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Full Length Research Article

HEAT TRANSFER ON MHD OSCILLATORY FLOW IN A VERTICAL DOUBLE-PASSAGE CHANNEL

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ABSTRACT:
Thermal propagation of MHD oscillatory flow of optically thin fluid in a vertical double-passage with varying temperature was investigated. The thermal distribution of the fluid flow is enhanced through a perfectly thin conductive baffle, which divides the channel into two passages. The equations governing the fluid flow are formulated based on purely oscillatory flow with pressure gradient. The flow velocity and thermal equations governing the flow are analytically solved. The closed-form results gotten were analysed for the influences of Reynolds number, magnetic term, thermal convection term, Peclet number and frequency of oscillation on the flow and heat transfer characteristics with the aid of graphs. It was observed that magnetic parameter reduces the flow rate in the channel.

Keywords: Oscillatory frequency, Hydromagnetic, Heat convection, and Closed form solution.

INTRODUCTION

Thermal distribution augmentation as to do with the enhancing the rate of thermal removal or deposition on a device. Many researchers have studied the influence of thermal distribution under various geometries due to its practical essential in the course of energy savings in engineering systems. For example, thermal connection distribution in a vertical device can be enhanced by insertion of a perfect thin conductive stump. This enhances heat distribution rate in the channel without a substantial pressure drop.

Consequently, Salah (1994) investigated the influence of stun on a well-developed convective laminar flow through a double-passage vertical device. The author observed that the presence of perfectly thin baffle significantly enhanced the heat propagation rate in the flow medium.

The author also presented the numerical investigation on the laminar convection in the channel to accentuate the result (Salah (2001) and (2002).). A perfectly thin baffle also has many applications in Oscillatory Flow Mixing Reactors (OFMRs), Continuous Oscillatory Baffled Rectors (COBRs), Meso-reactors, etc. Despite these applications, there is no significant theoretical investigation on oscillatory flow in a vertical flow device divide by means of a seamlessly thin conductive wall.

Although, the studies of oscillatory flow in various channels have been presented by many researchers. For instance, Rao and Deshikahar (1985) investigated oscillatory hydromagnetic flow of blood along channel of variable cross section and discovered that the magnetic field prevents the occurrence of separation of the blood in the channel. Accordingly, Venkateswarlu et al. (2019), Kafle et al. (2022) and Sasikumar and Senthamarai (2022) presented MHD oscillatory flow of physiology fluid in regular channels. The authors discussed that the effects of MHD on chemical reaction and viscous dissipation of the flow fluid parameters. Oscillatory heat dispersion magnetohydrodynamic stream along a partially filled porous channel was examined by Makinde and Mhone (2005). They gave account that MHD reduced Nusselt number at the wall. MHD oscillatory slip flow with temperature heat source in a filled with porosity was investigated by Disu (2014). In the work, the heat source increased the fluid velocity and temperature. The influences of species distribution on hydromagnetic oscillatory slip flow with an optical thin liquid along a porous saturated channel and varied channel walls temperature was studied by Disu et al. (2014). The authors revealed that Nusselt number increased at the cold plate but decreased at heated plate. Also, Venkateshwaralu at et al. (2017), Chitra and Suhasini (2018) and Govindarajan et al. (2018) examined MHD oscillatory flow in a porous medium with various effects of thermo-physical properties.

Muthuraj and Srinivas (2010) extended the study of oscillatory flow to asymmetric wavy channel. The researchers investigated the hydromagnetic oscillatory heat transfer flowing fluid in a wavy asymmetric medium. They observed that channel wall drags and Nusselt number increased MHD at both surfaces. Vijayalakshm and Govindarajan (2017) investigated reacting chemical species hydromagnetic oscillatory slippery flow through an asymmetric medium with both temperature and species variation. The authors observed that Schmidt number increased the species concentration. Sasikumar and Govindarajan (2018). have presented diffusion-thermo impact on the radiative chemical reacting oscillatory MHD flow with thermal generation along a permeable asymmetric wavy fixed medium. They have reported that concentration profiles are oscillating as Soret parameter increased.

In all the studies of oscillatory flow above, in horizontal, vertical, symmetric and asymmetric channels, oscillatory flow in a double channel medium has not been considered. Although, the impact of different thermal viscous dissipation on fully developed mixed convective laminar flow in a double vertical channel medium was discussed. Salah (2002) also, presented the influence of viscous thermal dissipation of convective laminar flow along a vertical double medium channel with unvarying wall thermal flux. In the studies, the inclusion of a perfect thin conduction baffle in horizontal and vertical channels was introduced to improve the thermal distribution in the channels according to baffle position.

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Consequently, Umavathi (2011) investigated micropolar mixed convective liquid in a double vertical channel medium. Kumar and Prema (2011) studied Walter's fluid free convective flow through a double medium wavy passage channel with thermal generation. Also, Sudharsa et al. (2021) considered dufour, thermal absorption and chemical reaction effects on MHD oscillatory fluid propagation in an asymmetric wavy channel.

More importantly, the baffles have been used in the design of OFMR which consist of baffles placed normal to the flow direction to develop medium modules. The liquid oscillated in the range 0.5 and 15Hz of 1-100 mm amplitude. The oscillating liquid flow interrelates with the baffles to develop vortices, which resulted into flowing fluid efficient and unvarying, mixed in space between the two baffles. Therefore, the oscillation increases the rate of heat transfer in the channel. Due to the usage of baffles in OFMRs, COBRs and Meso-reactors. In the light of the usefulness, the oscillatory flow in a vertical double-passage media is presented.

Formulation of the problem
Considering the unsteady laminar optical thin flowing fluid along a vertical medium divided into two channels by a perfect conductive and thin baffle (see **Fig. 1**). The flow in the channel is driven by pressure gradients $\left(-\frac{\partial P_i}{\partial X}\right)$ and temperature $\Delta T = T_h - T_c$ gradients, where T_h and T_c are the temperatures at the channel surface $y = 0$ and $y = b$ respectively. The temperatures at the walls are high enough for an inductive thermal radiation transfer in the channel.

Under these assumptions, the model flowing fluid equation and the thermal transfer equation are given as follows:

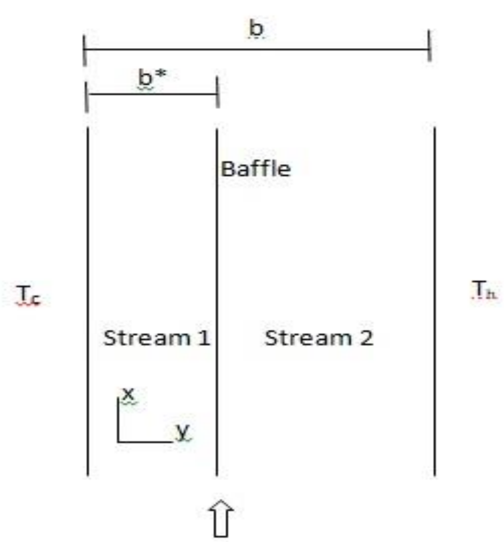

Figure 1: Physical configuration of the flow

$$\frac{\partial w_i}{\partial \bar{t}} = -\frac{1}{\rho}\frac{\partial \bar{P}_i}{\partial y} + \nu\frac{\partial^2 w_i}{\partial y^2} - \frac{\sigma\beta_0^2}{\rho} w_i + g\beta(T_i - T_r) \quad (1)$$

$$\frac{\partial T_i}{\partial \bar{t}} = \frac{k}{\rho C_p}\frac{\partial^2 T_i}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q_i}{\partial y}, \quad (2)$$

The subscript "$i = 1, 2$" represent stream I and stream II of the fluid flow in the channel.
The boundary conditions are:

$$\left.\begin{aligned} w_1 = 0,\ \ T_1 = T_c,\ \ &\text{at}\ \ y = 0 \\ w_1 = w_2 = 0, T_1 = T_2\ \ &\text{at}\ \ y = b^* \\ w_2 = 0,\ \ T_2 = T_h,\ \ &\text{at}\ \ y = b \end{aligned}\right\}, \quad (3)$$

where w is the axial velocity, $\bar{t}$ is the time, ρ is the fluid density, g is the gravitational force, β is the coefficient of thermal expansion, T_i is the fluid temperature, C_p is the specific heat at constant pressure and k is the thermal conductivity of the fluid. T_r is the reference heat which is the mean temperature of the wall temperatures and it is given by $T_r = \frac{T_c + T_h}{2}$.

Since, the fluid is optically thin with relatively low density. Ogulu and Bestman (1993) presented the mathematical model of the heat flux of such fluid as

$$\frac{\partial q_i}{\partial y} = 4\alpha^2(T_r - T_i). \quad (4)$$

The non-dimensional parameters for the Eqs. (1) and (2) with the boundary conditions are defined as follows:

$$\left.\begin{aligned} R_e = \frac{Ub}{\upsilon}, X = \frac{x}{b}, Y = \frac{Y}{b}, W = \frac{w}{U}, \theta = \frac{T - T_r}{T_h - T_c}, t = \frac{\bar{t}U}{b} \\ M^2 = \frac{\sigma\beta_0^2 b^2}{\rho\upsilon}\ P = \frac{\bar{P}b}{\rho\upsilon U},\ Gr = \frac{g\beta(T_h - T_c)}{\upsilon U},\ P_e = \frac{Ub\rho C_p}{k}, N = \frac{4\alpha^3 b}{k} \end{aligned}\right\}, \quad (5)$$

where R_e is the Reynold number, G_r is the thermal Grasshof number and P_e is the pelect number.
Eqs. (1) and (2) are given in non-dimension forms as:

$$R_e\frac{\partial W}{\partial t} = -\frac{\partial P_i}{\partial X} + \frac{\partial^2 W}{\partial Y^2} - M^2 W + Gr\theta_i, \quad (6)$$

$$P_e\frac{\partial \theta_i}{\partial t} = \frac{\partial^2 \theta_i}{\partial Y^2} + N^2\theta_i, \quad (7)$$

and the boundary conditions:

$$\left.\begin{aligned} W_1 = 0,\ \ \theta_1 = -\tfrac{1}{2}\ \ &\text{at}\ \ Y = 0 \\ W_1 = W_2 = 0, \theta_1 = \theta_2\ \ &\text{at}\ \ Y = Y^* \\ W_2 = 0,\ \ \theta_2 = \tfrac{1}{2},\ \ &\text{at}\ \ Y = 1 \end{aligned}\right\}. \quad (8)$$

Solution of the problem
The fluid flow is assumed purely oscillatory with pressure gradient, and then the velocity and temperature distributions are defined as follow:

$$\left.\begin{aligned} -\frac{\partial p_i}{\partial X} &= \lambda_i e^{i\omega t}, \\ W(Y,t) &= W_{0i}e^{i\omega t}, \\ \theta(Y,t) &= \theta_{0i}e^{i\omega t} \end{aligned}\right\}, \quad (9)$$

where λ_i are constants and ω is the frequency of oscillation.
Considering only the real part of $e^{i\omega t}$, Eq. (9) becomes

$$\left.\begin{aligned} -\frac{\partial p_i}{\partial X} &= \lambda_i \cos\omega t, \\ W(Y,t) &= W_{0i}\cos\omega t, \\ \theta(Y,t) &= \theta_{0i}\cos\omega t \end{aligned}\right\} \quad (10)$$

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Substituting Eq. (10) into Eqs. (6) and (7), the equations become

$$\frac{d^2W_{0i}}{dy^2} + n^2W_{0i} - M^2W_{0i} -= -\lambda_i - Gr\theta_{0i} \quad (11)$$

$$\frac{d^2\theta_{0i}}{dy^2} + m^2\theta_{0i} = 0, \quad (12)$$

with corresponding boundary conditions:

$$\left.\begin{array}{c} W_{01} = 0, \quad \theta_{01} = -\frac{1}{2} \quad \text{at} \quad Y = 0 \\ W_{01} = W_{02} = 0, \theta_{01} = \theta_{02} \quad \text{at} \quad Y = Y^* \\ W_{02} = 0, \quad \theta_{02} = \frac{1}{2}, \quad \text{at} \quad Y = 1 \end{array}\right\}, \quad (13)$$

where $m = \sqrt{N^2 + \omega Pe \tan \omega t}$ and $n = \sqrt{\omega Re \tan \omega t}$.

Solving Eqs. (11) and (12) with boundary conditions (13), we obtain:

$$\theta_{01} = \theta_{02} = \frac{1}{2}\left((\csc m + \cot m) \sin my - \cos my\right) \cos \omega t, \quad (14)$$

$$W_{01} = \left(\frac{\lambda}{n^2 \sin(nY^*)}\left(\sin ny (AGr \sin(mY^*) + \frac{\lambda}{2n^2(m^2-n^2)} \cos(nY^*) - \frac{\lambda}{2n^2(m^2-n^2)} + Gr \cos(nY^*) - Gr \cos(mY^*)\right) - \frac{\lambda}{n^2}\left(\cos(ny)\left(\frac{\lambda}{2n^2(m^2-n^2)} + Gr\right)\right) - \frac{\lambda}{n^2}(AGr \sin(my) - Gr \cos(my)) + 2n^2(m^2 - n^2)\right) \cos \omega t, \quad (15)$$

$$W_{02} = \left(\frac{\lambda}{n^2 (\sin n \cos(nY^*) - \cos n \sin(nY^*))}\left(\left(\sin(ny)(AGr \cos n \sin(mY^*) - AGr \sin m \cos(nY^*) - \frac{\lambda}{2n^2(m^2-n^2)} \cos n + \frac{\lambda}{2n^2(m^2-n^2)} \cos(mY^*) + Gr \cos m \cos(nY^*)\right)\right) - \frac{\lambda}{n^2 (\sin n \cos(nY^*) - \cos n \sin(nY^*))}\left(\cos(ny)\left(AGr \sin(mY^*) \sin n - AGr \sin m \sin(nY^*) - \frac{\lambda}{2n^2(m^2-n^2)} \sin n + \frac{\lambda}{2n^2(m^2-n^2)} \sin(nY^*) - Gr \cos(mY^*) \sin n + Gr \cos m \sin(nY^*)\right)\right) + \frac{\lambda}{2n^2}\left(\frac{A\, Gr \sin(my) - Gr \cos(my)}{(m^2-n^2)}\right) - \frac{\lambda}{n^2}\right) \cos \omega t \quad (16)$$

Following definition of Nusselt number by (14), the Nusselt number at the walls is given as:

$$Nu = Nu_c + Nu_h = \frac{b}{T_h - T_c}\frac{dT_1}{dy}\bigg|_{y=0} + \frac{b}{T_h - T_c}\frac{dT_2}{dy}\bigg|_{y=b} = \frac{d\theta_{01}}{dY}\bigg|_{Y=0} + \frac{d\theta_{02}}{dY}\bigg|_{Y=1} \quad (17)$$

$$Nu = \left(\frac{m}{2}((\csc m + \cot m)(1 + \cos m) + \sin n)\right) \cos \omega t, \quad (18)$$

The skin friction at the wall is given by

$$\tau = \mu \frac{dW_{0i}}{dy}\bigg|_{Y=0,Y=1} = \mu\left(\frac{dW_{01}}{dY}\bigg|_{Y=0,Y=Y^*} + \frac{dW_{02}}{dY}\bigg|_{Y=Y^*,Y=1}\right) \quad (19)$$

$$\tau = \left(-\frac{1}{2}\frac{1}{n \sin n \sin m\,(m^2-n^2)}[\cos ny\ (Gn^2 \sin m \cos m + 2 \sin m\ \lambda m^2 \cos n - 2 \sin m\ \lambda n^2 \cos n + Gn^2 \sin m - \cos n \sin m\ n^2 + \sin m\, n^2 \cos m - 2\,\lambda m^2 \sin m + 2\lambda n^2 \sin m\,)] + {} + 2\frac{(Gn^2(\cos m+1)m \cos my - \sin m\, n^2 m \sin my)}{(2m^2n^2 - 2n^4) \sin m} + \frac{1}{2}\frac{1}{n \sin m\,(-\sin n\, m^2 + \sin n\, n^2)}[\cos y\ (Gn^2 \sin m \cos m + 2 \sin m\, \lambda m^2 \cos n - 2 \sin m\, \lambda m^2 \cos n - 2 \sin m\, \lambda n^2 \cos n + Gn^2 \sin m - \cos n \sin m\ n^2 + \sin m\ n^2 \cos m\ - 2\lambda m^2 \sin m + 2\lambda n^2 \sin m)] - \frac{1}{2} \sin ny \frac{-\sin m \sin n\, n^2 + 2 \sin m \sin n\, \lambda\, m^2 - 2 \sin m \sin n\, \lambda\, n^2}{n(m^2-n^2) \sin n \sin m}\right) \cos \omega t$$

(20)

RESULTS AND DISCUSSION

The convective heat transfer of electromagnetic induced flowing fluid along a channel is analytically solved, and the thermos-fluid parametric sensitivities are demonstrated in the graphs. Various embedded parameters impact on the electrically conducting fluid are given with clear insight to assist in the field of engineering and industrial usages. As shown in the plots, the impact of oscillatory frequency ω and heat radiation N are respectively displayed in Figures 2 and 3. The flow velocity is raised with an increasing oscillatory frequency value as portrayed in Figure 2. The fluid particle random motion and collision is boosted to propel internal heating thereby energized the conducting fluid flow rate along the channel. Fluid bonding forces are damped leading to an enhanced velocity field. Meanwhile, Figure 3 shows a decrease in the flow velocity as the radiation term is raised. This is because the fluid particle interaction is discouraged, which in turn stimulates molecular bond. As well, heat source terms are discouraged, thus the flow velocity is damped. In Figures 4 and 5, the influence of Pelect and Grashof numbers is confirmed on the velocity distribution. Figure 4 shows that the flow velocity decreased with increasing Pelect numbers; the term depict a physical quantity that deals with thermal convection flow rate ratio to the thermal conduction flow rate under unvaried heat gradient. Hence, boosting the term Pe enhanced Lorentz force which damped the flow velocity. However, Figure 5 depicts that the thermal convection term G raises the velocity field due to an induced internal heating. The viscous forces are strongly reduced to propel particle collision that leads to an enhanced velocity distribution, this as well resulted from a change in the temperature gradient causes a change in the fluid density.

The response of the heat transfer to variation in the oscillatory frequency ω, Pelect number Pe and radiative heat N are separately offered in Figures 6, 7 and 8. As observed in the figures, the thermal migration and interaction of the fluid particles decreases at $y = 0$ boundary channel wall flow region due to the ambient heat dispersion. This causes a low heat transfer within the system; thus, the temperature distribution reduces for various rising values of the parameters. Meanwhile, along the increasing flow regime, the temperature field is gradually enhanced as the thermal boundary viscosity is raised to reduce heat diffusion. The fluid particle thermal migration at high thermal convection is boosted as the oscillatory frequency, thermal radiation and Pelect number are raised in the flow channel. The advection of the flowing fluid thermal physical term ratio to the diffusion rate of the driven fluid quantity with appropriate thermal gradient is inspired. As such, the heat propagation field is expanded as the flow regime is increased. Table 1 gives the computational values for the various engineering quantities under consideration. From the table, the channel wall friction and Nusselt number for different value of the parameters are presented. As seen, a reduction or an increase in the computed outcome for each varied parameter values are observed due to the boundary layer impact on the thermo-fluidic physical terms.

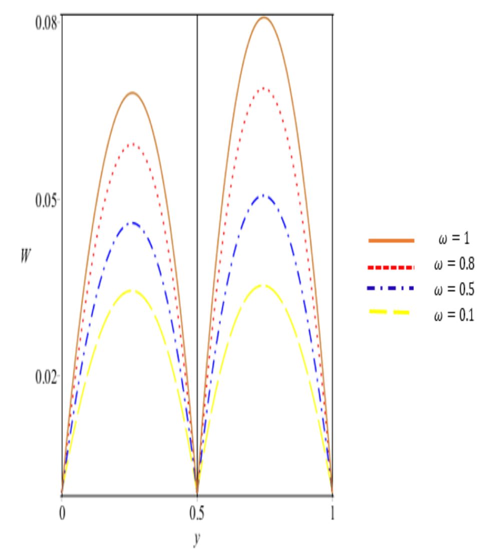

Figure 2: Velocity profiles for different values of ω

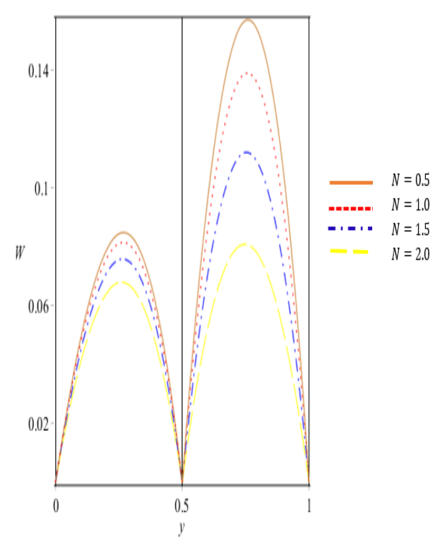

Figure 3: Velocity profiles for different values of N

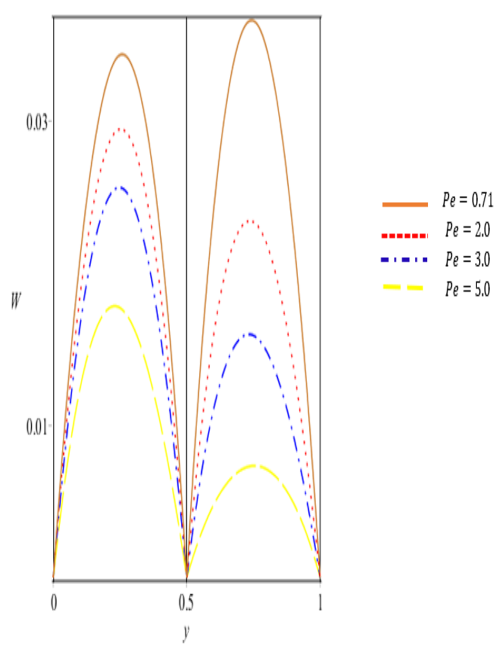

Figure 4: Velocity profiles for different values of Pe

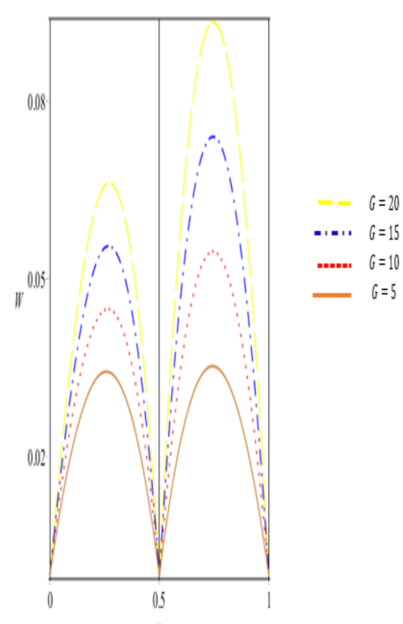

Figure 5: Velocity profiles for different values of G

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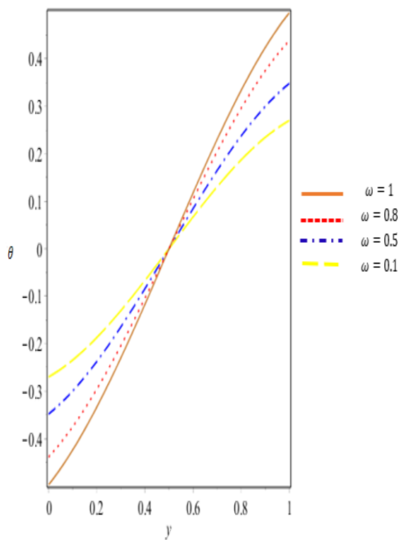

Figure 6: Temperature profiles for different values of ω

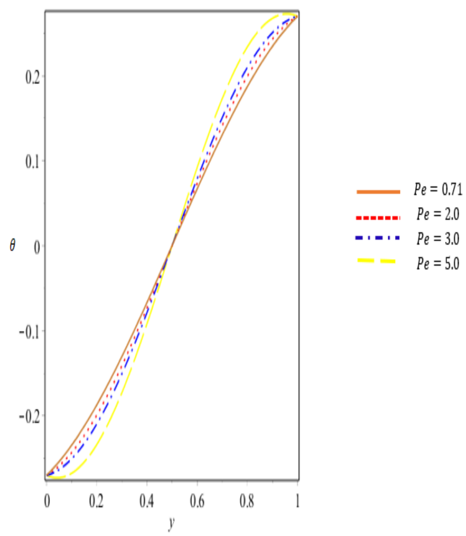

Fig. 7: Temperature profiles for different values of Pe

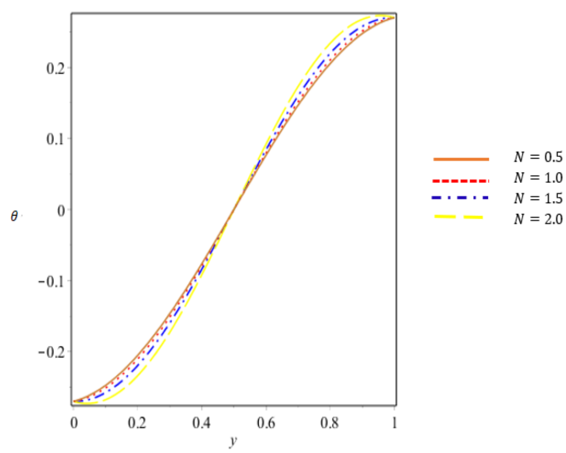

Figure 8: Temperature profiles for different values of N

Table 1: The skin friction and Nusselt number for different values of ω, Pe and N

Parameters	$\tau(y=0)$	$\tau(y=1)$	$Nu(y=0)$	$Nu(y=1)$
$\omega = 0.2$	0.9840561387	0.6210048888	0.0698299538	0.4055059450
$\omega = 0.5$	0.9022270048	0.5440043568	0.1724543491	0.3097297818
$\omega = 0.8$	0.7592466818	0.4097380509	0.2702997434	0.1646891544
$Pe = 0.7$	0.5564947685	0.2513584986	0.3321562596	0.3516286302
$Pe = 1.5$	1.3596968674	0.2167845723	0.6335517492	0.2346795966
$Pe = 3.0$	3.8537435768	0.1647828943	1.0397782601	0.1068415670
$N = 0.5$	0.3960624129	0.9876346650	0.4966404320	0.4141314488
$N = 1.0$	0.2479921337	0.9082366061	0.3321562591	0.3516286302
$N = 2.0$	0.0993787686	0.6322778177	0.1743388953	0.1344042516

Conclusion

Here, the heat transfer of oscillatory MHD flow with optical thin fluid in a channel with varying temperature is investigated. The equations governing the fluid flow are formulated based on purely oscillatory flow with pressure gradient $\left(-\frac{\partial p_i}{\partial X} = \lambda_i e^{i\omega t}\right)$ assumption. The flow velocity and energy equations of the thermal fluid flow model are solved analytically. From the closed-form solutions, the results show that the oscillatory frequency strongly influenced the flow velocity and heat fields. The temperature propagation is encouraged with rising values of the radiation, oscillatory frequency and the Pelect terms.

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