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Heat and mass transfer on three dimensional flow through vertical Channel with slip condition and radiation

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Abstract: *An analysis is made on the three dimensional free convection and mass transfer flow through a vertical channel in the presence of radiation in slip flow regime. The solutions have been obtained using perturbation technique. It is seen that the primary velocity decreases with increase in Schmidt number, slip parameter and radiation parameter for cooling of the plate . It is found that the primary velocity increases with increase in Reynolds number but for higher Reynolds number it decreases. The primary velocity also increases with increase in mass Grashoff number. The temperature distribution decreases with the increase of both radiation parameter and Reynolds number. The Concentration field also decreases with the increase of both Schmidt number as well as Reynolds number.*

Keywords: *Three-dimensional, injection, periodic suction, mass transfer, transpiration, free convection.*

I. INTRODUCTION

Many processes occur at high temperatures and it is important in Nuclear power plants, gas turbines, satellites and space vehicles. Takhar et al. (1996) examined the radiative flow past a vertical porous plate. Guria et al. (2010) have studied the effect of radiation through a vertical channel. Guria et al. (2011) also examined the in the presence of magnetic field.

Ahmed (2008) and Ahmed and Liu (2010) studied heat and mass transfer flow along a vertical plate. However, the interaction of radiation with mass transfer in three dimension vertical channel flow has received little attention. Guria (2015) has studied radiative heat and mass flow past a vertical porous plate.

Flow on slip flow regime has many applications in modern science. Gupta and Goyal (1995), Jothimani and Devi (2001), Jain and Tanija (2002) , Jain and Gupta (2006) have studied the flow taking slip effect. Guria (2016) have investigated the effect of slip condition on flow between two vertical porous plates. We study the slip effect on three dimensional heat and mass transfer flow through the between two vertical porous plates.

II. BASIC EQUATIONS

We consider the steady flow through between two vertical parallel porous plates at a distance d apart. We take the flow is in x^*- axis[see Fig.1]. T_w and $T_0(T_w \succ T_0)$ be the temperature at left and right plates respectively.

There is uniform injection V_0 and variable suction $v^* = -V_0\left[1+\varepsilon\cos\left(\frac{\pi z^*}{d}\right)\right]$, (1)

at left and right plates respectively, where $\varepsilon(\ll 1)$ is very small.

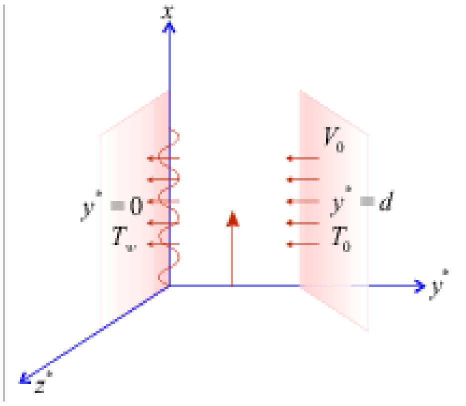

Fig.1. Geometry of the problem

All the components except pressure are independent of x^* since the channel is infinite long along x^*-direction. The governing equations are

$$\frac{\partial v^*}{\partial y^*}+\frac{\partial w^*}{\partial z^*}=0, \qquad (2)$$

$$v^*\frac{\partial u^*}{\partial y^*}+w^*\frac{\partial u^*}{\partial z^*}=\nu\left(\frac{\partial^2 u^*}{\partial y^{*2}}+\frac{\partial^2 u^*}{\partial z^{*2}}\right)+ \qquad (3)$$
$$g\beta(T^*-T_0)+g\beta(C^*-C_0)$$

$$v^*\frac{\partial v^*}{\partial y^*}+w^*\frac{\partial v^*}{\partial z^*}=-\frac{1}{\rho}\frac{\partial p^*}{\partial y^*}+\nu\left(\frac{\partial^2 v^*}{\partial y^{*2}}+\frac{\partial^2 v^*}{\partial z^{*2}}\right), \qquad (4)$$

$$v^*\frac{\partial w^*}{\partial y^*}+w^*\frac{\partial w^*}{\partial z^*}=-\frac{1}{\rho}\frac{\partial p^*}{\partial z^*}+\nu\left(\frac{\partial^2 w^*}{\partial y^{*2}}+\frac{\partial^2 w^*}{\partial z^{*2}}\right) \qquad (5)$$

$$v^*\frac{\partial T^*}{\partial y^*}+w^*\frac{\partial T^*}{\partial z^*}=\frac{1}{\rho C_p}\left(\frac{\partial^2 T^*}{\partial y^{*2}}+\frac{\partial^2 T^*}{\partial z^{*2}}\right)-\frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*}, \qquad (6)$$

$$v^*\frac{\partial C^*}{\partial y^*}+w^*\frac{\partial C^*}{\partial z^*}=D\left(\frac{\partial^2 C^*}{\partial y^{*2}}+\frac{\partial^2 C^*}{\partial z^{*2}}\right), \qquad (7)$$

where the symbols have their usual meaning.
The boundary conditions of the problem are

$$u^*=0, v^*=-V_0[1+\varepsilon\cos(\frac{\pi}{d}z^*)],$$
$$w^*=0, T^*=T_w, C^*=C_w \quad \text{at} \quad y^*=0,$$
$$u^*=U_0+L_1\frac{\partial u^*}{\partial y^*}, v^*=-V_0, w^*=0, \qquad (8)$$
$$T^*=T_0, p^*=p_\infty, C^*=C_\infty \quad \text{at} \quad y^*=d.$$

Assuming

$$y=\frac{y^*}{d}, z=\frac{z^*}{d}, p=\frac{p^*}{\rho V_0^2}, u=\frac{u^*}{V_0},$$
$$v=\frac{v^*}{V_0}, w=\frac{w^*}{V_0}, \theta=\frac{(T^*-T_0)}{(T_w-T_0)}, \qquad (9)$$

equations (2)-(7) become

$$\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0, \qquad (10)$$

$$v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\frac{1}{Re}\left(\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+Gr\theta+GmC, \qquad (11)$$

$$v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{Re}\left(\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right), \qquad (12)$$

$$v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{Re}\left(\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right), \qquad (13)$$

$$v\frac{\partial \theta}{\partial y}+w\frac{\partial \theta}{\partial z}=\frac{1}{RePr}\left(\frac{\partial^2 \theta}{\partial y^2}+\frac{\partial^2 \theta}{\partial z^2}\right)-F\theta, \qquad (14)$$

$$v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=\frac{1}{SRe}\left(\frac{\partial^2 C}{\partial y^2}+\frac{\partial^2 C}{\partial z^2}\right), \qquad (15)$$

where $Re=V_0 d/\nu$, the Reynolds number, $Pr=\nu/\rho$, the Prandtl number and $Gr=dg\beta(T_w-T_0)/V_0^2$, the Grashoff number, $F=4Id/\rho C_p V_0$, the radiation parameter. Using (8), the boundary conditions (7) become

$$u=0, v=-[1+\varepsilon\cos(\pi z)], w=0,$$
$$\theta=1, C=1 \quad \text{at} \quad y=0,$$
$$u=1+h\frac{\partial u}{\partial y}, v=-1, w=0, \theta=0, \qquad (16)$$
$$p=\frac{p_\infty}{\rho V^2}, C=0 \quad \text{at} \quad y=1.$$

where $h=\frac{L_1}{d}$, slip parameter.

III. SOLUTION OF THE PROBLEM

To solve equations (10)-(15), we assume $u(y,z)=u_0(y)+\varepsilon u_1(y,z)+\varepsilon^2 u_2(y,z)+\cdots,$

$$v(y,z)=v_0(y)+\varepsilon v_1(y,z)+\varepsilon^2 v_2(y,z)+\cdots,$$
$$w(y,z)=w_0(y)+\varepsilon w_1(y,z)+\varepsilon^2 w_2(y,z)+\cdots, \qquad (17)$$
$$p(y,z)=p_0(y)+\varepsilon p_1(y,z)+\varepsilon^2 p_2(y,z)+\cdots,$$
$$\theta(y,z)=\theta_0(y)+\varepsilon\theta_1(y,z)+\varepsilon^2\theta_2(y,z)+\cdots.$$

On substituting (17) in equations (10)-(15), we get the following system of differential equations (terms free from ε)

$$v_0'=0, \qquad (18)$$
$$u_0''-Rev_0u_0'=-ReGr\theta_0-\mathrm{Re}\,GmC_0, \qquad (19)$$
$$\theta_0''-RePrv_0\theta_0'-FRePr\theta_0=0, \qquad (20)$$
$$C_0''-SRev_0C_0'=0, \qquad (21)$$

The corresponding boundary conditions become

$$u_0=0, v_0=-1,\ \theta_0=1, C_0=1 \quad \text{at} \quad y=0 \qquad (22)$$
$$u_0=1+h\frac{\partial u_0}{\partial y}, v_0=-1,\ \theta_0=0, C_0=0 \text{ at } y=1. \qquad (23)$$

Solving (18) to (21), subject to the boundary conditions (22), we get

$$v_0(y)=-1, \qquad (24)$$
$$\theta_0(y)=\frac{1}{\left(e^{-\lambda_2}-e^{-\lambda_1}\right)}\left[e^{-\lambda_2}e^{-\lambda_1 y}-e^{-\lambda_1}e^{-\lambda_2 y}\right], \qquad (25)$$
$$C_0(y)=\frac{1}{\left(e^{-S\mathrm{Re}}-1\right)}\left[e^{-S\mathrm{Re}}-e^{-S\mathrm{Re}y}\right], \qquad (26)$$
$$u_0(y)=A_1+A_2e^{-\mathrm{Re}y}+A_3y+A_4e^{-S\mathrm{Re}y}+A_5e^{-\lambda_1 y}+A_6e^{-\lambda_2 y}, \qquad (27)$$

where

$$\lambda_{1,2}=\frac{1}{2}\left[RePr\pm\sqrt{Re^2Pr^2+4FRePr}\right],$$

$$A_1=\frac{-1}{\left(1-e^{-\mathrm{Re}}\right)}\Big[A_3+A_4\left(e^{-S\,\mathrm{Re}}-e^{-\mathrm{Re}}\right)+$$

$$A_5\left(e^{-\lambda_1}-e^{-\mathrm{Re}}\right)+A_6\left(e^{-\lambda_2}-e^{-\mathrm{Re}}\right)\Big]$$

$$A_2=\frac{1}{\left(1-e^{-\mathrm{Re}}\right)}\Big[A_3+A_4\left(e^{-S\,\mathrm{Re}}-1\right)+$$

$$A_5\left(e^{-\lambda_1}-1\right)+A_6\left(e^{-\lambda_2}-1\right)\Big],$$

$$A_3=\frac{-Gme^{-S\,\mathrm{Re}}}{(e^{-S\,\mathrm{Re}}-1)},$$

$$A_4=\frac{-Gme^{-S\,\mathrm{Re}}}{(e^{-S\,\mathrm{Re}}-1)S\,\mathrm{Re}(S-1)},$$

$$A_5=\frac{\mathrm{Re}\,Gre^{-\lambda_2}}{\left(e^{-\lambda_1}-e^{-\lambda_2}\right)\lambda_1\left(\lambda_1-\mathrm{Re}\right)},$$

$$A_6=\frac{-\mathrm{Re}\,Gre^{-\lambda_1}}{\left(e^{-\lambda_1}-e^{-\lambda_2}\right)\lambda_2\left(\lambda_2-\mathrm{Re}\right)},\qquad (28)$$

On substituting (17) in equations (10)-(15), we get (coefficient of ε)

$$\frac{\partial v_1}{\partial y}+\frac{\partial w_1}{\partial z}=0,\qquad (29)$$

$$v_0\frac{\partial u_1}{\partial y}+v_1\frac{\partial u_0}{\partial y}=\frac{1}{Re}\left(\frac{\partial^2 u_1}{\partial y^2}+\frac{\partial^2 u_1}{\partial z^2}\right)+ \qquad (30)$$

$$Gr\theta_1+GmC_1,$$

$$v_0\frac{\partial v_1}{\partial y}=-\frac{\partial p_1}{\partial y}+\frac{1}{Re}\left(\frac{\partial^2 v_1}{\partial y^2}+\frac{\partial^2 v_1}{\partial z^2}\right),\qquad (31)$$

$$v_0\frac{\partial w_1}{\partial y}=-\frac{\partial p_1}{\partial z}+\frac{1}{Re}\left(\frac{\partial^2 w_1}{\partial y^2}+\frac{\partial^2 w_1}{\partial z^2}\right),\qquad (32)$$

$$v_0\frac{\partial \theta_1}{\partial y}+v_1\frac{\partial \theta_0}{\partial y}=\frac{1}{RePr}\left(\frac{\partial^2 \theta_1}{\partial y^2}+\frac{\partial^2 \theta_1}{\partial z^2}\right)-F\theta_1.\qquad (33)$$

$$v_0\frac{\partial C_1}{\partial y}+v_1\frac{\partial C_0}{\partial y}=\frac{1}{SRe}\left(\frac{\partial^2 C_1}{\partial y^2}+\frac{\partial^2 C_1}{\partial z^2}\right).\qquad (34)$$

The corresponding boundary conditions become

$$u_1=0, v_1=-\cos(\pi z), w_1=0,$$

$$\theta_1=0, C_1=0 \quad \text{at} \quad y=0,$$

$$u_1=h\frac{\partial u_1}{\partial y}, v_1=0, w_1=0, \qquad (35)$$

$$\theta_1=0, C_1=0 \quad \text{at} \quad y=1.$$

(26)

Assume

$$u_1(y,z) = u_{11}(y)\cos(\pi z),$$
$$v_1(y,z) = v_{11}(y)\cos(\pi z),$$
$$w_1(y,z) = -\frac{1}{\pi}v_{11}^{'}(y)sin(\pi z), \qquad (36)$$
$$p_1(y,z) = p_{11}(y)\cos(\pi z),$$
$$\theta_1(y,z) = \theta_{11}(y)\cos(\pi z),$$
$$C_1(y,z) = C_{11}(y)\cos(\pi z),$$

Substituting (36) in (30)-(34) we get

$$v_{11}^{''} + Rev_{11}^{'} - \pi^2 v_{11} = Rep_{11}^{'}, \qquad (37)$$
$$v_{11}^{'''} + Rev_{11}^{''} - \pi^2 v_{11}^{'} = Re\pi^2 p_{11}, \qquad (38)$$
$$\theta_{11}^{''} + RePr\theta_{11}^{'} - (FRePr + \pi^2)\theta_{11} = RePrv_{11}\theta_0^{'}, \qquad (39)$$
$$C_{11}^{''} + S\,\mathrm{Re}\,C_{11}^{'} - \pi^2 C_{11} = S\,\mathrm{Re}\,v_{11}C_0^{'}, \qquad (40)$$
$$u_{11}^{''} + Reu_{11}^{'} - \pi^2 u_{11} = Rev_{11}u_0^{'} - Re(Gr\theta_{11} + GmC_{11}). \qquad (41)$$

The corresponding boundary conditions are

$$u_{11} = 0, v_{11} = -1, v_{11}^{'} = 0, \theta_{11} = 0, \quad C_{11} = 0 \quad \text{at} \quad y = 0, \qquad (42)$$
$$u_{11} = h\frac{\partial u_{11}}{\partial y}, v_{11} = 0, v_{11}^{'} = 0, \theta_{11} = 0, \quad C_{11} = 0 \quad \text{at} \quad y = 1.$$

Solutions of the equations (37)-(41) subject to (42) and on using (34) yield

$$v_1(y,z) = \left[B_1e^{-m_1y} + B_2e^{-m_2y} + B_3e^{\pi y} + B_4e^{-\pi y}\right]\cos(\pi z), \qquad (43)$$
$$w_1(y,z) = \frac{1}{\pi}\left[B_1m_1e^{-m_1y} + B_2m_2e^{-m_2y} - B_3\pi e^{\pi y} + B_4\pi e^{-\pi y}\right]\sin(\pi z), \qquad (44)$$
$$p_1(y,z) = \frac{1}{\pi}\left[A_7(\pi - 1/K)e^{\pi y} + A_8(\pi + 1/K)e^{-\pi y}\right]\cos(\pi z), \qquad (45)$$
$$\theta_1(y,z) = \left[G_1e^{-\mu_1 y} + G_2e^{-\mu_2 y} + G_3e^{-(m_1+\lambda_1)y} + G_4e^{-(m_2+\lambda_1)y} + G_5e^{(\pi-\lambda_1)y} + G_6e^{-(\pi+\lambda_1)y} + G_7e^{-(m_1+\lambda_2)y} + G_8e^{-(m_2+\lambda_2)y} + G_9e^{(\pi-\lambda_2)y} + G_{10}e^{-(\pi+\lambda_2)y}\right]\cos(\pi z), \qquad (46)$$
$$C_1(y,z) = \left[D_1e^{-\alpha_1 y} + D_2e^{-\alpha_2 y} + D_3e^{-(m_1+S\,\mathrm{Re})y} + D_4e^{-(m_2+S\,\mathrm{Re})y} + D_5e^{(\pi-S\,\mathrm{Re})y} + D_6e^{-(\pi+S\,\mathrm{Re})y}\right]\cos(\pi z), \qquad (47)$$

$$u_1(y,z)=\Big[E_1e^{-m_1y}+E_2e^{-m_2y}+E_3e^{-\mu_1y}+ E_4e^{-\mu_2y}+E_5e^{-(m_1+\lambda_1)y}+E_6e^{-(m_2+\lambda_1)y}+ E_7e^{(\pi-\lambda_1)y}+E_8e^{-(\pi+\lambda_1)y}+E_9e^{-(m_1+\lambda_2)y}+ E_{10}e^{-(m_2+\lambda_2)y}+E_{11}e^{(\pi-\lambda_2)y}+E_{12}e^{-(\pi+\lambda_2)y}+ E_{13}e^{-\alpha_1y}+E_{14}e^{-\alpha_2y}+E_{15}e^{-(m_1+S\,\mathrm{Re})y}+ E_{16}e^{-(m_2+S\,\mathrm{Re})y}+E_{17}e^{(\pi-S\,\mathrm{Re})y}+E_{18}e^{-(\pi+S\,\mathrm{Re})y} +E_{19}e^{-(m_1+\mathrm{Re})y}+E_{20}e^{-(m_2+\mathrm{Re})y}+ E_{21}e^{(\pi-\mathrm{Re})y}+E_{22}e^{-(\pi+\mathrm{Re})y}+E_{23}ye^{-m_1y} +E_{24}ye^{-m_2y}+E_{25}e^{\pi y}+E_{26}e^{-\pi y}\Big]\cos(\pi z), \tag{48}$$

where

$$m_{1,2}=\frac{1}{2}\left[Re\pm\sqrt{Re^2+4\pi^2}\right],$$
$$\mu_{1,2}=\frac{1}{2}\left[RePr\pm\sqrt{Re^2Pr^2+4(FRePr+\pi^2)}\right],$$
$$\alpha_{1,2}=\frac{1}{2}\left[SRe\pm\sqrt{S^2Re^2+4\pi^2}\right],$$
$$B_1=[\pi r_2(e^{\pi}-e^{-\pi})+r_4(e^{\pi}+e^{-\pi})]/2(r_1r_4-r_2r_3),$$
$$B_2=-[\pi r_1(e^{\pi}-e^{-\pi})+r_3(e^{\pi}+e^{-\pi})]/2(r_1r_4-r_2r_3),$$
$$B_3=-\frac{1}{2\pi}[\pi+A_5(\pi-m_5)+A_6(\pi-m_6)],$$
$$B_4=-\frac{1}{2\pi}[\pi+A_5(\pi+m_5)+A_6(\pi+m_6)],$$
$$r_1=e^{-m_5}-\frac{1}{2\pi}[e^{\pi}(\pi-m_5)+e^{-\pi}(\pi+m_5)],$$
$$r_2=e^{-m_6}-\frac{1}{2\pi}[e^{\pi}(\pi-m_6)+e^{-\pi}(\pi+m_6)], \tag{49}$$
$$r_3=m_5e^{-m_5}+\frac{1}{2}[e^{\pi}(\pi-m_5)-e^{-\pi}(\pi+m_5)],$$
$$r_4=m_6e^{-m_6}+\frac{1}{2}[e^{\pi}(\pi-m_6)-e^{-\pi}(\pi+m_6)].$$

The other constants are avoided due to reduce space.

IV. RESULTS AND DISCUSSION

The variation primary velocity for several values of S, h, F, Re, Gr and Gm are depicted in Figs.2-7. It is seen from Figs.2-4 that the primary velocity decreases with increase in S, h, F for cooling of the plate ($Gr > 0$). It is observed from Fig.5 that the it increases with increse in Reynolds number but for higher Reynolds number it decreases. It is seen from Fig.6 and 7 that it increases with increase in both Gr and Gm. We have

$$\tau_x^*=\mu\left(\frac{\partial u^*}{\partial y^*}\right)_{y^*=0}=\frac{\mu V_0}{d}\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{50}$$

The shear stress at the plate $y^*=0$ in non-dimensional form can be written as

$$\tau_x = \frac{\tau_x^* d}{\mu V_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = u_0'(0) + \varepsilon u_1'(0).$$
$$= -\left(A_2 \,\mathrm{Re} - A_3 + A_4 S \,\mathrm{Re} + A_5 \lambda_1 + A_6 \lambda_2\right) +$$
$$\varepsilon\left[E_1 m_1 + E_2 m_2 + E_3 \mu_1 + E_4 \mu_2 + E_5\left(m_1 + \lambda_1\right) +\right.$$
$$E_6\left(m_2 + \lambda_1\right) - E_7\left(\pi - \lambda_1\right) + E_8\left(\pi + \lambda_1\right) +$$
$$E_9\left(m_1 + \lambda_2\right) + E_{10}\left(m_2 + \lambda_2\right) - E_{11}\left(\pi - \lambda_2\right) + \quad (51)$$
$$E_{12}\left(\pi + \lambda_2\right) + E_{13}\alpha_1 + E_{14}\alpha_2 + E_{15}\left(m_1 + S\,\mathrm{Re}\right) +$$
$$E_{16}\left(m_2 + S\,\mathrm{Re}\right) - E_{17}\left(\pi - S\,\mathrm{Re}\right) + E_{18}\left(\pi + S\,\mathrm{Re}\right) +$$
$$E_{19}\left(m_1 + \mathrm{Re}\right) + E_{20}\left(m_2 + \mathrm{Re}\right) - E_{21}\left(\pi - \mathrm{Re}\right) +$$
$$\left.E_{22}\left(\pi + \mathrm{Re}\right) + E_{23} + E_{24} - E_{25}\pi + E_{26}\pi\right]\cos\left(\pi z\right).$$

The variation of τ_x is shown in Table.1 for different values of Re and S . τ_x increases with increase in Re but it decreases with increase in S .

Re	τ_x			
	S=0.3	S=0.6	S=0.66	S=0.78
2	8.69	8.33	8.24	8.04
3	12.64	11.8	11.62	11.21
4	17.42	15.9	15.64	15.01

Table.1 Shear stress component τ_x for $Gr = 5$, *Pr=0.71*, $\epsilon = 0.05$, $z = 0.0$.

The variation of temperature θ for several values of *F* and *Re* are depicted in Figs.8 and 9 for $Re = 5.0$, $Gr = 5.0$, $\epsilon = 0.05$, $z = 0.0$. It is observed that θ decreases with increase in *F* as well as *Re*. In Figs 10 and 11 we have presented $C(y)$ for several values of *S* and *Re*. It is found that the $C(y)$ decrease with increase in both *S* and *Re*.
We measure the rate of heat transfer as

$$q = -k\left(\frac{\partial T^*}{\partial y^*}\right)_{y^*=0} = -\frac{k\left(T_w - T\right)_0}{d}\left(\frac{\partial \theta}{\partial y}\right)_{y=0}. \quad (52)$$

Heat transfer coefficient(Nusselt number) at the plate $y = 0$ is given by

$$Nu_1 = \frac{qd}{k\left(T_w - T_0\right)} = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}$$
$$= -\theta_0'(0) - \varepsilon\theta_1'(0),$$
$$= \frac{1}{\left(e^{-\lambda_1} - e^{-\lambda_2}\right)}\left[\lambda_1 e^{-\lambda_2} - \lambda_2 e^{-\lambda_1}\right] + \quad (53)$$
$$\varepsilon\left\{G_1\mu_1 + G_2\mu_2 + G_3(m_1 + \lambda_1) +\right.$$
$$G_4(m_2 + \lambda_1) - G_5(\pi - \lambda_1) +$$
$$G_6(\pi + \lambda_1) + G_7(m_1 + \lambda_2) +$$
$$G_8(m_2 + \lambda_2) - G_9(\pi - \lambda_2) +$$
$$\left.G_{10}(\pi + \lambda_2)\right\}\cos\left(\pi z\right).$$

and that at the plate $y = 1$ is given
by

$$Nu_2 = \frac{qd}{k\left(T_w - T_0\right)} = -\left(\frac{\partial \theta}{\partial y}\right)_{y=1}$$
$$= -\theta_0^{'}(1) - \varepsilon\theta_1^{'}(1),$$
$$= \frac{\left(\lambda_1 - \lambda_2\right)e^{-(\lambda_1+\lambda_2)}}{\left(e^{-\lambda_1} - e^{-\lambda_2}\right)} + \varepsilon\left\{G_1\mu_1 e^{-\mu_1} + \right. \tag{54}$$
$$G_2\mu_2 e^{-\mu_2} + G_3(m_1+\lambda_1)e^{-(m_1+\lambda_1)} +$$
$$G_4(m_2+\lambda_1)e^{-(m_2+\lambda_1)} - G_5(\pi-\lambda_1)e^{(\pi-\lambda_1)} +$$
$$G_6(\pi+\lambda_1)e^{-(\pi+\lambda_1)} + G_7(m_1+\lambda_2)e^{-(m_1+\lambda_2)} +$$
$$G_8(m_2+\lambda_2)e^{-(m_2+\lambda_2)} - G_9(\pi-\lambda_2)e^{(\pi-\lambda_2)} +$$
$$\left. G_{10}(\pi+\lambda_2)e^{-(\pi+\lambda_2)}\right\}\cos\left(\pi z\right).$$

Re	Nu_1			
	F=2	F=3	F=4	F=5
2	2.77	3.09	3.38	3.64
3	3.67	4.08	4.44	4.76
4	4.57	5.04	5.45	15.01

Table.2 Rate of heat transfer coefficient Nu_1 for $Gr = 5, Pr = 0.71, \epsilon = 0.05, z = 0.0$.

Re	Nu_2			
	F=2	F=3	F=4	F=5
2	0.28	0.23	0.19	0.16
3	0.15	0.11	0.09	0.07
4	0.07	0.05	0.04	0.03

Table.3 Rate of heat transfer Nu_2 for $Gr = 5, Pr = 0.71, \epsilon = 0.05, z = 0.0$.

Nusselt number is plotted for different values of radiation parameter and Reynolds number and for $Gr = 5.0$, $\epsilon = 0.05$, $z = 0.0$. It is seen that it increases with increase in both radiation parameter and Reynolds number whereas the reversed effect is observed at the plate $y = 1$.

We have presented the non-dimensional mass flux (Sherwood number) is

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -C_0^{'} - \varepsilon C_1^{'}(0),$$
$$= \frac{-S\,\mathrm{Re}}{\left(e^{-S\,\mathrm{Re}} - 1\right)} + \varepsilon\left[D_1\alpha_1 + D_2\alpha_2 + \right. \tag{55}$$
$$D_3(m_1 + S\,\mathrm{Re}) + D_4(m_2 + S\,\mathrm{Re}) -$$
$$\left. D_5(\pi - S\,\mathrm{Re}) + D_6(\pi + S\,\mathrm{Re})\right]\cos(\pi z).$$

Re	Sh			
	S=0.3	S=0.6	S=0.66	S=0.78
2	1.29	1.62	1.69	1.83
3	1.45	1.98	2.10	2.33
4	1.62	2.38	2.54	2.87

Table.4 Sherwood number for $Gr = 5.0, Pr = 0.71, \epsilon = 0.25, z = 0.0$.

The mass flux at the plate y=0 increases with increase in both Schmidt number and Reynolds number.

V. CONCLUSION

Flow through the vertical channel in slip flow regime has been studied in the presence of radiation. The primary velocity decreases with increase in Schmidt number, slip parameter and radiation parameter for cooling of the plate. With increase in both thermal Grashoff number and mass Grashoff number it increases. With increase in both radiation parameter or Reynolds number the temperature profile decreases for cooling of the plate. The Concentration field also decrease with the increase of both Schmidt number as well as Reynolds number.

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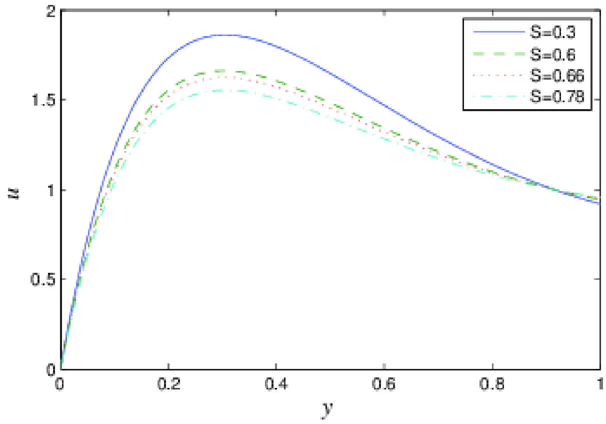

Fig.2: Primary velocity u for $Gr = 5, Gm = 5, Re = 4, Pr = 0.71, F = 2, h = 0.1$.

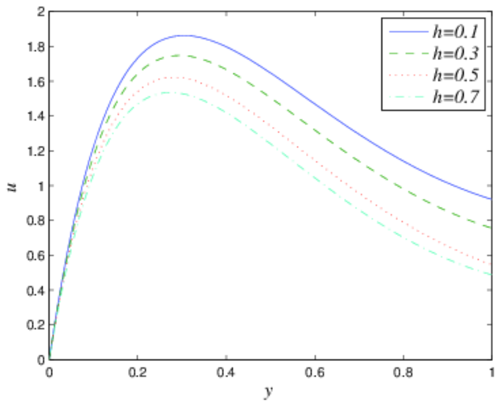

Fig.3: Primary velocity u for $Gr = 5, Gm = 5, Re = 4, Pr = 0.71, F = 2, S = 0.3$.

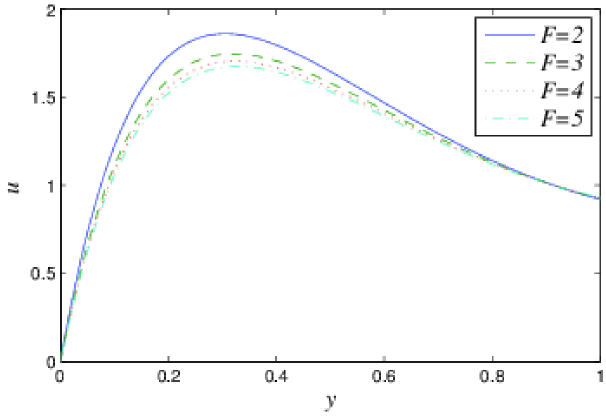

Fig.4: Primary velocity u for $Gr = 5, Gm = 5, Re = 4, Pr = 0.71, S = 0.3, h = 0.1$.

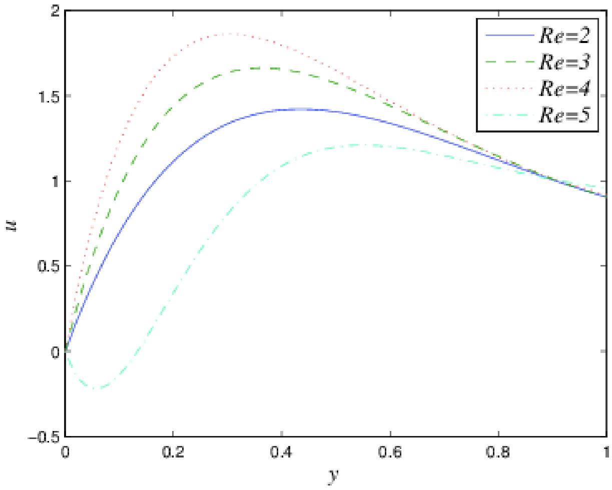

Fig.5:Primary velocity u for $Gr = 5, Gm = 5, Pr = 0.71, F = 2, S = 0.3, h = 0.1$.

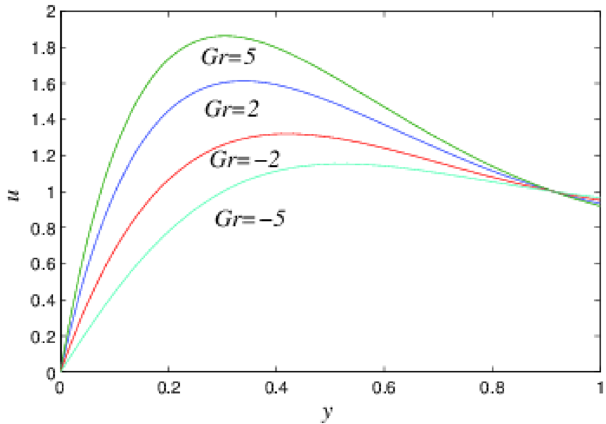

Fig.6: Primary velocity u for $Gm = 5, Re = 4, Pr = 0.71, F = 2, S = 0.3, h = 0.1$.

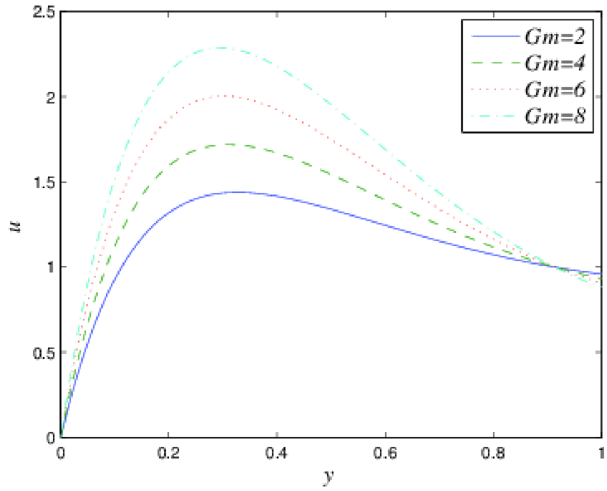

Fig.7: Primary velocity u for $Gr = 5, Re = 4, Pr = 0.71, F = 2, S = 0.3, h = 0.1$.

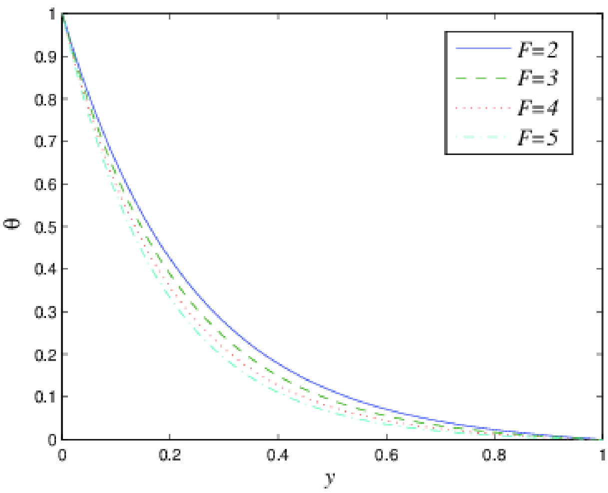

Fig.8:Temperature profile θ for $Re = 4, Pr = 0.71$.

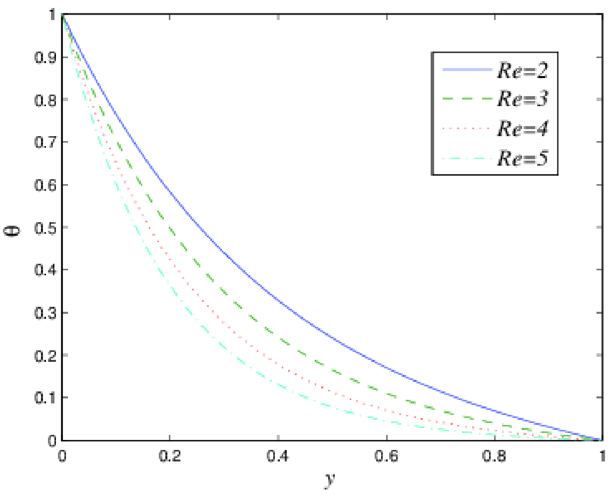

Fig.9:Temperature profile for $Pr = 0.71, F = 2$.

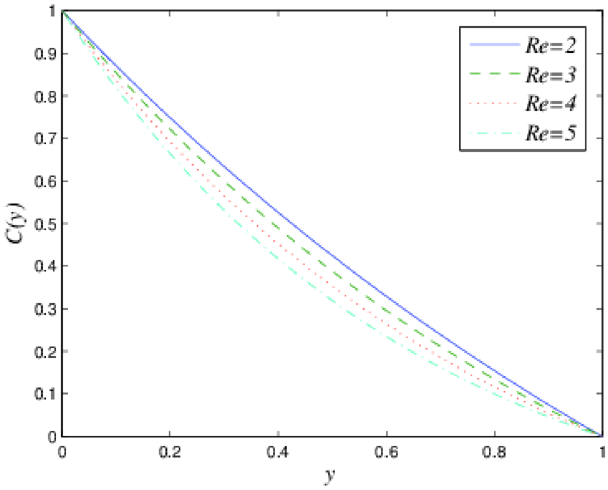

Fig.10:Concentration field for $S = 0.3$

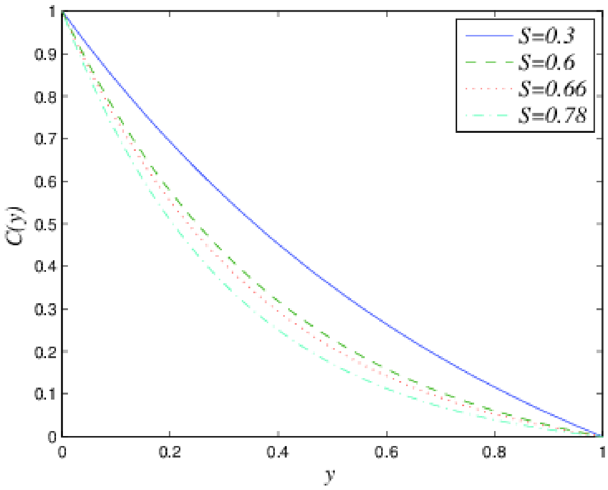

Fig.11: Concentration field for $Re = 4$.