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EFFECT OF CHEMICAL REACTION ON UNSTEADY CONVECTIVE HEAT AND MASS TRANSFER FLOW IN A VERTICAL CHANNEL WITH WALLS MAINTAINED AT OSCILLATARY TEMPERATURE AND CONCENTRATION

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ABSTRACT

We analyze the effect of chemical reaction and thermal radiation on unsteady convective heat and mass transfer flow in a vertical channel whose walls are maintained at oscillatory temperature and concentration. The governing equations are solved by a perturbation technique. The velocity, temperature and concentration, the rate of heat and mass transfer are discussed for different variations of the governing parameters.

Key Words: *Chemical reaction, Radiation, heat sources, Vertical channel.*

1. INTRODUCTION

The process of free convection as a mode of heat transfer has wide applications in the fields of Chemical Engineering, Aeronautical and Nuclear power generation. It was shown by Gill and Casal [9a] that the buoyancy significantly affects the flow of a low Prandtal number fluid which is highly sensitive to gravitational force and the extent to which the buoyancy force influences a forced flow is a topic of interest. Free convection flows between two long vertical plates have been studied for many years because of their engineering applications in the fields of nuclear reactors, heat exchangers, cooling appliances in electronic instruments. These flows were studied by assuming the plates at two different constant temperatures or temperature of the plates varying linearly along the plates etc. The study of fully developed free convection flow between two parallel plates at constant temperature was initiated by Ostrach [19]. Combined natural and forced convection laminar flow with linear wall temperature profile was also studied by Ostrach [20]. The first exact solution for free convection in a vertical parallel plate channel with asymmetric heating for a fluid of constant properties was presented by Anug [2]. Many of the early works on free convection flows in open channels have been reviewed by Manca *et al.* [11]. Several authors [7, 10, 15, 16, 21,27,28] have investigated convective heat transfer flow in channels under different conditions. There are many reasons for the flow to become unsteady. When the current is periodic due to on-off control mechanisms or due to partially rectified *a-c* voltage, there exist periodic heat inputs. Hence, it is important to study the effects of periodic heat flux on the unsteady natural convection, imposed on one of the plates of a channel formed by two long vertical parallel plates, the other being held at a constant initial fluid temperature. Recently Narahari [17] has discussed the unsteady free convection flow of dissipative viscous incompressible fluid between two long vertical parallel plates in which the temperature of one of the plates is oscillatory whereas that of the other plate is uniform.

In the context of space technology and in processes involving high temperatures, the effects of radiation are of vital importance. Recent developments in hypersonic flights, missile reentry, rocket combustion chambers, power plants for inter planetary flight and gas-cooled nuclear reactors have focused attention on thermal radiation as a mode of energy transfer and emphasize the need for improved understanding of radiative transfer in these processes. Several researchers [3-6, 8, 12, 13, 21a, 22-26] have studied the effect of thermal radiation on convective heat transfer flow in channels under varied conditions. The thermal radiation effects on heat transfer in magneto-aerodynamic boundary layers has also received some attention, owing to astronautically re-entry, plasma flows in astrophysics, the planetary magneto-boundary layer and MHD propulsion systems. Mosa [14] discussed one of the first models for combined radiative hydromagnetic heat transfer, considered the case of free convective channel flows with an axial temperature gradient. Nath *et al.* [18] obtained a set of similarity solutions for radiative – MHD stellar point explosion dynamics using shooting methods. Abd-El-Naby *et al* [1] presented a finite difference solution of radiation effects on MHD unsteady free convection flow over a vertical porous plate.

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In this paper, we investigate the effect of chemical reaction and thermal radiation on unsteady convective heat and mass transfer flow in a vertical channel whose walls are maintained at oscillatory temperature and concentration. The governing equations are solved by a perturbation technique. The velocity, temperature and concentration, the rate of heat and mass transfer are discussed for different variations of the governing parameters.

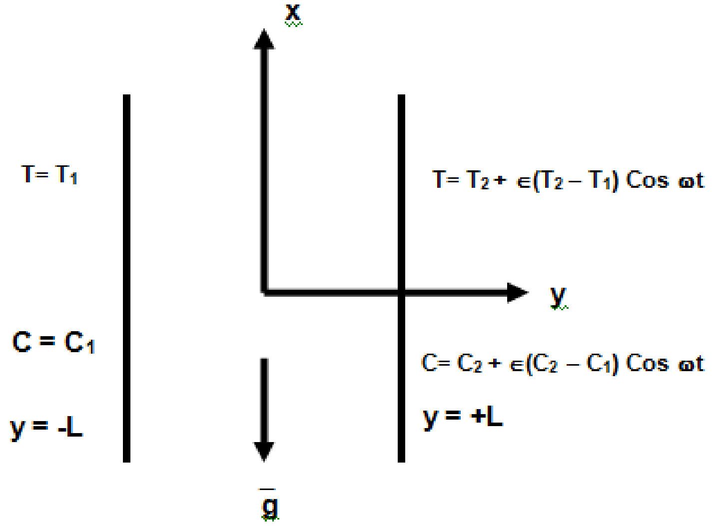


Fig. 1 – Configuration of the problem

2. FORMULATION AND SOLUTION OF THE PROBLEM

We consider the unsteady flow of a viscous incompressible fluid in a vertical channel bounded by flat walls in the presence of temperature dependent heat sources. The unsteadiness in the flow is due to the oscillatory temperature and concentration prescribed on the boundaries. We choose a Cartesian coordinate system 0(x y) with walls at y = ± L by using Boussinesq approximation we consider the density variation only on the buoyancy term also the kinematic viscosity υ,the thermal conductivity k are treated as constants. The equations governing the flow and heat transfer are

$$\frac{\partial u}{\partial t}=\frac{\mu}{\rho}\frac{\partial^2 u}{\partial y^2}-(\sigma\mu_e^2 H_o^2/\rho_o)u-\rho\,\bar{g} \tag{1}$$

$$\rho_0 C_p\frac{\partial T}{\partial t}=K_f\frac{\partial^2 T}{\partial y^2}-Q(T-T_0)-\frac{\partial(q_R)}{\partial y} \tag{2}$$

$$\frac{\partial C}{\partial t}=D_B\frac{\partial^2 C}{\partial y^2}-k_1 C \tag{3}$$

$$\rho-\rho_o=-\beta_0(T-T_o)-\beta^\bullet(C-C_o) \tag{4}$$

where u is a velocity component in x-direction, T, C are the temperature, Concentration, p is a pressure, ρ is a density, k is the permeability of the porous medium,μ is dynamic viscosity, k_f is coefficient of thermal conductivity, βo is coefficient of volume expansion, $\beta^\bullet$ is the volumetric coefficient of expansion with mass fraction, D_1 is the molecular diffusivity, Q is the strength of heat source, σ is the electrical conductivity, μe is the magnetic permeability of the medium.

The boundary conditions are

u = 0, $T = T_1$, $C = C_1$ y = -L
u = 0, $T = T_1 + \in(T_2 - T_1)\cos(\omega t)$,
$C = C_1 + \in(C_2 - C_1)\cos(\omega t)$ on y=+L (5)

By Rosseland approximation (Brewester [5]) the energy equation reduces to

$$\rho_0 C_p\frac{\partial T}{\partial t}=k_f\frac{\partial^2 T}{\partial y^2}-Q(T-T_0)+\frac{16\sigma^* T_e^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2}$$

Introducing the non - dimensional variables

$$u'=\frac{u}{\gamma/L},\ y'=y/L,\ \theta=\frac{T-T_1}{T_2-T_1},\ C'=\frac{C-C_1}{C_2-C_1},\ t'=\omega t,$$

Equations (1 - 3) reduce to (dropping the dashes)

$$\gamma^2 \frac{\partial u}{\partial t} = G(\theta^2 + NC) + \frac{\partial^2 u}{\partial y^2} - (M^2)u \tag{6}$$

$$P\gamma^2 \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - \alpha\,\theta + \frac{4}{3N_1}\frac{\partial^2 \theta}{\partial y^2} \tag{7}$$

$$Sc\gamma^2 \frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} - KC \tag{8}$$

where

$G = \beta g L^3 \dfrac{(T_2 - T_1)}{\gamma^2}$ (Grashof number), $M^2 = \dfrac{\sigma\mu_e^2 H_o^2 L^2}{\nu^2}$ (Hartmann Number)

$P = \dfrac{\mu C_P}{K_f}$ (Prandtl number), $\alpha = \dfrac{Q.L^2}{K_f}$ (Heat source parameter),

$\gamma^2 = \dfrac{\omega L^2}{\nu}$ (Wormsely Number), $N_1 = \dfrac{4\sigma^{\bullet} T_e^3}{3\beta_R k_f}$ (Radiation parameter)

$N_2 = \dfrac{3N_1}{3N_1 + 4}$ $\quad P_1 = PN_2$ $\quad \alpha_1 = \alpha N_2,$ $\quad M_1^2 = M^2$

The transformed boundary conditions are

$$\left.\begin{aligned} &u = 0, \quad \theta = 0,\ C=1 \quad \text{at } y = -1 \\ &u = 0, \quad \theta = 1 + \epsilon \cos(\omega t), \\ &C = 1 + \epsilon \cos(\omega t) \quad \text{at } y = +1 \end{aligned}\right\} \tag{9}$$

In view of the boundary conditions (5) we assume

$$\left.\begin{aligned} &u = u_0 + \epsilon\, e^{it} u_1 \\ &\theta = \theta_0 + \epsilon\, e^{it} \theta_1 \\ &C = C_0 + \epsilon\, e^{it} C_1 \end{aligned}\right\} \tag{10}$$

Substituting the series expansion (2.10) in equations (6 - 8) and separating the steady and transient terms we get

$$\frac{\partial^2 u_0}{\partial y^2} - M_1^2 u_0 = -G(\theta_0 + NC_0) \tag{11}$$

$$\frac{\partial^2 u_1}{\partial y^2} - (M_1^2 + i\,\gamma^2)u_1 = -G(\theta_1 + NC_1) \tag{12}$$

$$\frac{\partial^2 \theta_0}{\partial y^2} - \alpha_1\,\theta_0 = 0 \tag{13}$$

$$\frac{\partial^2 \theta_1}{\partial y^2} - (\alpha_1 + iP_1\gamma^2)\theta_1 = 0 \tag{14}$$

$$\frac{\partial^2 C_0}{\partial y^2} - kC_0 = 0 \tag{15}$$

$$\frac{\partial^2 C_1}{\partial y^2} - (k + iSc\gamma^2)\phi_1 = 0 \tag{16}$$

The solutions of equations (11) - (16) are

$$C_0 = \frac{Ch(\beta_1 y)}{Ch(\beta_1)}$$

$$\theta_0 = a_3\left(Ch(\beta_1 y) - Ch(\beta_1)\frac{Ch(\beta_2 y)}{Ch(\beta_2)}\right) + a_4\left(Sh(\beta_1 y) - Sh(\beta_1)\frac{Sh(\beta_2 y)}{Sh(\beta_2)}\right) + 0.5\left(\frac{Sh(\beta_2 y)}{Sh(\beta_2)} + \frac{Ch(\beta_2 y)}{Ch(\beta_2)}\right)$$

$$u_0 = a_{11}\left(Sh(\beta_2 y) - Sh(\beta_2)\frac{Sh(M_1 y)}{Ch(M_1)}\right) + a_{12}\left(Ch(\beta_2 y) - Ch(\beta_2)\frac{Ch(M_1 y)}{Ch(M_1)}\right) + a_{13}\left(Ch(\beta_1 y) - Ch(\beta_1)\frac{Ch(M_1 y)}{Ch(M_1)}\right) + a_{14}\left(Sh(\beta_1 y) - Sh(\beta_1)\frac{Sh(M_1 y)}{Ch(M_1)}\right)$$

$$C_1 = 0.5\left(\frac{Ch(\beta_3 y)}{Ch(\beta_3)} + \frac{Sh(\beta_3 y)}{Sh(\beta_3)}\right)$$

$$\theta_1 = a_{107}\left(Ch(\beta_3 y) - Ch(\beta_3)\frac{Ch(\beta_4 y)}{Ch(\beta_4)}\right) + a_{108}\left(Sh(\beta_3 y) - Sh(\beta_3)\frac{Sh(\beta_4 y)}{Sh(\beta_4)}\right) + 0.5\left(\frac{Ch(\beta_4 y)}{Ch(\beta_4)} + \frac{Sh(\beta_4 y)}{Sh(\beta_4)}\right)$$

$$u_1 = a_{109}\left(Ch(\beta_4 y) - Ch(\beta_4)\frac{Ch(\beta_5 y)}{Ch(\beta_5)}\right) + a_{110}\left(Sh(\beta_4 y) - Sh(\beta_4)\frac{Sh(\beta_5 y)}{Sh(\beta_5)}\right) + a_{111}\left(Ch(\beta_3 y) - Ch(\beta_3)\frac{Ch(\beta_5 y)}{Ch(\beta_5)}\right) + a_{112}\left(Sh(\beta_3 y) - Sh(\beta_3)\frac{Sh(\beta_5 y)}{Sh(\beta_5)}\right)$$

Where

$$M_1^2 = M^2, \qquad \beta_1^2 = \gamma, \qquad \beta_2^2 = \alpha$$
$$\beta_3^2 = \gamma + iSc\gamma_1^2 \qquad \beta_4^2 = \alpha + iP\gamma_1^2 \qquad \beta_5^2 = M_1^2 + i\gamma_1^2$$
$$k_1 = M_1 + \beta_2, \qquad k_2 = M_1 - \beta_2, \qquad k_3 = \beta_2 + \beta_1$$
$$k_4 = \beta_2 - \beta_1, \qquad k_5 = M_1 + \beta_1, \qquad k_6 = \beta_1 - M_1$$

Where a_1, a_2, a_3,…………a_{112} are constants involving parameters.

COMPARISON: For N=0 and α = 0 our results are in good agreement with Narahari [17].

3. SHEAR STRESS, NUSSELT NUMBER and SHERWOOD NUMBER

The Shear stress at the boundaries $\tau = \mu\left(\frac{du}{dy}\right)_{\pm L}$ which in the non - dimensional form reduces to

$$\tau^{\bullet} = \frac{\tau}{\left(\frac{\nu^2}{L^2}\right)} = \left(\frac{du}{dy}\right)_{y=\pm 1}$$

The Rate of heat transfer (Nusselt number) at y = ± L is given by $Nu(\pm 1) = \left(\frac{d\theta}{dy}\right)_{y=\pm 1}$

The Rate of mass transfer (Sherwood number) at y = ± L is given by $Sh(\pm 1) = \left(\frac{dC}{dy}\right)_{y=\pm 1}$

4. RESULTS AND DISCUSSION

In this analysis we investigate the effect of chemical reaction, thermal radiation and heat sources on unsteady convective heat and mass transfer flow of a viscous electrically conducting fluid in vertical channel .The unsteadiness in the flow is due to the oscillatory temperature and concentration.

The axial velocity u is shown in figures (2-5) for different values of N, N1, K and α. Figure 2 represents u with buoyancy ratio N. It is found that when the molecular buoyancy force dominates over the thermal buoyancy force the actual velocity enhances in the flow region, when the buoyancy forces are in the same direction and for the forces acting in opposite direction, |u| enhances in the left half and reduces in the right half. Fig. 3 represents u with chemical reaction parameter K. It is found that u depreciates with increase in K in the entire flow region.

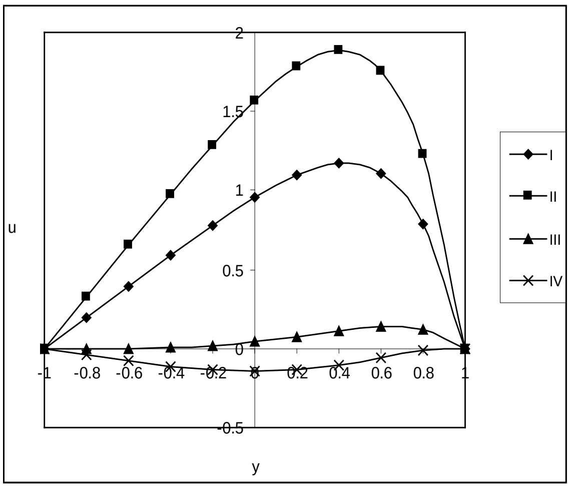


Fig 2 : Variation of u with N

	I	II	III	IV
N	1	2	-0.5	-0.8

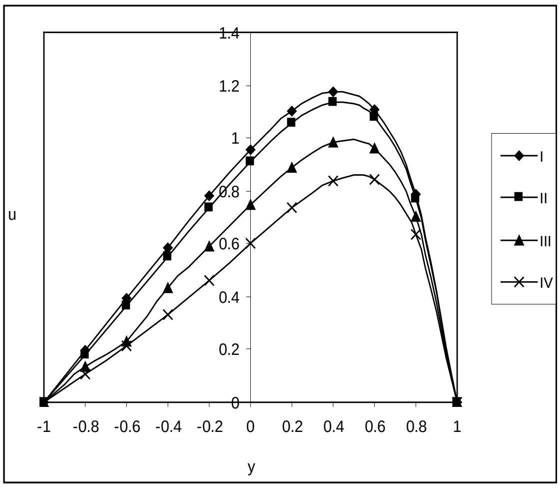


Fig 3 : Variation of u with k

	I	II	III	IV
k	0.2	0.4	1.4	3.5

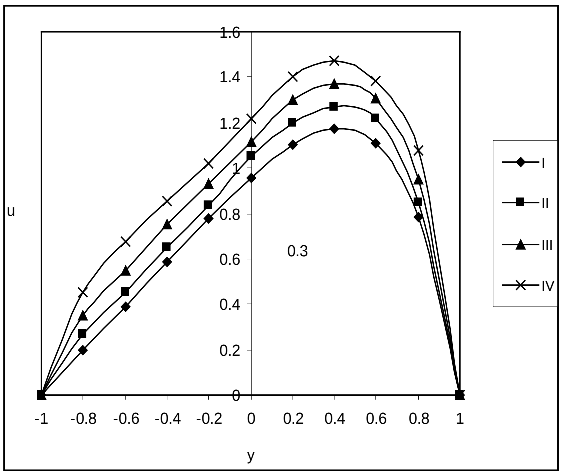


Fig. 4: Variation of u with N_1

	I	II	III	IV
N_1	0.5	1.5	3.5	5

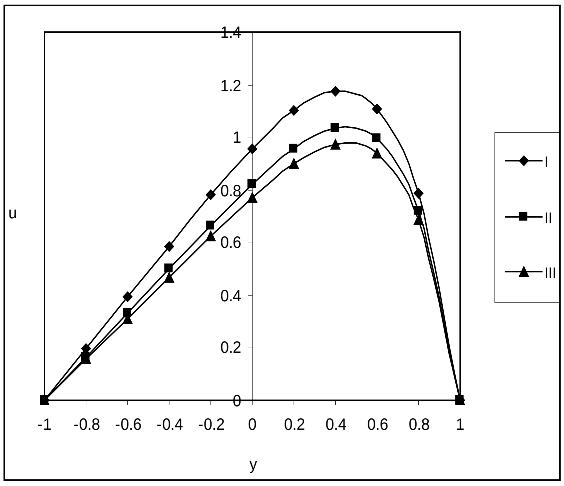
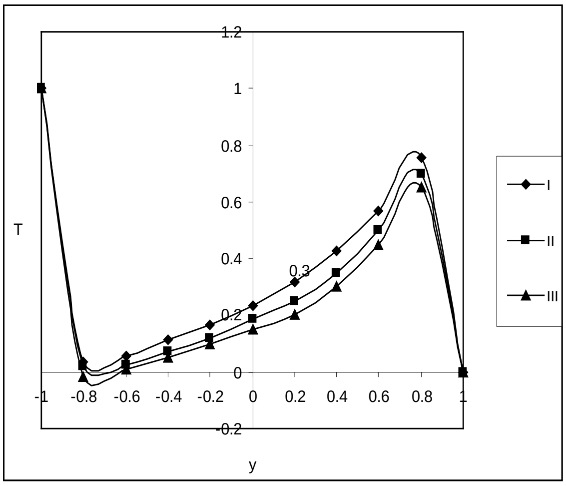


Fig. 5: Variation of u with α

	I	II	III
α	2	4	6

Fig 4 shows the variation of u with radiation parameter N1.It is found that higher the radiative heat flux larger u in the flow region. An increase in the strength of the heat source parameter α reduces the velocity in the flow region (fig5).



Fig; 6 Variation of θ with N_1

	I	II	III
N_1	0.5	1.5	3.5

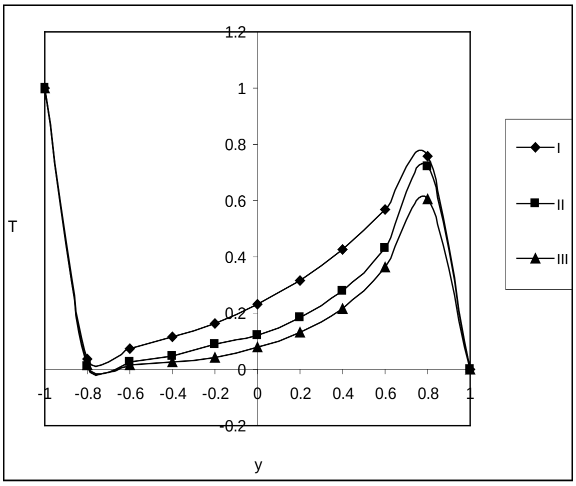


Fig .7: Variation of θ with α

	I	II	III
α	2	4	6

The temperature distribution θ is shown in fig (6-7) for different values of α, N1, Fig 6 represents θ with radiation parameter N1. It is found that the temperature reduces with increase in N1.It is found from fig 7 that the actual temperature depreciates with increase in α.

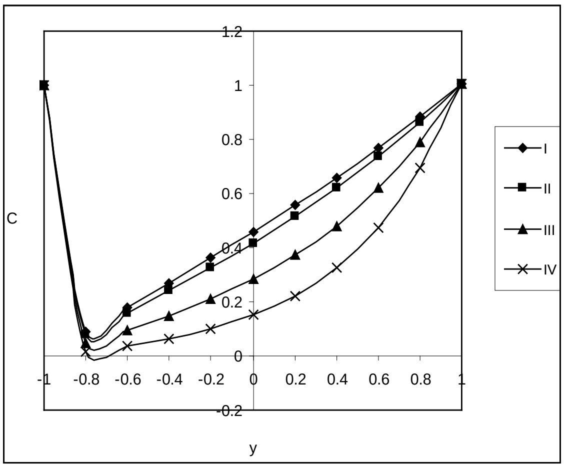


Fig. 8: Variation of C with k

	I	II	III	IV
k	0.2	0.4	1.4	3.5

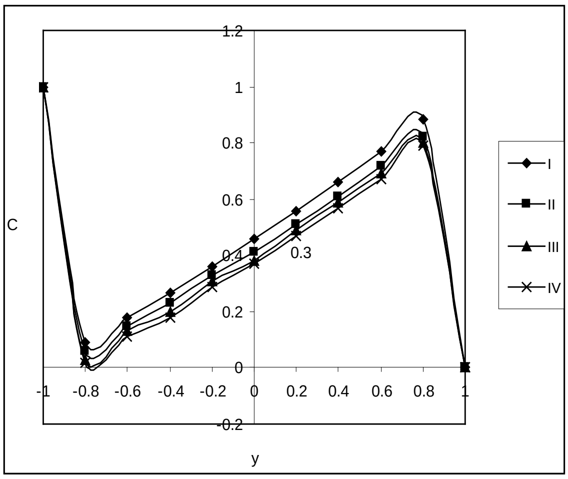


Fig 9: Variation of C with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

The concentration C is executed in figures (8-9) for different parametric values. Fig 8 represents C with chemical reaction parameter K. It is found that the concentration depreciates in a degenerating chemical reaction case. From fig 9 we notice that lesser the molecular diffusivity smaller the concentration in the left half and larger in the right half.

The skin friction at the plates y=±1 is shown in tables (1-2) for different values at K, α, N_1. It is find that the skin friction enhances with increase in |G|. | τ | enhances with≤4 and with higher α≥6 at both the walls. An increase in chemical reaction parameter k and heat source parameter α at both the walls. With reference to Sc we notice that lesser the molecular diffusivity smaller | τ | at y=+1 and larger at y=-1.

Table – 1: Shear Stress (τ) at y = 1

G	I	II	III	IV	V	VI
10^3	4.73929	4.4954	4.02999	3.75125	4.83929	5.12929
$3x10^3$	14.21249	13.48081	12.08743	11.25283	14.5298	14.9289
-10^3	-4.73391	-4.49002	-4.02745	-3.75083	-4.83929	-5.12929
$-3x10^3$	-14.2071	-13.47543	-12.08489	-11.25191	-14.5298	-14.9289
K	.5	1.5	.5	.5	.5	.5
α	2	2	4	6	2	2
N1	0.5	0.5	0.5	0.5	1.5	5.0

Table – 2: Shear Stress (τ) at y = – 1

G	I	II	III	IV	V	VI	VII	VIII
10^3	50.26863	45.2866	40.1245	25.51244	17.38888	9.53230	48.20016	47.79514
$3x10^3$	150.81130	142.3208	139.0217	76.54269	52.17204	28.60230	144.6030	143.3863
-10^3	-50.27402	-45.2866	-40.1245	-25.5178	-17.3942	-9.53769	-48.2027	-47.7960
$-3x10^3$	-150.8167	-142.320	-139.021	-76.5480	-52.1774	-28.6076	-144.605	-143.387
N_1	0.5	1.5	3.5	0.5	0.5	0.5	0.5	0.5
K	0.5	0.5	0.5	1.5	2.5	3.5	0.5	0.5
α	2	2	2	2	2	2	4	6

The rate of heat transfer (Nusselt number) is exhibited in tables 3 for different values of α, N_1, It is found that an increase in the strength of heat source enhances |Nu| at y=+1 and reduces at y=-1. As time elapses we notice a depreciation in |Nu | at y= ±1. An increase in N_1 enhances |Nu| at y=±1.

Table – 3: Nusselt Number (Nu) at y = ± 1

α	**Nu at y = + 1**			**Nu at y = - 1**		
	I	II	III	IV	V	VI
2	1.43416	1.4845	1.5467	0.16885	0.53091	0.63129
4	2.0154	2.1156	2.3467	0.07361	0.75182	0.85254
6	2.46698	2.5678	2.6789	0.03668	1.18364	2.06354
N1	0.5	1.5	3.5	0.5	1.5	3.5

Table – 4: Sherwood Number (Sh) at y =± 1

Sc	Sh at y = + 1			Sh at y = - 1		
	I	II	III	IV	V	VI
0.24	0.63111	0.80154	1.2519	0.44219	0.36802	0.21458
0.6	0.63105	0.80148	1.25186	0.44222	0.36804	0.21460
1.3	0.63094	0.80138	1.24638	0.44227	0.36808	0.21330
2.01	0.63082	0.80128	1.25171	0.44233	0.36812	0.21464
K	0.5	1.5	2.5	0.5	1 .5	2.5

Table – 5: Sherwood Number (Sh) at y = ± 1

K	**Sh at y = + 1**				**Sh at y = - 1**			
	I	II	III	IV	V	VI	VII	VIII
0.2	0.63094	0.62641	0.62052	0.63281	0.44227	0.43921	0.43469	0.44498
0.5	0.80138	0.79567	0.78805	0.80370	0.36808	0.36553	0.36177	0.36902
1.5	1.24638	1.24294	0.62052	0.64285	0.21330	0.21313	0.20869	0.341829
t	π/4	π/2	π	2π	π/4	π/2	π	2π

The rate of mass transfer is shown in tables 4-5 for different values of Sc, k, and t. It is found that the rate of mass transfer enhances at y=+1 and depreciates at y=-1 with increase in Sc. An increase in chemical reaction parameter k results in a depreciation in |Sh| at y=-1 and enhancement at y=+1. An increase in time t results in a depreciation in |Sh| at y=-1 and enhancement at y=+1.

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