Thermal Energy Transmission In Free Convective MHD Flow Of A Rotating Oldroyd Fluid Past An Infinite Vertical Porous Plate With Mass Transport, Chemical Reaction And Heat Sources Subjected To Constant Suction

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Abstract-- This paper deals with the study of thermal energy transmission in free convective MHD flow of a rotating Oldroyd fluid past an infinite vertical porous plate with mass transport, chemical reaction, heat sources subjected to constant suction. Effects various fluid parameters on the flow pattern have been analyzed by graphs and tables obtained from numerical computation. It is observed that increase in rotation parameter increases primary velocity, but reverse effect is marked in case of secondary velocity. Temperature shows uniform decrease with the distance from the porous plate and the concentration falls with the rise of the Schmidt number (Sc).

Index Terms -- Convective flow, Mass transport, MHD, Oldroyd fluid, Porous plate, Suction, Thermal energy

1 Introduction

The motivation of the present study is the fact that both free and forced convection exist simultaneously in many applications. This is particularly relevant in situations where the Grashof number is large, as in the extractions of crude oil, when free-convection effect is important.

One of the most basic problems in natural convection heat transfer is the buoyant boundary layer flow along a heated vertical wall adjacent to a fluid saturated porous medium. The basic problem was analyzed for the first time by Cheng and Minkowycz[1] and similarly solutions were obtained.

An experimental investigation of free convection for a heated vertical plate was made by Cheng et al.[2] to study the non-Darcian effects. Cheng and Ali[3] performed an experimental investigation for free convection over heated inclined surface in a porous media. Also Kaviany and Mittal[4] studied natural convection from a vertical plate experimentally for high permeability porous medium.

Natural convection over a non-isothermal body of arbitrary geometry placed in a porous medium with viscous dissipation term in the energy equation was analyzed by Nakayama and Pop[5].

Chen and Chen[6] were the first to consider the free convection flow of non-Newtonian fluids past an isothermal vertical flat plate embedded in a porous medium. Boundary layer flow and heat transfer of non-Newtonian fluids in a porous medium was investigated by Wang and Tu[7].

The stimulus for scientific research on rotating fluid systems is basically originated from geophysical and fluid engineering applications. Many aspects of the motion of terrestrial and planetary atmospheres are also highly influenced by the effect of rotation. Rotating flow theory is utilized in determining the viscosity of the fluid in the construction of the turbine and other centrifugal machines.

The problem of free convection MHD flow through porous media of a rotating / non rotating fluid with heat and mass transfer has been a subject of interest of several researchers. Hossain and Mohammad[8] studied the effect of Hall current on hydromagnetic free convection flow near an accelerated porous plate. Effects of magnetic field on the free

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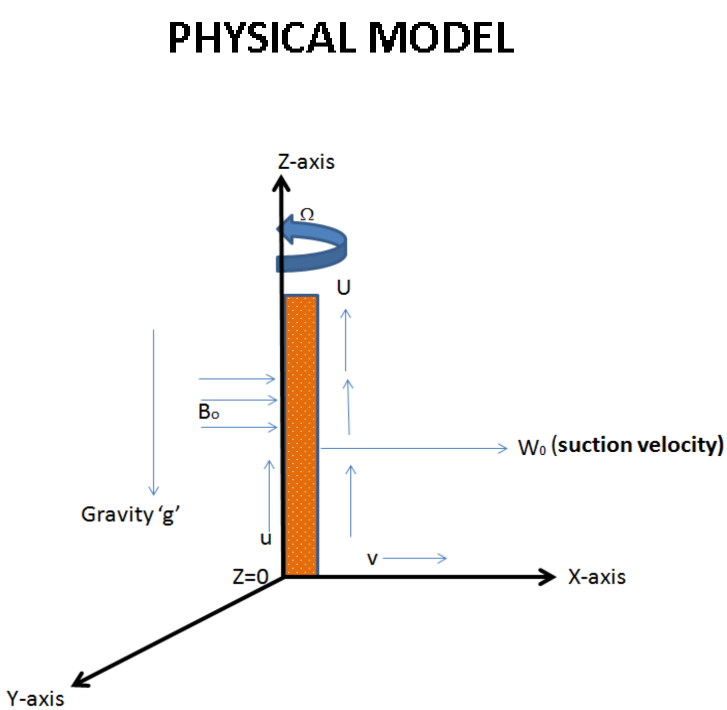
convection and mass transfer flow through porous medium with constant suction and heat flux was studied by Acharya et al.[9], Dash and Rath[10] have investigated the effect of Hall current and hydromagnetic free convection flow near an exponentially accelerated porous plate with mass transfer. The hydromagnetic Rayleigh problem in a rotating fluid has been studied by Rapties and Singh[11].

Ece[12] has studied the free convection flow about a cone under mixed thermal boundary conditions and a magnetic field. Acharya et. al.[13] have studied non-parallel vertex instability of natural convection flow over a non-isothermal inclined flat plate with simultaneous thermal and mass diffusion. Free convection heat and mass transfer from a horizontal cylinder of elliptic cross section in micropolar fluids has been studied by Yang[14]. Guria et. al.[15] have investigated the three dimensional free convection flow in a vertical channel filled with a porous medium.

From the literature it is observed that a very few problem of generalized Darcy free convective flow of non-Newtonian fluids on a vertical surface in a rotating frame of reference has been reported so far. The main objective of the present problem is to study thermal energy transmission in free convective MHD flow of a rotating Oldroyd[16] B′ fluid past an infinite vertical porous plate with mass transport, chemical reaction and heat sources subjected to constant suction.

2 Formulation of the Problem



In the present study the steady free convective flow and mass transfer associated with a rotating elastico-viscous electrically conducting fluid (Oldroyd fluid) through porous media occupying a semi-infinite region of the space bounded by an infinite vertical porous plate with constant suction and heat flux subject to a transverse magnetic field and species concentration at the free stream are assumed to be constant. We consider a Cartesian co-ordinate system rotating uniformly with the fluid in rigid state of rotation with constant angular velocity Ω about z-axis. The vertical plate is assumed to coincide with the plane z=0. Here, the physical variables except the pressure are functions of z only. Thus the equation of continuity gives $W=-W_0$, $W_0 > 0$ is the suction velocity normal to the plate.

Taking into account the Boussinesq approximation, the equations which govern the flow are

$$-W_0 \frac{du}{dz} - 2\Omega v = -\frac{1}{\rho}\frac{dP'_{13}}{dz} + g\beta(T-T_\infty) + g\beta^*(C-C_\infty) - \frac{\sigma B_0^2 u}{\rho} - \frac{\nu u}{k^*}, \quad (2.1)$$

$$-W_0 \frac{dv}{dz} + 2\Omega u = \frac{1}{\rho}\frac{dP'_{23}}{dz} - \frac{\sigma B_0^2 v}{\rho} - \frac{\nu u}{k^{*'}}, \quad (2.2)$$

$$-W_0 \frac{dT}{dz} = \frac{k}{\rho C_p}\frac{d^2T}{dz^2} + S'(T-T_\infty), \quad (2.3)$$

$$-W_0 \frac{dc}{dz} = D\frac{d^2C}{dz^2} - \lambda^n, \quad (2.4)$$

where ρ is the density of the fluid,

ν is the coefficient of kinematic viscosity

g is the acceleration due to gravity,

β is the volumetric coefficient of thermal expansion,

β^* is the volumetric coefficient of concentration expansion

σ is the electrical conductivity,

k^* is the permeability parameter,

B_0 is the magnetic induction,

k is thermal conductivity,

C_P is the specific heat of the fluid,

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D is the mass diffusion coefficient,

$S^{/}$ is the source strength parameter,

λ^n is the reaction rate term.

The initial boundary conditions are

$$\left.\begin{array}{l} u=0\ ,\ \mathrm{v}=0\ ,\ \dfrac{dT}{dz}=\dfrac{-q}{k}\ ,\ C=C_w \quad \text{at} \quad z=0 \\ u\to 0\ ,\ \mathrm{v}\to 0\ ,\ T\to T_\infty\ ,\ C\to C_\infty\ \text{ as } z\to\infty \end{array}\right\} \tag{2.5}$$

where the components of stress tensor P'_{13} and P'_{23} are expressed by the implicit relations.

$$\left(1-\lambda_1 W_0\frac{d}{dz}\right)P'_{13} = \eta_0\left[\frac{du}{dz}-\lambda_2 W_0\frac{d^2u}{dz^2}\right], \tag{2.6}$$

$$\left(1-\lambda_1 W_0\frac{d}{dz}\right)P'_{23} = \eta_0\left[\frac{d\mathrm{v}}{dz}-\lambda_2 W_0\frac{d^2\mathrm{v}}{dz^2}\right], \tag{2.7}$$

In the equations (2.6) and (2.7), η_0, λ_1, λ_2 which are all positive denote the coefficient of viscosity stress relaxation and strain retardation time respectively with $\lambda_1>\lambda_2$. The subscripts w and ∞ mean the conditions at the porous surface and far away from the plate. Eliminating P'_{13} and P'_{23} from equation (2.1) and (2.2) with the help of equations (2.6) and (2.7) taking $U = u+i\mathrm{v}$ and introducing the non-dimensional quantities.

$$U'=\frac{U}{W_0}\ ,\ z'=\frac{W_0 z}{\nu}\ ,\ \alpha_1=\frac{\lambda_1 W_0^2}{\nu}\ ,\ \alpha_2=\frac{\lambda_2 W_0^2}{\nu}\ ,$$

$$T'=(T-T_\infty)\frac{kW_0}{q\nu}\ ,\ C'=\frac{C-C_\infty}{C_w-C_\infty}\ ,\ R=\frac{\Omega\nu}{W_0^2}\ ,$$

$$G_r=\frac{g\beta\nu^2 q}{kW_0^4}\ ,\ G_c=\frac{\gamma g\beta^*(C-C_\infty)}{W_0^3}\ ,\ M=\sqrt{\frac{\sigma B_0^2\nu}{\rho W_0^2}}\ ,$$

$$P_r=\frac{\rho\nu C_P}{W}\ ,\ S_c=\frac{\nu}{D}\ ,\ K_P=\frac{W_0^2 k^*}{\nu^2}\ ,$$

$$K_n=\left(\frac{\lambda^n C}{C_w-C_\infty}\right)\frac{\nu}{W_0^2}\ ,\ S=\frac{S'\nu}{W_0^2}\ ,$$

equations (2.1) – (2.4) become (dropping the primes)

$$\alpha_2\frac{d^3u}{dz^3}+(\alpha_1-1)\frac{d^2u}{dz^2}-\left\{1+2i\alpha_1 R+(M^2+\frac{1}{K_P})\alpha_1\right\}\frac{du}{dz}$$

$$+\left(2iR+M^2+\frac{1}{K_P}\right)U = G_rT+G_cC-\alpha_1 G_r\frac{dT}{dz}-\alpha_1 G_c\frac{dC}{dz}, \tag{2.8}$$

$$\frac{d^2T}{dz^2}+P_r\frac{dT}{dz}+P_r\,ST = 0\ , \tag{2.9}$$

$$\frac{d^2C}{dz^2}+S_c\frac{dC}{dz}-K_n S_c C = 0\ , \tag{2.10}$$

Subject to the boundary conditions

$$\left.\begin{array}{l} U=0\ ,\ \dfrac{dT}{dz}=-1\ ,\ C=1 \quad \text{at} \quad z=0 \\ U\to 0\ ,\ T\to 0\ ,\ C\to 0\ \text{ as } z\to\infty \end{array}\right\} \tag{2.11}$$

3 Solutions of the Equations

The solutions of equations (2.9) and (2.10) under the boundary conditions (2.11) are

$$T = \frac{1}{\frac{1}{2}(P_r+\sqrt{P_r^2-4P_rS}}\,.\,e^{-\frac{(P_r+\sqrt{P_r^2-4P_r S}}{2}} \tag{3.1}$$

$$C=e^{-\left(S_c+\sqrt{S_c^2+4K_nS_c}\right)z} \tag{3.2}$$

Inserting equations (3.1) and (3.2) in equation (2.8), we get

$$\alpha_2\frac{d^3U}{dz^3}+(\alpha_1-1)\frac{d^2U}{dz^2}-A_8\frac{dU}{dz}+A_{10}U = A_3G_r\,e^{-A_3 z}$$

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$$+G_c\, e^{-A_4 z} - \alpha_1\, G_r e^{-A_3 z} + \alpha_1 G_c A_4 e^{-A_4 z}$$
(3.3)

Integrating the above equations once with respect to z, we have

$$\alpha_2 \frac{d^2U}{dz^2} + (\alpha_1 - 1)\frac{dU}{dz} - A_{11}U = -G_r e^{-A_3 z} - \frac{G_c}{A_4 e^{-A_4 z}}$$
$$+\frac{\alpha_1 G_r}{A_3 e^{-A_3 z}} - \alpha_1\, G_c\, e^{-A_4 z} + C_1$$
(3.4)

Dividing by α_2 to both the sides of equation (3.4), we get

$$\frac{d^2U}{dz^2} + A_{12}\frac{dU}{dz} - A_{13}U = A_{14}e^{-A_3 z} - A_{15}e^{-A_4 z} + A_{16}e^{-A_3 z}$$
$$-A_{17}e^{-A_4 z} + C_1 \quad (3.5)$$

where $A_{12} = \dfrac{\alpha_1 - 1}{\alpha_2}$, $A_{15} = \dfrac{G_c}{\alpha_2 A_4}$

$A_{13} = \dfrac{A_{11}}{\alpha_2}$, $A_{16} = \dfrac{\alpha_1 G_r}{\alpha_2 A_3}$

$A_{14} = \dfrac{-G_r}{\alpha_2}$, $A_{17} = \dfrac{\alpha_1 G_c}{\alpha_2}$

Solving equation (3.5), we get

$$U = A_{24}C_1 + C_2 e^{-A_{18} z} + C_3\, e^{-A_{19} z} + A_{25}\, e^{-A_3 z} - A_{26}\, e^{-A_4 z}$$
(3.6)

Using boundary conditions

when $z \to 0$, $U = 0$

$z \to \infty$, $U = 0$

to equations (2.11) – (3.6), we have

$$U = A_{29}\, e^{-A_{18} z} + A_{28}\, e^{-A_{19} z} + A_{25}\, e^{-A_3 z} - A_{26} e^{-A_4 z}$$
(3.7)

where $A_{20} = \dfrac{A_{14}}{A_3^2 - A_3 A_{12} - A_{13}}$

$$A_{21} = \frac{A_{15}}{A_4^2 - A_4 A_{12} - A_{13}}$$

$$A_{22} = \frac{A_{16}}{A_3^2 - A_3 A_{12} - A_{13}}$$

$$A_{23} = \frac{A_{17}}{A_4^2 - A_4 A_{12} - A_{13}}$$

Substituting the values of the constants in equation (3.7), we get

$$U = \Big(A_{49} \cos A_{52}\, z\, e^{-A_{51} z} - A_{50} \sin A_{52}\, z\, e^{-A_{51} z} + A_{47} \cos A_{54}\, z\, e^{-A_{53} z}$$
$$-A_{48} \sin A_{54}\, z\, e^{-A_{53} z} + A_{35}\, e^{-A_3 z} - A_{37}\, e^{-A_4 z}\Big)$$
$$+i\Big(A_{49} \sin A_{52}\, z\, e^{-A_{51} z} + A_{50} \cos A_{52}\, z\, e^{-A_{51} z} - A_{47} \sin A_{54}\, z\, e^{-A_{53} z}$$
$$-A_{48} \cos A_{54}\, z\, e^{-A_{53} z} - A_{36}\, e^{-A_3 z} + A_{38}\, e^{-A_4 z}\Big)$$
(3.8)

where $U = u + i\mathrm{v}$,

$$u = A_{49} \cos A_{52}\, z\, e^{-A_{51} z} - A_{50} \sin A_{52}\, z\, e^{-A_{51} z}$$
$$+A_{47} \cos A_{54}\, z\, e^{-A_{53} z} - A_{48} \sin A_{54}\, z\, e^{-A_{53} z}$$
$$+A_{35}\; e^{-A_3 z} - A_{37}\; e^{-A_4 z}$$

and

$$\mathrm{v} = A_{49} \sin A_{52}\, z\, e^{-A_{51} z} + A_{50} \cos A_{52}\, z\, e^{-A_{51} z}$$
$$-A_{47} \sin A_{54}\, z\, e^{-A_{53} z} - A_{48} \cos A_{54}\, z\, e^{-A_{53} z}$$
$$-A_{36}\; e^{-A_3 z} + A_{38}\; e^{-A_4 z}$$

Skin-frictions :

$$\tau_P = \left[\frac{\partial u}{\partial z} + (\alpha_1 - \alpha_2)\frac{\partial^2 u}{\partial z^2}\right]_{z=0}$$
$$= \big(-A_{49}A_{51} - A_{50}A_{52} - A_{47}A_{53} - A_{48}A_{54} - A_3\, A_{35} + A_4 A_{37}\big)$$
$$+(\alpha_1 - \alpha_2)\,\big(A_{49}A_{51}^2 - A_{49}A_{52}^2 + 2A_{50}A_{51}A_{52} + A_{47}A_{53}^2$$

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$$-A_{47}\,A_{54}^2+2A_{48}A_{53}\,A_{54}+A_3^2A_{35}-A_4^2A_{37}\Big)$$

$$\tau_P^* = \left[\frac{\partial u}{\partial z}+(\alpha_1-\alpha_2)\frac{\partial^2 u}{\partial z^2}\right]_{z=\infty}=0$$

$$\tau_S = \left[\frac{\partial v}{\partial z}+(\alpha_1-\alpha_2)\frac{\partial^2 v}{\partial z^2}\right]_{z=0}$$

$$=\big(A_{49}A_{52}-A_{50}A_{51}-A_{47}A_{54}+A_{48}A_{53}+A_3\,A_{36}-A_4A_{38}\big)$$

$$+(\alpha_1-\alpha_2)\,\Big(2A_{47}A_{53}A_{54}-2A_{49}A_{51}A_{52}+A_{50}A_{51}^2$$

$$-A_{50}\,A_{52}^2-A_{48}A_{53}^2+A_{48}A_{54}^2\Big)$$

$$\tau_S^* = \left[\frac{\partial v}{\partial z}+(\alpha_1-\alpha_2)\frac{\partial^2 v}{\partial z^2}\right]_{z=\infty}=0$$

Rate of heat transfer :

We have

$$T=\frac{1}{\tfrac{1}{2}(P_r+\sqrt{P_r^2-4P_rs})}\cdot e^{-\frac{1}{2}(P_r+\sqrt{P_r^2-4P_rs})z}$$

$$Nu_0=-\left.\frac{dT}{\partial z}\right|_{z=0}$$

$$=\frac{1}{-\tfrac{1}{2}(P_r+\sqrt{(P_r^2-4P_rs)}}\times\left\{-\tfrac{1}{2}(P_r+\sqrt{P_r^2-4P_rs}\right\}\times e^{-\frac{1}{2}(\sqrt{P_r^2-4P_rs})z}$$

$$\therefore\ Nu=1$$

$$Nu_1=-\left.\frac{\partial T}{\partial z}\right|_{z=1}=e^{-\frac{1}{2}(P_r+\sqrt{P_r^2-4P_rs})}$$

Concentration Gradient :

We have $C=e^{-\frac{1}{2}(S_c+\sqrt{S_c^2+4K_nS_c})z}$

$$CG_0=-\left.\frac{\partial C}{\partial z}\right|_{z=0}$$

$$=-\left\{-\tfrac{1}{2}(S_c+\sqrt{S_c^2+4K_nS_c})\right\}\,e^{-\frac{1}{2}(S_c+\sqrt{S_c^2+4K_nS_c})z}$$

$$CG_0=\tfrac{1}{2}\left(S_c+\sqrt{S_c^2+4K_nS_c}\right)$$

$$CG_1=-\left.\frac{\partial C}{\partial z}\right|_{z=1}$$

$$=\tfrac{1}{2}(S_c+\sqrt{S_c{}^2+4K_nS_c})\;e^{-\frac{1}{2}(S_c+\sqrt{S_c{}^2+4K_nS_c})z}$$

4 Results and discussion

In this chapter, we have studied the thermal energy transmission in free convective magnetohydrodynamic flow of a rotating Oldroyd fluid past an infinite vertical porous plate with mass transport, chemical reaction, heat sources, subjected to constant suction. Effects of various fluid parameters on the flow pattern have been analysed by graphs and tables obtained from numerical computation. The fluid parameters involved in the problem are the non-dimensional parameters given earlier. Let us portray the effects of such fluid parameters illuminated from the graphs drawn for primary and secondary velocity profiles.

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Fig. 1 : Primary and Secondary velocity profiles

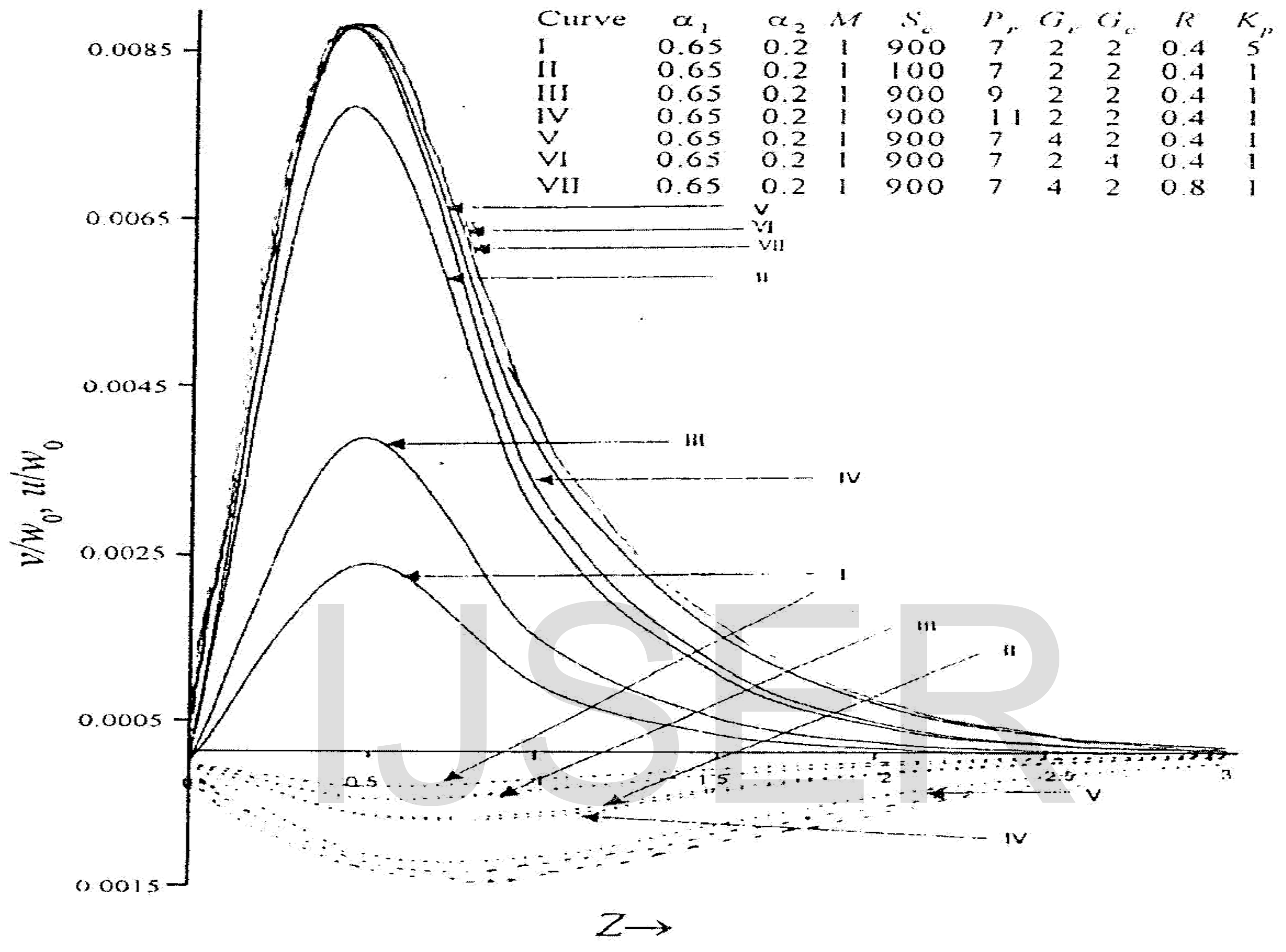

Fig. 1 presents the primary and secondary profiles varied with the various fluid parameters. It is observed that the decrease in the porosity parameter (K_P) raises the primary velocity component (u/w). Increase in Prandtl number reduces the primary velocity (curve III) and decease in Prandtl number sharply raises the primary velocity (curve IV). Increase in the thermal Grashof number (G_r) increases the primary velocity (curve V). Same effect is marked in case of modified Grashof number (G_c). Increasing the rotation parameter (R), the primary velocity is increased. The secondary velocity shows a reverse nature relative to the primary velocity as shown in Fig. 1.

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Fig-2 Temperature profile for z = 0, α_1 = 0.5, α_2 = 0.2, M = 1, R = 0.2, G_r = 5, G_c = 2, K_p = 1, S_c = 9, K_n = 5

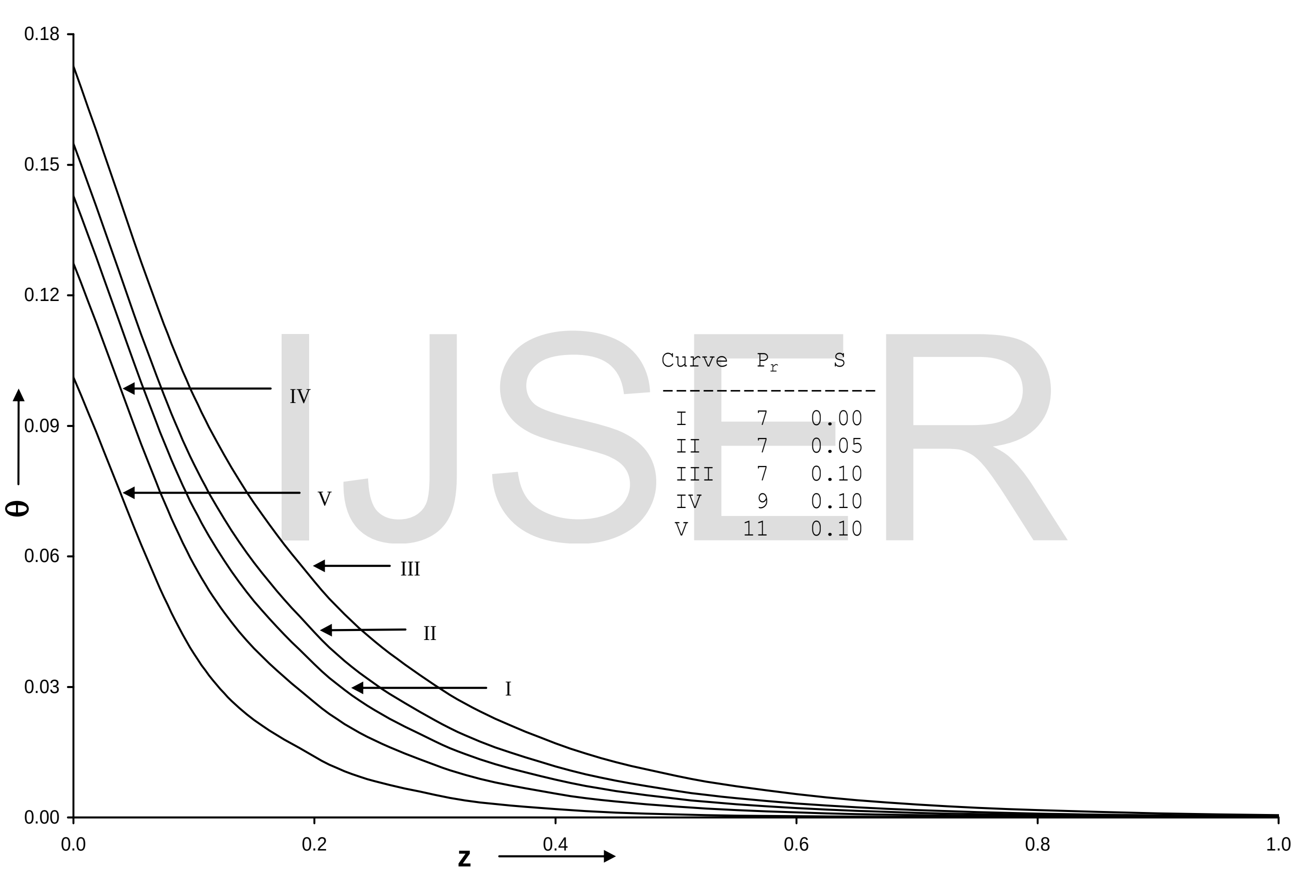

Fig. 2 shows the variation of temperature (θ) with the change of Prandtl number P_r and source parameter S. Temperature shows uniform decrease with the distance from the porous plate. As the source parameter increases the temperature raises (curve I, II, III). On the other hand, increase in the value of Prandtl number lowers the temperature of the fluid.

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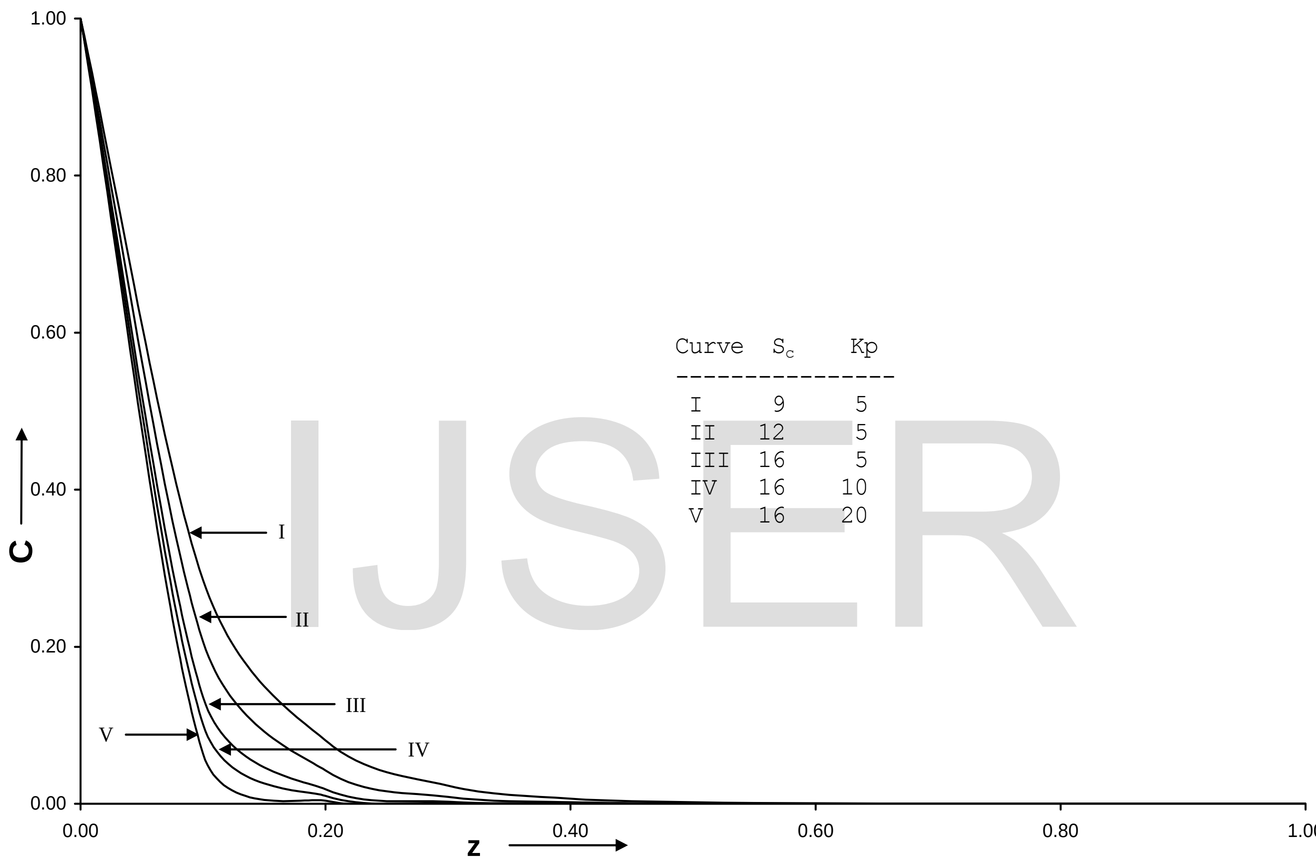
Fig-3 Concentration profile for $P_r = 7$, $z = 0$, $S = 0.05$, $\alpha_1 = 0.5$, $\alpha_2 = 0.2$, $M = 1$, $R = 0.2$, $G_r = 5$, $G_c = 2$, $Kp = 1$



Variation of concentration with the change of Schmidt number (S_c) and permeability parameter (K_P) has been reflected in Fig.3. As the value of S_c increases, the concentration falls. Same effect is also observed in case of permeability parameter (K_P).

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Skin-friction :

Table - 1

Values of the skin-friction τ_p of the primary flow

α_1	α_2	M	G_r	G_c	R	K_p	τ_p
0.5	0.2	1	5	2.00	0.2	1	9.2732
0.5	0.4	1	5	2.00	0.2	1	-1.7192
0.5	0.4	2	5	2.00	0.2	1	-12.6022
0.5	0.4	2	10	2.00	0.2	1	-26.8161
0.5	0.4	2	10	4.00	0.2	1	-25.2044
0.5	0.4	2	10	4.00	0.4	1	-24.7960
0.5	0.4	2	10	4.00	0.4	3	-19.8091
0.5	0.4	2	10	4.00	0.4	5	-18.8062

The values of the skin-friction τ_P of the primary flow are entered in the table-1 for various values of the fluid parameters involved in the problem. From these numerical values of the skin-friction, it is observed that increasing α_2, the skin-friction τ_P decreases and attains a negative value.

The increase in the magnetic field strength, further reduces the skin-friction τ_P. Same effect is marked in case of thermal Grashof number G_r, but reverse effect is seen in case of modified Grashof number G_c. Increase in rotation parameter R decreases the skin-friction. Same effect is noticed in case of permeability parameter (K_P).

Table – 2
Values of the skin-friction τ_s of the secondary flow

α_1	α_2	M	G_r	G_c	R	K_p	τ_s
0.5	0.2	1	5	2.00	0.2	1	-8.3622
0.5	0.4	1	5	2.00	0.2	1	-1.7261
0.5	0.4	2	5	2.00	0.2	1	-2.5083
0.5	0.4	2	10	2.00	0.2	1	-5.3961
0.5	0.4	2	10	4.00	0.2	1	-5.0165
0.5	0.4	2	10	4.00	0.4	1	-10.0639
0.5	0.4	2	10	4.00	0.4	3	-10.3119
0.5	0.4	2	10	4.00	0.4	5	-10.3917

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Table -2 presents the values of the skin-friction τ_S of the secondary flow. It is observed that the rise in the value of α_2 raises the value of τ_S. Increase in the value of magnetic parameter (*M*) decreases the skin-friction τ_S. When thermal Grashof number (G_r) takes higher values, the skin-friction decreases. Rise in the value of modified Grashof number (G_c) raises the skin-friction slightly. Increase in rotation parameter (*R*) decreases the skin-friction τ_S. Similar effect is marked in case of permeability parameter (K_P).

Table - 3

Values of the rate of heat transfer Nu_0 and Nu_1 of the flow

P_r	S	Nu_0	Nu_1
7	0.00	1.00000	0.00091
7	0.05	1.00000	0.00096
7	0.10	1.00000	0.00101
9	0.05	1.00000	0.00013
11	0.05	1.00000	0.00002
9	0.10	1.00000	0.00014

Values of the rate of heat transfer Nu_0 and Nu_1 of the flow are entered in table-3. It is seen that the increase in the source parameter (*S*) increases the rate of heat transfer Nu_1 at a distance *z*=1 from the plate. Increase in the value of Prandtl number (P_r) reduces the value of Nu_1. However, there is no change in the rate of heat transfer at the plate (*z* = 0), i.e. the rate of heat transfer Nu_0 at the plate remains constant.

Table - 4

Values of the concentration gradient CG_0 & CG_1 of the flow

S_c	Kp	CG_0	CG_1
9	5	12.57775	0.00004337
12	5	15.79796	0.00000218
16	5	20.00000	0.00000004
9	10	15.00000	0.00000459
9	20	18.65097	0.00000015
16	10	22.96663	0.00000000

Table-4 contains the values of the concentration gradients CG_0 and CG_1 of the flow at the plate and away from the plate. It is observed that increase in the value of Schmidt number (S_c) increases concentration gradient (CG_0) at the plate and reduces CG_1 at a distance *z*=1 away from the plate. Rise in the value of the permeability parameter K_p raises the concentration gradient CG_1. It is worth-mentioning here that when K_P takes 10 and S_c = 16, the concentration gradient CG_1 becomes zero.

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5 Conclusions

Following conclusions are gleaned from the above discussions.

(i) Increase in rotation parameter increases primary velocity. But reverse effect is marked in case of secondary velocity.

(ii) Decrease in the permeability parameter (K_P) increases the primary velocity.

(iii) Temperature shows uniform decrease with the distance from the porous plate.

(iv) Rise in the value of source parameter raises the temperature of the fluid.

(v) Increase in the value of Prandtl number lowers the temperature of the fluid.

(vi) The concentration falls with the rise of the Schmidt number (S_c) .

(vii) Permeability parameter K_P plays the same role as the Schmidt number (S_c).

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