' > 0: u' = u_0 exp(a't'), T' = T'_\infty + (T'_w - T'_\infty)At'$$
$$C' = C'_\infty + (C'_w - C'_\infty)At' \ \ at \ \ y' = 0,$$
$$and \ \ u' = 0, T' \to T'_\infty, C' \to C'_\infty \ as \ y' \to \infty$$
$$\to \infty \quad (4)$$

Where $A = \frac{u_0^2}{v}$. 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'_∞ neglecting the higher order terms, and 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:

$$u = \frac{u'}{u_0}, t = \frac{t'u_0^2}{v}, y = \frac{y'u_0}{v}, \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}$$
$$C = \frac{C' - C'_\infty}{C'_w - C'_\infty}, G_r = \frac{g\beta v(T'_w - T'_\infty)}{u_0^3}, M = \frac{\sigma B_o^2 v}{\rho u_0^2}$$
$$G_m = \frac{g\beta^* v(C'_w - C'_\infty)}{u_0^3}, P_r = \frac{\mu C_\rho}{\kappa}, S_c = \frac{v}{D}$$
$$R = \frac{16a^* v^2 \sigma T'^3_\infty}{\kappa u_0^2}, a = \frac{a'v}{u_0^2}, k = \frac{u_0^2 k'}{v^2} \quad (8)$$

We get the following governing equations which are dimensionless

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

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

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

The initial and boundary conditions in dimensionless form as follows

$$t \ \leq 0 \ : \ u = 0, \ \theta = 0, \ C = 0 \ \ for \ \ all \ \ y,$$
$$t \ > 0 \ : \ u = exp(at), \theta = t, C = t \ \ at \ y = 0$$
$$and \ u \to 0, \quad \theta \to 0, \quad C \to 0 \ \ as \ \ y \to \infty. \quad (12)$$

Solution of the problem :

The appeared physical parameters are defined in the nomenclature. The dimensionless governing equations from (9) to (11), subject to the boundary conditions (12) are solved by usual Laplace transform technique and the solutions are expressed in terms of exponential and complementary error functions.

$$\theta(y,t)=\left(\frac{t}{2}+\frac{yPr}{4\sqrt{R}}\right)e^{y\sqrt{R}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}+\sqrt{\frac{Rt}{Pr}}\right)+\left(\frac{t}{2}-\frac{yPr}{4\sqrt{R}}\right)e^{-y\sqrt{R}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}-\sqrt{\frac{Rt}{Pr}}\right) \quad (13)$$

$$C(y,t)=\left[\left(t+\frac{y^2Sc}{2}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right)-y\sqrt{\frac{tSc}{\pi}}e^{\frac{-y^2Sc}{4t}}\right] \quad (14)$$

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

$$-\frac{A}{2}\left[\begin{matrix}e^{y\sqrt{M'}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{M't}\right)+\\ e^{-y\sqrt{M'}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{M't}\right)\end{matrix}\right]$$

$$+B\left[\begin{matrix}\left(\frac{t}{2}+\frac{y}{4\sqrt{M'}}\right)e^{y\sqrt{M'}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{M't}\right)+\\ \left(\frac{t}{2}-\frac{y}{4\sqrt{M'}}\right)e^{-y\sqrt{M'}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{M't}\right)\end{matrix}\right]$$

$$+\frac{E}{2}e^{-ct}\left[\begin{matrix}e^{y\sqrt{M'-c}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(M'-c)t}\right)+\\ e^{-y\sqrt{M'-c}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(M'-c)t}\right)\end{matrix}\right]$$

$$+\frac{G}{2}e^{et}\left[\begin{matrix}e^{y\sqrt{M'+e}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(M'+e)t}\right)+\\ e^{-y\sqrt{M'+e}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(M'+e)t}\right)\end{matrix}\right]$$

$$+\frac{E}{2}\left[\begin{matrix}e^{y\sqrt{R}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}+\sqrt{\frac{Rt}{Pr}}\right)+\\ e^{-y\sqrt{R}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}-\sqrt{\frac{Rt}{Pr}}\right)\end{matrix}\right]$$

$$-D\left[\begin{matrix}\left(\frac{t}{2}+\frac{yPr}{4\sqrt{R}}\right)e^{y\sqrt{R}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}+\sqrt{\frac{Rt}{Pr}}\right)+\\ \left(\frac{t}{2}-\frac{yPr}{4\sqrt{R}}\right)e^{-y\sqrt{R}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}-\sqrt{\frac{Rt}{Pr}}\right)\end{matrix}\right]$$

$$-\frac{E}{2}e^{-ct}\left[\begin{matrix}e^{y\sqrt{R-cPr}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}+\sqrt{\left(\frac{R}{Pr}-c\right)t}\right)+\\ e^{-y\sqrt{R-cPr}}erfc\left(\frac{y\sqrt{Pr}}{2\sqrt{t}}-\sqrt{\left(\frac{R}{Pr}-c\right)t}\right)\end{matrix}\right]$$

$$+Gerfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right)+F\left[\begin{matrix}\left(t+\frac{y^2Sc}{2}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}\right)\\ -y\sqrt{\frac{tSc}{\pi}}e^{\frac{-y^2Sc}{4t}}\end{matrix}\right]$$

$$-\frac{G}{2}e^{et}\left[\begin{matrix}e^{y\sqrt{eSc}}erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}+\sqrt{et}\right)+\\ e^{-y\sqrt{eSc}}erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}-\sqrt{et}\right)\end{matrix}\right] \quad (15)$$

Where

$$b=\frac{Grcos\alpha}{Pr-1},\ c=\frac{R-M'}{Pr-1},\ d=\frac{Gmcos\alpha}{Sc-1},\ e=\frac{M'}{Sc-1}$$

$$A=\frac{Grcos\alpha(Pr-1)}{(R-M')^2}+\frac{Gmcos\alpha(Sc-1)}{M'^2},\ M'=M+\frac{1}{k}$$

$$B=\frac{M'(Gr+Gm)cos\alpha-RGmcos\alpha}{M'(R-M')},\ D=\frac{Grcos\alpha}{(R-M')}$$

$$E=\frac{Grcos\alpha(Pr-1)}{(R-M')^2},\ F=\frac{Gmcos\alpha}{M'},$$

$$G=Gmcos\alpha\left(\frac{Sc-1}{M'}\right)^2$$

Skin-friction :

From velocity field, now we study skin-friction (rate of change of velocity in flow with respect to y) which is given in non-dimensional form as

$$\tau = -\left[\frac{du}{dy}\right]_{y=0} \tag{16}$$

From equations (15) and (16), we get skin-friction as follows

$$\tau = e^{at}\left[\frac{1}{\sqrt{\pi t}}e^{-(\boldsymbol{M'}+a)t} + \sqrt{\boldsymbol{M'}+a}\ \ erf\sqrt{(\boldsymbol{M'}+a)t}\right]$$
$$-A\left[\frac{1}{\sqrt{\pi t}}e^{-\boldsymbol{M'}t} + \sqrt{\boldsymbol{M'}}\ \ erf\sqrt{\boldsymbol{M'}t}\right]$$
$$+B\left[\sqrt{\frac{t}{\pi}}\ e^{-\boldsymbol{M'}t} + \left(t\sqrt{\boldsymbol{M'}} + \frac{1}{2\sqrt{\boldsymbol{M'}}}\right)\ erf\sqrt{\boldsymbol{M'}t}\right]$$
$$+Ee^{-ct}\left[\frac{1}{\sqrt{\pi t}}e^{-(\boldsymbol{M'}-c)t} + \sqrt{\boldsymbol{M'}-c}\ \ erf\sqrt{(\boldsymbol{M'}-c)t}\right]$$
$$+Ge^{et}\left[\frac{1}{\sqrt{\pi t}}e^{-(\boldsymbol{M'}+e)t} + \sqrt{\boldsymbol{M'}+e}\ \ erf\sqrt{(\boldsymbol{M'}+e)t}\right]$$
$$+E\left[\sqrt{\frac{Pr}{\pi t}}\ e^{-\frac{Rt}{Pr}} + \sqrt{R}\ \ erf\sqrt{\frac{Rt}{Pr}}\right]$$
$$-D\left[t\sqrt{R}\ \ erf\left(\sqrt{\frac{Rt}{Pr}}\right) + \sqrt{\frac{tPr}{\pi}}\ \ e^{-\frac{Rt}{Pr}} + \frac{Pr}{2\sqrt{R}}\ \ erf\left(\sqrt{\frac{Rt}{Pr}}\right)\right]$$
$$-Ee^{-ct}\left[\sqrt{\frac{Pr}{\pi t}}e^{-\left(\frac{R}{Pr}-c\right)t} + \sqrt{R-cPr}\ \ erf\sqrt{\left(\frac{R}{Pr}-c\right)t}\right] + G\sqrt{\frac{Sc}{\pi t}}$$
$$+2F\sqrt{\frac{tSc}{\pi}} - Ge^{et}\left[\sqrt{\frac{Sc}{\pi t}}e^{-et} + \sqrt{eSc}\ \ erf\sqrt{et}\right]$$

Nusselt number :

From temperature field, now we study Nusselt number (rate of change of heat transfer) which is given in non-dimensional form as

$$Nu = -\left[\frac{d\theta}{dy}\right]_{y=0} \tag{17}$$

From equations (13) and (17), we get Nusselt number as follows:

$$Nu = \left[t\sqrt{R}\ \ erf\left(\sqrt{\frac{Rt}{Pr}}\right) + \sqrt{\frac{tPr}{\pi}}\ \ e^{-\frac{Rt}{Pr}} + \frac{Pr}{2\sqrt{R}}\ \ erf\left(\sqrt{\frac{Rt}{Pr}}\right)\right]$$

Sherwood number :

From concentration field, now we study Sherwood number (rate of change of mass transfer) which is given in non-dimensional form as

$$Sh = -\left[\frac{dC}{dy}\right]_{y=0} \tag{18}$$

From equations (14) and (18), we get Sherwood number as follows:

Results and Discussion

As a result of the numerical computations, the dimensionless velocities, temperature, concentration distributions in addition with the rate of heat transfer, the rate of mass transfer are displayed in figures 1-13 for different values of M (magnetic parameter), Gr (thermal Grashof number), Gm (mass Grashof number), Sc (schmidt number), Pr (prandtl number), R (radiation parameter), k(permeability parameter), a (accelerate parameter), α (inclination parameter) and time (t). throughout the calculations the values of thermal and mass Grahsof numbers are taken to be Gr=20 and Gm=5 which correspond to a cooling problem that appears generally in nuclear engineering in connection with cooling of reactor. The rest of physical parameters are chosen arbitrarily.

The effects of magnetic field parameter M on the flow transport are shown in figure 1. It is observed that the increase of magnetic field leads to decrease in the velocity field. This conclusion meets the logic that the magnetic field exerts a retarding force on free convection flow. And it is also observed that the fluid has higher velocity when the surface is vertical (α=0) than when inclined (α=45) because of the fact that the buoyancy effect decreases due to gravity components (g cosα), as the plate is inclined. From figure 2-6, it is found that the velocity decreases with increasing values of R, Sc and Pr while it increases with increasing values of Gr or Gm or k. Figure 7 reveals the velocity profiles for different values of time t. from this figure it is seen that the velocity increases as the time t increases. The variation in velocity for different values of accelerated parameter is exhibited in figure 8. It is seen that the velocity increases as accelerated parameter a increases. In all above investigations, it is also observed that the fluid has higher velocity when the surface is vertical (α=0) than when inclined (α=45) because of the fact that the buoyancy effect decreases due to gravity components (g cosα), as the plate is inclined. The effect of inclination of the surface on the velocity field is shown in figure 9. Form this figure it is observed that the velocity decreases for increasing angle α.

The effect of Schmidt parameter Sc on the concentration field is shown in figure 10. It is seen that the concentration decreases with increase in Sc. The temperature profiles for different values of R when Pr=0.71 (air) are presented in figure 11. It is found that the temperature decreases with increasing values of radiation parameter R.

In figures 12 and 13, the Sherwood number and Nusselt number are presented against time t respectively. Form these figures, we conclude that the Sherwood number increases with increase of Sc and the Nusselt number is observed to increase with increase in R for both water (Pr=7) and air (Pr=0.71). It is also observed that Nusselt number for water (Pr=7) is higher than that of air (Pr=0.71). The reason is that the smaller values of Pr are equivalent to increasing the thermal conductivities and therefore heat is able to diffuse away from the plate more rapidly than higher values of hence the rate of heat transfer is reduced. Finally, the skin-friction is presented in Table1. It is seen that skin-friction increases with increase in M, R, Sc, Pr, α while it decreases with increase in Gr or Gm or k or t.

Graphs and Tables :

Table 1. Skin-friction

Pr	M	R	Sc	k	Gr	Gm	t	α	Skin-friction
0.71	1	14	2.01	5	20	5	0.2	45	1.36021051599330
0.1	1	14	2.01	5	20	5	0.2	45	1.32725437449168
0.71	3	14	2.01	5	20	5	0.2	45	1.84843477441094
0.71	1	18	2.01	5	20	5	0.2	45	1.38029442929162
0.71	1	14	3	5	20	5	0.2	45	1.37112140836962
0.71	1	14	2.01	8	20	5	0.2	45	1.34076454359404
0.71	1	14	2.01	5	25	5	0.2	45	1.26360002294298
0.71	1	14	2.01	5	20	10	0.2	45	1.26371403490557
0.71	1	14	2.01	5	20	5	0.4	45	0.57758107661124
0.71	1	14	2.01	5	20	5	0.2	30	1.25167257541875

Figure 1. Velocity profiles
for different values of M when R = 14,
Sc = 2.01, Pr = 0.71, k = 5, a = 0.5, t = 0.4

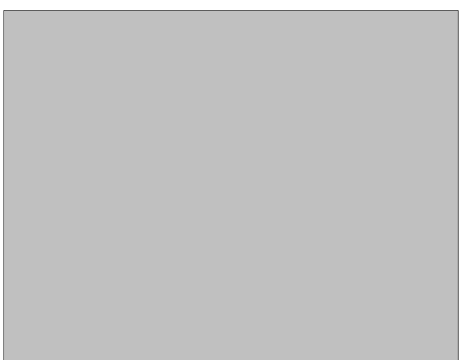

Figure 2. Velocity profiles
for different values of R when M = 3, Sc = 2.01,
Pr = 0.71, k = 5, a = 0.5, t = 0.4

Figure 3. Velocity profiles
for different values of Sc when R=14, M=3,
Pr=0.71, k=5, a=0.5, t=0.4

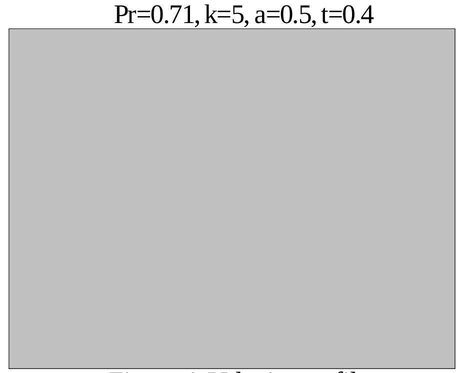

Figure 4. Velocity profiles
for different values of Pr when R=14, Sc=2.01,
M=3,k=5, a=0.5, t=0.4

Figure 5. Velocity profile
when Gr and Gmwhen R=14, M=3, Sc=2.01,
Pr=0.71, k=5, a=0.5, t=0.4

Figure 6. Velocity profiles
for different values of k when R=14, M=3,
Sc=2.01, Pr=0.71, a=0.5, t=0.4.

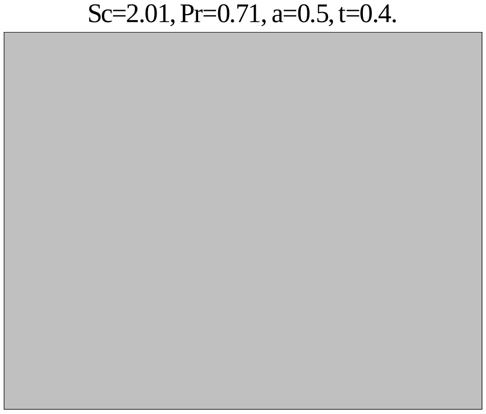

Figure 7. Velocity profiles
for different time t when R=14, M=3, Sc=2.01,
Pr=0.71, k=5, a=0.5

Figure 8. Velocity profiles
for different values of a when R=14, M=3,
Sc=2.01, Pr=0.71,k=5, t=0.4

Figure 9. Velocity profiles
for different α when R=14, M=3, Sc=2.01, Pr=0.71,
a=0.5, k=5, t=0.4.

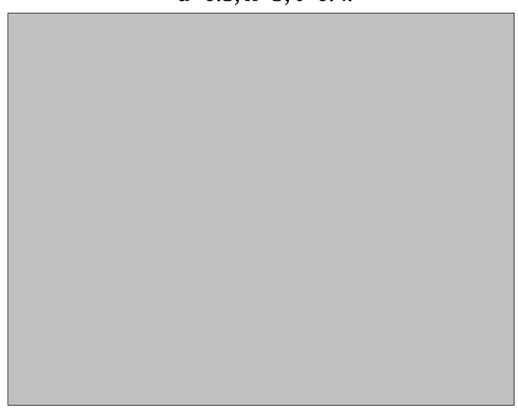

Figure 10. Concentration profiles
for different Sc

Figure 11. Temperature profiles for different R when Pr=0.71 and t=0.4.

Figure 12. Sherwood number for different Sc

Figure 13. Nusselt number

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