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Study of Free Convection and Mass Transfer Flow of Chemical Reacting Fluid over the Porous Stretching Surface In Presence of Magnetohydrodynamics

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ABSTRACT: The magneto-hydrodynamics free convection heat and mass transfer problem of chemical reacting fluid from radiate an isothermal sheet embedded in a saturated porous medium is investigated . The effects of transverse magnetic field, radiation heat transfer and chemical reaction mass transfer are examined. The sheet is linearly stretched in the presence of uniform free stream of constant velocity, temperature and concentration. The resultant governing boundary-layer equations, highly non-linear and a coupled form of partial differential equations have been solved numerically using shooting method with Runge–Kutta scheme. A parametric study is performed to illustrate the effects of the Darcy number, radiation parameter, magnetic parameter and chemical reaction parameter on the profiles of the velocity, temperature and concentration functions, as well as local shear stress, local Nusselt number and local Sherwood number.

1. INTRODUCTION

Coupled heat and mass transfer driven by buoyancy, due to temperature and concentration variations in a saturated porous medium, has several important applications in geothermal and geophysical engineering such as the migration of moisture through the air contained in fibrous insulation, the extraction of geothermal energy, underground disposal of nuclear wastes, and the spreading of chemical contaminants through water-saturated soil.Recent books by Nield and Bejan [1] and Ingham andPop [2,3] present a comprehensive account of theavailable information in the field.

Also, in many engineering applications such as nuclear reactor safety, combustionsystems, solar collectors, metallurgy, and chemical engineering there are many transport processes that are governed by the joint action of the buoyancy forces from both thermal and mass diffusion in the presence of chemical reaction effects. Representative applications of interest include: solidification of binary alloy and crystal growth, dispersion of dissolved materials or particulate water in flows, drying and dehydration operations in chemical and food processing plants, and combustion of atomized liquid fuels. Furthermore, the presence of a foreign mass in air or water is causes some kind of chemical reaction. During a chemical reaction between two species heat is also generated. Diffusion and chemical reactions in an isothermal laminar flow along a soluble flat plate were studied by Fairbanks and Wike [4]. The effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction were studied by Das et al.[5]. Andersson et al. [6] studied the flow and mass diffusion of a chemical species with first-order and higher order reactions over a linearly stretching surface. Anjalidevi and Kandasamy [7] studied the steady laminar flow along a semi-infinite horizontal plate in the presence of a species concentration and chemical reaction. They [8] also, studied effects of chemical reaction, heat and mass transfer on non-linear MHD laminar boundary layer flow over a wedge with suction and injection.

Fan et al. [9] studied the mixed convective heat and mass transfer over a horizontal moving plate with a chemical-reaction effect. A similarity solution is obtained by applying transformation group theory. Takhar et al. [10] investigated the flow and mass diffusion of a chemical species with first-order and higher order reactions over a continuously stretching sheet with an applied magnetic field. Muthucumaraswamy [11] studied the effects of a chemical reaction on a moving isothermal vertical infinitely long surface with suction. Chamkha [12] presented analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, and electrically-conducting and heat generation absorption. The effects of radiation and chemical reactions, in the presence of a transverse magnetic field, on free convective flow and mass transfer of electrically conducting fluid past a vertical isothermal cone surface are investigated by Afify [13]. Kandasamy et al. [14] studied the nonlinear MHD flow with heat and mass transfer characteristics of an incompressible, viscous, electrically conducting and Boussinesq fluid on a vertical stretching surface with chemicalreaction and thermal stratification effects. Seddeek [15] took into account the homogeneous chemical reaction of first-order in boundary-layer hydromagnetic flow with heat and mass transfer over a heat surface with the effects of thermophoresis, variable viscosity andheat generation/absorption. Abo-Eldahab and Salem [16] analyzedthe MHD flowand heat transfer of an electrically conducting non-Newtonian fluid with diffusion and chemical reaction over a moving cylinder.Mohamed et al. [17] investigated the influence of chemical reactions on the problem of coupled heat and mass transfer by natural convection from a vertical stretching surface in the presence of a space- or temperature-dependent heat source effect. EL-Kabeir and Modather [18] studied theeffect of nonlinear MHD flow with heat and mass transfer characteristics of anelectrically conducting fluid on with chemical reaction and heat generation.The heat and mass transfer characteristics ofnatural convection about a vertical surface embedded ina saturated porous medium subjected to a chemicalreaction hasbeen analyzed by numerically Postelnicu [19].

The purpose of this work is to generalize the work of Abo-Eldahab [20]by including thedouble-diffusive free convective heat and mass transfer of a chemically-reacting Newtonian fluid flowing through aDarcian porous regime adjacent to an isothermal vertical sheet embedded in a non-uniform porous mediumwith chemical reaction and thermal radiation effects. The sheet is linearly stretched at uniform constant temperature T_w and uniform concentration C_w and higher of that the fluid T_∞ and C_∞ respectively. Numerical solutions are obtained for different values of magnetic parameter$M$, Darcy number Da,radiation parameter R_d andchemicalreaction parameter $\gamma$the profiles of the velocity, temperature and concentration functions, as well as local shear stress, local Nusselt number and local Sherwood number.

2. MATHEMATICAL ANALYSIS

Consider the laminar, steady, free convection flow and mass transfer of an incompressible,viscous, electrically-conducting and Newtonianfluid adjacent to a vertical sheet embedded in a non-uniform porous medium in the presence of chemical reactionand thermal radiation effects.The x-axis is located parallel to the vertical surface and the y-axis normal to it. A uniform magnetic field of strength B_0 is imposed along they-axis.The fluid propertiesare assumed to be constant in a limited temperaturerange. The Soret and Dufour effects are neglected as the concentration of diffusing species is very small in comparison to other chemical species and the concentration ofspecies far from the wall, C_∞ is infinitesimally small Byron Bird [21].The chemical reactionsare taking place in the flow and the physical propertiesμ, ρ,D and the rate of chemical reaction, K_1 are constantthroughout the fluid. It is assumed that the inducedmagnetic field, the external electric field and the electricfield due to the polarization of charges are negligible.Under these conditions, the governing boundary layerequations of momentum, energy, mass and diffusion neglectingviscous and Joules dissipation under Boussinesq'sapproximation are

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

$$\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}}+\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}}=\nu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}+g\beta(T-T_\infty)+ g\beta^*(C-C_\infty)-\frac{\nu}{K}\bar{u}-\frac{\sigma B_0^2}{\rho}\bar{u} \quad ,(2)$$

$$\bar{u}\frac{\partial T}{\partial \bar{x}}+\bar{v}\frac{\partial T}{\partial \bar{y}}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial \bar{y}^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial \bar{y}}, \quad (3)$$

$$\bar{u}\frac{\partial C}{\partial \bar{x}}+\bar{v}\frac{\partial C}{\partial \bar{y}}=D\frac{\partial^2 C}{\partial \bar{y}^2}-K_1(C-C_\infty), \quad (4)$$

where u and v are the velocity components in the x- and y-directions, respectively, T is the temperature, C is the concentration, g is the acceleration due to gravity, ν is the fluid kinematics viscosity, ρ is the density, σ is the electricconductivity, β is the coefficient of thermal expansion, β^* is the coefficient of concentration expansion, K Darcy permeability, K_1 dimensional chemical reaction parameter, k is the thermal conductivity and C_p is the specificheat at constant pressure,

The appropriate boundary conditions of the problem are

$$\bar{u}=c\bar{x},\ \bar{v}=0,\ T=T_w,\ C=C_w \text{ at } \bar{y}=0,$$

$$\bar{u}\to u_\infty, T\to T_\infty, C\to C_\infty \text{ at } \bar{y}\to\infty. \quad (5)$$

where $c>0$, T_w and C_w are the constant temperature and concentration of the sheet, and T_∞ and C_∞ are the constant temperature and concentration far away from thesheet.In addition, the radiative heat flux q^r is described according to the Rosseland approximation such that:

$$\frac{\partial q^r}{\partial \bar{y}}=-\frac{4\sigma_1}{3\chi}\frac{\partial T^4}{\partial \bar{y}}, \quad (6)$$

where σ_1 and χ are the Stefan-Boltzmann constant and the mean absorption coefficient, respectively. As done by Raptis [22,23], the fluid-phase temperature differences within the flow are assumed to be sufficiently small so that T^4 may be expressed as a linear function of temperature. This is done by expanding T^4 in a Taylor series about the free-stream temperature T_∞ and neglecting higher-order

terms to yield

$$T^4=4T_\infty^4 T-3T_\infty^4, \quad (7)$$

By using Eqs. (6) and (7) in the last term of Eq. (3), we obtain

$$\frac{\partial q^r}{\partial \bar{y}}=-\frac{16\sigma_1 T_\infty^3}{3\chi}\frac{\partial^2 T}{\partial \bar{y}^2}. \quad (8)$$

Introducing the following non-dimensional parameters

$$x=\frac{c\bar{x}}{u_\infty},\quad y=\frac{c\bar{y}}{u_\infty}\mathrm{Re},\quad u=\frac{\bar{u}}{u_\infty},\quad v=\frac{\bar{v}}{u_\infty}\mathrm{Re},$$

$$\theta=\frac{T-T_\infty}{T_w-T_\infty},\ \phi=\frac{C-C_\infty}{C_w-C_\infty}. \quad (9)$$

one can obtain the governing equation in dimensionless form as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \quad (10)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+Gr\theta+Gc\phi-\left(M+\frac{1}{Da}\right)u \quad ,(11)$$

$$u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}=\frac{1}{\mathrm{Pr}}\left(1+\frac{4}{3}R_d\right)\frac{\partial^2 \theta}{\partial y^2}, \quad (12)$$

$$u\frac{\partial \phi}{\partial x}+v\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2}-\gamma\phi, \quad (13)$$

with the boundary conditions

$$u=x,\ v=0,\ \theta=1,\ \phi=1 \text{ at } y=0,$$

$$u\to 1, \theta\to 0, \phi\to 0 \text{ at } y\to\infty. \quad (14)$$

where $M = \sigma B_0^2 / \rho c$ is the magnetic parameter, $Da = Kc/\nu$ is the Darcy number, $\mathrm{Re} = u_\infty / \sqrt{c\nu}$ is the Reynolds number, $Gr = g\beta(T_w - T_\infty)/cu_\infty$ is the Grashof number, $Gc = g\beta^*(C_w - C_\infty)/cu_\infty$ is the modified Grashof number, $R_d = 4\sigma_1 T_\infty^3 / k\chi$ is the radiation parameter, $\gamma = K_1 / c$ is the non-dimensional chemical reaction parameter, $\Pr = \mu C_p / k$ is the Prandtl number, $Sc = \nu / D$ is the Schmidt number. Introducing the stream function ψ defined in the usual way $u = \frac{\partial \psi}{\partial y}, v = -\frac{\partial \psi}{\partial x}$,

(15)

Where $\psi(y) = f(y) + xg(y)$.(16)

In view of equations of (10)-(14) and by equating coefficients of x^0 and x^1, we obtain the coupled nonlinear ordinarydifferential equations

$$f''' = f'g' - gf'' + \left(M + \frac{1}{Da}\right)f' - Gr\theta - Gc\phi,$$

(17)

$$g''' = g'^2 - gg'' + \left(M + \frac{1}{Da}\right)g' \quad (18)$$

$$\frac{1}{\Pr}\left(1 + \frac{4}{3}R_d\right)\theta'' + g\theta' = 0 \quad (19)$$

$$\frac{1}{Sc}\phi'' + g\phi' - \gamma\phi = 0 \quad (20)$$

The primes above indicate differentiation with respect to y only. The boundary conditions (14), in viewof (16), are reduced to

$$f(0) = f'(0) = g(0) = g'(\infty) = \theta(\infty) = \phi(\infty) = 0,$$

$$g'(0) = \theta(0) = \phi(0) = f'(\infty) = 1. \quad (21)$$

The main physical quantities of interest in this problem are the skin frictioncoefficient, Local Nusselt number and local Sherwood number,which are defined, respectively, by

$$\tau_w = \mu \left.\frac{\partial u}{\partial y}\right|_{y=0}, \quad Nu = -\frac{k}{\rho C_p (T_w - T_\infty)} \left.\frac{\partial T}{\partial y}\right|_{y=0},$$

$$Sh = -\frac{D}{(C_w - C_\infty)} \left.\frac{\partial C}{\partial y}\right|_{y=0}. \quad (22)$$

Using (16), quantities (22) can be expressed as

$$\tau_w = \mu c \,\mathrm{Re}\left(f''(0) + xg''(0)\right),$$

$$Nu = -\frac{ck\,\mathrm{Re}}{u_\infty \rho C_p}\theta'(0),\ Sh = -\frac{cD\,\mathrm{Re}}{u_\infty}\phi'(0).$$

(23)

3. RESULTS AND DISCUSSION

The set of equations (17)-(20) under the boundary conditions (21) have beensolved numerically by applying the shooting iterationtechnique together with Runge-Kutta forth-order integration scheme. From theprocess of numerical computation, the local skin-friction coefficients, the localNusselt number and the local Sherwood number, which are respectively proportionalto $f''(0), -g''(0), -\theta'(0)$ and $-\phi'(0)$, are also worked out and their numerical valuesare presented in a tabular form.

The exact solution of the Eq. (18) with boundary conditions (19) is also given by:

$$g(y) = \frac{1}{\alpha}\left(1 + e^{-\alpha y}\right),$$

Where $\alpha = (Da^{-1} + M + 1)^{1/2}$, (24)

Numerical calculations have been carried out for different values of *M*, *Da*,R_d, $\gamma$and for fixed values of *Pr*, *Sc*, *Gr*, and *Gc*. The value of Prandtl number(*Pr*) is taken to be 0.71 which corresponds to air and the value of Schmidt number(*Sc*) is chosen to represent hydrogen at 25^0C and 1 atm. Thedimensionless parameter *Gr* takes the value 1, which corresponds to the free convection problem positive, and the corresponding parameter *Gc* takes the valuefor low concentration.

The numerical results for the velocity, temperature and concentration profilesare displayed in Figs. 1-2. The effects of Darcy number *Da* and radiation parameter R_d on the velocityfields are shown in Fig. 1a. The presence of a porous medium in the flow presents resistance to flow, thus, slowing the flow and increasing the pressure drop across it. Therefore, is seen from this figure that the velocity profilesincrease monotonically with the increase of Darcy number *Da* and radiation parameter R_d. The effect of Darcy number *Da* and radiation parameter R_d on the temperature and concentration field are displayed in Fig. 1band Fig. 1c, respectively and we see that both the temperature and concentration decreases with the increase of Darcy number, while it decreases with the decrease of radiation parameter. This result was expected because the presence of thermal radiation works as a heat source and so the quantity of heat added to the fluid increases. Also, this figure shows that the thermal boundary layer becomes thicker as R_d increases. Moreover, it is obvious that the governing equations (18)-(20) are uncoupled. Therefore, changes in the values of R_d will cause no changes in both of the distributions of velocity g' and concentration of fluid, and for this reason, no figures for these variables are presented herein.

The effects of magnetic and chemical reaction parameters on the velocity field are shown inFig. 1a. We observe that quantitatively the velocity boundary layer decreases with an increase the magnetic field *M*, and at the same time the temperature and concentration increases, the effect of the magnetic field on this case is to decrease the heat and mass transfer rates.As *M* increases, the Lorentz force, which opposes the flow, also increases and leads to enchanted deceleration of the flow. This result quantitatively with the expectations [20], since the magnetic field exerts a retarding force on the free convection flow. However, the velocity boundary layer decreases with an increase chemical reaction parameter γ, and at the same time the concentration increases.Sucking decelerated fluid particles through the sheet reduce the growth of the fluid boundary layer as well asconcentration boundary layers. no effect on both of the distributions of velocity g' and temperature of fluid for the same reason as obvious above.

Table 1 illustrates the effects of Darcy number, magnetic field, radiation and chemical reaction parameters on the shear stress ($f''(0)$ and $-g''(0)$), local Nusselt number $-\theta'(0)$ and local Sherwood number $-\phi'(0)$ at the surface. It is worth mentioning that wall shear stress $f''(0)$ decreases as the chemical reaction , magnetic and radiationparameters whereas it increases asDarcy number increases. In addition, we observe that quantitatively the magnitude of the wall-temperaturegradient decreases as the radiation parameter$R_d$and magnetic parameter *M*increases or whereas it increases asDarcy number *Da* increases.Furthermore, the negative values of the wall-temperature gradient, for all values of the dimensionlessparameters, are indicative of the physical fact that the heat flows from the sheet surface to ambientfluid the radiation effect on the rate of the heat $-\theta'(0)$ is greater than that of the skin friction $f''(0)$. Finally, is obvious that local Sherwood number $-\phi'(0)$ at the surfacethe increases as the chemical reaction parameter and Darcy number increases whereas the opposite effect with magnetic parameter.

4. CONCLUSIONS

In this paper we have studied numerically the magneto-hydrodynamics effect on free convection heat and mass transfer flow fromradiate an isothermal sheet embedded in a saturated porous medium embedded in a porousmedium for a hydrogen-air mixture as the chemical reacting fluid pair. The effects of transverse magnetic field, radiation heat transfer and chemical reaction mass transfer are examined. The resultant governing boundary-layer equations, highly non-linear and a coupled form of partial differential equations, have been solved numerically using shooting method with Runge–Kutta scheme. A representative set of numerical results for thevelocity, temperature, and concentration profiles as well as the local skin-frictioncoefficient, local Nusselt number, and the local Sherwood number with various values physical parameters was presentedgraphically and discussed.

Table 1. Variation of $f''(0)$, $-g''(0)$, $-\theta'(0)$, $-\phi'(0)$ the plate surface withvarious valuesof*M*, γ, *Da* and R_d at *Pr*=0.71, *Sc*=0.22, *Gr*=0.3 and *Gc*=0.1.

M	γ	Da	R_d	$f''(0)$	$-g''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.0	0.0	10	0.5	0.52413	1.04881	0.30547	0.18014
0.0	0.5	10	0.5	0.46395	1.04881	0.30547	0.40124
0.0	1.0	10	0.5	0.44711	1.04881	0.30547	0.52731
0.2	0.0	10	0.5	0.43886	1.14018	0.29088	0.17050
0.2	0.5	10	0.5	0.40116	1.14018	0.29088	0.39756
0.2	1.0	10	0.5	0.38901	1.14018	0.29088	0.52466
0.4	0.0	10	0.5	0.38778	1.22475	0.27827	0.16253
0.4	0.5	10	0.5	0.36012	1.22475	0.27827	0.39447
0.4	1.0	10	0.5	0.35052	1.22475	0.27827	0.52241
0.02	0.5	1.0	0.0	0.26741	1.42127	0.38330	0.38826
0.02	0.5	1.0	0.5	0.29583	1.42127	0.25212	0.38826
0.02	0.5	1.0	1.0	0.31151	1.42127	0.19040	0.38826
0.02	0.5	10.0	0.0	0.37124	1.05830	0.44721	0.40084
0.02	0.5	10.0	0.5	0.45611	1.05830	0.30391	0.40084
0.02	0.5	10.0	1.0	0.52372	1.05830	0.23238	0.40084
0.02	0.5	100	0.0	0.39256	1.01489	0.45563	0.40271
0.02	0.5	100	0.5	0.49557	1.01489	0.31114	0.40271
0.02	0.5	100	1.0	0.58659	1.01489	0.23854	0.40271

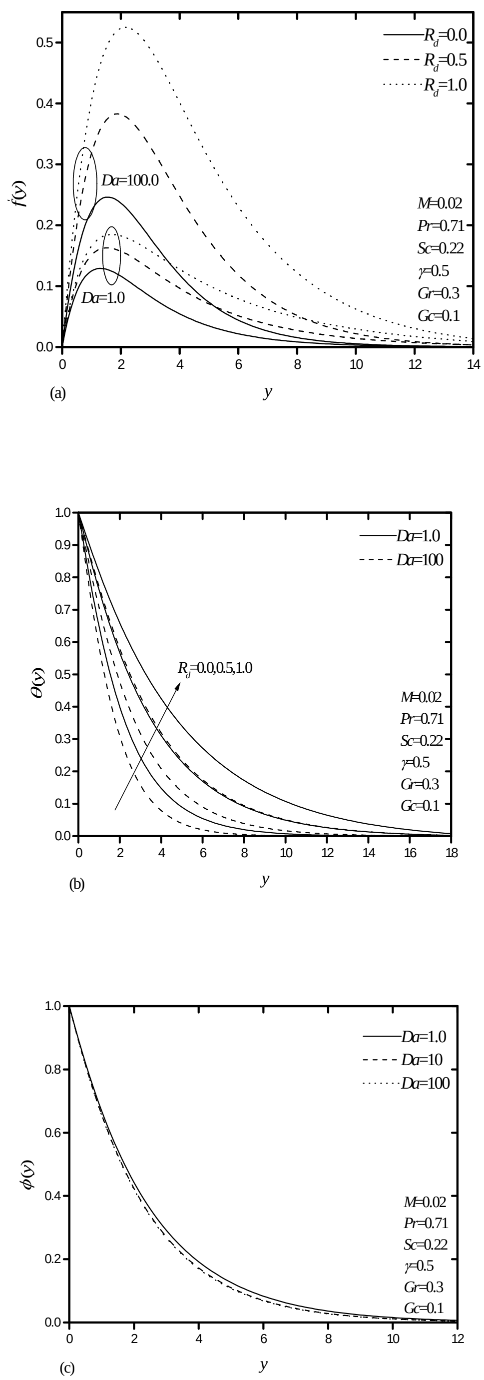

Fig. 1. Effects of Darcy number and radiation parameter on (a) velocity profiles (b) temperature profiles(c) concentration profiles.

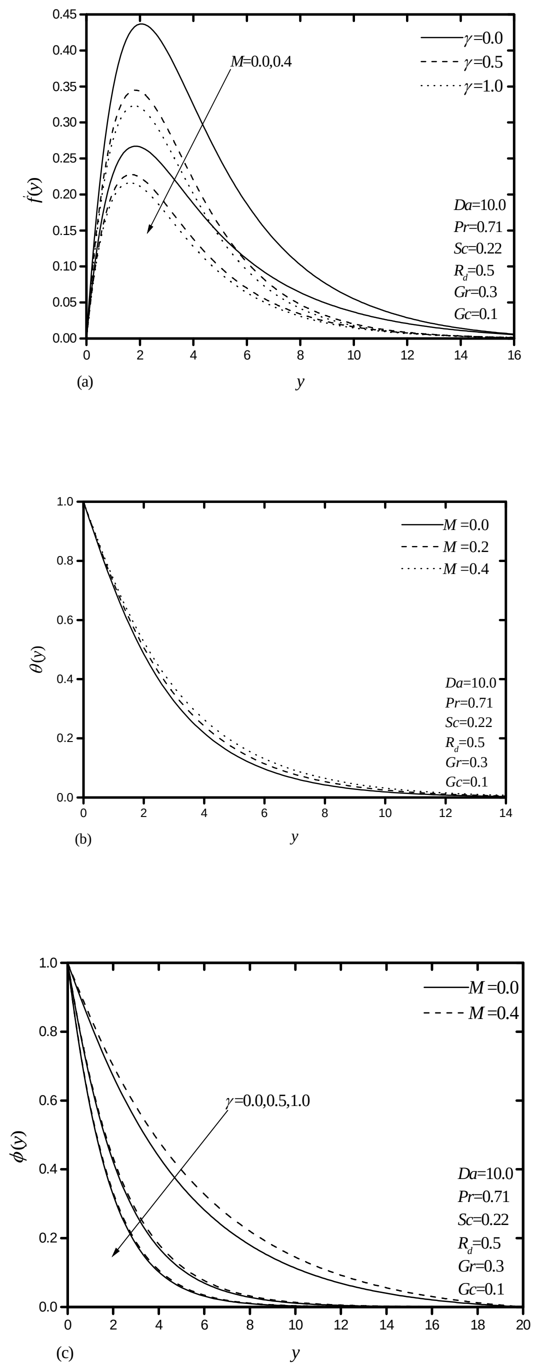

Fig. 2. Effects of magnetic and chemical reaction parameters on (a)velocity profiles (b) temperature profiles (c) concentration profiles.

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