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Unsteady Mhd Free Convective Fluid Flow Past A Vertical Porous Plate With Ohmic Heating In The Presence Of Suction Or Injection

M.Rajaiah[1], Dr.A.Sudhakaraiah[2], Dr.P.Venkatalakshmi[3] and M. Sivaiah[4]

[1] *Professor & HOD, Department of H&S, Audisankara College of Engg. &Tech., Gudur, Nellore, A.P (INDIA)*

[2] *Senior Assistant professor, Department of Future Studies, S.V.University, Tirupati, A.P (INDIA)*

[3] *Professor, Department of H&S, Audisankara College of Engg. &Tech., Gudur, Nellore, A.P (INDIA)*

[4] *HOD,Department of Mathematics, N.B.K.R Science & Arts College, Vidyanagar, Nellore, A.P (INDIA)*

Author's Address

M. Rajaiah, Door No.25-2-300, Flotno.4,Newmilitary colony, 3rd Cross, Vedayapalem, Nellore(Dt), Pin.524004,AP,India, Phone number: 919493914808,919248748415,email Id:rajagopal1402@gmail.com

Abstract

An unsteady MHD free convective fluid flow of a viscous incompressible and electrically conducting fluid past a vertical porous plate in the presence of suction or injection is considered. The non–linear partial differential equations governing the flow have been solved numerically using finite difference method. The effect of Ohmic heating, on the velocity and temperature distributions and also on the mass transfer is comprehensively discussed in this paper. The effects of the various parameters on the velocity, temperature and concentration profiles are presented graphically and values of skin– friction coefficient, Nusselt number and Sherwood number for various values of physical parameters are also analyzed through tables.

Keywords *Soret number, Dufour number, MHD free convective flow, Vertical porous plate, Finite difference method.*

1. Introduction

The hydromagnetic convection with heat and mass transfer in porous medium has been studied due to its significant importance in the design of MHD generators and accelerators in geophysics, under ground water energy storage system, soil-sciences, astrophysics, nuclear power reactors and so on. Magnetohydrodynamics is currently undergoing a period of great enlargement and differentiation of subject matter. The interest in these new problems generates from their importance in liquid metals, electrolytes and ionized gases. Because of their varied importance, these flows have been studied by several notable authors. Shercliff [1], Ferraro and Plumpton [2], Crammer and Pai [3] and Elbashbeshy [4] have carefully studied heat and mass transfer along a vertical plate in the presence of magnetic field. Hossian and Rees [5] examined the effects of combined buoyancy forces from thermal and mass diffusion by natural convection flow from a vertical wavy surface. Combined heat and mass transfer in MHD free convection from a vertical surface has been studied by Chein [6]. Hossain and Alim [7] studied the radiation effects on free and forced convection flows past a vertical plate, including various physical aspects.

For the problem of coupled heat and mass transfer in MHD free convection, the effect of Ohmic heating has not been considered in the above investigations. However, it is more realistic to include this effect to explore the impact of the magnetic field on the thermal transport in the boundary layer. With this awareness, the effect of Ohmic heating on the MHD free convection heat transfer has been examined for a Newtonian fluid by Hossain [8]. Chen [9] studied the problem of combined heat and mass transfer of an electrically conducting fluid in MHD natural convection, adjacent to a vertical surface with Ohmic heating. Ganesan and Palani [10] obtained numerical solution of Unsteady MHD flow past a semi- infinite isothermal vertical plate. Ganesan and Palani [11] studied numerical solution of transient free convection MHD flow of an incompressible viscous fluid flow past a semi-infinite inclined plate with variable surface heat and mass flux. Orhan Aydin and Ahmet Kaya [12] investigated mixed convection heat transfer about a permeable vertical plate in the presence of magneto and thermal radiation effects. The problem of steady laminar magneto hydrodynamic (MHD) mixed convection heat transfer about a vertical plate is solved numerically by Orhan Aydin and Ahmet Kaya [13], taking into account the effect of Ohmic heating and viscous dissipation. K. Sarada and B. Shanker[14] investigated the effects of Soret and Dufour on an unsteady MHD free convective fluid flow of a viscous incompressible and electrically conducting fluid past a vertical porous plate in the presence of suction or injection.

The main object of this paper is to analyze the heat and mass transfer effects on an unsteady MHD free convective fluid flow of a viscous incompressible and electrically conducting fluid past a vertical porous plate in the presence of suction or injection. The dimensionless governing equations of the flow have been comprehensively solved numerically using finite difference method.

2. NOMENCLATURE

β	Coefficient of volume expansion for heat transfer
β^*	Coefficient of volume expansion for mass transfer
κ	Thermal conductivity, W/ mK

σ	Electrical conductivity of the fluid
ν	Kinematic viscosity
θ	Non – dimensional temperature
ρ	Density of the fluid
τ	Skin – friction
$C^{'}, C_w^{'}$, and $C_\infty^{'}$	Concentration of the fluid near the plate, far away of the fluid from the plate, and at infinity respectively
$T^{'}, T_w^{'}$, and $T_\infty^{'}$	Temperature of fluid near the plate, far away of the fluid from the plate, and at infinity respectively
$u^{'}$ and $v^{'}$	Velocity components in x' and y' – directions respectively
u	Dimensionless velocity component in x – direction
$x^{'}$ and $y^{'}$	Co–ordinate system in the dimensional form
x and y	Dimensionless coordinates
B_0	Magnetic field component along y – axis
c_s	Concentration susceptibility
g	Acceleration of gravity
k_T	Thermal diffusion ratio

$$Du = \frac{D\, k_T \left(C_w^{'} - C_\infty^{'}\right)}{C_S\, C_P \left(T_w^{'} - T_\infty^{'}\right)}$$ Dufour Number

$$Ec = \frac{v_0^{\,2}}{C_P \left(T_w^{'} - T_\infty^{'}\right)}$$ Eckert Number

$$Gc = \frac{g\, \beta^{*} \left(C_w^{'} - C_\infty^{'}\right)}{v_0^{\,3}}$$ Modified Grashoff Number

$$Gr = \frac{g\, \beta \left(T_w^{'} - T_\infty^{'}\right)}{v_0^{\,3}}$$ Grashoff Number

$$M = \frac{\sigma\, B_0^{\,2}\, \nu}{\rho\, v_0^{\,2}}$$ Hartmann Number

$$\Pr = \frac{\mu C_P}{k}$$ Prandtl Number

$$\mathrm{Re}_x = -\frac{v_o\; x'}{\nu}$$ Reynolds Number

$$Sc = \frac{\nu}{D}$$ Schmidt Number

$$Sr = \frac{D\, k_T \left(T_w' - T_\infty'\right)}{\nu\, T_m \left(C_w' - C_\infty'\right)}$$ Soret Number

3. Formulation of the problem

An unsteady two – dimensional MHD free convection flow of a viscous incompressible and electrically conducting fluid past a vertical porous plate in the presence of suction or injection is considered under the following assumptions.

1. In Cartesian coordinate system, let x' −axis is taken along the plate and the y' − axis along the normal to the plate. Since the plate is considered infinite in x' −direction, it is assumed that all the physical quantities will be independent of x' −direction.

2. Let the components of velocity along x' and y' axes be u' and v', which are chosen in the upward direction along the plate and normal to the plate respectively.

3. Initially, the plate and the fluid are at the same temperature T_∞' and the concentration C_∞'. At time $t' > 0$, the plate temperature and concentration are raised to T_w' and C_w' respectively and are maintained constantly thereafter.
4. A uniform magnetic field of magnitude B_0 is applied in the direction perpendicular to the plate. The fluid is assumed to be slightly conducting and hence the magnetic Reynolds number is much lesser than unity and the induced magnetic field is negligible in comparison with the applied magnetic field.
5. Magnetic dissipation (Joule heating of the fluid) is considered.

6. The homogeneous chemical reaction of first order with rate constant between the diffusing species and the fluid is neglected.
7. The Hall Effect of MHD is neglected.

8. It is also assumed that all the fluid properties are constant except that the influence of the density variation with temperature and concentration in the body force term (Boussinesq's approximation).

The governing equations under the assumptions are given by

$$\frac{\partial v'}{\partial y'} = 0 \qquad (1)$$

$$\frac{\partial u'}{\partial t'} - v' \frac{\partial u'}{\partial y'} = \frac{\partial^2 u'}{\partial y'^2} - \left(\frac{\sigma B_0^2}{\rho} + \frac{\nu}{K'}\right) u' + g\,\beta\left(T' - T'_\infty\right) + g\,\beta^*\left(C' - C'_\infty\right) \tag{2}$$

$$\frac{\partial T'}{\partial t'} - v \frac{\partial T'}{\partial y'} = \frac{k}{\rho C_P} \frac{\partial^2 T'}{\partial y'^2} + \frac{D\,k_T}{C_S\,C_P} \frac{\partial^2 C'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho C_P}\left(u'\right)^2 \tag{3}$$

$$\frac{\partial C'}{\partial t'} - v \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} + \frac{D\,k_T}{T_m} \frac{\partial^2 T'}{\partial y'^2} \tag{4}$$

The initial and boundary conditions are

$$\begin{aligned} &t' \le 0 : \quad u' = 0, \quad v' = 0, \quad T' = T'_\infty, \quad C' = C'_\infty \quad \textit{for all } y' \\ &t' > 0 \quad \begin{cases} u' = 0, \quad v' = v(t), \; T' = T'_w, \; C' = C'_w & \textit{for } y' = 0 \\ u \to 0, \; T' \to T'_\infty, \; C' \to C'_\infty & \textit{as } y' \to \infty \end{cases} \end{aligned} \tag{5}$$

Introducing the non – dimensional quantities

$$\begin{aligned} &y = \frac{y'\,v_0}{\nu} \qquad t = \frac{t'\,v_0{}^2}{\nu} \qquad u = \frac{u'}{v_0} \qquad v = \frac{v'}{v_0} \\ &\theta = \frac{T' - T_\infty{}'}{T_w{}' - T_\infty{}'} \qquad \phi = \frac{C' - C_\infty{}'}{C_w{}' - C_\infty{}'} \qquad k = \frac{k'\,v_0{}^2}{\nu^2} \end{aligned} \tag{6}$$

with the physical parameters defined in the nomenclature into the equations (2) to (4) and the boundary conditions (5), the governing equations and the corresponding initial and boundary conditions are reduced to the following non – dimensional form.

$$\frac{\partial u}{\partial t} - v_0 \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right) u + Gr\,\theta + Gc\,\phi \tag{7}$$

$$\frac{\partial \theta}{\partial t} - v_0 \frac{\partial \theta}{\partial y} = \frac{1}{\Pr} \frac{\partial^2 \theta}{\partial y^2} + Du \frac{\partial^2 \phi}{\partial y^2} - M\,Ec\,u^2 \tag{8}$$

$$\frac{\partial \phi}{\partial t} - v_0 \frac{\partial \phi}{\partial y} = \frac{1}{\mathrm{Sc}} \frac{\partial^2 \phi}{\partial y^2} + Sr \frac{\partial^2 \theta}{\partial y^2} \tag{9}$$

$$\begin{aligned} &t \le 0 \qquad u = 0, \; \theta = 0, \; \phi = 0 \qquad \textit{for all } y \\ &t > 0 \quad \begin{cases} u = 0, \quad \theta = 1, \quad \phi = 1 & \textit{for } y = 0 \\ u \to 0, \; \theta \to 0, \; \phi \to 0 & \textit{as } y \to \infty \end{cases} \end{aligned} \tag{10}$$

From the equation (1), $v^{'}$ is either a constant or a function of time. So assuming suction velocity is oscillatory about a non–zero constant mean, then equation (1) becomes

$$v^{'} = -v_0 \tag{11}$$

Here the negative sign indicates that the suction velocity is directed towards the plate.

4. Finite difference Technique

The coupled non–linear partial differential governing equations (7) to (9) are solved using the initial and boundary conditions (10). The exact solutions are not possible for this set of equations; hence, an explicit finite difference method has been employed. The finite difference scheme corresponding to the governing equations (7) to (9) and the initial and boundary conditions (10) are given by

$$\frac{\partial u}{\partial t} = \frac{u(i,\ j+1) - u(i,\ j)}{\Delta t}$$

$$\frac{\partial \theta}{\partial t} = \frac{\theta(i,\ j+1) - \theta(i,\ j)}{\Delta t}$$

$$\frac{\partial \phi}{\partial t} = \frac{\phi(i,\ j+1) - \phi(i,\ j)}{\Delta t}$$

$$\frac{\partial u}{\partial y} = \frac{u(i+1,\ j) - u(i,\ j)}{\Delta y}$$

$$\frac{\partial \theta}{\partial y} = \frac{\theta(i+1,\ j) - \theta(i,\ j)}{\Delta y}$$

$$\frac{\partial \phi}{\partial y} = \frac{\phi(i+1,\ j) - \phi(i,\ j)}{\Delta y}$$

$$\frac{\partial^2 u}{\partial y^2} = \frac{u(i+1,\ j) - 2u(i,\ j) + u(i-1,\ j)}{\Delta y^2}$$

$$\frac{\partial^2 \theta}{\partial y^2} = \frac{\theta(i+1,\ j) - 2\theta(i,\ j) + \theta(i-1,\ j)}{\Delta y^2}$$

$$\frac{\partial^2 \phi}{\partial y^2} = \frac{\phi(i+1,\ j) - 2\phi(i,\ j) + \phi(i-1,\ j)}{\Delta y^2}$$

Here the suffix *i* corresponds to *y* and *j* corresponds to *t* and $\Delta t = t(j+1) - t(j)$ and $\Delta y = y(i+1) - y(i)$. The computations were carried out for different values of the various physical parameters. The procedure is repeated until the steady state. During computation Δt was chosen as 0.001. These computations are carried out for Pr= 0.71,1,7 and11 and for different values of Ec. To judge the accuracy of the convergence of the finite difference scheme, the same program was run with the Δt=0.0009, 0.00125 and no significant change was observed. Hence, we conclude the finite difference scheme is stable and convergent.

The physical quantities of primary interest include Skin-friction co-efficient, Nusselt number and Sherwood number. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress *(i.e., skin – friction)* given by (12).

$$\tau = \frac{\tau_w}{\rho\ u_w^2} \text{ where } \tau_w = \left(\mu \frac{\partial u'}{\partial y'}\right)_{y'=0} = \rho v_0^2\ u'(0) \qquad \text{i.e. } \tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{12}$$

Knowing the temperature field, it is interesting to study the effect of the free convection and radiation on the rate of heat transfer. We can now calculate the rate of heat transfer given by (13).

$$Nu(x') = -\left[\frac{x'}{T_w' - T_\infty'}\left(\frac{\partial T'}{\partial y'}\right)_{y'=0}\right]$$

$$\text{i.e.} \qquad Nu = \frac{Nu(x')}{\mathrm{Re}_x} = -\left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{13}$$

From the definitions of the local mass flux (i.e., Sherwood number) is given by (14)

$$Sh(x') = -\left[\frac{x'}{C_w' - C_\infty'}\left(\frac{\partial C'}{\partial y'}\right)_{y'=0}\right]$$

$$\text{i.e. } Sh = \frac{Sh(x')}{\mathrm{Re}_x} = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} \tag{14}$$

5. Results and Discussion

In order to get a physical insight into the problem, extensive computations have been performed to study the effects of various influencing parameters on the dimensionless velocity, temperature and concentration profiles and also on the Skin-friction, Nusselt number and Sherwood number.

In figures 1 to 12, the velocity profiles are drawn for various parameters such as Hartmann number (M), Eckert number (Ec), thermal Grashoff number (Gr), Soret number (Sr), Dufour number (Du), the Solutal Grashoff number (Gc), and the suction or injection parameter (v_o) etc.

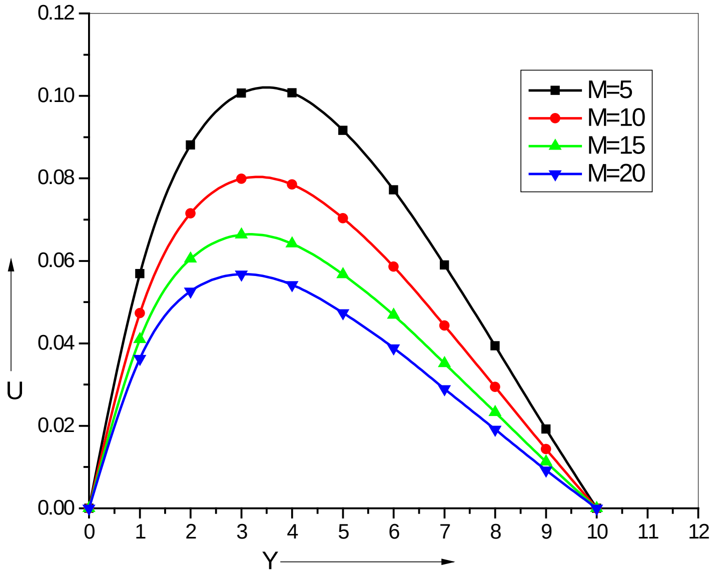

Fig. 1
Velocity profile for different values of M

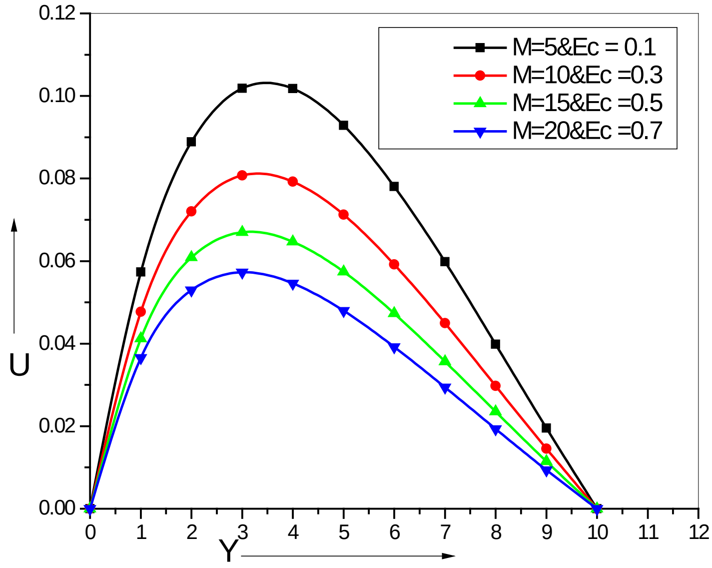

Fig. 2
Velocity profiles for different values of M&Ec

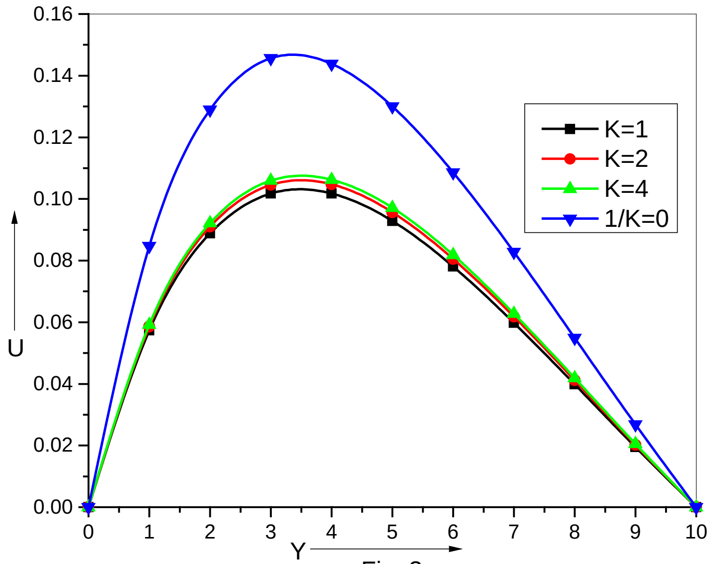

Fig. 3
Velocity profiles for different values of K

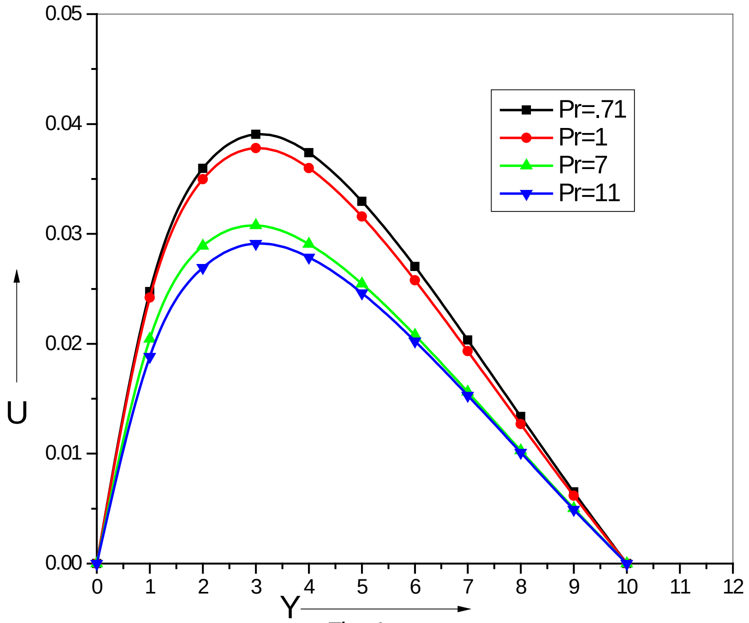

Fig. 4
Velocity profiles for different values of Pr

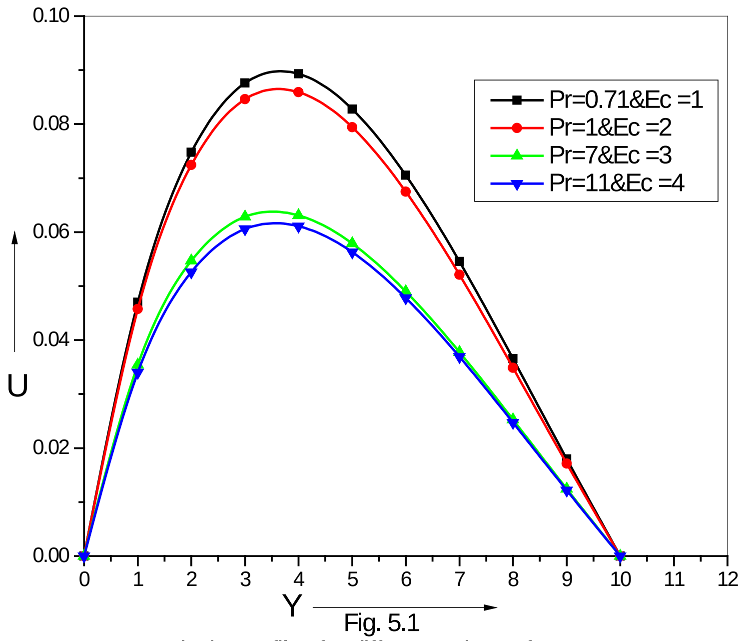

Fig. 5.1
Velocity profiles for different values of Pr&Ec

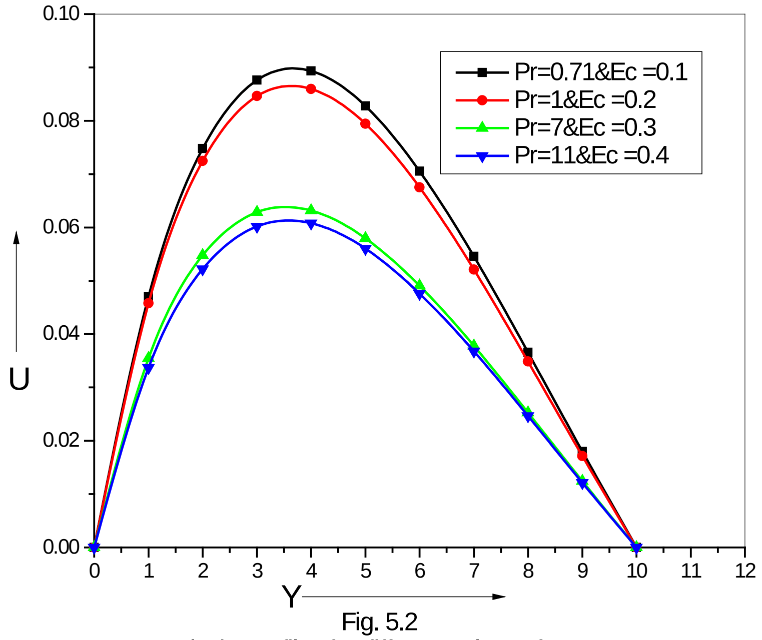

Fig. 5.2
Velocity profiles for different values of Pr&Ec

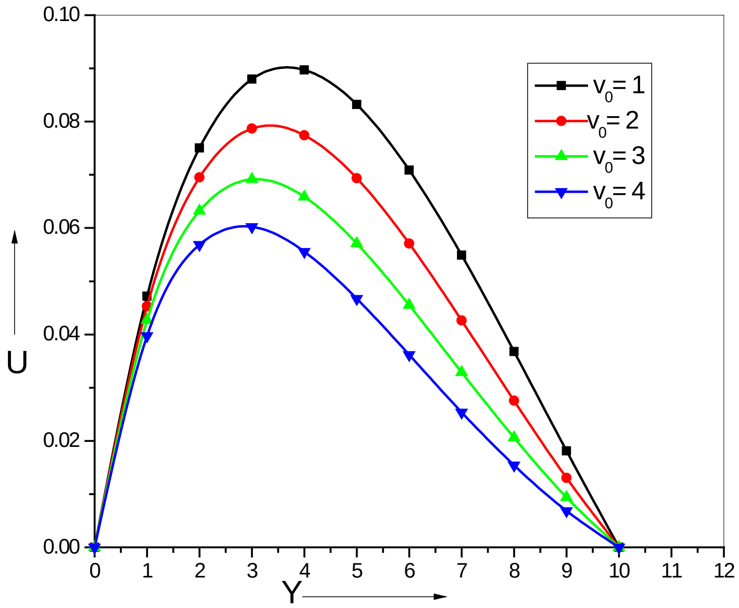

Fig. 6
Velocity profiles for different values of v_0

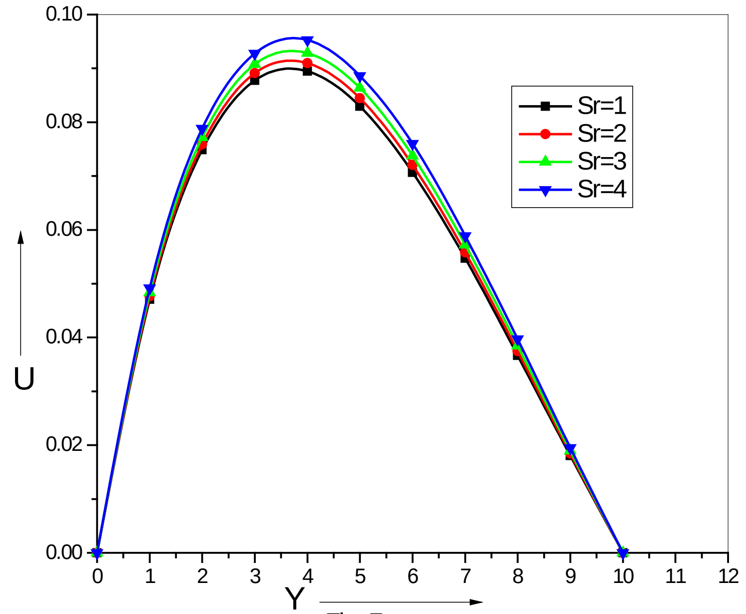

Fig. 7
Velocity profiles for different values of Sr

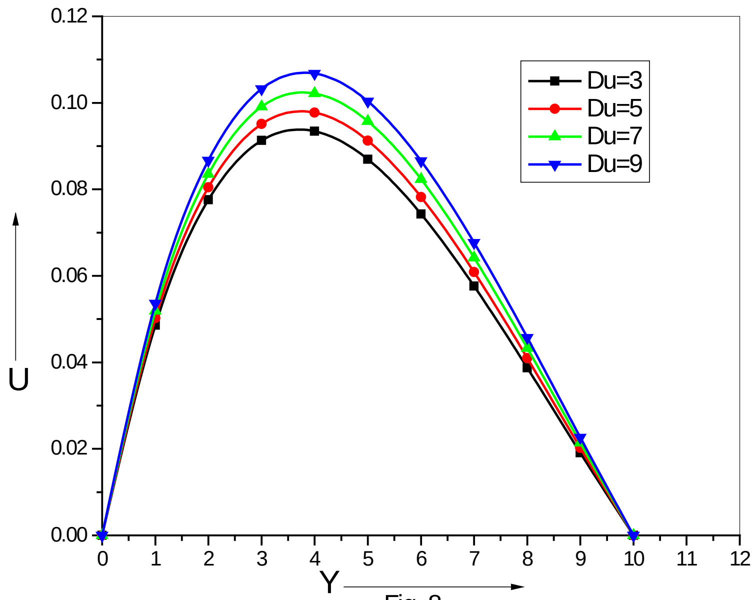

Fig. 8
Velocity profiles for different values of Du

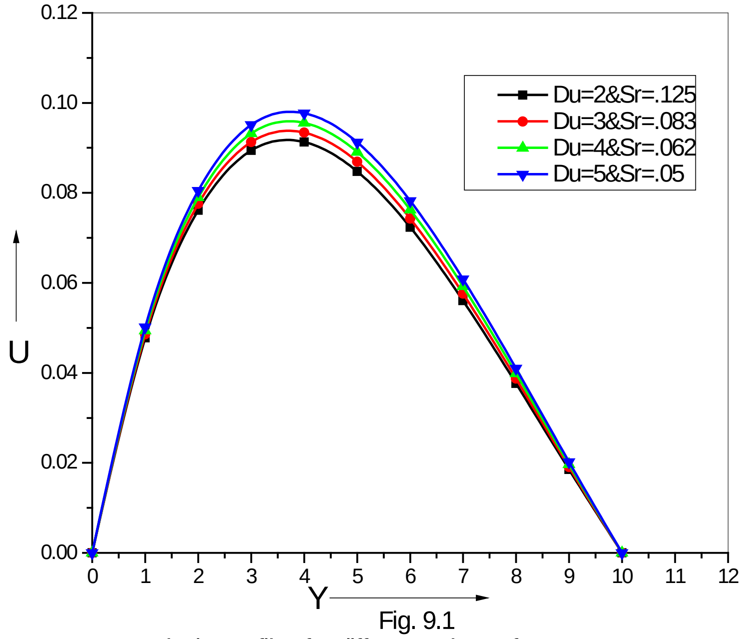

Fig. 9.1
Velocity profiles for different values of Du & Sr

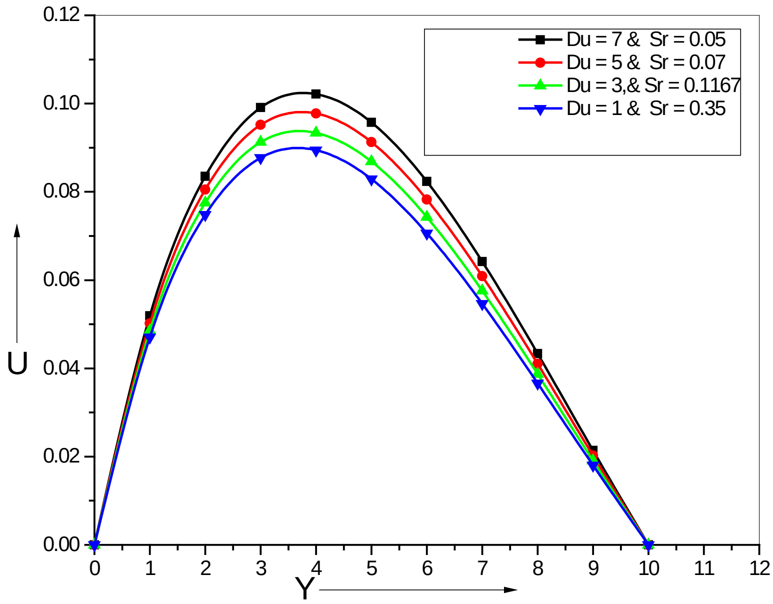

Fig. 9.2
Velocity profiles for different Du and Sr

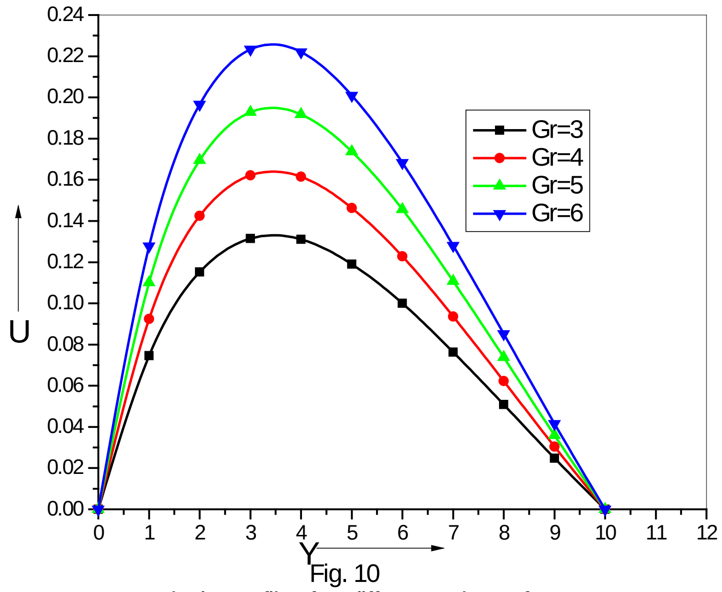

Fig. 10
Velocity profiles for different values of Gr

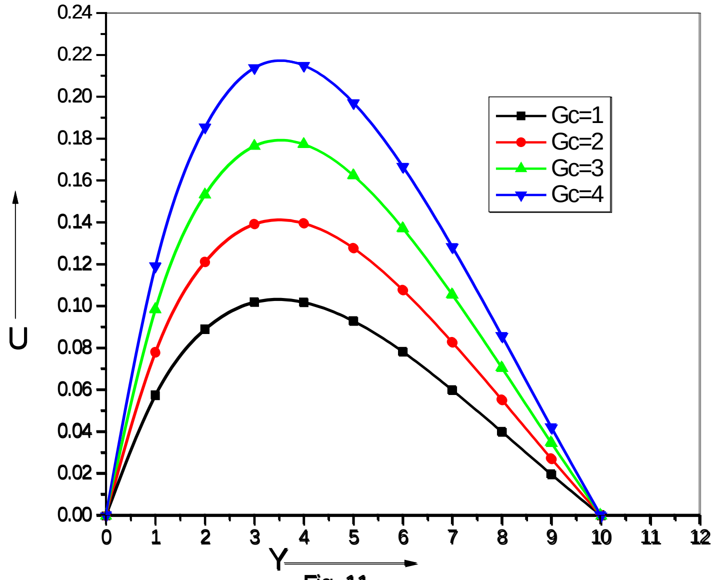

Fig. 11
Velocity profiles for different values of Gc

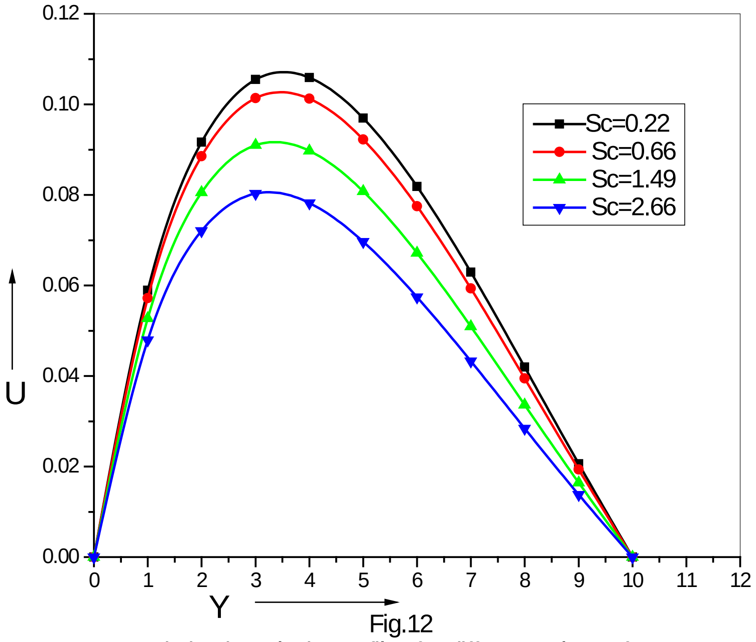

Fig.12
Variation in Velocity profiles for different values of Sc

From fig. 1 it is observed that velocity decreases when the magnetic parameter M increases. This result agrees with the fact that as M increases, the Lorentz force which opposes the flow, leads to a decrease in velocity. The figure 2 illustrates that as the Eckert number increases, the velocity decreases in the presence of increasing magnetic field.

The increase of velocity distribution in the boundary layer can be observed from the figure 3. This effect can be reduced with the holes of the porous medium is decreased. The figure 4 clearly shows the decrease of velocity in the boundary layer with the increase of Prandtl number (Pr). An increase in the Prandtl number results in decrease of the thermal boundary layer thickness within the boundary layer.

The effect of Prandtl number, on the velocity distribution is discussed in figures 5.1 and 5.2, with lower and higher values of Eckert number. From the figures, it is clear that, for increasing values of Prandtl number, the velocity decreases with the increase of Eckert number.

The variation in the velocity of the flow to the change in the suction / injection is shown in the figure 6. As the suction / injection of the fluid through the plate increases, the plate is cooled down and in consequence, the viscosity increases which results in the decrease of velocity.

The influence of the Soret number and Dufour number on the velocity profile is plotted in figures 7, 8, 9.1 and 9.2. It is observed that an increase in Soret number and Dufour number leads to increase in Velocity.

The variation of velocity distribution to the thermal Grashoff number is discussed in the figure 10. The thermal Grashoff number is the relative effect of the thermal buoyancy force to the viscous hydrodynamic force in the boundary layer. The positive values of Grashoff number indicate the cooling of the plate. The rise in the velocity is observed due to the enhancement of the thermal buoyancy force. As thermal buoyancy increases, the velocity increases rapidly near the plate and gradually decreases to free stream velocity.

The effects of Solutal Grashoff number and Schmidt number are given in the figures 11 and 12. Similar to the thermal Grashoff number, the Solutal Grashoff number effect is also to increase in the velocity. The rise in the velocity distribution is observed in the figure 11. The behaviour of velocity distribution in the presence of foreign species such as Hydrogen (Sc = 0.22), Oxygen (Sc = 0.66), Sc = 1.49(Heptane), and Sc = 2.66(Octane) is discussed in the figure 12. The decrease of flow field due to the foreign presence of heavier diffusing species is observed.

The substantial change in the temperature of the flow with variation of parameters like Prandtl number, Eckert number, Suction / Injection Parameter, Dufour number are discussed through figures 13 to 17.

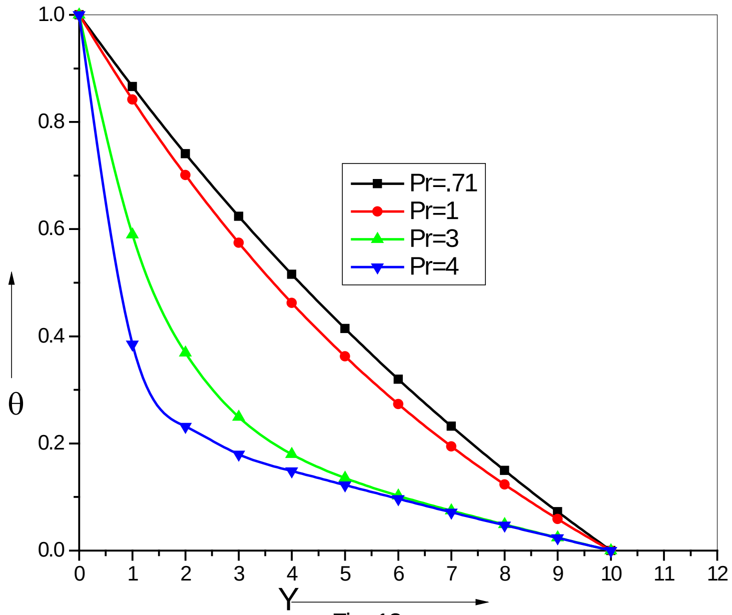

Fig. 13
Temperature profiles for different values of Pr

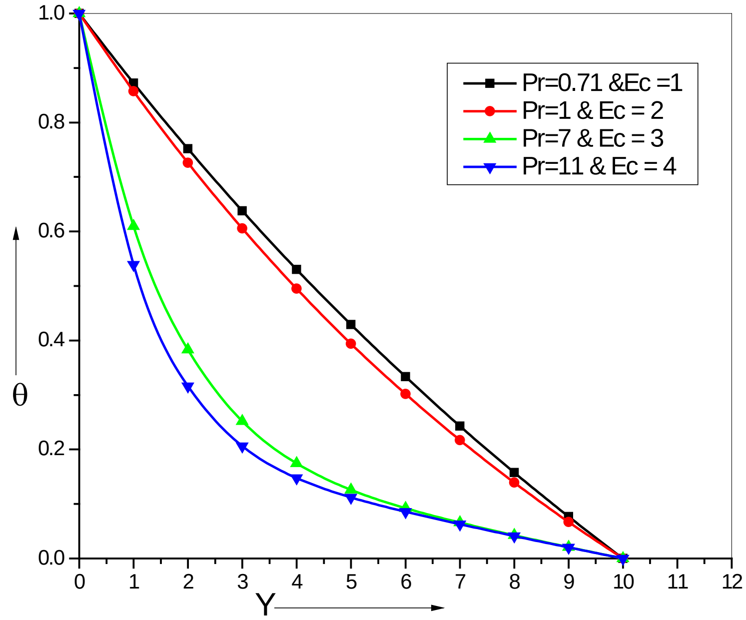

Fig. 14.1
Temperature profiles for different values of Pr&Ec

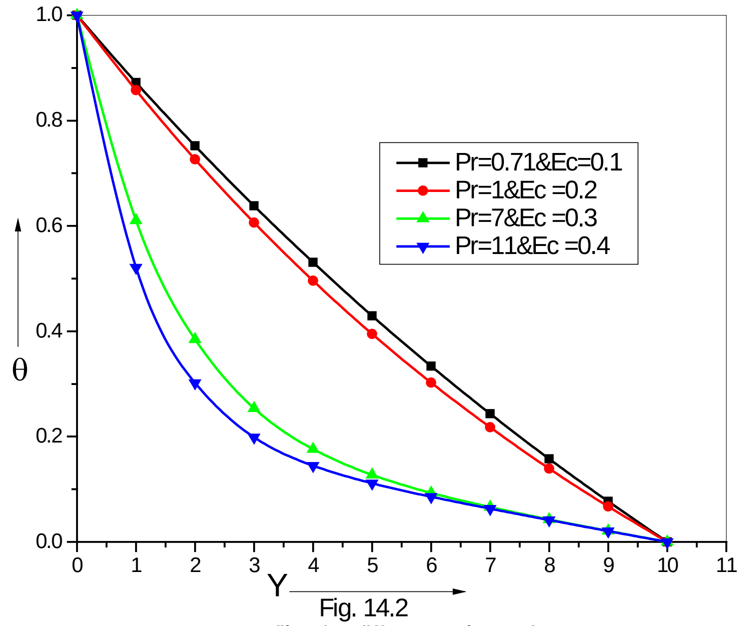

Fig. 14.2
Temperature profiles for different values of Pr & Ec

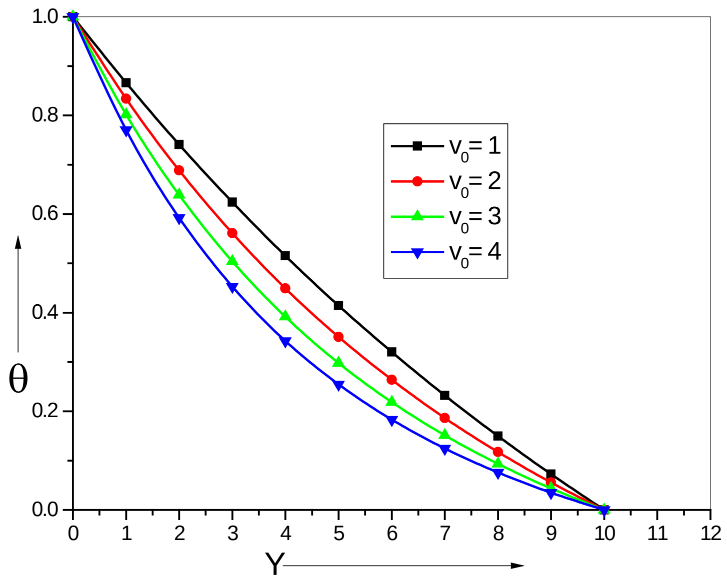

Fig. 15
Temperature profiles for different values of v_0

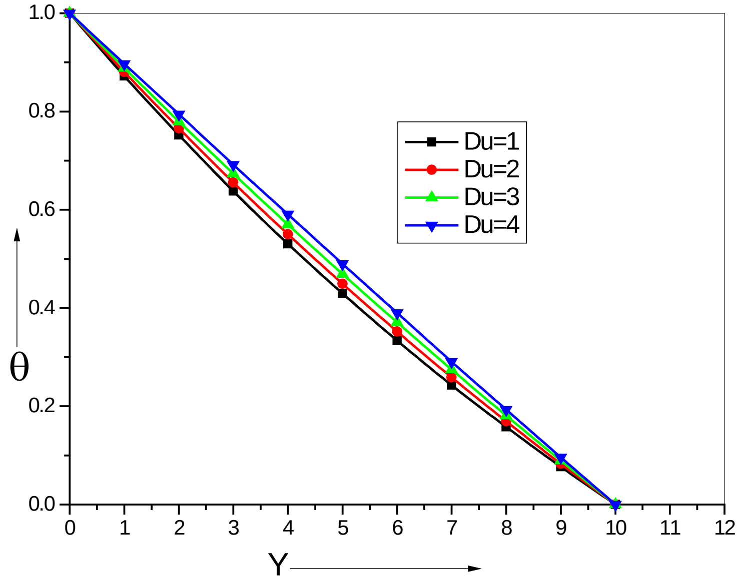

Fig.16.1
Temperature profiles for different values of Du

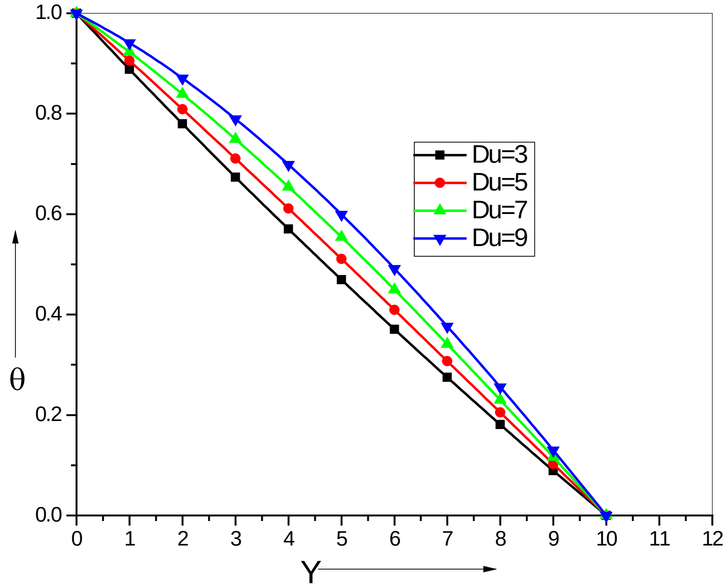

Fig. 16.2
Temperature profiles for different values of Du

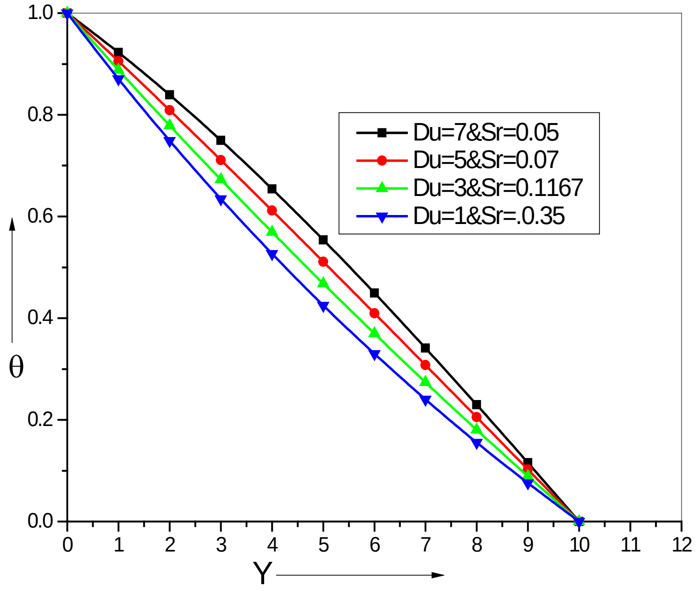

Fig. 17
Temperature profiles for different values of Du&Sr

The decrease of temperature in the boundary layer is clearly observed from the figure 13 for an increase in the Prandtl number. A comparative study is shown in the figures 14.1 to 14.3. Here the decrease of temperature is observed for different values of Eckert number.

The temperature of the flow field is found to be decreasing in the presence of increasing suction / injection. The temperature profile becomes much linear in the absence of suction / injection. The presence of suction / injection, more amount of fluid pushed into the flow through the plate due to which the temperature of the flow field decreases. This effect is evidently observed from the figure 15.

The effects of Dufour and Soret numbers are studied through the figures 16 and 17. The increase of temperature with the increase of Dufour number is observed through the figures 16.1 and 16.2. From the figure 17, it is observed that the temperature decreases with the decrease of Dufour number and increase of Soret number.

The substantial change in the Concentration distribution with variation of parameters like Schmidt number, Prandtl number, Suction / Injection Parameter, Dufour number are discussed through figures 18 to 22.

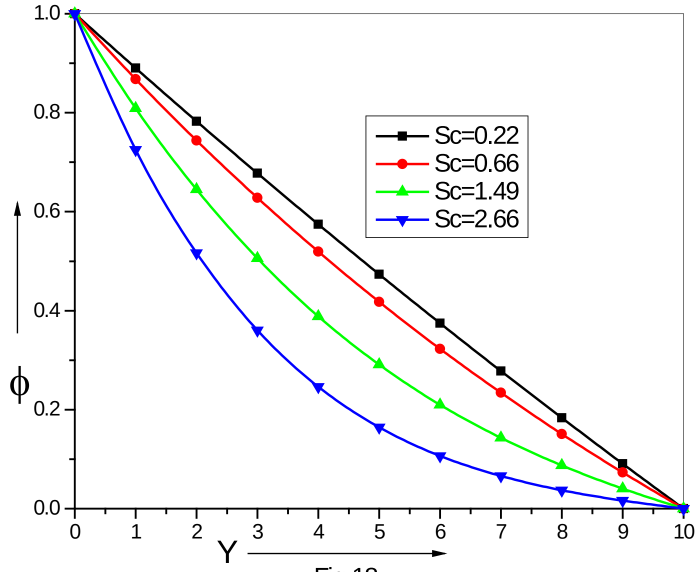

Fig.18
Concentration profiles for different values of Sc

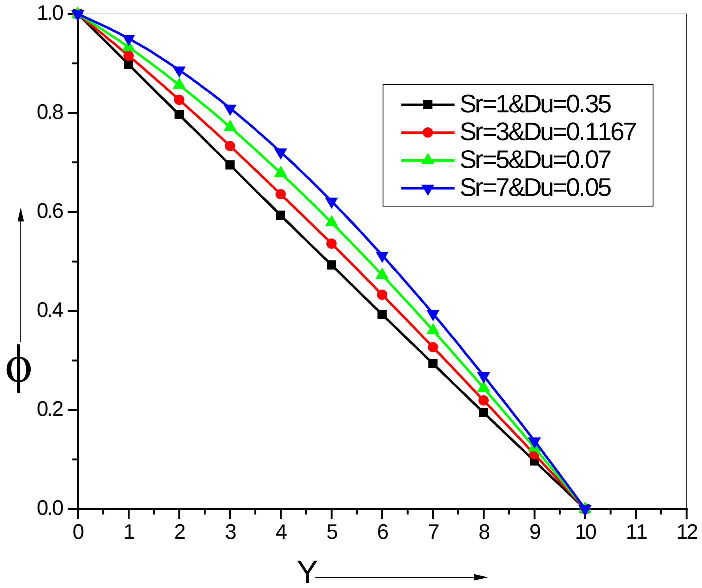

Fig. 19
Concentration profiles for different values of Sr&Du

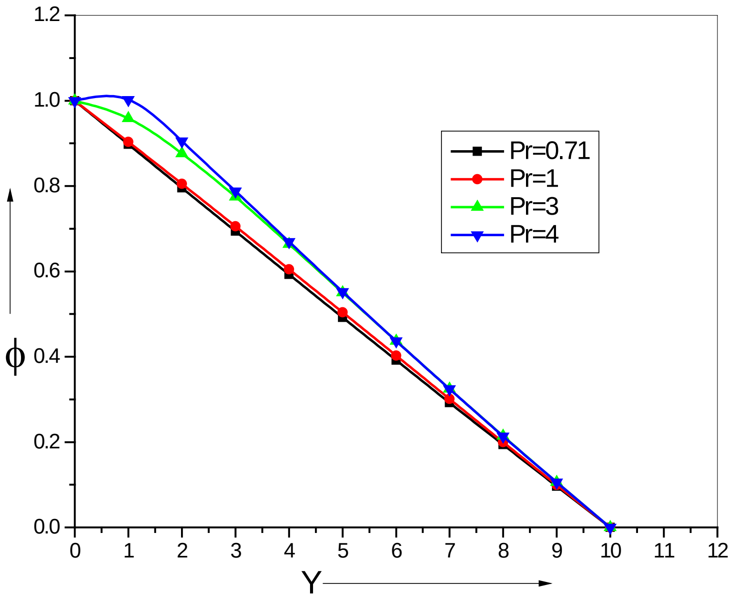

Fig. 20
Concetration profiles for different values of Pr

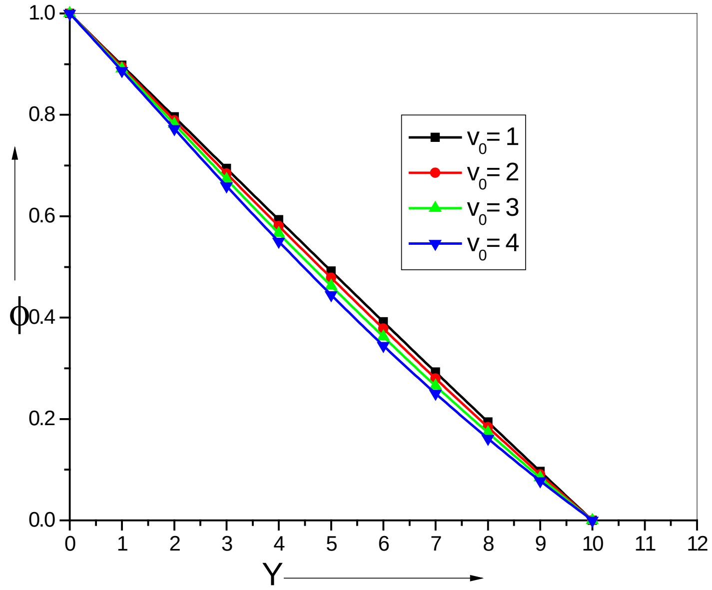

Fig. 21
Concentration profiles for different values of v_0

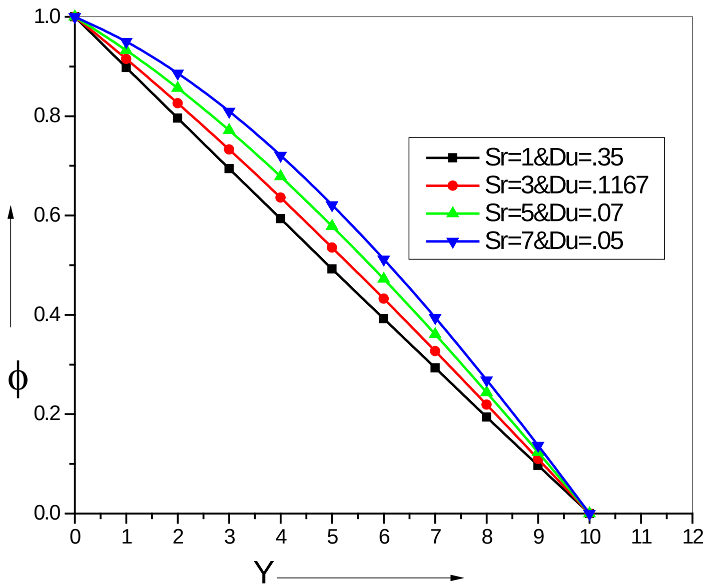

Fig. 22
Concentration profiles for different values of Sr&Du

The concentration distribution is vastly affected by the presence of foreign species such as Helium (Sc = 0.30) and Water vapor (0.60) which is given in the figure 18. The concentration profile is decreased with the increase of the Schmidt number i.e. with the presence of heavy foreign species.

The effects of Soret and Prandtl numbers on concentration profiles are shown in the figures 19 and 20. The increase of concentration of the fluid with the increase of Soret and Prandtl numbers is observed from these figures.

The effect of suction / injection is presented in the figure 21. When suction / injection increases the mass diffusion is higher and the concentration is decreased and then the plate cools faster. From the comparative study of Soret and Dufour numbers on the concentration distribution of the flow field is presented in figure 22. It is observed that the concentration distribution increases with increase of Soret number and decrease of Dufour number.

Table I Skin-Friction Coefficient (τ)

Gr	Gc	Pr	Sc	M	K	Sr	Du	v_0	Ec	τ
3	2	0.71	0.22	5	1	0.05	1	1	0.3	1.227162
5	2	0.71	0.22	5	1	0.05	1	1	0.3	1.704656
3	3	0.71	0.22	5	1	0.05	1	1	0.3	2.431493
3	2	1	0.22	5	1	0.05	1	1	0.3	1.195053
3	2	0.71	0.3	5	1	0.05	1	1	0.3	1.229276
3	2	0.71	0.22	10	1	0.05	1	1	0.3	1.052397
3	2	0.71	0.22	5	2	0.05	1	1	0.3	1.249185
3	2	0.71	0.22	5	1	0.35	1	1	0.3	1.226268
3	2	0.71	0.22	5	1	0.05	3	1	0.3	1.264324
3	2	0.71	0.22	5	1	0.05	1	3	0.3	1.191251
3	2	0.71	0.22	5	1	0.05	1	1	0.5	1.22632

Table I shows numerical values of the Skin–friction coefficient for various values of thermal Grashof number *Gr*, Solutal Grashof number *Gc*, Hartmann number *M* , Permeability parameter *K*, Prandtl number Pr , Soret number *Sr*, Schmidt number *Sc*, Dufour number *Du,* Suction or Injection parameter v_o and Eckert number Ec. From the table, we observed that, an increase in the Hartmann number, Prandtl number, Soret number and Suction or Injection parameter causes decrease in the value of the skin – friction coefficient while an increase in the thermal Grashof number, Solutal Grashof number, Schmidt number, Permeability parameter, Eckert number and Dufour number causes increase in the value of the skin–friction coefficient.

Table II Nusselt number (Nu)

Pr	M	Ec	Nu
0.71	5	0.30	-1.289214
0.71	10	0.30	-1.327993
1	5	0.30	-1.504724
0.71	5	0.50	-1.331331

Table II gives the numerical values of heat transfer coefficient in terms of Nusselt number Nu for various values of Prandtl number (Pr), Hartmann Number (M), and Eckert Number (Ec). It is clear that with the increase in the magnetic field (M) and the Prandtl number (Pr) leads to the rate of heat transfer decrease and an increase in the Eckert number (Ec) results in increase the rate of heat transfer.

Table III Sherwood number (Sh)

Sc	M	E	Sh
0.22	5	0.30	-1.10998
0.30	5	0.30	-1.368567
0.22	10	0.30	-1.10899
0.22	5	0.50	-1.108969

It is noticed that from table III, an increase in the Schmidt number Sc causes decrease in the value of mass transfer coefficient and as Eckert number and Hartmann number M increases the mass transfer increases.

6. **Conclusions**

A mathematical model has been presented for an unsteady MHD free convective fluid flow of a viscous incompressible and electrically conducting fluid past a vertical porous plate in the presence of suction or injection with variable velocity, temperature and concentration. From the study, the following conclusions can be made.

1. An increase in Gr, Gm, K, Sr and Du leads to increase in velocity profiles.
2. The velocity profile decreases with an increase in Sc, v_0, M, Pr and Ec.
3. An increase in the values of Pr, Ec, v_0 causes to decrease in temperature.

4. It is observed that decrease in Du and increase in Sr cause decrease in temperature.
5. It is observed that the effect of increasing Du results decrease in temperature.
6. An increase in Schmidt number Sc and Suction or injection parameter v_0 leads to decrease in concentration.
7. An increase in Pr and Sr and decrease in Du causes increase in concentration.
8. The local Skin-friction co-efficient increases with increase in Gr, Gm, Sc, K, Du and Ec where as the skin-friction co-efficient decreases with increase in M, Pr, Sr and v_0.
9. The local Nusselt number increases as Ec increases where as the Nusselt number decreases with increase in Pr and M.
10. The local Sherwood number increases when M, Ec increase and decreases as Sc increases.

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7. References

1. J.A.Shercliff. A text book of Magnetohydrodynamics", Pergamon Press, London, **1965**.
2. V.C.A.Ferraro, C. Plumption. An Introdution to Magneto Fluid Mechanics", ClarandonPress, Oxford, **1966**.
3. K.P.Crammer and S.L.Pai, "Magneto-fluid Dynamics for Engineers and Applied Physicist, Mc-Graw Hill book co., New York, **1973**
4. E.M.A.Elbashbeshy, Heat and mass transfer along a vertical plate in the presence of magnetic field *Int. Eng. Sc.* 34, P515-522, **1997**.
5. M.A.Hossain and D.A.S.Rees, The effects of combined buoyancy forces from thermal and mass diffusion by natural convection flow from a vertical wavy surface, *Acta Mech*., 136, P133-141, **1999**.

6 Chein – Hsin-Chen, Combined heat and mass transfer in MHD free convection from a vertical surface, *Int.J.Eng.Science*, 42, P699-713, **2004**.

7 M. A. Hossain, M. A. Alim and D. A. Rees, The radiation effects on free and forced convection flows past a vertical plate, *Int. J. Heat and Mass transfer*, 42, P131, **1999**.

8 M. A. Hossain, The effect of Ohmic heating on the MHD free convection heat transfer has been examined for a Newtonian fluid, *Int. J. Heat and Mass transfer*, 35, P3485, **1992**.

9 Chien-Hsin-Chen, The problem of combined heat and mass transfer of an electrically conducting fluid in MHD natural convection, adjacent to a vertical surface with Ohmic heating, *Int. J. Engineering Science*, 42, P699, **2004**.

10 P. Ganesan and G. Palani, Numerical solution of unsteady MHD flow past a semi infinite isothermal vertical plate, in: *Proceedings of the 6th ISHMT/ASME Head and Mass Transfer Conference and 17th National Heat and Mass Transfer Conference, January 5 –7, 2004, Kalpakkam, India*, P184–187, **2004**.

11 P. Ganesan and G. Palani, The numerical solution of transient free convection MHD flow of an incompressible viscous fluid flow past a semi- infinite inclined plate with variable surface heat and mass flux, *Int. J. Heat Mass Tran.*, **47**, P4449–4457, **2004**.

12 O. Aydin and A. Kaya, The mixed convection heat transfer about a permeable vertical plate in the presence of magneto and thermal radiation effects, *Heat Mass Transfer*, **45**, P239–246, **2008**.

13 O. Aydin, and A. Kaya, The problem of steady laminar magneto hydrodynamic (MHD) mixed convection heat transfer about a vertical plate, *Appl. Math. Model.*, **33** (11), P4086–4096, **2009**.

14 K.Sarada and B. Shanker, The effects of Soret and Dufour on an unsteady MHD free convective fluid flow of a viscous incompressible and electrically conducting fluid past a vertical porous plate in the presence of suction or injection, *Int.J. of Engineering and Science*, 2,7, P13-25, **2013**

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Figure titles:

1. Figure.1: Velocity profiles for different values of M.
2. Figure.2: Velocity profiles for different values of M&Ec.
3. Figure.3: Velocity profiles for different values of K.
4. Figure.4: Velocity profiles for different values of Pr.
5. Figure.5.1: Velocity profiles for different values of large Pr & Ec.
6. Figure.5.2: Velocity profiles for different values of Pr & Ec.
7. Figure.6: Velocity profiles for different values of v_0.
8. Figure.7: Velocity profiles for different values of Sr.
9. Figure.8: Velocity profiles for different values of Du.
10. Figure.9.1: Velocity profiles for different values of Sr & Du.
11. Figure.9.2: Velocity profiles for different values of Du &Sr.
12. Figure.10: Velocity profiles for different values of Gr.
13. Figure.11: Velocity profiles for different values of Gc.
14. Figure.12: Velocity profiles for different values of Sc.
15. Figure.13: Temperature profiles for different values of Pr.
16. Figure.14.1: Temperature profiles for different values of large Pr & Ec.
17. Figure.14.2: Temperature profiles for different values of Pr & Ec.
18. Figure.15: Temperature profiles for different values of v_0.
19. Figure.16.1: Temperature profiles for different values of Du.
20. Figure.16.2: Temperature profiles for different values of large Du.
21. Figure.17: Temperature profiles for different values of Du & Sr.
22. Figure.18: Concentration profiles for different values of Sc.
23. Figure.19: Concentration profiles for different values of Sr & Du.
24. Figure.20: Concentration profiles for different values of Pr.
25. Figure.21: Concentration profiles for different values of v_0.
26. Figure.22: Concentration profiles for different values of Du &Sr.