Oscillatory Mixed Convention in a Porous Medium

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ABSTRACT

Oscillating mixed convection on the fully developed flow between two infinitely long vertical walls heated asymmetrically in a porous medium, has been studied. It experiences g-jitter force associated with microgravity in the field of space science with reference to crystal growth in space. Our present study can be exposed to a real life situation of a microgravity field. The time varying gravity field generates oscillatory free convection velocity field. This is combined with the forced oscillating flow driven by a pressure gradient.

Keywords: g-jitter forces, Porous medium, Darcy number, Critical Grashof number, Free convection and forced convection.

NOMENCLATURE

\( a \) defined in equation (15)  

\( P \) dimensionless pressure  

\( D_a \) \( = \frac{k}{L^2} \) Darcy number  

\( r_t \) \[ = \left( \frac{T_1 - T_0}{T_2 - T_0} \right) \] temperature ratio parameter  

\( F \) \( = u_i L / \nu \) Dimensionless velocity component  

\( t \) time  

\( \text{Real}(Fe^{i\omega t}) \) real part of \( Fe^{i\omega t} \)  

\( \text{Gr} \) \[ = g_o \beta v^2 (T_2 - T_1) \] Grashof number  

\( u \) velocity component in \( x \) direction  

\( (Gr)_c \) critical value of Grashof number  

\( u_o \) velocity scale  

\( i = \sqrt{-1} \) complex quantity  

\( k' \) permeability of a porous medium \( (x, y, z) \) Cartesian co-ordinates  

\( L \) width of the channel  

\( \alpha \) \[ = \frac{L \int -d\Pi d\xi}{(\rho v^2)} \] dimensionless pressure gradient  

\( M_a \) \( = \frac{\mu}{L} \) viscosity ratio  

\( \beta \) Coefficient of thermal expansion  

\( n \) Frequency parameter  

\( \eta \) \( = y L \) non-dimensionalized width of the channel  

\( p \) pressure gradient in \( x \)-direction  

\( \theta \) \[ = \frac{(T - T_1)}{(T_2 - T_0)} \] dimensionless temperature  

\( \lambda \) defined in equation (31)  

\( \rho \) fluid density
1. INTRODUCTION

An excellence of a study of a porous medium flow is the subject motivated by several important applications in science and engineering. Due to its broad range of applications in science and industry, this field has gained extensive attention lately. In a broad sense, the study of porous medium embraces fluid and thermal sciences, geothermal, petroleum and combustion engineering. Over the past decades, several studies have been taken into account of a porous medium flow with reference to Nield and Bejan (2006), Bejan (1974), Kaviany (1995), Vafai and Kim (1995) and Ingham and Pop (2002). All these authors have been studied in a prospective way to determine its flow behavior of several aspects of fluid engineering, thermal science and combustion engineering. However several studies have been taken into account of a porous medium flow. A literature survey reveals to study of Debruge and Han (1972), Du and Bilgen (1992), Hessain and Wilson (2002), Guria et al. (2009), Beg et al. (2011), Chamkha (1997), Satapathy et al. (1998), Chamkha et al. (2004), Raptis and Perdikis (2004) and Jana et al. (2012). Our present study deals with mixed convection with asymmetric heating of the wall embedded in a porous medium with reference to a study of Aung and Worku (1986). Aung and Worku (1986) studied mixed convection flow in the absence of Darcy number. The study of mixed convection flow in the presence of a magnetic field has been developed by Ghosh and Nandi (2000), Ghosh et al. (2002) and Guria et al. (2007). A recent study has been developed with g-jitter force to exert its influence of mixed convection flow with asymmetric heating of the wall in the presence of a magnetic field. This has been studied by Bo Pan and Ben Q (1998). However, a transverse magnetic field effect on g-jitter driven flow associated with oscillating pressure gradient in a channel has been studied by Lehoczky et al. (1994), Antar and Nuotio-Antar (1993) and Nelson (1991). Recently, a transient approach to radiative heat transfer free convection flow with ramped wall temperature has been analyzed by Patra et al. (2012).

The aim of the present investigation is to deal with the study of an oscillating mixed convection driven by g-jitter flow associated with microgravity field with a decisive importance to a highly permeable medium. A g-jitter driven flow in a cavity bears direct relevance to crystal growth in space so that the net mass flow rate of the system is zero. The better model can be considered by representing the flow system of a long parallel plate channel with significant effect of pressure gradient. The practical application of unsteadiness and g-jitter force is of great importance to a microgravity field in taking into account of space fluid system design. In a realistic situation, the co-relation of unsteadiness and g-jitter force becomes relevant to time varying gravity field driven by a time harmonic g-jitter components with a frequency of oscillation and the flow at the entrance also oscillates because of an applied pressure gradient. The representation of g-jitter forces is the time varying gravity field to generate oscillatory free convection velocity field. This is combined with the forced oscillating flow driven by a pressure gradient. The importance of a study of this problem has many applications of geothermal, combustion engineering and astrophase science. We have considered g-jitter forces driven by oscillating mixed convection of a viscous incompressible fluid flow in a porous medium between two infinitely long vertical walls. Here we considered the Brinkman equation subject to the limit $k' \rightarrow 0$ that gives Darcy flow and the limit $k' \rightarrow \infty$ gives the viscous flow, $k'$ being the permeability of the porous medium. It is found that the velocity decreases near the channel walls while it increases at the middle of the channel with an increase in Darcy number $D$. The critical value of the buoyancy force $Gr$ for which there is no flow reversal near the cold wall and it decreases with an increase in Darcy number $D$.

2. MATHEMATICAL FORMULATION AND ITS SOLUTION

Consider the mixed convection of viscous incompressible fluid flow in a porous medium between two infinitely long vertical walls separated by a distance $L$. The fluid is at temperature $T_0$ and flows due to temperature and pressure gradient in between two parallel walls. The walls are infinitely long along $x$-axis and $z$-direction with different wall temperatures [see Fig.1]. We consider the fully developed unsteady flow in a porous medium. We assume that the g-jitter field under consideration is spatially constant and otherwise varies with time harmonically.
Further, the flow at the entrance of the channel also oscillates harmonically due to an applied pressure gradient. An oscillatory free convection velocity will generate because of the variation of the gravity field. Thus, the problem becomes a free and forced convection oscillating flow in the presence of pressure gradient.

The equation of motion under the usual Boussinesq approximation is

\[
\frac{\partial u}{\partial t} + \frac{1}{\rho} \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + g(T-T_0) - \frac{\mu}{\rho} k \frac{\partial^2 u}{\partial x^2},
\]

where \(k\) the permeability of the porous medium, \(\beta\) the thermal expansion co-efficient, \(\mu\) the fluid viscosity, \(\eta\) the effective viscosity of the fluid saturated by porous medium and \(\rho\) the fluid density.

The energy equation is

\[
\frac{d^2 T}{dy^2} = 0.
\]

The velocity and temperature boundary conditions are

\[
\begin{align*}
    u &= 0 \quad \text{at} \quad y = 0 \quad \text{and} \quad u = 0 \quad \text{at} \quad y = L, \\
    T &= T_1 \quad \text{at} \quad y = 0 \quad \text{and} \quad T = T_2 \quad \text{at} \quad y = L.
\end{align*}
\]

Assuming \(u = u(y)e^{im}g(t)\), \(g(t) = g_0 e^{im}, \quad p = P(x) e^{im}\),

the Eq. (1) becomes

\[
\begin{align*}
    \frac{d}{dx} \left( \frac{dP}{dx} \right) + \frac{\mu}{\rho} \frac{d^2 u}{dx^2} + g_0 \beta(T - T_0) = \frac{\mu}{\rho} k \frac{\partial^2 u}{\partial x^2}.
\end{align*}
\]

Introducing non-dimensional variables

\[
\eta = \frac{y}{L}, \quad F = \frac{uL}{v}, \quad \theta = \frac{T - T_0}{T_2 - T_0},
\]

Eqs. (6) and (2) become

\[
\begin{align*}
    \frac{d^2 F}{d\eta^2} - \left(\frac{1}{Ma D_{y_x}} + i\omega\right) F &= -(\alpha + Gr \theta), \quad \text{Eq. (8)} \\
    \frac{d^2 \theta}{d\eta^2} &= 0, \quad \text{Eq. (9)}
\end{align*}
\]

where \(Gr = \frac{g_0 \beta L(T_2 - T_0)}{v^2}\) is the Grashof number,

\(\omega = \frac{gL^2}{v}\) the frequency parameter, \(\alpha = \frac{L}{v^2} \left(\frac{dP}{dx}\right)\)

the non-dimensional pressure gradient, \(Ma = \frac{\rho}{\mu}\) the viscosity ratio and \(D_y = \frac{k}{L}\) the Darcy number. It may be noted that the limit \(D_y \to \infty\) gives a clear fluid and the limit \(D_y \to 0\) gives the unmitigated Darcy flow.

The corresponding boundary conditions for \(F(\eta)\) and \(\theta(\eta)\) are

\[
\begin{align*}
    F(0) = 0 &= F(1), \quad \text{Eq. (10)} \\\n    \theta(0) &= r_1, \quad \theta(1) = 1, \quad \text{Eq. (11)}
\end{align*}
\]

where \(r_1 = \frac{T_1 - T_0}{T_2 - T_0}\) is temperature ratio parameter.

The solution of the Eq. (9) subject to the boundary conditions Eq. (11) is

\[
\theta(\eta) = (1 - r_1)\eta + r_1.
\]

On the use of Eq. (12), the Eq. (8) becomes

\[
\frac{d^2 F}{d\eta^2} - \left(\frac{1}{Ma D_{y_x}} + i\omega\right) F = -(\alpha + Gr \theta)\eta.
\]

The solution of the Eq. (13) subject to the boundary conditions Eq. (10) is

\[
F(\eta) = \frac{1}{\alpha^2} \left(\alpha + Gr \theta\right) \left[1 - \sinh a \frac{\sinh a(1 - \eta)}{\sinh a}\right]
\]

\[
+ Gr(1 - r_1) \left\{\eta - \sinh a \frac{\sinh a(1 - \eta)}{\sinh a}\right\},
\]

where

\[
a = \frac{1}{\sqrt{2}} \left[\frac{1}{Ma D_{y_x}} + \omega^2\right] \pm \frac{1}{Ma D_{y_x}}.
\]

The pressure gradient \(\alpha\) is determined by requiring that the flow satisfies the following condition,

\[
\int_{0}^{1} F(\eta)d\eta = 1.
\]

On the use of the Eq. (14) in the above equation, the mass conservation equation for \(\alpha\) as

\[
\alpha = \frac{a^2 \sinh a}{a \sinh a + 2(1 - \cosh a)} - \frac{1}{2} Gr(1 + r_1).
\]

If the rate of mass flow is zero, the pressure pressure gradient \(\alpha\) reduces to

\[
\alpha = -\frac{1}{2} Gr(1 + r_1).
\]

On the use of Eq. (16), the Eq. (14) becomes

\[
F(\eta) = \frac{1}{a^2} \left[\frac{a^2 \sinh a}{a \sinh a + 2(1 - \cosh a)} - \frac{1}{2} Gr(1 - r_1)\right]
\]

\[
\times \left\{1 - \sinh a \frac{\sinh a(1 - \eta)}{\sinh a} - \sinh a \frac{\sinh a(1 - \eta)}{\sinh a}\right\} + Gr(1 - r_1) \left\{\eta - \sinh a \frac{\sinh a(1 - \eta)}{\sinh a}\right\}.
\]

It is interesting to note that the velocity distribution given by Eq. (18) for \(Gr = 0\) (the pure forced
convection) at any values of \( r_i \) and for \( r_e = 1 \) for any values of \( Gr \) are identical and the solution for \( F(\eta) \) given by Eq. (18), reduces to

\[
F(\eta) = \frac{1}{a^2} \left[ \frac{a^2 \sinh a}{a \sinh a + 2(1 - \cosh a)} \right] \times \frac{\sinh a \eta - \sinh a(1-\eta)}{\sinh a} 
\]

(19)

In a free convection process, substituting \( \alpha = 0 \) into the solution Eq. (14), we have

\[
F(\eta) = \frac{Gr}{a^2} \left[ r_i \left\{ \frac{\sinh a \eta - \sinh a(1-\eta)}{\sinh a} \right\} \right] + (1-r_i) \left\{ \eta - \sinh a \eta \right\}.
\]

(20)

In the limit \( D_e \rightarrow \infty \) (for a clear fluid), \( \omega \rightarrow 0 \) and \( r_e = 1 \) the Eq. (20) becomes

\[
F(\eta) = \frac{1}{2} Gr \left( \eta - \eta^* \right).
\]

(21)

In the vicinity of the central section of the channel, the velocity is given by Eq. (21) reduces to

\[
F(\eta) = \frac{1}{8} Gr.
\]

(22)

We shall now discuss some limiting cases:

### 2.1 Solution \( D_a \gg 1 \) and \( \omega << 1 \)

The velocity distribution and the pressure gradient are given by Eq. (14) and Eq. (16) respectively, become

\[
F(\eta) = 6(\eta - \eta^*) - \frac{1}{12} Gr \left( 1 - r_i \right) \left( \eta - 3\eta^* + 2\eta^* \right) + \left( \frac{1}{D_e} + i\omega \right) \left[ \frac{1}{10} (\eta - 6\eta^* + 10\eta^* - 5\eta^*) \right] + \frac{1}{720} Gr \left( 1 - r_i \right) \left[ \eta - 10\eta^* + 15\eta^* - 6\eta^* \right]
\]

and

\[
\alpha = 12 \left[ 1 + \frac{1}{10} \left( \frac{1}{D_e} + i\omega \right) \right] - \frac{1}{2} Gr \left( 1 + r_i \right).
\]

(24)

In the limit \( D_e \rightarrow \infty \), the Eq. (23) becomes

\[
F(\eta) = 6(\eta - \eta^*) - \frac{1}{12} Gr \left( 1 - r_i \right) \left( \eta - 3\eta^* + 2\eta^* \right) + \frac{i\omega}{720} \left[ 72(\eta - 6\eta^* + 10\eta^* - 5\eta^*) \right] + Gr \left( 1 - r_i \right) \left[ \eta - 10\eta^* + 15\eta^* - 6\eta^* \right]
\]

The velocity distribution given by Eq. (23) is dependent on Grashof number, Darcy number and frequency of oscillation. For \( r_i = 1 \) (uniform temperature variation along the wall) the velocity distribution is closely resemblance to a forced convection flow due to absence of Grashof number. Hence the velocity distribution is independent of Grashof number but dependent on Darcy number and frequency of oscillation. The expression for pressure gradient given by Eq. (24) plays a significant role with reference to temperature ratio parameter \( r_i \) so that the effect of buoyancy force becomes predominant for the constant rate of flow. The expression for the velocity distribution given by Eq. (25) leads to the clear fluid and the buoyancy force accelerates the entire flow situation on the velocity field.

### 2.2 Solution for an oscillating mixed convection with Darcy number \( D_a \rightarrow \infty \) (clear fluid)

The Eq. (14) together with the expression Eq.(16) yields

\[
F(\eta) = \frac{1}{i\omega} \left[ \frac{1}{10} (i\omega)^2 \cosh 2i\omega}{\cosh 2i\omega + 2(1 - \cosh 2i\omega)} \right] \times \left\{ \frac{\sinh 2i\omega \eta - \sinh 2i\omega(1-\eta)}{\sinh 2i\omega} \right\}
\]

\[
- \frac{1}{2} G \left( 1 - r_i \right) \left[ 1 - 2\eta + \frac{\sinh 2i\omega \eta}{\sinh 2i\omega} - \frac{\sinh 2i\omega(1-\eta)}{\sinh 2i\omega} \right]
\]

(26)

If frequency of the oscillations is very large, the above Eq. (26) becomes

\[
F(\eta) = \frac{1}{2i\omega} \left[ 1 - e^{-2\cosh 2i\omega} - e^{-2\cosh 2i\omega} \right]
\]

(27)

At the limit of \( \omega \rightarrow \infty \), we have

\[
\lim_{\omega \rightarrow \infty} F(\eta) = 1 - e^{-2\cosh 2i\omega} - e^{-2\cosh 2i\omega}.
\]

(28)

If the frequency of oscillations is very large the expression for the velocity given by Eq. (27) is an exponential in nature with the frequency of oscillations and Grashof number plays an important role in determining the flow behavior. In this situation, the frequency of oscillations survives exponentially on the velocity field with significant effect of buoyancy force. The Eq. (28) shows that a thin stokes layer form near the walls for large frequency of the oscillating flows.

The thickness of the layer is \( \mathcal{O} \left( \frac{2}{\omega} \right) \).
corresponding to decrease with an increase in frequency of oscillations.

3. RESULTS AND DISCUSSION

The quantity plotted along the vertical axis is 
\[ \text{Imag}(F e^{i\omega \tau}) = \text{Real}(F) \cos \omega \tau + \text{Imag}(F) \sin \omega \tau, \]
which represents the measurable value for a driving force 
\[ g = \text{Imag}(g e^{i\omega \tau}) = g_0 \sin \omega \tau \]
and 
\[ u_r(r) = u_0 \sin \omega \tau , \]
where Imag stands for imaginary part. It is noted that

form Fig. 2 that at around \( \omega \tau = \pi \) and \( \omega \tau = 2\pi \) the velocity profile oscillates along the width of the channel but for other times the velocity profile is approximately parabolic, as expected for the symmetrically heated walls \( (r_c = 1) \) and for forced convection in a channel. It is evident from Fig. 3 that the profiles are skewed near the cold wall as expected for higher buoyancy while the velocity profiles are of oscillatory character near the cold wall due to asymmetric heating of the wall whereas the velocity profiles oscillate at around \( \omega \tau = \pi \) and \( \omega \tau = 2\pi \) along the width of the channel.

Fig. 2. Velocity profile for \( \omega \tau \) with \( r_c = 1 \).
\[ Gr = 20, \quad D_a = 0.05, \quad \omega = 10, \quad M_a = 1 \]

Fig. 3. Velocity profile for \( \omega \tau \) with \( r_c = 0.2 \).
\[ Gr = 100, \quad D_a = 0.05, \quad \omega = 10, \quad M_a = 1 \]

Fig. 4 demonstrates that at higher buoyancy \( (Gr = 100) \) the profile becomes parabolic at \( r_c = 1 \).

This indicates that the flow is characterised by a uniform temperature distribution (symmetrically heated wall) when \( r_c = 1 \). In the case of asymmetric heating of the wall the velocities increase at the cold wall while the velocities decrease at the hot wall with increase in \( R_f \) whereas at each value of \( r_c \), every profile coincides with the mid plane of the central section of the channel.

Fig. 4. Velocity profile for \( r_c \) with \( D_a = 0.05 \),
\[ Gr = 100, \quad \omega = 10, \quad \omega \tau = \frac{\pi}{4}, \quad M_a = 1 \]

It is noticed from Fig. 5 that the effect of Darcy number leads to increase the velocities near the cold wall as well as near the hot wall while the effect of Darcy number becomes predominant over the central region. In the central region, the velocities are markedly increased with increase in Darcy number. This situation reveals that the velocities depend on permeability of the porous medium to boost up the velocities in the central region for moderate values of Darcy number. Fig. 6 reveals that the velocity profile becomes parabolic when the buoyancy force is absent \( (Gr = 0) \).

Fig. 5. Velocity profile for \( D_a \) with \( r_c = 0.2 \).
\[ Gr = 20, \quad \omega = 10, \quad \omega \tau = \frac{\pi}{4}, \quad M_a = 1 \]

It is seen from Fig. 6 that the velocity increases near the hot wall with increase in Grashof number \( Gr \) while a flow reversal occurs near the cold wall with increase in
Grashof number $Gr$ with reference to higher buoyancy $Gr \geq 300$. The nature of velocity profile on Fig. 6 is closely resemblance to the study of Aung and Worku (1986).

![Fig. 6. Velocity profile for $Gr$ with $r_e = 0.2$, $\omega = 10$, $D_a = 0.05$, $\omega \tau = \frac{\pi}{4}$, $Ma = 1$](image)

The shear stresses at the cold wall $\eta = 0$ and the hot wall $\eta = 1$ are respectively given by

$$\tau_1 = \text{Real} \left( \frac{dF}{d\eta} \right)_{\eta=0} e^{i\omega t}$$

and

$$\tau_2 = \text{Real} \left( \frac{dF}{d\eta} \right)_{\eta=1} e^{i\omega t},$$

where

$$\left( \frac{dF}{d\eta} \right)_{\eta=0} = -\frac{1}{a^2 \sinh a} \left[ 2a(1-cosh a) + \frac{Gr}{2}(1-r_e)[a(1+cosh a) - 2sinh a] \right]$$

and

$$\left( \frac{dF}{d\eta} \right)_{\eta=1} = \frac{1}{a^2 \sinh a} \left[ 2a(1-cosh a) + \frac{Gr}{2}(1-r_e)[2sinh a - a(1+cosh a)] \right],$$

with $r_e = 0.2$, $\omega = 10$, $D_a = 0.05$, $\omega \tau = \frac{\pi}{4}$, $Ma = 1$.

The numerical values of the shear stresses $\tau_1$ and $\tau_2$ at the wall $\eta = 0$ and $\eta = 1$ are shown in the Figs. 7-8 against $r_e$ for several values of $\omega$ and $D_a$ when $Ma = 1$. Figure 7 shows that the shear stress $\tau_1$ at the wall $\eta = 0$ and the magnitude of the shear stress $\tau_2$ at the wall $\eta = 1$ increases with an increase in frequency parameter $\omega$. It is remarked here that the permeability of the porous medium plays an important role in determining the nature of shear stress when the frequency of oscillation $\omega$ is taken into account. In turn the effects of shear stresses become relevant to the case of an inverse permeability of the porous medium propelled by the viscosity of the fluid so that shear stresses increase with increase in frequency parameter $\omega$. It is noticed from Fig. 8 that the shear stress $\tau_2$ at the wall $\eta = 0$ and the magnitude of the shear stress $\tau_2$ at the wall $\eta = 1$ decreases with an increase in Darcy number $D_a$. Thus it arrives at an interesting conclusion that the permeability of the porous medium leads to slow down the particle so that shear stresses increase with increase on Darcy number. Further, for fixed value of $\omega$ and $Da$, $\tau_1$ steadily increases while magnitude of $\tau_2$ steadily decreases with an increase in temperature ratio parameter $r_e$.

![Fig. 7. Shear stresses $\tau_1$ and $\tau_2$ at the walls $\eta = 0, \eta = 1$ for $\omega$ with $D_a = 0.05$, $Gr = 20$, $\omega \tau = \frac{\pi}{4}$](image)

![Fig. 8. Shear stresses $\tau_1$ and $\tau_2$ at the walls $\eta = 0, \eta = 1$ for $D_a$ with $Gr = 20$, $\omega = 10$, $\omega \tau = \frac{\pi}{4}$](image)
The critical value of $Gr_0$ for which there is no flow reversal near the cold wall $\eta = 0$ to obtained from
\[
\left( \frac{dF}{d\eta} \right)_{\eta=0} = 0, \text{ which is}
\]
\[
Gr_0 = -\text{Real} \left[ \frac{2\alpha(1 - \cosh \alpha)}{(1 - r_i)\alpha(1 + \cosh \alpha) - 2\sinh \alpha} \right].
\]
where $\alpha$ is given by Eq. (15) and the corresponding value of the critical Grashof number at the hot wall $\eta = 1$ is given by $Gr_0 = -Gr_e$. The values of the critical Grashof number $Gr_0$ are entered in Table 1 for different values of $D_c$ and $r_i$. It is seen from Table 1 that the critical Grashof number $Gr_0$ at the wall $\eta = 0$ increases with increase in the temperature ratio parameter $r_i$ whereas it decreases with increase in the Darcy number $D_c$. Although buoyancy force accelerates the fluid particle to become flow reversal at higher buoyancy [see Fig. 6]. Critical Grashof number is obtained where no flow reversal occurs at the cold wall but a tendency of increasing remains unaltered.

**Table 1** Variation of $10^{-4}Gr_0$

<table>
<thead>
<tr>
<th>$r_i \backslash Da$</th>
<th>0.02</th>
<th>0.04</th>
<th>0.05</th>
<th>0.01</th>
</tr>
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<tr>
<td>0.0</td>
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<td>0.1206</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>0.1602</td>
</tr>
<tr>
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<td>0.3321</td>
<td>0.3015</td>
<td>0.2403</td>
</tr>
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</table>

The values of the pressure gradient $\alpha$ are entered in Table 2 for different values of $D_c$ and $r_i$. It is seen from Table 2 that the pressure gradient $\alpha$ decreases with increase in both the temperature ratio parameter $r_i$ and Darcy number $D_c$.

**Table 2** Variation of $10^{-4} \alpha$

<table>
<thead>
<tr>
<th>$r_i \backslash Da$</th>
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<th>0.04</th>
<th>0.05</th>
<th>0.01</th>
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<td>0.0196</td>
<td>0.0079</td>
</tr>
</tbody>
</table>

4. CONCLUSION

Oscillatory mixed convection viscous incompressible flow in porous medium between two infinitely long vertical walls is considered. It is found that the velocity profile is almost parabolic in nature for the small value of buoyancy force $Gr$ while the skewness is characterised by the higher buoyancy and at large value of $Gr$ there arise flow reversal near the cold wall. It is found that the velocity profile increases near the cold wall of the channel while it decreases near the hot wall of that channel with increase in temperature ratio parameter $r_i$. In the presence of Darcy number, the magnitude of the shear stresses $r_i$ at the wall $\eta = 0$ increases while that of the shear stress $r_i$ at the wall $\eta = 1$ decreases with increase in $r_i$. The critical Grashof number, for which there is no flow reversal near the wall $\eta = 0$ and it decreases with increase in Darcy number.

REFERENCE


