Global Journal of Science Frontier Research
Mathematics and Decision Sciences
Volume 13 Issue 9 Version 1.0 Year 2013
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Radiating Heat Transfer on Unsteady Free Convective Flow through Rotating Porous Medium with Fluctuating Heat Flux

By Pawan Kumar Sharma & Sushil Kumar Saini

Amity School of Engineering and Tchnology, India

Abstract - This communication investigates the effect of radiating heat transfer on unsteady free convection flow past a vertical surface in a rotating porous medium. It is assumed that surface is rotating with angular velocity Ω. The variable heat flux is assumed on the vertical surface varies with time; the governing equations are solved by adopting complex variable notations. The analytical expressions for velocity and temperature fields are obtained. The effects of various parameters on mean velocity, mean temperature, transient velocity and transient temperature have been discussed and shown graphically.

Keywords : *porous medium, incompressible fluid, heat flux, radiating heat transfer.*

GJSFR-F Classification : *MSC 2010: 00A69*

RADIATING HEAT TRANSFER ON UNSTEADY FREE CONVECTIVE FLOW THROUGH ROTATING POROUS MEDIUM WITH FLUCTUATING HEAT FLUX

Strictly as per the compliance and regulations of :

Radiating Heat Transfer on Unsteady Free Convective Flow through Rotating Porous Medium with Fluctuating Heat Flux

Pawan Kumar Sharma [α] & Sushil Kumar Saini [σ]

Abstract - This communication investigates the effect of radiating heat transfer on unsteady free convection flow past a vertical surface in a rotating porous medium. It is assumed that surface is rotating with angular velocity Ω. The variable heat flux is assumed on the vertical surface varies with time; the governing equations are solved by adopting complex variable notations. The analytical expressions for velocity and temperature fields are obtained. The effects of various parameters on mean velocity, mean temperature, transient velocity and transient temperature have been discussed and shown graphically.

Keywords : porous medium, incompressible fluid, heat flux, radiating heat transfer.

I. Introduction

The buoyancy-induced flows in fluid-saturated porous media have been a prime topic of many studied during the past several years. This is now considered to be an important field in the general areas of fluid mechanics and heat transfer through radiation. In view of the importance in various engineering and technological applications such as in the field of agriculture engineering to study underground water resources, seepage of water under a dam, in petroleum technology to study the movement of natural gas, oil and water through the oil reservoirs, in chemical engineering for filtration and purification processes, in underground coal gasification, heat recovery from geothermal systems, etc.

In view of geophysical applications of the flow through porous medium, a series of investigations has been made by Raptis et.al [1-3], where the porous medium is either bounded by horizontal, vertical surfaces or parallel porous plates. Singh et.al [4] and Lai and Kulacki [5] heve been studied the free convective flow past vertical wall. Nield [6] studied convection flow through porous medium with inclined temperature gradient. The oscillatory Couette flows in a rotating system have been studied by

Ref

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

Author α : Department of Applied Mathematics, Amity School of Engineering and Technology, New-Delhi 110061 India.
E-mail : drpawanksharma@yahoo.com
Author σ : Department of Mathematics, Dronacharya Government College, Gurgaon, Haryana 122001 India.
E-mail: sksainihes29@rediffmail.com

Muzumder [7] and Ganapathy [8]. Singh et sl. [9] also studied periodic solution on oscillatory flow through channel in rotating porous medium. Further due to increasing scientific and technical applications on the effect of radiation on flow characteristic has more importance in many engineering processes occurs at very high temperature and acknowledge radiative heat transfer such as nuclear power plant, gas turbine and various propulsion devices for aircraft, missile and space vehicles. The effect of radiation on flow past different geometry a series of investigation have been made by Hassan [10], Seddeek [11] and Sharma et al [12].

Therefore the object of the present paper is to investigate the effect of radiation on unsteady free convection flow past a porous vertical surface in a rotating porous medium. Assuming periodic thermal diffusion at the plate, the analytical solution is obtained using regular perturbation technique and discussed graphically.

a) Mathematical Formulation of the Problem

We consider the unsteady viscous incompressible fluid through a porous medium, occupying a semi-infinite region of the space bounded by a vertical infinite porous surface in a rotating system, when the temperature of the surface, varies with time. We assume the effect of radiation on vertical surface which is subjected to uniform constant suction velocity in the direction perpendicular to surface. We consider the vertical infinite porous surface rotating with constant angular velocity Ω about an axis which is perpendicular to the vertical plane confined with a viscous fluid occupying the porous region. Vertical porous plane is taken to be $z^* = 0$ plane with z^* axis normal to it. X^* axis is selected vertically upwards and y^* axis in the perpendicular direction in $z^* = 0$ plane. The flow is assumed to be along the plane $z^*=0$. With the above frame of reference and assumptions, with physical variables, except the pressure p, are the function of z^* and t^* only. The flow in porous medium involves small velocities permitting the neglect of heat due to viscous dissipation in governing equation. The equation expressing the conservation of mass and energy transfer in rotating frame of reference are given by

$$\frac{\partial w^*}{\partial z^*} = 0, \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} + w^* \frac{\partial u^*}{\partial z^*} - 2\Omega v^* = g\beta(T^* - T^*) + \nu \frac{\partial^2 u^*}{\partial z^{*2}} - \frac{\nu u^*}{k^*}, \tag{2}$$

$$\frac{\partial v^*}{\partial t^*} + w^* \frac{\partial v^*}{\partial z^*} + 2\Omega u^* = \nu \frac{\partial^2 v^*}{\partial z^{*2}} - \frac{\nu v^*}{k^*}, \tag{3}$$

Ref

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

Global Journal of Science Frontier Research (F) Volume XIII Issue IX Version I Year 2013

$$0 = -\frac{1}{\rho}\frac{\partial p^*}{\partial z^*} - \frac{\nu w^*}{k^*}, \tag{4}$$

$$\frac{\partial T^*}{\partial t^*} + w^*\frac{\partial T^*}{\partial z^*} = \alpha\frac{\partial^2 T^8}{\partial z^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial z^*}, \tag{5}$$

Notes

where u*, v* w^* are components of velocity, g is the acceleration due to gravity, β is the volumetric coefficient of thermal expansion, T* is the temperature, T^*_∞ 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, q_r^* is radiative heat flux, p* is the pressure, ρ is the density, t* is the time and α is the thermal diffusivity.

The boundary conditions of the problem are

$$\left.\begin{array}{l} z = 0:\ u^* = 0,\quad v^* = 0,\quad \dfrac{\partial T^*}{\partial z^*} = -\dfrac{q_w^*}{\kappa}(1+\varepsilon\, e^{i\omega^* t^*}) \\ z\to\infty:\ u^*\to 0,\ v^*\to 0,\quad T^*\to T^*_\infty\ . \end{array}\right\} \tag{6}$$

where q_w^* is the heat flux at wall ω^* is the frequency of fluctuation and κ is the thermal conductivity of the plate, For constant suction, we have from equation (1) ,

$$w = -w_0 \tag{7}$$

Considering u + iv = U and taking into account equation (7), the equations (2) and (3) can be written as

$$\frac{\partial U^*}{\partial t^*} - w_0\frac{\partial U^*}{\partial z^*} + 2\iota\Omega U^* = g\beta(T^* - T^*_\infty) + \nu\frac{\partial^2 U^*}{\partial z^{*2}} - \frac{\nu U^*}{k^*}, \tag{8}$$

We introduce the following non-dimensional quantities as:

$$z = \frac{w_0 z^*}{\nu},\quad U = \frac{U^*}{w_0},\quad t = \frac{t^* w_0^2}{\nu},\quad \omega = \frac{\nu\omega^*}{w_0^2},\quad \theta = \frac{\kappa(T^* - T^*_\infty)w_0}{q_w^*\nu}, \tag{9}$$

$$k = \frac{w_0^2 k^*}{\nu^2},\ \text{R (rotation parameter)} = \frac{\Omega\nu}{w_0^2},\ \alpha\,(\text{thermal diffusivity}) = \frac{\kappa}{\rho C_p},$$

$$\text{Gr (Grashof number)}\quad \frac{g\beta q_w^*\nu^2}{w_0^4\kappa},\ \text{Pr (Prandtal number)} = \frac{\nu}{\alpha}.$$

$$F\,(\text{radiation parameter}) = \frac{4\,\nu\,I}{\rho\,C_p\,w_0^2},$$

The Radiative heat flux Cogley [13] $\dfrac{\partial q_r^*}{\partial z^*} = 4\,(T^* - T_\infty^*)\,I^*$,

$I^* = \int_0^\infty \kappa_{\lambda\omega} \dfrac{\partial e_{b\lambda}}{\partial T^*} d\lambda$, $\kappa_{\omega\lambda}$ is the absorption coeffieient at the wall and $e_{b\lambda}$ is Planck's function.

Substituting these non-dimensional quantities in equations (8) and (5), we get

$$\frac{\partial U}{\partial t} - \frac{\partial U}{\partial z} - 2iRU = Gr\,\theta + \frac{\partial^2 U}{\partial z^2} - \frac{U}{k}, \tag{10}$$

$$\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial z} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial z^2} - F\,\theta, \tag{11}$$

and the boundary conditions (6) become

$$\left.\begin{array}{ll} z = 0: \; U = 0, & \dfrac{\partial \theta}{\partial z} = -(1 + \varepsilon\, e^{i\omega t}) \\ z \to \infty: \; U \to 0, & \theta \to 0. \end{array}\right\} \tag{12}$$

II. 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

$$\left.\begin{array}{l} U(z,t) = U_0(z) + \varepsilon\, U_1(z)\, e^{\iota\omega t} + \ldots\ldots\ldots\ldots \\ \theta(z,t) = \theta_0(z) + \varepsilon\,\theta_1(z)\, e^{\iota\omega t} + \ldots\ldots\ldots\ldots \end{array}\right\} \tag{13}$$

Substituting (13) in equations (10) and (11), and equating the coefficient of identical powers of ε and neglecting those of ε^2, ε^3 etc., we get

$$U_0'' + U_0' - 2\iota R U_0 - \frac{U_0}{k} = -\,Gr\,\theta_0, \tag{14}$$

$$U_1'' + U_1' - 2\iota R U_1 - \iota\omega U_1 - \frac{U_1}{k} = -\,Gr\,\theta_1, \tag{15}$$

$$\theta_0'' + Pr\,\theta_0' - F\,Pr\,\theta_0 = 0, \tag{16}$$

$$\theta_1'' + Pr\,\theta_1' - (F + \iota\omega)\,\theta_1\,Pr = 0. \tag{17}$$

The corresponding boundary conditions (12) reduce to

Notes

$$\left.\begin{aligned} z = 0 &: U_0 = 0,\ U_1 = 0,\ \frac{\partial \theta_0}{\partial z} = -1,\ \frac{\partial \theta_1}{\partial z} = -1 \\ z \to \infty &: U_0 \to 0,\ U_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0. \end{aligned}\right\} \tag{18}$$

Solving equations (14) to (17) under corresponding boundary conditions (18), we get

Notes

$$U_0(z) = c_4 \left(e^{-c_1 z} - e^{-c_3 z} \right) \tag{19}$$

$$U_1(z) = c_6 \left(e^{-c_2 z} - e^{-c_5 z} \right) \tag{20}$$

$$\theta_0(z) = \frac{1}{c_1} e^{-c_1 z}, \tag{21}$$

$$\theta_1(z) = \frac{1}{c_2} e^{-c_2 z}. \tag{22}$$

where

$$c_1 = \frac{1}{2}\left[Pr + \sqrt{Pr^2 + 4 F Pr} \right]$$

$$c_2 = \frac{1}{2}\left[Pr + \sqrt{Pr^2 + 4 Pr (F + \iota \omega)} \right]$$

$$c_3 = \frac{1}{2}\left[1 + \sqrt{1 + 8 \iota R + \frac{4}{k}} \right]$$

$$c_4 = -\frac{Gr}{c_1 \left(c_1^2 - c_1 - 2 \iota R - \frac{1}{k} \right)}$$

$$c_5 = \frac{1}{2}\left[1 + \sqrt{1 + 4(2 \iota R + \iota \omega) + \frac{4}{k}} \right]$$

$$c_6 = -\frac{Gr}{c_2 \left(c_2^2 - c_2 - 2 \iota R - \iota \omega - \frac{1}{k} \right)}$$

III. Results

a) Steady Flow

We take $U_0 = u_0 + \iota v_0$ in equation (19) and subsequent comparison of the real and imaginary parts gives the mean primary $\frac{u_0}{w_0}$ and mean secondary $\frac{v_0}{w_0}$ velocity fields as

$$\left.\begin{aligned} \frac{u}{w_0} &= a_5\, e^{-c_1 z} - a_5\, e^{-a_3 z} \cos a_4 z - a_6\, e^{-a_3 z} \sin a_4 z \\ \frac{v}{w_0} &= a_6\, e^{-c_1 z} + a_5\, e^{-a_3 z} \sin a_4 z - a_6\, e^{-a_3 z} \cos a_4 z \end{aligned}\right\}, \tag{23}$$

b) *Unsteady Flow*

Replacing the unsteady parts

$U_1(z,t) = M_r + \iota M_i$, and $\theta_1(z,t) = T_r + \iota T_i$ respectively in equation (20), we get

$$[U(z,t), \theta(z,t)] = [U_0(z), \theta_0(z)] + \varepsilon\, e^{\iota \omega t} [(M_r + \iota M_i), (T_r + \iota T_i)] \tag{24}$$

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

$$\frac{u}{w_0}(z,t) = u_0 + \varepsilon (M_r \cos \omega t - M_i \sin \omega t) \tag{25}$$

$$\frac{v}{w_0}(z,t) = v_0 + \varepsilon (M_r \sin \omega t + M_i \cos \omega t) \tag{26}$$

Taking $\omega t = \frac{\pi}{2}$ in equations (24) , (25) and (26), we get the expression for transient primary velocity, transient secondary velocity and transient temperature as

$$\frac{u}{w_0}\left(z, \frac{\pi}{2\omega}\right) = u_0(z) - \varepsilon\, M_1(z), \tag{27}$$

$$\frac{v}{w_0}\left(z, \frac{\pi}{2\omega}\right) = v_0(z) + \varepsilon\, M_r(z), \tag{28}$$

$$\theta\left(z, \frac{\pi}{2\omega}\right) = \theta_0(z) - \varepsilon\, T_i(z). \tag{29}$$

where

$$M_r = a_{11} [e^{-a_1 z} \cos a_2 z - e^{-a_7 z} \cos a_8 z] - a_{12} [e^{-a_7 z} \sin a_8 z - e^{-a_1 z} \sin a_2 z]$$

$$M_i = a_{12} [e^{-a_1 z} \cos a_2 z - e^{-a_7 z} \cos a_8 z] + a_{11} [e^{-a_7 z} \sin a_8 z - e^{-a_1 z} \sin a_2 z]$$

$$T_i = -\frac{e^{-a_1 z}}{a_1^2 + a_2^2} [a_1 \sin a_2 z + a_2 \cos a_2 z]$$

Notes

Notes

$$c_2 = a_1 + \imath\, a_2 \;,\; c_3 = a_3 + \imath\, a_4 \;,\; c_4 = a_5 + \imath\, a_6 \;,\; c_5 = a_7 + \imath\, a_8 \;,\; c_6 = a_{11} + \imath\, a_{12}$$

$$a_1 = \frac{1}{2}\left[\, Pr + \sqrt{\sqrt{(Pr^2 + 4\,F\,Pr)^2 + 16\,\omega^2\,Pr^2}}\;\; . \;\frac{(Pr^2 + 4\,F\,Pr)^2 - 16\,\omega^2\,Pr^2}{(Pr^2 + 4\,F\,Pr)^2 + 16\,\omega^2\,Pr^2}\right]$$

$$a_2 = \frac{1}{2}\left[\sqrt{\sqrt{(Pr^2 + 4\,F\,Pr)^2 + 16\,\omega^2\,Pr^2}}\;\; . \;\frac{8\,\omega\,Pr\,(Pr^2 + 4\,F\,Pr)}{(Pr^2 + 4\,F\,Pr)^2 + 16\,\omega^2\,Pr^2}\right]$$

$$a_3 = \frac{1}{2}\left[1 + \sqrt{\sqrt{\left(1+\frac{4}{k}\right)^2 + 64\,R^2}}\;\; . \;\frac{\left(1+\frac{4}{k}\right)^2 - 64\,R^2}{\left(1+\frac{4}{k}\right)^2 + 64\,R^2}\right]$$

$$a_4 = \frac{1}{2}\left[\sqrt{\sqrt{\left(1+\frac{4}{k}\right)^2 + 64\,R^2}}\;\; . \;\frac{16\,R\left(1+\frac{4}{k}\right)}{\left(1+\frac{4}{k}\right)^2 + 64\,R^2}\right]$$

$$a_5 = -\frac{Gr\left(c_1^3 - c_1^2 - \frac{c_1}{k}\right)}{\left(c_1^3 - c_1^2 - \frac{c_1}{k}\right)^2 + 4\,R^2\,c_1^2}\,,$$

$$a_6 = -\frac{2\,Gr\,R\,c_1}{\left(c_1^3 - c_1^2 - \frac{c_1}{k}\right)^2 + 4\,R^2\,c_1^2}\,,$$

$$a_7 = \frac{1}{2}\left[1 + \sqrt{\sqrt{\left(1+\frac{4}{k}\right)^2 + 16\,(2\,R+\omega)^2}}\;\; . \;\frac{\left(1+\frac{4}{k}\right)^2 - 64\,(2\,R+\omega)^2}{\left(1+\frac{4}{k}\right)^2 + 64\,(2\,R+\omega)^2}\right]$$

$$a_8 = \frac{1}{2}\left[\sqrt{\sqrt{\left(1+\frac{4}{k}\right)^2 + 16\,(2\,R+\omega)^2}}\;\; . \;\frac{8\,(2\,R+\omega)\left(1+\frac{4}{k}\right)}{\left(1+\frac{4}{k}\right)^2 + 64\,(2\,R+\omega)^2}\right]$$

$$a_9 = a_1^2 - a_2^2 - a_1 - \frac{1}{k}\;,$$

$$a_{10} = 2\,a_1\,a_2 - a_2 - 2\,R - \omega\;,$$

$$a_{11} = -\frac{Gr\,(a_1\,a_9 - a_2\,a_{10})}{(a_1\,a_9 - a_2\,a_{10})^2 + (a_2\,a_9 + a_1\,a_{10})^2}\;,$$

$$a_{12} = \frac{Gr\,(a_2\,a_9 + a_1\,a_{10})}{(a_1\,a_9 - a_2\,a_{10})^2 + (a_2\,a_9 + a_1\,a_{10})^2}\;.$$

IV. Discussion and Conclusions

From equation (23), it has been found that steady part of the mean primary velocity field has a two layer character. These layers may be identified as suction layer and thermal layer. The suction layer is due to rotation and porosity of the medium. The thermal layer is arising due to interaction of the thermal field due to radiation and the velocity field and is dependent on Prandtl Number and Radiation Parameter.

For physical interpretation of the problem, the numerical values of the mean primary and mean secondary velocity profiles have been computed for fixed values of physical parameter, for Grashof number Gr = 2, Prandtl number Pr= 0.71 (air), frequency of fluctuation ω = 0.5 and for different values of Rotation parameter R, Radiation parameter F and permeability of porous medium k. From fig.1 we observe that the mean primary velocity increases with increase in either rotation parameter R or permeability k. This shows that the viscosity and rotation of porous medium exert retarding influence on the primary flow. It has also been observed that it decreases with increasing radiation parameter F. the mean primary velocity increases in the vicinity of the surface and than decreases with perpendicular distance from the surface.

The mean secondary velocity is given in fig.2 for fixed values of Gr = 2, Pr = 0.71 (air) and ω =0.5. It is observed that it decreases sufficiently higher with increasing rotation parameter F. It is interesting to note that mean secondary velocity increases with rotation parameter and permeability for $z<0.5$, while reverse phenomena is observed for $z>0.5$, showing that the effect of flow parameter is more significant for relatively small values of z. The transient primary velocity profiles are presented in fig.3 for fixed values of Gr = 2, Pr = 0.71 (air) and ω =0.5. It is observed that the

Notes

transient primary velocity increases with increasing either permeability or rotation parameter. It is interesting to note that it increases with increasing radiation parameter for $z<0.9$ than it decreases for $z \geq 0.9$.

The transient secondary velocity is given in fig.4. It is observed that transient velocity increases in the vicinity of vertical surface while, reverse effect is observed with increasing radiation parameter. It is also observed that it increases with increasing rotation parameter and permeability for small value of z, while it decreases with higher value of z.

Fig.5 shows the variation of mean and transient temperature profiles for different values of ω and F. The mean temperature and transient temperature both decreases with increasing radiation parameter. Also the transient temperature increases with increasing ω. It is interesting to note that both are decreasing exponentially with distance far away from the vertical surface.

References Références Referencias

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

(2) Raptis,A., Tzivanidis,G. and Kafousias,N.: 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 (1981), 417-424.

(3) Raptis,A., Kafousias,N. and Massalas,C.: 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.

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

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

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

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

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

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

(10) Hassan, A.M. and El-Arabawy, Effect of suction/injection on the flow of a micropolar fluid past a continuously moving plate in the presence of radiation, Int. J. Heta Mass Transfer, 46(8), (2003), 1471-1477.

(11) Seddeek, M.A. ; The effect of variable viscosity on hydromagnetic flow and heat transfer past a continuously moving porous boundary with radiation, Int. Comm., Heat Mass Transfer, 27(7), (2000), 1037-1046.

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

(13) Cogley A.C., Vinceti W.G. and Gilles S.E.; Differential approximation for radiation transfer in a nongray near equilibrium, AIAA Journal, 6, (1968), 551-553.

Notes

Notes

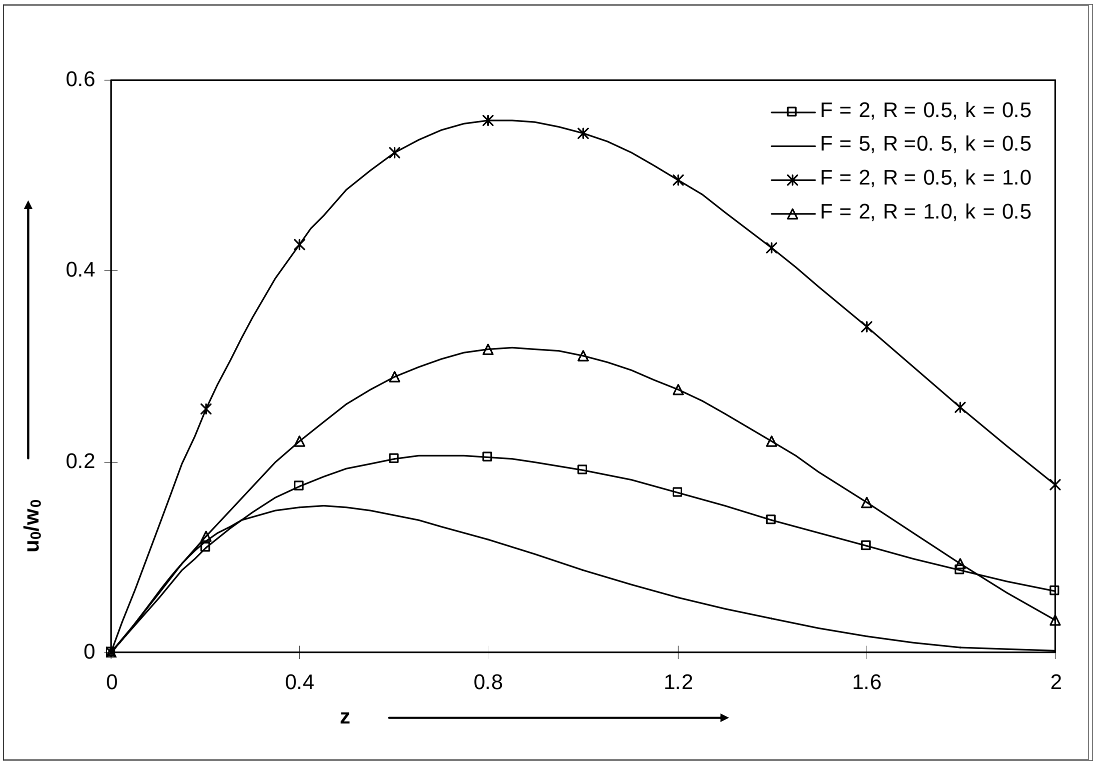

Figure 1 : Mean primary velocity for Pr=0.71, Gr=2 and ω=0.5

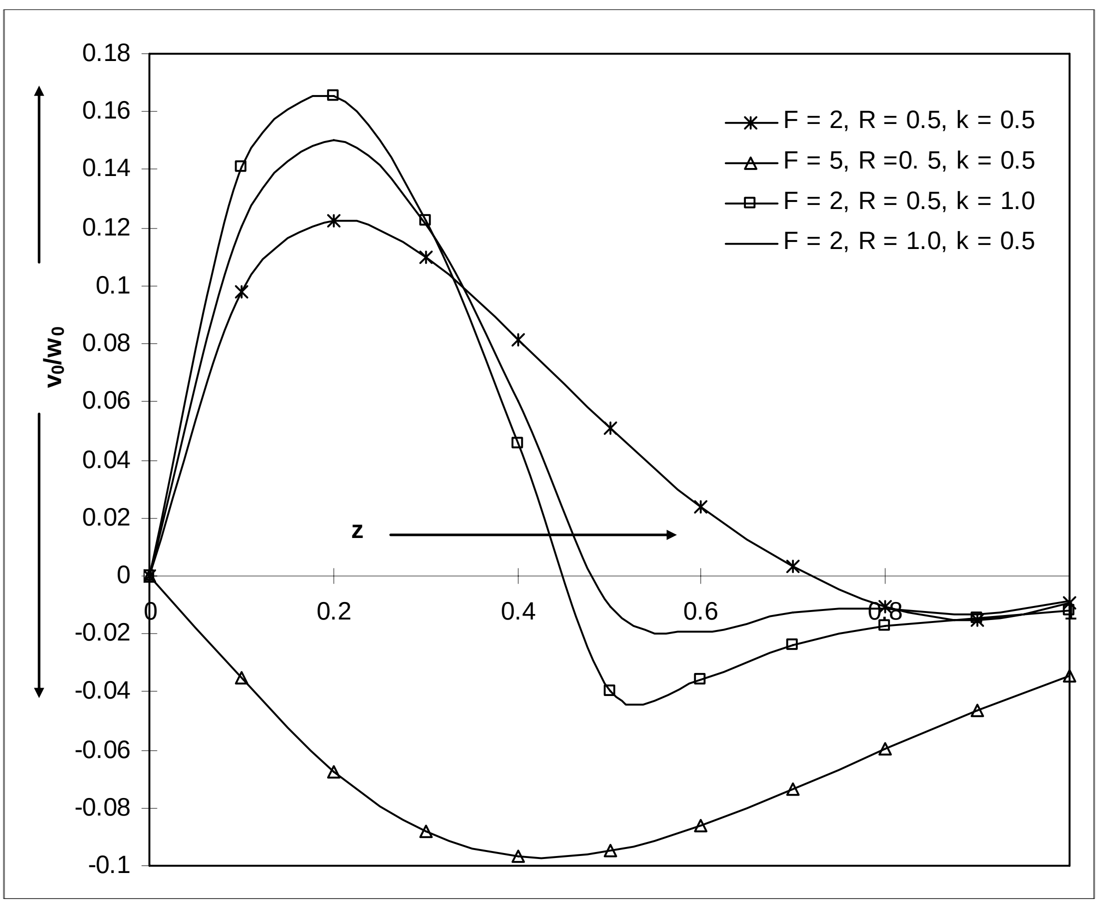

Figure 2 : Mean secondary velocity for Gr=2, Pr=0.71 and ω=0.5

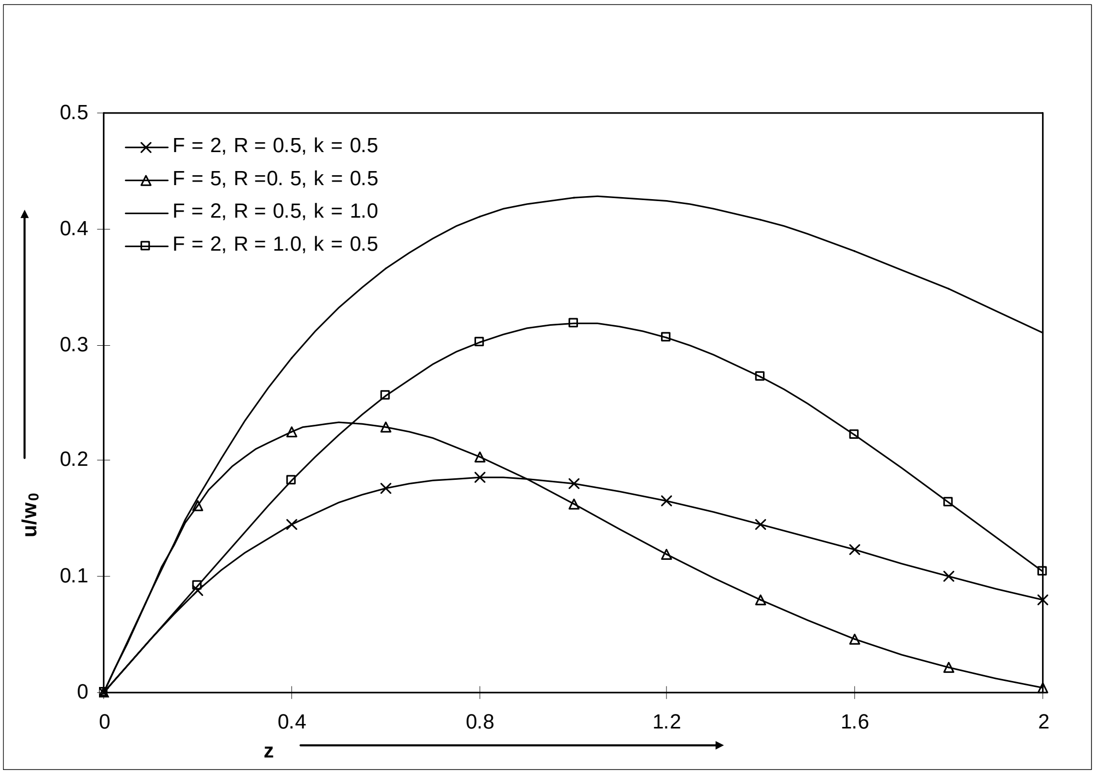

Figure 3 : Transient primary velocity for Pr=0.71, Gr = 2 and ω = 0.5

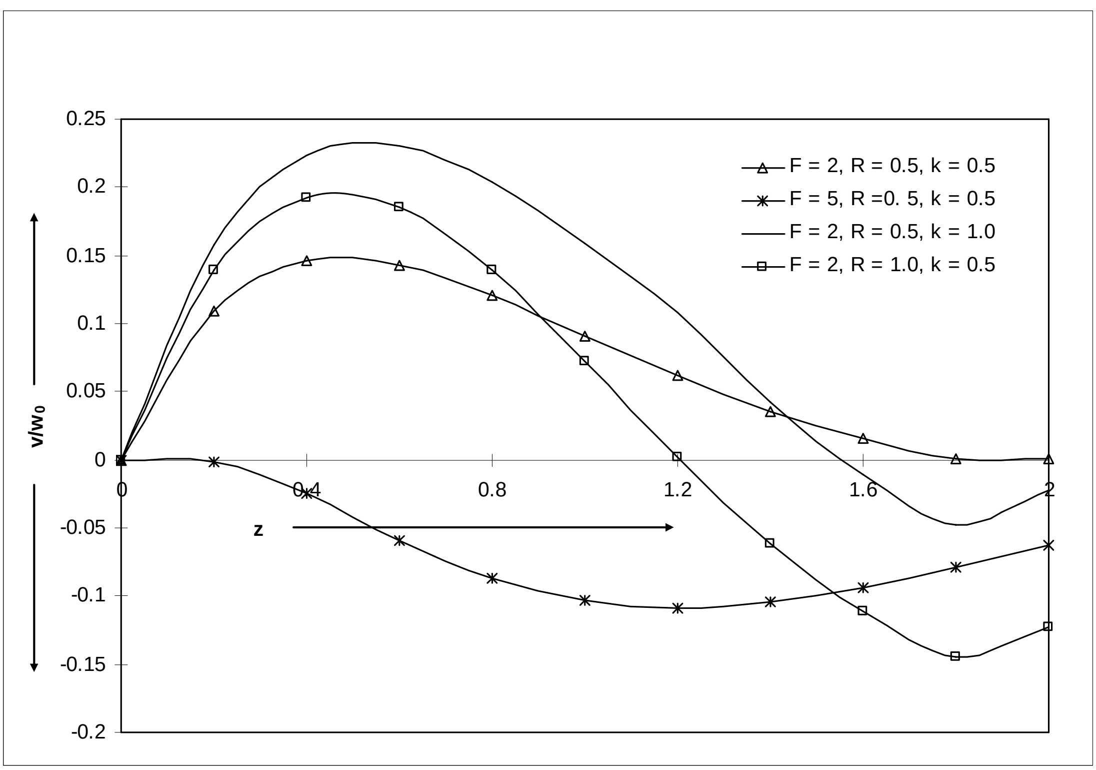

Figure 4 : Transient secondary velocity for Pr=0.71, Gr=2 and ω = 0.5

Notes

Notes

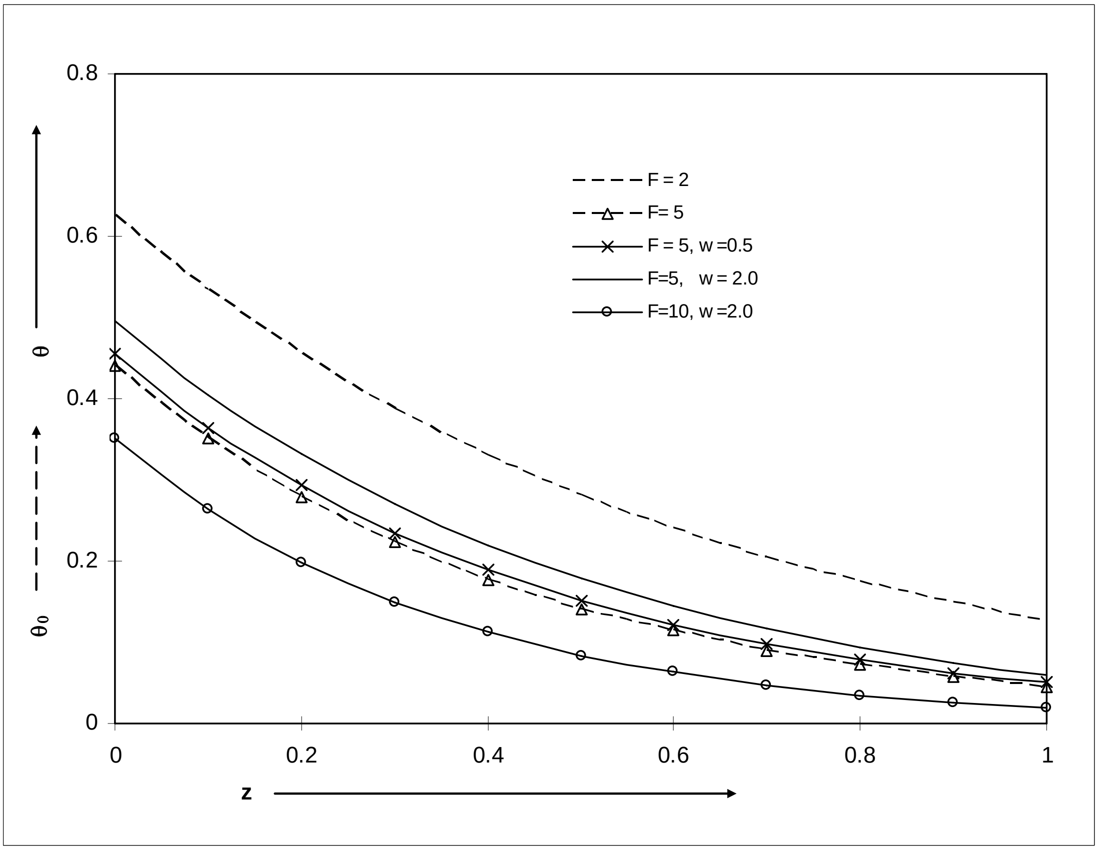

Figure 5 : Mean temperature θ_0 and Transient temperature (ε= 0.2 and $\omega t=\pi/2$) for air Pr = 0.71