ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 05, pp.31579-31586, May, 2016

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

OSCILLATORY NATURAL CONVECTION FLOW PAST PARALLEL PLATES WITH FLUCTUATING THERMAL AND MASS DIFFUSION

[1]Sushil Kumar Saini and *,[2]Pawan Kumar Sharma

[1]Department of Mathematics, Shri Venkateshwara University, Gajraula, Amroha, Utter Pradesh-244236, (India)
[2]Department of Mathematics, Amity School of Engineering and Technology, New-Delhi 110061 (India)

ARTICLE INFO

Article History:
Received 20th February, 2016
Received in revised form
24th March, 2016
Accepted 12th April, 2016
Published online 30th May, 2016

Key words:

Porous medium, Incompressible fluid, Natural convection, Heat and mass transfer.

ABSTRACT

This communication investigates the oscillatory flow with the combined effects of fluctuating heat and mass transfer past vertical parallel porous flat plates. It is assumed that vertical channel is rotating with angular velocity Ω. The periodic suction velocity is assumed at the plate and other plate oscillating with periodic free stream velocity. The governing equations are solved by adopting complex variable notations. The analytical expressions for velocity and temperature fields are obtained using perturbation technique. The effects of various parameters on mean primary, mean secondary velocity, mean temperature, mean concentration, transient velocity, transient temperature, transient concentration and rate of heat and mass transfer in terms of amplitude and phase differences have been discussed and shown graphically.

Citation: Sushil Kumar Saini and Pawan Kumar Sharma, 2016. "Oscillatory natural convection flow past parallel plates with fluctuating thermal and mass diffusion", *International Journal of Current Research*, 8, (05), 31579-31586.

INTRODUCTION

In recent years, the requirements of modern technology have stimulated interest in fluid flow studies, which involve the interaction of several phenomena. One such study is related to the flows of fluid through porous medium due to their applications in many branches of science and technology, viz. in the fields of agricultural engineering to study the under ground water resources, seepage of water in river-beds, in petroleum technology to study the movement of natural gas, oil, water through the oil reservoirs and in chemical engineering for filtration and purification processes. Such problems have also important applications in geo-thermals reservoirs and geo-thermal energy extractions. It is obvious that in order to utilize the geo-thermal energy to maximum, one should have a complete and precise knowledge of the amount of perturbations needed to generate flow in geo-thermal fluids. Also, the knowledge of quantity of perturbations essential to initiate flow in mineral fluid found in earth's crust helps, one to utilize minimal energy to extract the minerals.

***Corresponding author: *Pawan Kumar Sharma*,**
Department of Mathematics, Amity School of Engineering and Technology, New-Delhi 110061 (India).

In view of geophysical applications of the flow through porous medium, a series of investigations has been made by Raptis *et al.* (1981, 1982), where the porous medium is either bounded by horizontal, vertical surfaces or parallel porous plates. Singh *et al.* (1989) and Lai and Kulacki (1990) have been studied the free convective flow past vertical wall. Nield (1994) studied convection flow through porous medium with inclined temperature gradient.

The studies on the response of a laminar boundary layer flow due to free stream oscillations are prime importance in many industrial and aerodynamic flow problems. Typical problem arise in the study of aircraft response to atmospheric gusts, aerofoil lift hysteresis at the stall, flutter phenomena involving wing, panel and stalling flutter, as well as the prediction of flow over helicopter rotor blades and through turbo-machinery-blade cascades. In view of increasing scientific and technical applications, Kelleher *et al.* (1968) studied the heat transfer response of laminar free convection boundary layers along vertical heated plates to surface temperature oscillations. Sharma *et al.* (2007) studied the unsteady free convection oscillatory flow through porous medium with periodic temperature variation. Also the oscillatory Couette flows in a rotating system have been studied by Jana and Datta (1980) Muzumder (1991), and Ganapathy (1994). Raptis and Peridikis

(1985) also studied the oscillatory flow through porous medium in the presence of convection. The three dimensional oscillatory flow through porous medium investigated by Singh and Verma (1995) and Sharma *et al*. (2011). Singh *et al*. (2005) also studied periodic solution on oscillatory flow through channel in rotating porous medium. Therefore the object of the present paper is to investigate the oscillatory flow through porous vertical channel in the presence of fluctuating thermal and mass diffusion with periodic suction velocity. The entire system rotates about an axis perpendicular to the plane of the plates. The analytical solution for mean primary, mean secondary velocity, transient velocity, transient temperature and concentration are obtained using regular perturbation technique. The effect of various parameters on flow characteristic are discussed and shown graphically.

Mathematical Formulation of the problem

Consider an oscillatory free convective flow of a viscous incompressible fluid through highly porous medium bounded between two infinite vertical porous plates distance d apart. The periodic suction velocity is applied at the stationary plate $z^*=0$ and other plate at $z^* = d$, which is oscillating in its own plane with a velocity U^* about a non zero constant mean velocity U_0. The origin is assumed to be at the plate $z^*=0$ and the channel is oriented vertically upward along the x^*-axis. The channel rotates as a rigid body with uniform angular velocity Ω^* about z^*-axis, which is perpendicular to the vertical plane confined with a viscous fluid occupying the porous region. Since the plates are infinite in extent, all the physical quantities except the pressure, depend only on z^* and t^*. Denoting the velocity components u^*, v^*, w^* in the x^*, y^*, z^* directions, respectively, temperature by T^* and concentration by C^*. The flow in porous medium involves small velocities permitting the neglect of heat due to viscous dissipation in governing equation. The equations expressing the conservation of mass, momentum, energy and mass transfer in rotating frame of reference are given by

$$w^* = -w_0 (1+\varepsilon\cos\omega^* t^*), \quad \ldots (1)$$

$$\frac{\partial u^*}{\partial t^*} + w^* \frac{\partial u^*}{\partial z^*} - 2\Omega^* v^* = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + g\beta(T^* - T_d^*) + g\beta_c (C^* - C_d^*) + \nu \frac{\partial^2 u^*}{\partial z^{*2}} - \frac{\nu u^*}{k^*}, \quad \ldots (2)$$

$$\frac{\partial v^*}{\partial t^*} + w^* \frac{\partial v^*}{\partial z^*} + 2\Omega^* u^* = -\frac{1}{\rho}\frac{\partial p^*}{\partial y^*} + \nu \frac{\partial^2 v^*}{\partial z^{*2}} - \frac{\nu v^*}{k^*}, \quad \ldots (3)$$

$$\frac{\partial T^*}{\partial t^*} + w^* \frac{\partial T^*}{\partial z^*} = \frac{\kappa}{\rho c_p}\frac{\partial^2 T^*}{\partial z^{*2}}, \quad \ldots (4)$$

$$\frac{\partial C^*}{\partial t^*} + w^* \frac{\partial C^*}{\partial z^*} = D\frac{\partial^2 C^*}{\partial z^{*2}} \quad \ldots. (5)$$

where g is the acceleration due to gravity, β is the volumetric coefficient of thermal expansion, β_c is the volumetric coefficient of expansion for concentration, T^* is the temperature, T_d^* is the temperature in free stream, ν is the kinematic viscosity, Ω^* is the angular velocity, k^* is the permeability, C_p is the specific heat at constant pressure, p^* is the pressure, ρ is the density, t^* is the time and κ is the thermal conductivity, ω^* frequency of fluctuations.

The boundary conditions of the problem are

$$\left.\begin{aligned} z = 0: u^* = 0, \quad v^* = 0, \quad & T^* = T_0^* + \varepsilon(T_0^* - T_d^*)\cos\omega^* t^*, \\ & C^* = C_0^* + \varepsilon(C_0^* - C_d^*)\cos\omega^* t^* \\ z = d: u^* = v^* = U^* = U_0(1+\varepsilon\cos\omega^* t^2),\ & T^* = T_d,\ C^* = C_d\,. \end{aligned}\right\} \ldots (6)$$

Considering u + iv = U and eliminating the pressure gradient from (2) and (3), we have

$$\frac{\partial U^*}{\partial t^*} + w^* \frac{\partial U^*}{\partial z^*} + 2i\Omega^* U^* = g\beta(T^* - T_d^*) + g\beta_c (C^* - C_d^*) + \nu \frac{\partial^2 U^*}{\partial z^{*2}} - \frac{\nu U^*}{k^*}, \quad \ldots (7)$$

We introduce the following non-dimensional quantities as:

$$z = \frac{z^*}{d},\ u = \frac{u^*}{U_0},\ v = \frac{v^*}{U_0},\ \omega = \frac{d^2\omega^*}{\nu},\ \theta = \frac{(T^* - T_d^*)}{(T_0^* - T_d^*)},$$

$$k = \frac{k^*}{d^2},\ t = \omega^* t^*,\ \lambda\,(\text{Suction parameter}) = \frac{d\,w_0}{\nu},$$

$$\alpha\,(\textit{Thermal diffusivity}) = \frac{\kappa}{\rho C_p},$$

$$\text{Gr (Grashof number)} = \frac{g\beta(T_0^* - T_d^*)d^2}{\nu U_0},\ \text{Pr (Prandtl number)} = \frac{\nu}{\alpha},$$

$$C = \frac{(C^* - C_d^*)}{(C_0^* - C_d^*)}$$

$$\text{Gc (modified Grashof number)} = \frac{g\beta_c(C_0^* - C_d^*)d^2}{\nu U_0}$$

Substituting these non-dimensional quantities in equations (7), (4) and (5), we get

$$\omega\frac{\partial U}{\partial t} - (1+\varepsilon\cos t)\lambda\frac{\partial U}{\partial z} + 2iRU = Gr\,\lambda^2\theta + Gc\,\lambda^2 C + \frac{\partial^2 U}{\partial z^2} - \frac{U}{k}, \quad \ldots (8)$$

$$\omega\frac{\partial\theta}{\partial t} - (1+\varepsilon\cos t)\lambda\frac{\partial\theta}{\partial z} = \frac{1}{Pr}\frac{\partial^2\theta}{\partial z^2}, \quad \ldots (9)$$

$$\omega \frac{\partial C}{\partial t} - (1+\varepsilon \cos t)\lambda \frac{\partial C}{\partial z} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2}, \quad \ldots (10)$$

The corresponding boundary conditions (6) become

$$\left.\begin{array}{l} z = 0: U = 0, \quad \theta = 1+\varepsilon \cos t, \; C = 1+\varepsilon \cos t \\ z = d: U = 1+\varepsilon \cos t, \quad \theta = 0, \quad C = 0. \end{array}\right\} \ldots (11)$$

Solution of the problem

In order to solve the problem, we assume the solutions of the following form because amplitude ε (< < 1) of the variation of temperature is very small

$$\left.\begin{array}{l} U(z,t) = U_0(z) + \varepsilon U_1(z)\, e^{-it} + \ldots\ldots\ldots\ldots \\ \theta(z,t) = \theta_0(z) + \varepsilon \theta_1(z)\, e^{-it} + \ldots\ldots\ldots\ldots \\ C(z,t) = C_0(z) + \varepsilon C_1(z)\, e^{-it} + \ldots\ldots\ldots\ldots \end{array}\right\} \ldots (12)$$

Substituting (12) in equations (8), (9) and (10), and equating the coefficient of identical powers of ε and neglecting those of ε^2, ε^3 etc., we get

$$U_0'' + \lambda U_0' - 2iR\,U_0 - \frac{U_0}{k} = -Gr\,\lambda^2 \theta_0 - Gc\,\lambda^2 C_0, \quad \ldots (13)$$

$$U_1'' + \lambda U_1' - 2iR\,U_1 + i\omega U_1 - \frac{U_1}{k} = -Gr\,\lambda^2 \theta_1 - Gc\,\lambda^2 C_1 - \lambda U_0', \quad \ldots (14)$$

$$\theta_0'' + \lambda \Pr \theta_0' = 0, \quad \ldots (15)$$

$$\theta_1'' + \lambda \Pr \theta_1' + i\omega \Pr \theta_1 = -\lambda \Pr \theta_0' \quad \ldots (16)$$

$$C_0'' + \lambda Sc\, C_0' = 0, \quad \ldots (17)$$

$$C_1'' + \lambda Sc\, C_1' + i\omega\, Sc\, C_1 = -\lambda Sc\, C_0' \quad \ldots (18)$$

The corresponding boundary conditions (11) reduce to

$$\left.\begin{array}{l} z = 0: U_0 = 0, \; U_1 = 0, \; \theta_0 = 1, \; \theta_1 = 1, \; C_0 = 1, \; C_1 = 1 \\ z = d: U_0 = 1, \; U_1 = 1, \; \theta_0 = 0, \; \theta_1 = 0, \; C_0 = 0, \; C_1 = 0. \end{array}\right\} \ldots (19)$$

Solving equations (13) to (18) under corresponding boundary conditions (19), we get

$$U_0(z) = n_{17} e^{n_{11} z} + n_{16} e^{n_{12} z} + n_{13} e^{-\lambda \Pr z} + n_{14} e^{-\lambda Sc z} + n_{15} \quad \ldots (20)$$

$$U_1(z) = n_{31} e^{n_{18} z} + n_{30} e^{n_{19} z} + n_{20} e^{n_{11} z} + n_{21} e^{n_{12} z} + n_{22} e^{-\lambda \Pr z} + n_{23} e^{-\lambda Sc z} + n_{24} e^{n_2 z} + n_{25} e^{n_1 z} + n_{26} e^{n_7 z} + n_{27} e^{n_6 z} \quad \ldots (21)$$

$$\theta_0(z) = \frac{1}{(1 - e^{-\lambda \Pr})}\left(e^{-\lambda \Pr z} - e^{-\lambda \Pr}\right) \quad \ldots (22)$$

$$\theta_1(z) = n_4 e^{n_2 z} + n_5 e^{n_1 z} + n_3 e^{-\lambda \Pr z} \quad \ldots (23)$$

$$C_0(z) = \frac{1}{(1 - e^{-\Lambda Sc})}\left(e^{-\lambda Sc z} - e^{-\lambda Sc}\right) \quad \ldots (24)$$

$$C_1(z) = n_9 e^{n_7 z} + n_{10} e^{n_6 z} + n_8 e^{-\lambda Sc z} \quad \ldots (25)$$

Where

$$n_1 = \frac{1}{2}\left[-\lambda \Pr + \sqrt{\lambda^2 \Pr^2 - 4 i\omega \Pr}\right]$$

$$n_2 = \frac{1}{2}\left[-\lambda \Pr - \sqrt{\lambda^2 \Pr^2 - 4 i\omega \Pr}\right]$$

$$n_3 = \frac{\lambda^2 \Pr}{i(1 - e^{-\lambda \Pr})\omega}$$

$$n_4 = \frac{e^{n_1} - n_3(e^{n_1} - e^{-\lambda \Pr})}{(e^{n_1} - e^{n_2})}$$

$$n_5 = -\left[\frac{e^{n_2} - n_3(e^{n_2} - e^{-\lambda \Pr})}{(e^{n_1} - e^{n_2})}\right]$$

$$n_6 = \frac{1}{2}\left[-\lambda Sc + \sqrt{\lambda^2 Sc^2 - 4 i\omega Sc}\right]$$

$$n_7 = \frac{1}{2}\left[-\lambda Sc - \sqrt{\lambda^2 Sc^2 - 4 i\omega Sc}\right]$$

$$n_8 = \frac{\lambda^2 Sc}{i(1 - e^{-\lambda Sc})\omega}$$

$$n_9 = \frac{e^{n_6} - n_8(e^{n_6} - e^{-\lambda Sc})}{(e^{n_6} - e^{n_7})}$$

$$n_{10} = -\left[\frac{e^{n_7} - n_3(e^{n_6} - e^{-\lambda Sc})}{(e^{n_6} - e^{n_7})}\right]$$

$$n_{11} = \frac{1}{2}\left[-\lambda + \sqrt{\lambda^2 + 4\left(2iR + \frac{1}{k}\right)}\right]$$

$$n_{12} = \frac{1}{2}\left[-\lambda - \sqrt{\lambda^2 + 4\left(2iR + \frac{1}{k}\right)}\right]$$

$$n_{13} = -\frac{Gr\,\lambda^2}{(1 - e^{-\lambda \Pr})[\lambda^2 \Pr^2 - \lambda^2 \Pr - (2iR + \frac{1}{k})]}$$

$$n_{14} = -\frac{Gc\,\lambda^2}{(1 - e^{-\lambda Sc})[\lambda^2 Sc^2 - \lambda^2 Sc - (2iR + \frac{1}{k})]}$$

$$n_{15} = -\frac{Gr\,\lambda^2\,e^{-\lambda \Pr}}{(1-e^{-\lambda \Pr})\,(2\,i\,R+\frac{1}{k})} - \frac{Gc\,\lambda^2\,e^{-\lambda Sc}}{(1-e^{-\lambda Sc})\,(2\,i\,R+\frac{1}{k})}$$

$$n_{16} = \frac{1+(n_{13}+n_{14}+n_{15})\,e^{n_{11}} - n_{13}\,e^{-\lambda \Pr} - n_{14}\,e^{-\lambda Sc} - n_{15}}{e^{n_{12}} - e^{n_{11}}}$$

$$n_{17} = -n_{16} - n_{13} - n_{14} - n_{15}$$

$$n_{18} = \frac{1}{2}\left[-\lambda + \sqrt{\lambda^2 - 4(i\omega - 2\,i\,R - \frac{1}{k})}\right]$$

$$n_{19} = \frac{1}{2}\left[-\lambda - \sqrt{\lambda^2 - 4(i\omega - 2\,i\,R - \frac{1}{k})}\right]$$

$$n_{20} = -\frac{\lambda\,n_{11}\,n_{17}}{n_{11}^2 + \lambda\,n_{11} + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{21} = -\frac{\lambda\,n_{12}\,n_{16}}{n_{12}^2 + \lambda\,n_{12} + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{22} = \frac{\lambda^2\,n_{13}\,\Pr}{\lambda^2\,\Pr^2 - \lambda^2\,\Pr + (i\,\omega - 2\,i\,R - \frac{1}{k})} - \frac{\lambda^2\,n_3\,Gr}{\lambda^2\,\Pr^2 - \lambda^2\,\Pr + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{23} = \frac{\lambda^2\,n_{14}\,Sc}{\lambda^2 Sc^2 - \lambda^2\,Sc + (i\,\omega - 2\,i\,R - \frac{1}{k})} - \frac{\lambda^2\,n_8\,Gc}{\lambda^2 Sc^2 - \lambda^2\,Sc + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{24} = -\frac{Gr\,\lambda^2\,n_4}{n_2^2 + \lambda\,n_2 + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{25} = -\frac{Gr\,\lambda^2\,n_5}{n_1^2 + \lambda\,n_1 + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{26} = -\frac{Gc\,\lambda^2\,n_9}{n_7^2 + \lambda\,n_7 + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{27} = -\frac{Gc\,\lambda^2\,n_{10}}{n_6^2 + \lambda\,n_6 + (i\,\omega - 2\,i\,R - \frac{1}{k})}$$

$$n_{28} = n_{20} + n_{21} + n_{22} + n_{23} + n_{24} + n_{25} + n_{26} + n_{27}$$

$$n_{29} = 1 - n_{20}\,e^{n_{11}} - n_{21}e^{n_{12}} - n_{22}e^{-\lambda \Pr} - n_{23}e^{-\lambda Sc} - n_{24}\,e^{n_2} - n_{25}\,e^{n_1} - n_{26}e^{n_7} - n_{27}e^{n_6}$$

$$n_{30} = \frac{n_{29} + n_{28}\,e^{n_{18}}}{e^{n_{19}} - e^{n_{18}}}, \quad n_{31} = -n_{30} - n_{28}.$$

DISCUSSION

(i) Steady flow

We take $U_0 = u_0 + i\,v_0$ in equation (20) and subsequent comparison of the real and imaginary parts gives the mean primary velocity u_0 and mean secondary velocity v_0. The mean primary velocity is presented in Fig. 1 for fixed values of Gr, Gc and Sc=0.60 (for CO_2) in air (Pr = 0.71). The graph reveals that velocity increases with increasing suction parameter λ and reverse effect is observed for R (rotation parameter) and k (permeability of porous medium). This shows that the porosity and rotation of porous medium exert retarding influence on the primary flow. Fig.2 also shows mean primary velocity for different values of Gr (Grashof Number), Gc (Modified Grashof Number) and Sc(Schmidt Number). It is observed from the figure that the mean primary velocity increases rapidly with increasing either Gr or Gc. The magnitude of velocity is lesser in case of Sc=0.78 (NH_3) than that of Sc=0.60 (CO_2). Furthermore the mean primary velocity increases in the vicinity of the plate.

Fig.1. Mean primary velocity for Pr = 0.71, Gr = 2, Gc = 2 and Sc = 0.60

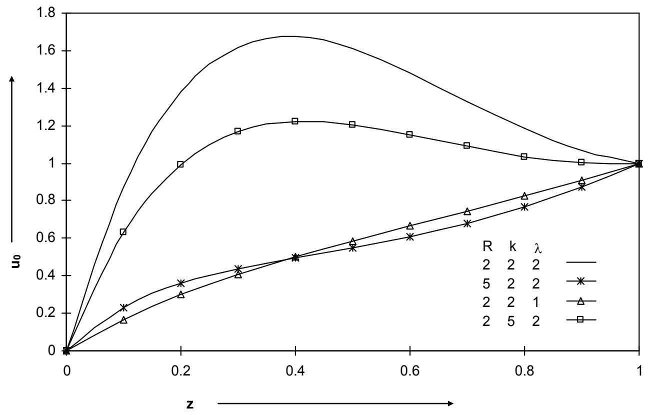


Fig.2. Mean primary velocity profiles for Pr = 0.71, R = 2, k = 2 and λ = 2

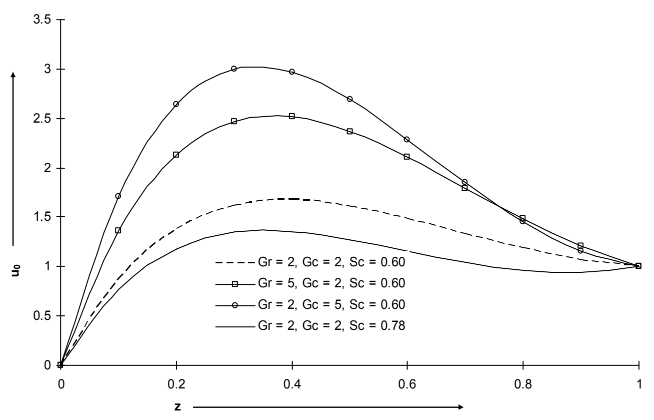
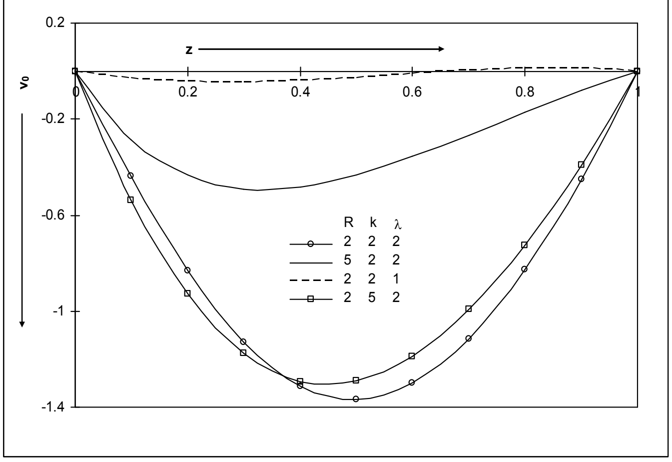


Fig.3. Mean secondary velocity profiles for Pr = 0.71, Gr = 2, Gc = 2 and Sc = 0.60



The mean secondary velocity profiles is shown in Fig. 3 for the fixed values of Gr, Gc Sc and Pr=0.71(air). It is observed that it increases with increasing R while reverse phenomena is observed for λ. It is interesting to note that mean primary velocity increases while mean secondary velocity decreases with R and λ. It is also observed that due to increase in k mean secondary velocity decreases upto middle half of the channel then it increases. Fig.4 also showed the mean secondary velocity for different values of parameters. It is observed that it decreases with increasing either Gr, Gc and Sc. The magnitude is lower in case of NH_3 than that of CO_2. The amount of secondary velocity is much lower for Gc than that of Gr.

Fig.4. Mean secondary velocity profiles for Pr = 0.71, R = 2, k = 2 and λ = 2

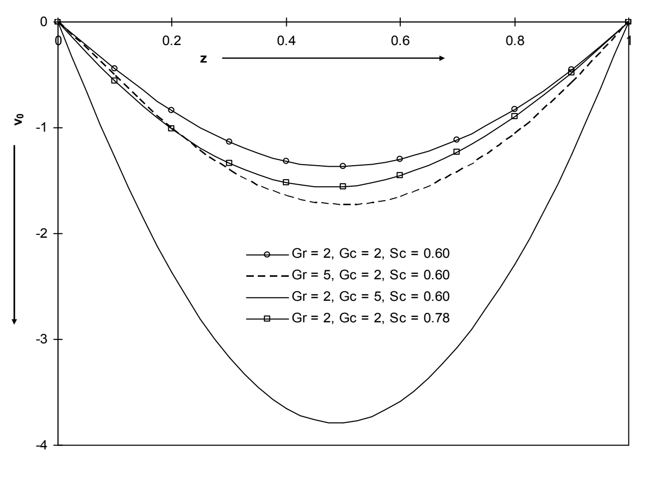
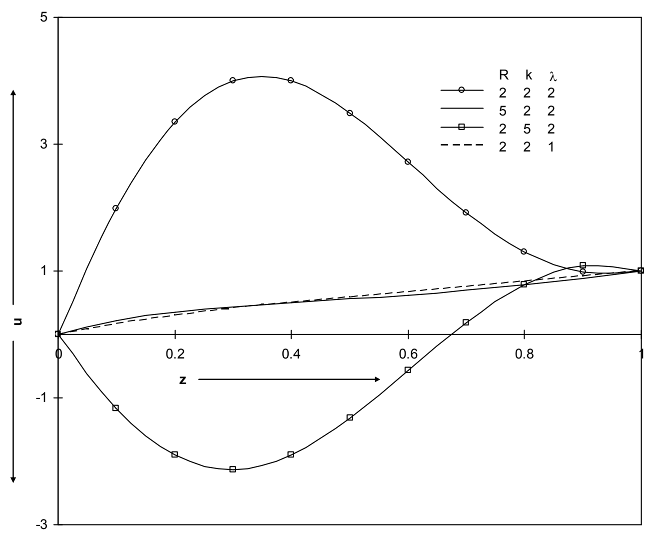


Fig.5. Transient primary velocity profiles fpr Pr = 0.71, Gr = 2, Gc = 2, ε = 0.2, Sc = 0.60, ω = 2 and t = π/2



The mean temperature and concentration is presented in Fig.9. It is observed that both decreases with increasing λ. The mean temperature and concentration decreases exponentially, the magnitude of concentration is less in case of NH_3 than that of CO_2

(ii) Unsteady flow

Replacing the unsteady parts

$$U_1(z,t)=M_r+iM_i,\ \theta_1(z,t)=T_r+iT_i,\ and\ C_1(z,t)=C_r+iC_i$$

respectively in equations (21), (23) and (25) we get

$$[U(z,t),\theta(z,t),C(z,t)]=[U_0(z),\theta_0(z),C_0(z)] + \varepsilon e^{-it}[(M_r+iM_i),(T_r+iT_i),(C_r+iC_i)] \quad \ldots(26)$$

The primary, secondary velocity fields, temperature and concentration in terms of the fluctuating components are

$$u(z,t)=u_0+\varepsilon(M_r\cos t+M_i\sin t) \quad \ldots(27)$$

$$v(z,t)=v_0+\varepsilon(M_i\cos t-M_r\sin t) \quad \ldots(28)$$

$$\theta(z,t)=\theta_0+\varepsilon(T_r\cos t+T_i\sin t) \quad \ldots(29)$$

$$C(z,t)=C_0+\varepsilon(C_r\cos t+C_i\sin t) \quad \ldots(30)$$

Taking $t=\frac{\pi}{2}$ in equations (27) to (30) we get the expression for transient primary velocity, transient secondary velocity transient temperature and concentration as

$$u\left(z,\frac{\pi}{2}\right)=u_0(z)-\varepsilon M_1(z), \quad \ldots(31)$$

$$v\left(z,\frac{\pi}{2}\right)=v_0(z)+\varepsilon M_r(z), \quad \ldots(32)$$

$$\theta\left(z,\frac{\pi}{2}\right)=\theta_0(z)-\varepsilon T_i(z) \quad \ldots(33)$$

$$C\left(z,\frac{\pi}{2}\right)=C_0(z)-\varepsilon C_i(z) \quad \ldots(34)$$

The transient primary velocity component is shown in Fig.5 for fixed values of Pr, Gr, Gc, Sc and ω. It is observed that it decreases with increasing either R and k while transient primary velocity increases with increasing suction parameter λ. It is interesting to note that initially there is decrease in transient primary and than it increasing near the other plate which is fluctuating with free stream velocity. Fig.6 also shows that due to increase in Gr and Gc the transient primary velocity increases. An increase in ω, the frequency of fluctuation transient velocity behave sinusoidally. The transient primary velocity increases with increasing Sc near the plate upto z<0.6 than it decreases. The transient secondary velocity profiles is given in Fig.7 for different values of R, k and λ. It is observed that transient secondary velocity increases with increasing either R and k, while it decreasing with increase in λ. The amount of decrease in velocity is much lower due to increase in permeability of the porous medium. Physically this is true because the porous material offers resistance to the flow, so velocity decreases in porous medium. Fig.8 also represented transient secondary velocity for different values of Gr, Gc, Sc and ω. The graph reveals that transient secondary velocity decreases with either Gr and Gc. It is interesting to note that value of transient secondary velocity is greater in case of NH_3 than that of CO_2.

Fig.6. Transient primary velocity profiles for Pr = 0.71, R = 2, k = 2, ε = 0.2, λ = 2 and t = π/2

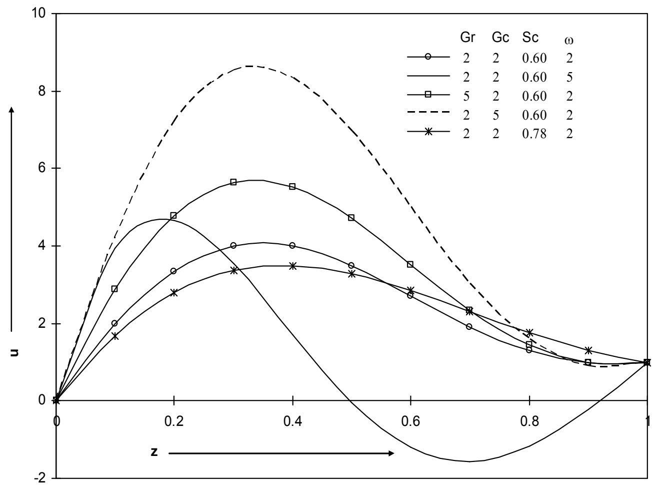


Fig.7. Transient secondary velocity profiles fpr Pr = 0.71, Gr = 2, Gc = 2, ε = 0.2, Sc = 0.60, ω = 2 and t = π/2

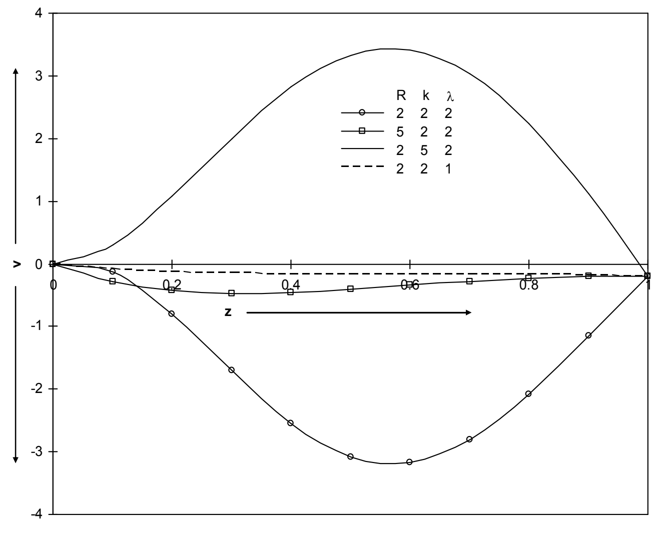


Fig.8. Transient secondary velocity profiles for Pr = 0.71, R = 2, k = 2, ε = 0.2, λ = 2 and t = π/2

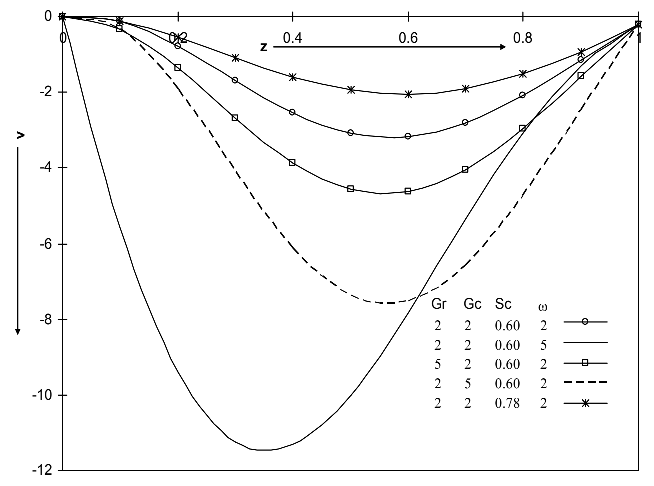


Fig.9. Mean temperature (Pr = 0.71) and concentration profiles

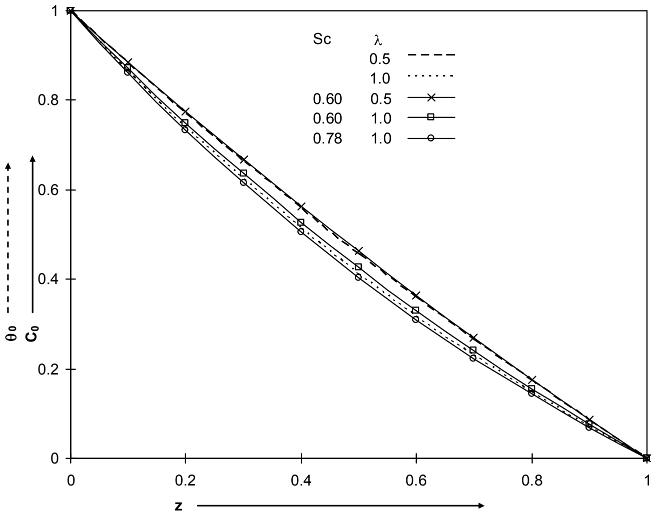


Fig.10 Transient temperature (Pr = 0.71) and transient concentration (Sc = 0.60) profiles for ε = 0.2, ω = 0.5 and t = π/2

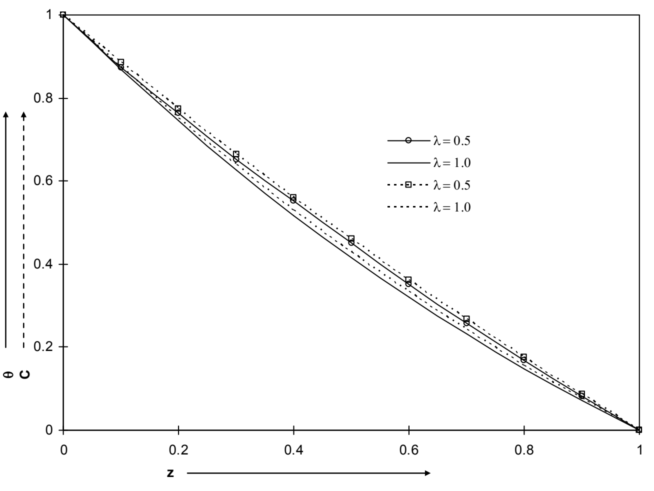


Fig.11 Amplitudes of rate of heat transfer (Pr = 0.71) I H I and rate of mass transfer I S I

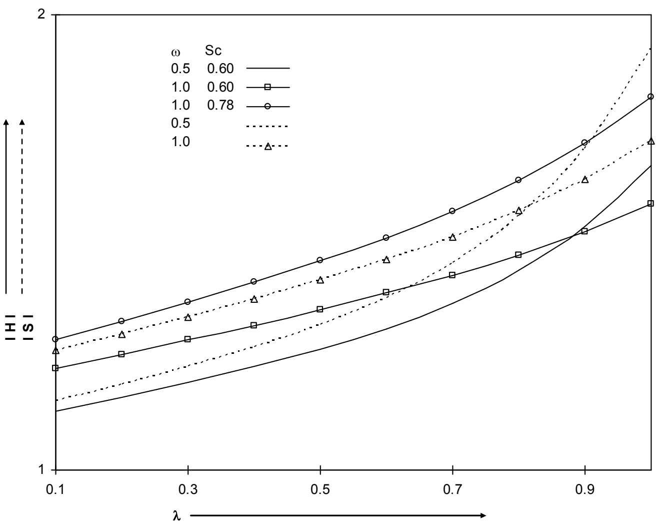
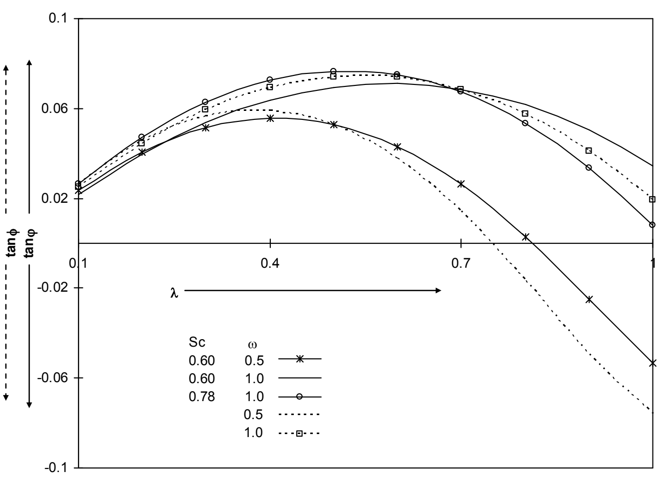


Fig.12 Phases of rate of heat transfer (tanϕ) for Pr = 0.71 and rate of mass transfer (tanφ)



Furthermore velocity decreases rapidly in the vicinity of the plate with ω than it increases near the other the plate which is fluctuating with free stream velocity.

Transient temperature and transient concentration are given in Fig.10. It is observed that transient temperature and concentration both are decreasing with suction parameter. The temperature and concentration are decreasing exponentially with distance apart vertical channel.

Heat Transfer: In the dynamics of viscous fluid one is not much interested to know all the details of the velocity and temperature fields but would certainly like to know quantity of heat exchange between the body and the fluid. Since at the boundary the heat exchanged between the fluid and the body is only due to conduction, according to Fourier's law, we have

$$q_w^* = -\kappa \left(\frac{\partial T^*}{\partial z^*}\right)_{z^*=0} \qquad \ldots(35)$$

where z* is the direction of the normal to the surface of the body. We can calculate the dimensionless coefficient of heat transfer in terms of Nusselt Number as follows

$$Nu = -\frac{q_w^* \, d}{\kappa \,(T_0^* - T_d^*)} = \left(\frac{\partial \theta}{\partial z}\right)_{z=0} = \left(\frac{\partial \theta_0}{\partial z}\right)_{z=0} + \varepsilon\, e^{-it} \left(\frac{\partial \theta_1}{\partial z}\right)_{z=0} \ldots(36)$$

In terms of the amplitude and phase the rate of heat transfer can be written as:

$$Nu = \left(\frac{\partial \theta_0}{\partial z}\right)_{z=0} + \varepsilon \left|H\right| \cos(\phi - t) \qquad \ldots(37)$$

where

$$H = H_r + i\, H_i = \textit{coefficient of } \varepsilon e^{-it} \textit{ in equation } (37)$$

$$\left|H\right| = \sqrt{Hr^2 + Hi^2} \quad , \quad \tan\phi = H_i / H_r \, .$$

Mass Transfer: According to Fick's Law the dimensionless coefficient of mass transfer at the plate in terms of Shearwood Number is given as follows

$$Sh = \left(\frac{\partial C}{\partial z}\right)_{z=0} = \left(\frac{\partial C_0}{\partial z}\right)_{z=0} + \varepsilon\, e^{-it} \left(\frac{\partial C_1}{\partial z}\right)_{z=0} \qquad \ldots(38)$$

In terms of the amplitude and phase the rate of mass transfer can be written as:

$$Sh = \left(\frac{\partial C_0}{\partial z}\right)_{z=0} + \varepsilon \left|S\right| \cos(\varphi - t) \qquad \ldots(39)$$

where

$$S = S_r + i\, S_i = \textit{coefficient of } \varepsilon e^{-it} \textit{ in equation} (39)$$

$$\left|S\right| = \sqrt{Sr^2 + Si^2} \quad , \quad \tan\varphi = S_i / S_r \, .$$

The amplitudes of rate of heat and mass transfer in presented in Fig.11. The graph reveals that both are increases with increasing ω the frequency of fluctuations upto λ <0.8 than they decreases for higher values of suction parameter. It is also observed that amplitude of mass transfer is higher in case of NH_3 than that of CO_2.

Fig.12 shows the phases of rate of heat and mass transfer. It is observed from the figure that phases of heat and mass transfer increases with increasing ω. The phase of mass transfer increases with increase in Sc. The magnitude is higher for NH_3 than that of CO_2. It is also observed from the figure that phases of heat and mass transfer increases for λ<0.5 than they decreases and become negative for small values of ω.

REFERENCES

Raptis, A., Perdikis, G. and Tzivanidis, G. 1981. Free convection flow through a porous medium bounded by a vertical surface. *J. Phys. D. Appl. Phys*., 14, 99-102.

Raptis, A., Tzivanidis, G. and Kafousias, N. 1981. Free convection and mass transfer flow through a porous medium bounded by an infinite vertical limiting surface with constant suction. *Letters Heat Mass Transfer*, 8, 417-424.

Raptis, A., Kafousias, N. and Massalas, C. 1982. Free convection and mass transfer flow through a porous medium bounded by an infinite vertical porous plate with constant heat flux. ZAMM, 62 (1982), 489-491.

Singh, P., Misra, J.K. and Narayan, K.A. 1989. Free convection along a vertical wall in a porous medium with periodic permeability variation. *Int. J. Numer. Anal. Methods Geometh*., 13, 443-450.

Lai, F.C. and Kulacki, F.A. 1990. The effect of variable viscosity on convective heat transfer along a vertical surface in a saturated porous media. *Int. J. Heat Mass Transfer*, 33, 1028-1031.

Nield, D.A. 1994. Convection in a porous medium with inclined temperature gradient: an additional results. *Int. J. Heat Mass Transfer*, 37, 3021-3025.

Kelleher, M. D. and Yang, K. T. 1968. Heat transfer response of laminar free convection boundary layers along vertical heated plate to surface temperature oscillations, ZAMP, 19, 31- 44.

Sharma, Pawan Kumar, Sharma, Bhupendra Kumar and Chaudhary, R.C. 2007. Unsteady free convection oscillatory Couette flow through a porous medium with periodic wall temperature, *Tamkang Journal of Mathematics*, 38, 93-102.

Jana, R.N. and Datta, N. 1980. Hall effect on MHD Couette flow in a rotating system, *Czech. J. Phys. B* 30, 659-667.

Muzumder, B.S. 1991. An exact solution of oscillatory Couette flow in a rotating system. *J. Appl. Mech*., 58, 1104-1107.

Ganapathy, R. 1994. A note on Oscillatory Couette flow in a rotating system. *J. Appl. Mech*., 61, 208-209.

Raptis, A. and Perdikis, C.P. 1985. Oscillatory flow through a porous medium by the presence of free convective flow, *Int. J. Engg. Sci*., 23, 51-55.

Singh, K.D. and Verma, G.N. 1995. Three dimensional oscillatory flow through a porous medium, ZAMM, 75(8), 599-604.

Sharma, B.K., Sharma, P.K. and Tara Chand, 2011. Effect of radiation on temperature distribution in three-dimensional Couette flow with heat source/sink, *Int. J. of Applied Mechanics and Engineering*, 16(2), 531-542.

Singh, K.D., Gorla, M.G., and Hans Raj, 2005. A periodic solution of oscillatory Couette flow through porous medium in rotating system, Indian, *J. Pure Appl. Math*., 36 (3), 151-159.

****