# HALL EFFECTS ON PERISTALTIC FLOW OF A NEWTONIAN FLUID THROUGH A POROUS MEDIUM IN A CHANNEL WITH LONG WAVELENGTH WITH HEAT TRANSFER

**1.RudraRaviKumar Palegari 2.Dr.R.Siva Prasad**
Department of Mathematics, RGUKT-APIIIT, Idupulapaya, Kadapa District, A.P., India.

**Abstract :** The effect of hall on the peristaltic flow of a Newtonian fluid through a porous medium in a two dimensional channel with heat transfer under the assumption of long wavelength. A closed form solution is obtained for axial velocity, temperature field and pressure gradient. The effects of various emerging parameters on the pressure gradient, time-averaged volume flow rate and temperature field.

**Keywords:** Hall effect, Newtonian fluid, Porous Medium, Heat Transfer, Peristaltic flow.

## 1. INTRODUCTION

The study of the mechanism of peristalsis in both mechanical and physiological situations has recently become the object of scientific research, since the first investigation of Latham [8. Several theoretical and experimental attempts have been made to understand peristaltic action in different situations. A review of much of the early literature is presented in an article by Jaffrin and Shapiro [7]. A summary of most of the experimental and theoretical investigations reported with details of the geometry, fluid Reynolds number, wavelength parameter wave amplitude parameter and wave shape has been given by Srivastava and Srivastava [17].

The magnetohydrodynamic (MHD) flow of a fluid in a channel with peristalsis is of interest in connection with certain flow problems of the movement of conductive physiological fluids, (e.g., the blood flow in arteries). The effect of magnetic field on blood flow was first studied by Sud et al. [20] and it is found that the effect of suitable magnetic field accelerates the speed of blood. Srivastava and Agrawal [18] and Prasad and Ramacharyulu [13] by taking into account the blood as an electrically conducting fluid and constitutes a suspension of red cell in plasma. Also, Agrawal and Anwaruddin [1] studied the effect of magnetic field on the peristaltic flow of blood using long wavelength approximation method and observed for the flow of blood in arteries with arterial stenosis or arteriosclerosis, that the influence of magnetic field may be utilized as blood pump in carrying out cardiac operations. Li et al., [9] have used an impulsive magnetic field in the combined therapy of patients with stone fragments in the upper urinary tract. It was found that the impulsive Magnetic field (IMF) activates the impulsive activity of the ureteral smooth muscles in 100% of cases. Mekheimer [11] studied the peristaltic transport of blood under effect of a magnetic field in non uniform channels. Hayat et al. [6] have first investigated the Hall effects on the peristaltic flow of a Maxwell fluid trough a porous medium in channel. Recently Eldabe [4] have studied the Hall Effect on peristaltic flow of third order fluid in a porous medium with heat and mass transfer.

Moreover, flow through a porous medium has been of considerable interest in recent years particularly among geophysical fluid dynamicists. Examples of natural porous media are beach sand, stand stone, limestone, rye bread, wood, the human lung, bile duct, gall bladder with stones and in small blood vessels. The first study of peristaltic flow through a porous medium is presented by Elsehawey et al. [2]. Elsehawey et al. [3] have studied peristaltic motion of a generalized Newtonian fluid through a porous medium. Peristaltic transport through a porous medium in an inclined planar channel has investigated by Mekheimer [10] taking the gravity effect on pumping characteristics. Recently, Subba Reddy and Prasnath Reddy [19] have investigated the effect of variable viscosity on peristaltic flow of a Jeffrey fluid through a porous medium in a planar channel.

Understanding of bio-heat transport is important in the beneficial applications of heat and cold for medical treatment. Recent advances in the application of heat (hyperthermia), radiation (laser therapy), and coldness (cryosurgery), as means to destroy undesirable tissues, such as cancer, have stimulated much interest in the study of thermal modeling in tissue. In the case of hyperthermia, it is noted that tissue can be destroyed when heated to 42 – 45° C (Field and Franconi, [5]. Vajravelu et al. [22] have studied the peristaltic flow of a Newtonian fluid in a vertical porous annulus with heat transfer. The effect of heat transfer on the peristaltic flow of a Newtonian fluid in a vertical annulus under the effect of magnetic field was analyzed by Mekheimer and Elmaboud [12]. Srinivas and Kothandapani [16] have investigated the influence of MHD and heat transfer on the peristaltic flow of a Newtonian in an asymmetric channel. Effect of heat transfer on peristaltic transport of a Newtonian fluid through a porous medium in an asymmetric vertical channel was discussed by Vasudev et al. [21]. Recently, Ranjitha and Subba Reddy [14] have studied the peristaltic flow of a Williamson fluid through a porous medium in a planar channel by considering the radiation effects.

In view of these, we studied the effect of hall on the peristaltic flow of a Newtonian fluid through a porous medium in a two dimensional channel with heat transfer under the assumption of long wavelength. A closed form solution is obtained for axial velocity, temperature field and pressure gradient. The effects of various emerging parameters on the pressure gradient, time-averaged volume flow rate and temperature field are discussed with the help of graphs.

## 2. MATHEMATICAL FORMULATION

We consider the peristaltic pumping of a conducting Newtonian fluid flow through a porous medium in a channel of half-width $a$. A longitudinal train of progressive sinusoidal waves takes place on the upper and lower walls of the channel. For simplicity, we restrict our discussion to the half-width of the channel as shown in the Fig.1. The wall deformation is given by

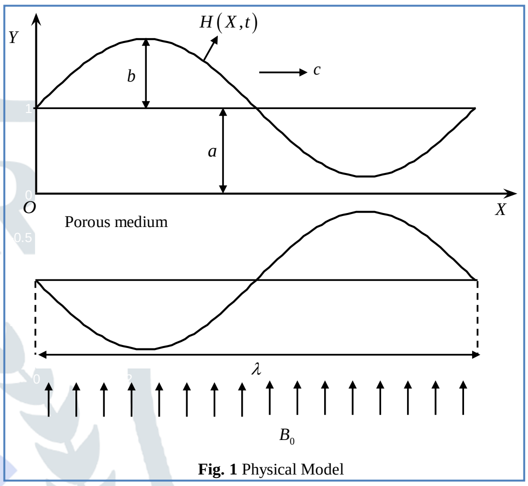

**Fig. 1** Physical Model

$$H(X,t) = a + b\sin\left[\frac{2\pi}{\lambda}(X - ct)\right] \quad (2.1)$$

where $b$ is the amplitude, $\lambda$ the wavelength and $c$ is the wave speed.

Under the assumptions that the channel length is an integral multiple of the wavelength $\lambda$ and the pressure difference across the ends of the channel is a constant, the flow becomes steady in the wave frame $(x, y)$ moving with velocity c away from the fixed (laboratory) frame $(X, Y)$. The transformation between these two frames is given by

$$x = X - c\,t,\ y = Y,\ u = U - c,\ v = V \text{ and } p(x) = P(X, t), \quad (2.2)$$

where $(u, v)$ and $(U, V)$ are the velocity components, $p$ and $P$ are pressures in the wave and fixed frames of reference, respectively.

The equations governing the flow in wave frame are given by

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (2.3)$$

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{\sigma B_0^2}{1+m^2}\left(mv - (u+c)\right) - \frac{\mu}{k}(u+c) \quad (2.4)$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\sigma B_0^2}{1+m^2}\left(m(u+c) + v\right) - \frac{\mu}{k}v \quad (2.5)$$

$$\zeta\left[u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right] = \frac{\mathrm{K}}{\rho}\nabla^2 T + \nu\left\{2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right\} \quad (2.6)$$

where $\rho$ is the density $\sigma$ is the electrical conductivity, $B_0$ is the magnetic field strength, $m$ is the Hall parameter, $k$ is the permeability of the porous medium, $\zeta$ is the specific heat at constant volume, $\nu$ is kinematic viscosity of the fluid, $\mathrm{K}$ is thermal conductivity of the fluid and $T$ is temperature of the fluid.

The dimensional boundary conditions are

$$u = -c \quad \text{at} \quad y = H \quad (2.7)$$

$$\frac{\partial u}{\partial y}=0 \quad \text{at} \quad y=0 \tag{2.8}$$

$$T=T_1 \quad \text{at} \quad y=H \tag{2.9}$$

$$\frac{\partial T}{\partial y}=0 \quad \text{at} \quad y=0 \tag{2.10}$$

Introducing the non-dimensional quantities

$$\bar{x}=\frac{x}{\lambda},\bar{y}=\frac{y}{a},\bar{u}=\frac{u}{c},\bar{v}=\frac{v}{c\delta},\delta=\frac{a}{\lambda},\bar{p}=\frac{pa^2}{\mu c\lambda},\bar{t}=\frac{ct}{\lambda},h=\frac{H}{a},\phi=\frac{b}{a},$$

$$\bar{q}=\frac{q}{ac},M^2=\frac{\sigma a^2 B_0^2}{\mu},\ \theta=\frac{T-T_0}{T_1-T_0},\Pr=\frac{\rho\nu\zeta}{\mathrm{K}},E=\frac{c^2}{\zeta(T_1-T_0)},Da=\frac{k}{a^2}$$

Into equations (2.3) to (2.5), we get

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{2.10a}$$

$$\operatorname{Re}\delta\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\left(\delta^2\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{M^2}{1+m^2}\left(m\delta v-(u+1)\right)-\frac{1}{Da}(u+1) \tag{2.11}$$

$$\operatorname{Re}\delta^3\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\delta^2\left(\delta^2\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{\delta M^2}{1+m^2}\left(m(u+1)+\delta v\right)-\frac{\delta^2}{Da}v \tag{2.12}$$

$$\operatorname{Re}\delta\left[u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}\right]=\frac{1}{\Pr}\left(\delta^2\frac{\partial^2 \theta}{\partial x^2}+\frac{\partial^2 \theta}{\partial y^2}\right)$$
$$+E\left\{4\delta^2\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial u}{\partial y}\right)^2+\delta^4\left(\frac{\partial v}{\partial x}\right)^2+2\delta^2\frac{\partial u}{\partial y}\frac{\partial v}{\partial x}\right\} \tag{2.13}$$

Here $\operatorname{Re}$ is the Reynolds number, $M$ is the Hartmann number, $Da$ is the Darcy number, $\Pr$ is the Prandtl number and $E$ is the Eckert number.

Using long wavelength (i.e., $\delta<<1$) approximation, the equations (2.11) to (2.13) become

$$\frac{\partial^2 u}{\partial y^2}-\beta^2 u=\frac{\partial p}{\partial x}+\beta^2 \tag{2.14}$$

$$\frac{\partial p}{\partial y}=0 \tag{2.15}$$

$$\frac{1}{\Pr}\left[\frac{\partial^2 \theta}{\partial y^2}\right]+E\left[\frac{\partial u}{\partial y}\right]^2=0 \tag{2.16}$$

where $\beta=\sqrt{\frac{M^2}{1+m^2}+\frac{1}{Da}}$.

From Eq. (2.15), it is clear that $p$ is independent of $y$. Therefore Eq. (2.14) can be rewritten as

$$\frac{\partial^2 u}{\partial y^2}-\beta^2 u=\frac{dp}{dx}+\beta^2 \tag{2.17}$$

The corresponding non-dimensional boundary conditions are given as

$$u=-1 \quad \text{at} \quad y=h=1+\phi\sin 2\pi x \tag{2.18}$$

$$\frac{\partial u}{\partial y}=0 \quad \text{at} \quad y=0 \tag{2.19}$$

$$\theta=1 \quad \text{at} \quad y=h=1+\phi\sin 2\pi x \tag{2.20}$$

$$\frac{\partial \theta}{\partial y}=0 \quad \text{at} \quad y=0 \tag{2.21}$$

Knowing the velocity, the volume flow rate $q$ in a wave frame of reference is given by

$$q = \int_0^h u dy. \tag{2.22}$$

The instantaneous flow $Q(X,t)$ in the laboratory frame is

$$Q(X,t) = \int_0^h U dY = \int_0^h (u+1) dy = q + h \tag{2.23}$$

The time averaged volume flow rate $\bar{Q}$ over one period $T\left(=\frac{\lambda}{c}\right)$ of the peristaltic wave is given by

$$\bar{Q} = \frac{1}{T}\int_0^T Q dt = q + 1 \tag{2.24}$$

## 3. SOLUTION

Solving Eq. (2.17) together with the boundary conditions (2.18) and (2.19), we get

$$u = \frac{1}{\beta^2}\frac{dp}{dx}\left[\frac{\cosh \beta y}{\cosh \beta h} - 1\right] - 1 \tag{3.1}$$

Substituting Eq. (3.1) into the Eq. (2.16) and solving the Eq. (2.16), using the boundary conditions (2.20) and (2.21), we get

$$\theta = 1 - \frac{\Pr E\left(\frac{dp}{dx}\right)^2}{8\beta^4 \cosh^2(\beta h)}\left\{\left[\cosh(2\beta y) - \cosh(2\beta h)\right] - 2\beta^2\left(y^2 - h^2\right)\right\} \tag{3.2}$$

The volume flow rate $q$ in a wave frame of reference is given by

$$q = \frac{1}{\beta^3}\frac{dp}{dx}\left[\frac{\sinh \beta h - \beta h \cosh \beta h}{\cosh \beta h}\right] - h \tag{3.3}$$

From Eq. (3.3), we write

$$\frac{dp}{dx} = \frac{(q+h)\beta^3 \cosh \beta h}{\sinh \beta h - \beta h \cosh \beta h} \tag{3.4}$$

The dimensionless pressure rise per one wavelength in the wave frame is defined as

$$\Delta p = \int_0^1 \frac{dp}{dx} dx \tag{3.5}$$

The heat transfer coefficient at the upper wall is defined by

$$Z = \frac{\partial \theta}{\partial y}\frac{\partial h}{\partial x}\bigg|_{y=h} = 2\pi\phi \cos 2\pi x \left[\frac{\Pr E\left(\frac{dp}{dx}\right)^2}{4\beta^3 \cosh^2(\beta h)}\left\{2\beta h - \sinh(2\beta h)\right\}\right] \tag{3.6}$$

Note that, as $Da \to \infty$ our results coincide with the results of ***Ravindranath Reddy et al.*** [15].

## 4. RESULTS AND DISCUSSION

Fig. 2 depicts the variation of axial pressure gradient $\frac{dp}{dx}$ with Hartmann number $M$ for $Da = 0.1$, $\phi = 0.6$ and $m = 0.3$. It is found that, the axial pressure gradient $\frac{dp}{dx}$ increases with increasing $M$.

The variation of axial pressure gradient $\frac{dp}{dx}$ with Hall parameter $m$ for $Da = 0.1$, $\phi = 0.6$ and $M = 1$ is depicted in Fig. 3. It is observed that, the axial pressure gradient $\frac{dp}{dx}$ decreases with increasing $m$.

Fig. 4 shows the variation of axial pressure gradient $\frac{dp}{dx}$ with Darcy number $Da$ for $\phi = 0.6$, $M = 1$ and $m = 0.3$. It is noted that, the axial pressure gradient $\frac{dp}{dx}$ decreases with increasing $Da$.

The variation of axial pressure gradient $\frac{dp}{dx}$ with amplitude ratio $\phi$ for $Da = 0.1$, $M = 1$ and $m = 0.3$ is shown in Fig. 5. It is noticed that, the axial pressure gradient $\frac{dp}{dx}$ increases with increasing $\phi$.

Fig. 6 depicts the variation of pressure rise $\Delta p$ with time-averaged flow rate $\overline{Q}$ for different values of Hartmann number $M$ with $Da = 0.1$, $\phi = 0.6$ and $m = 0.3$. It is found that, the time-averaged flow rate $\overline{Q}$ increases in the pumping region $(\Delta p > 0)$ with increasing $M$, while it decreases in both the free-pumping $(\Delta p = 0)$ and co-pumping $(\Delta p < 0)$ regions with increasing $M$.

The variation of pressure rise $\Delta p$ with time-averaged flow rate $\overline{Q}$ for different values of Hall parameter $m$ with $Da = 0.1$, $\phi = 0.6$ and $M = 1$ is depicted in Fig. 7. It is observed that, the time-averaged flow rate $\overline{Q}$ decreases in the pumping region with an increase in $m$, while it increases in both the free-pumping and co-pumping regions with increasing $m$.

Fig. 8 represents the variation of pressure rise $\Delta p$ with time-averaged flow rate $\overline{Q}$ for different values of Darcy parameter $Da$ with $m = 0.3$, $\phi = 0.6$ and $M = 1$. It is observed that, the time-averaged flow rate $\overline{Q}$ decreases in the pumping region with an increase in $Da$, while it increases in both the free-pumping and co-pumping regions with increasing $Da$.

The variation of pressure rise $\Delta p$ with time-averaged flow rate $\overline{Q}$ for different values of amplitude ratio $\phi$ with $Da = 0.1$, $M = 1$ and $m = 0.3$ is shown in Fig. 9. It is found that that the time-averaged flow rate $\overline{Q}$ increases with increasing amplitude ratio $\phi$ in both the pumping and free pumping regions, while it decreases with increasing amplitude ratio $\phi$ in the co-pumping region for chosen $\Delta p(< 0)$.

Fig. 10 depicts the variation of temperature $\theta$ with Hartmann number $M$ for $m = 0.3, \phi = 0.6$, $Da = 0.1$, $x = 0.1$, $\overline{Q} = -1$ and $\Pr E = 1$. It is found that the temperature $\theta$ decreases with increasing Hartmann number $M$.

The variation of temperature $\theta$ with Hall parameter $m$ for $M = 1, \phi = 0.6$, $Da = 0.1$, $x = 0.1$, $\overline{Q} = -1$ and $\Pr E = 1$ is depicted in Fig. 11. It is noticed that the temperature $\theta$ increases with increasing hall parameter $m$.

Fig. 12 shows the variation of temperature $\theta$ with $Da$ for $m = 0.3, \phi = 0.6$, $\Pr E = 1$, $x = 0.1$, $\overline{Q} = -1$ and $M = 1$. It is observed that the temperature $\theta$ increases with increasing $Da$.

The variation of temperature $\theta$ with $\Pr E$ for $m = 0.3, \phi = 0.6$, $Da = 0.1$, $x = 0.1$, $\overline{Q} = -1$ and $M = 1$ is shown in Fig. 13. It is found that the temperature $\theta$ increases with increasing Hartmann number $\Pr E$.

Fig. 14 illustrates the variation of temperature $\theta$ with amplitude ratio $\phi$ for $m = 0.3, M = 1$, $Da = 0.1$, $x = 0.1$, $\overline{Q} = -1$ and $\Pr E = 1$. It is noted that the temperature $\theta$ decreases with increasing amplitude ration $\phi$ except near the channel wall.

In order to see the effects of $M, m, Da, \phi$ and $\Pr E$ on the heat transfer coefficient $Z$ we plotted the Table-1. It is found that, the heat transfer coefficient $Z$ decreases with increasing $M$ and $\Pr E$, where as it increases with increasing $m, Da$ and $\phi$.

## 5. CONCLUSIONS

In this chapter, the effect of hall on the peristaltic flow of a conducting fluid through a porous medium in a symmetric channel with heat transfer under the assumption of long wavelength approximation is investigated. The expressions for the velocity field and temperature field and pressure gradient are obtained analytically. It is found that, the pressure gradient and the time-averaged flow rate in the pumping region are increases with increasing Hartmann number $M$ and amplitude ratio $\phi$ , while they decreases with increasing hall parameter $m$ and Darcy number $Da$. Also it is observed that, the maximum temperature decreases with increasing Hartmann number $M$ and amplitude ratio $\phi$, whereas it increases with increasing hall parameter $m$, Darcy number and $\Pr E$. Further it is found that, the heat transfer coefficient $Z$ decreases with increasing $M$ and $\Pr E$, where as it increases with increasing $m, Da$ and $\phi$.

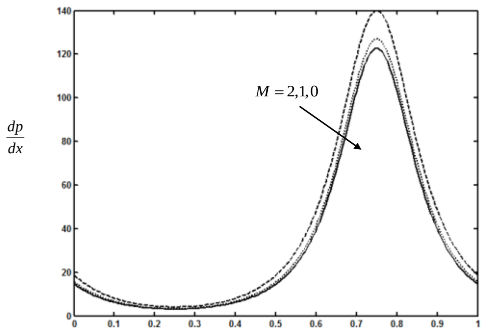


**Fig. 2.** The variation of axial pressure gradient $\frac{dp}{dx}$ with Hartmann number $M$ for $\phi = 0.6$, $Da = 0.1$ and $m = 0.3$ .

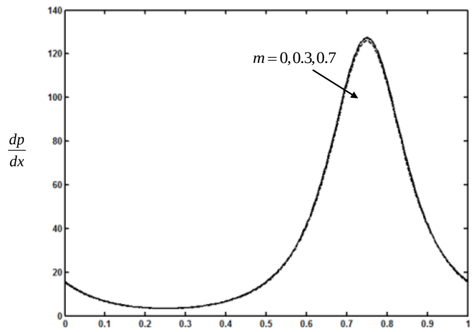


**Fig. 3.** The variation of axial pressure gradient $\frac{dp}{dx}$ with Hall parameter $m$ for $\phi = 0.6$, $Da = 0.1$ and $M = 1$ .

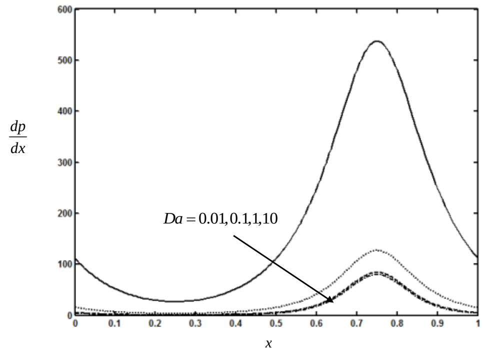


**Fig. 4.** The variation of axial pressure gradient $\frac{dp}{dx}$ with Darcy number $Da$ for $\phi = 0.6$, $m = 0.3$ and $M = 1$ .

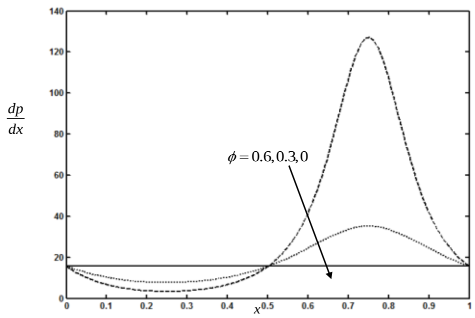


**Fig. 5.** The variation of axial pressure gradient $\frac{dp}{dx}$ with amplitude ratio $\phi$ for $M = 1$, $Da = 0.1$ and $m = 0.3$.

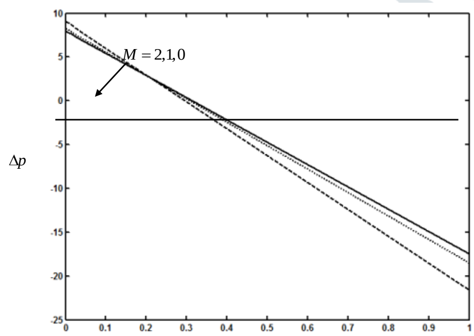


**Fig. 6.** The variation of pressure rise $\Delta p$ with time-averaged flow rate $\overline{Q}$ for different values of Hartmann number $M$ with $Da = 0.1$, $\phi = 0.6$ and $m = 0.3$.

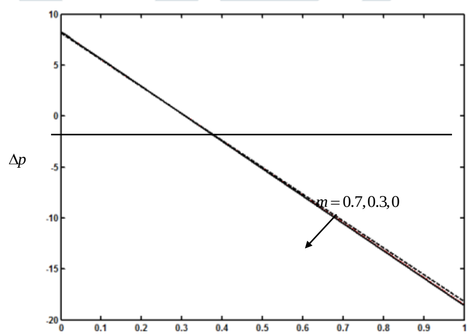


**Fig. 7.** The variation of pressure rise $\Delta p$ with time-averaged flow rate $\overline{Q}$ for different values of Hall parameter $m$ with $Da = 0.1$, $\phi = 0.6$ and $M = 1$.

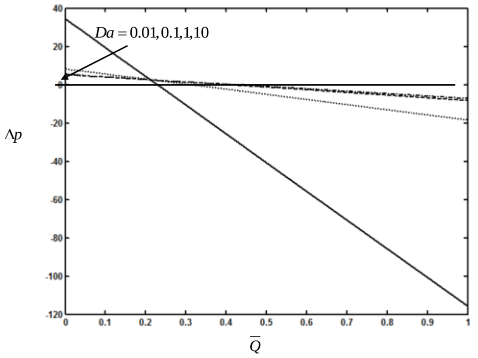


**Fig. 8.** The variation of pressure rise $\Delta p$ with time-averaged flow rate $\bar{Q}$ for different values of Darcy number $Da$ with $m = 0.3$, $\phi = 0.6$ and $M = 1$.

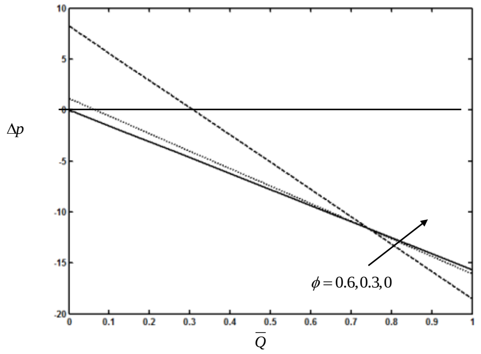


**Fig. 9.** The variation of pressure rise $\Delta p$ with time-averaged flow rate $\bar{Q}$ for different values of amplitude ratio $\phi$ with $M = 1$ and $m = 0.3$.

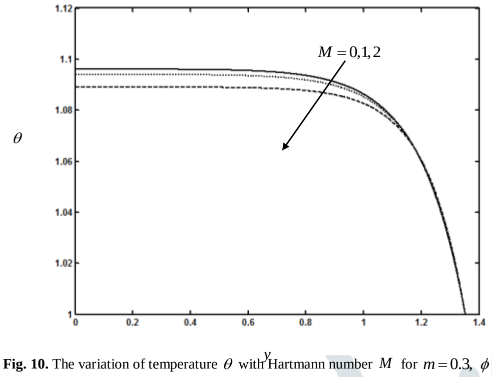


**Fig. 10.** The variation of temperature $\theta$ with Hartmann number $M$ for $m = 0.3$, $\phi = 0.6$, $x = 0.1$, $Da = 0.1$, $\bar{Q} = -1$ and $\Pr E = 1$.

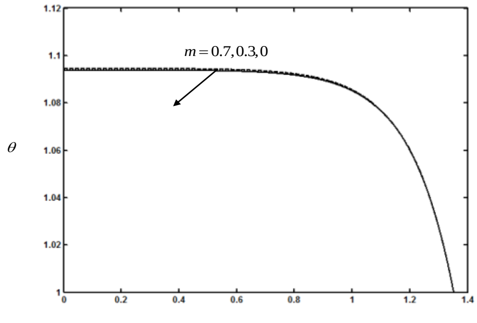


**Fig. 11.** The variation of temperature $\theta$ with Hall parameter $m$ for $M = 1, \phi = 0.6$, $x = 0.1$, $Da = 0.1$, $\bar{Q} = -1$ and $\Pr E = 1$.

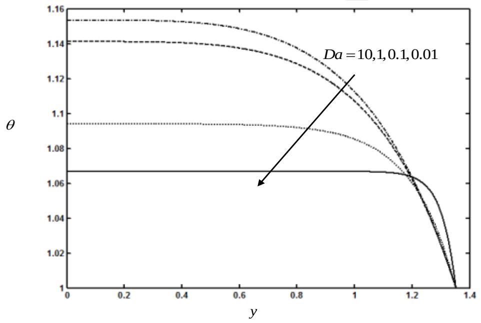


**Fig. 12.** The variation of temperature $\theta$ with Darcy number $Da$ for $M = 1, \phi = 0.6$, $x = 0.1$, $m = 0.3$, $\bar{Q} = -1$ and $\Pr E = 1$.

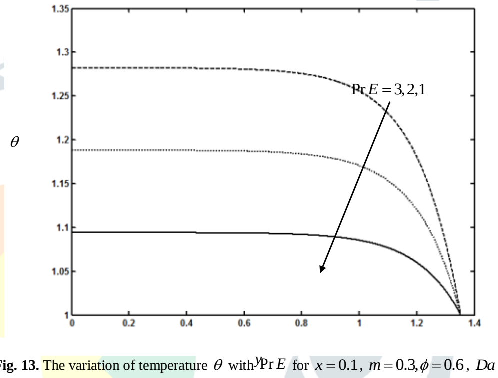


**Fig. 13.** The variation of temperature $\theta$ with $\Pr E$ for $x = 0.1$, $m = 0.3, \phi = 0.6$, $Da = 0.1$, $\bar{Q} = -1$ and $M = 1$.

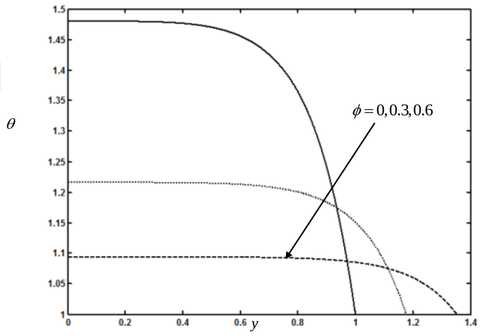


**Fig. 14.** The variation of temperature $\theta$ with amplitude ratio $\phi$ for $m = 0.3, M = 1$, $x = 0.1$, $Da = 0.1$, $\bar{Q} = -1$ and $\Pr E = 1$.

**Table 1.** The variation of heat transfer coefficient $Z$ with $x = 0.1$ and $\bar{Q} = -1$.

| $M$ | $m$ | $Da$ | $\phi$ | $\Pr E$ | $Z$ |
|---|---|---|---|---|---|
| 1 | 0.3 | 0.1 | 0.6 | 1 | -1.9097 |
| 2 | 0.3 | 0.1 | 0.6 | 1 | -2.0152 |
| 1 | 0.7 | 0.1 | 0.6 | 1 | -1.9001 |
| 1 | 0.3 | 1 | 0.6 | 1 | -1.5764 |
| 1 | 0.3 | 0.1 | 0.7 | 1 | -1.6530 |
| 1 | 0.3 | 0.1 | 0.6 | 2 | -3.8195 |

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