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Two-phase MHD Flow through Porous Medium with Heat Transfer in a Horizontal Channel

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Authors' contributions

This work was carried out in collaboration among all authors. Author DK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors B. Satyanarayana and RK managed the analyses of the study. Authors Bholey Singh and RKS managed the literature searches. All authors read and approved the final manuscript.

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Abstract

The present study deals with two layered MHD immiscible fluid flow through porous medium in presence of heat transfer through parallel plate channel. The fluids are incompressible, and flow is fully developed. The fluids are of different viscosities and thermal conductivities so flowing without mixing each other. Two different phases are accounted for study and are electrically conducting. Temperature of the walls of parallel plate channel is constant. Rheological properties of the immiscible fluids are constant in nature. The flow is governed by coupled partial differential equations which are converted to ordinary differential equations and exact solutions are obtained. The velocity profile and temperature distribution are evaluated and solved numerically for different heights and viscosity ratios for the two immiscible fluids. The effect of magnetic field parameter M and porosity parameter K is discussed for velocity profile and temperature distribution. Combined effects of porous medium and magnetic fields are accelerating the flow which, can be helpful in draining oil from oil wells.

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Keywords: Two phase MHD flow; porous medium; heat transfer; horizontal channel.

Nomenclatures

Cp : *specific heat*
Φ : *dissipation function*
ρ : *fluid density*
g : *gravity*
T_w : *wall temperature*
θ_1, θ_2 : *temperature distribution for fluid phases*
K_1, K_2 : *Permeability of porous medium of fluid phases*
μ_1, μ_2 : *viscosity of fluid phases*
h_1, h_2 : *heights of the fluid region*
k_1, k_2 : *thermal conductivity of fluid phases*
α : *ratio of viscosities of two fluids*
β : *ratio of fluid region heights,*
γ : *ratio of thermal conductivities of two fluids*
ΔT : *température différence* $= T_0 - T$
δ : *ratio of electrical conductivities*
Re : *Electrical field loading parameter*
G : *pressure gradient*
M_1, M_2 : *Magnetic field parameter*
u_1, u_2 : *fluid velocities*

1 Introduction

Apart from multiphase flow multilayered flow has been of greater interest for the researcher. Recently industry encountered a demand of work in manufacturing process, crude oil purification, water purification and oil transportation and many more. A huge amount of work is done in horizontal, inclined, rectangular and pipes to flow low density flows by mixing other fluid. Shail [1] worked on MHD flow through a channel of horizontal plates of infinite length and insulating in nature. In the channel upper layer is of non-conducting fluid where other is conducting. He expressed that flow rates of conducting fluid with suitable ratios of heights and viscosities can be increased up to 30% with some appropriate values of the Hartmann number.

In early 1960's [2] extensive study started in the field of heat transfer laminar flow through channel of parallel plates. That provided a platform to construct MHD generators, cross field accelerators, shock tubes and pumps. Roming [3] provided an extensive review of multilayered fluid flow. Alpher [4], Perlmutteer and Siegel [5], Siegel [6], who have presented detailed investigation on effects of forced convection over flow of electrically conducting fluid flowing through a parallel plate channel in presence of magnetic field, applied normal to the plates. Alireza and Sahai [7], Lohrasbi and Sahai [8] studied MHD heat transfer in a two-phase flow with fluid in one phase being electrically conducting. Malashetty and Leena [9] have studied short circuit situation of MHD heat transfer in a two-phase flow.

The coal-fire MHD generator channel is subjected to an unusually severe thermal environment. Postlethwaite and Sluyter [10] worked on detailed study of heat transfer in MHD generator. Sinha and Deka [11] provided their view on heat transfer and two phase MHD fluid flow in a horizontal Chanel. Cruz and Pinho [12] have study isothermal flow of PTT fluid model. Raju et al. [13] have provided their study on two layered flow with slip flow between parallel plates. Siddhiqui et al. [14,15] studied heat transfer in two immiscible PTT fluids in concentric layers, flowing through a pipe.

Two-phase flow studies are very much important in bio-rheological studies. Human body is controlled throughout by circulatory systems of bio fluids. Blood is multiphase biofluid containing plasma and blood cells. Eldesoky [16] studied on MHD pulsatile flow which is flowing through artery. Relaxation time and body acceleration of fluid suspensions is found in their research. Eldesoky et al. [17-19] have examined combined effect of magnetic field and heat transfer in two-phase peristaltic flow.

Multiphase fluid flow problems are of greater interest for the purpose of industrial applications. Two fluids or fluids with particulate suspensions are done by many researchers. Two-phase flow studies through porous medium are proven sound in crude oil industry. Most recently Fakour et al. [20-25] provided extensive research on heat transfer in nanofluids with permeable vessel. Authors have examined in detail that applications of heat transfer in presence of magnetic field for two-phase fluids are well enough to useful interfere in flow rates. Malashetty et al. [9] studied two fluid flow under the effect of magnetic field. Authors have done convective studies in inclined channel. Prakash et al. [26] studied flow of two-phase conducting fluid through porous medium. Authors studied effects of free convection and heat transfer on MHD stokes fluid flow. Rahbari et al. [27]. Studied combined effects of heat transfer and magnetic field in blood flow with nanoparticles through porous vessels. They provided one dimensional analytical result. Kumar et al. [28]. Studied MHD flow of dusty gas through porous medium. In their study they evaluated effects of thermal diffusion and mass transfer. Surseh and Sekar [29] provided his research on unsteady MHD blood flow through parallel plate channel. They find through mathematical analysis the effect of heat source o blood flow in presence of magnetic field.

Inspiring from the previous studies in the field of two-phase flow through porous medium, we are discussing two-phase (fluid-fluid model) MHD flow through porous medium with heat transfer in a horizontal channel.

2 Formulation of the Problem

The fluid flow channel is of two infinite parallel plates extending in the x and z- directions. The region $0 \leq y \leq h_1$, is taken by fluid of viscosity μ_1, electrical conductivity σ_1, and thermal conductivity k_1 and the region $-h_2 \leq y \leq 0$, is occupied by a film of immiscible fluids of viscosity μ_2, electrical conductivity σ_2 and thermal conductivity k_2. The rheological properties of both the fluids are constant. The fluid flows in *x-axis* a constant magnetic field B_0 is applied in *y-axis*. Wall temperature T_w for both the walls is constant and same. The fluid flow is at common pressure gradient $P = -\frac{\partial p}{\partial x}$ for both the fluids. The fluid velocity and the magnetic field distributions are $\vec{V} = [u(y), 0, 0]$ and $\vec{V} = [0,\ B_0,\ 0]$respectively. The well-developed flow is steady, laminar and incompressible.

3 Governing Equations

The governing equation of momentum and energy for the two phases, under above stated assumptions are:

$$\nabla . \vec{V} = 0 \tag{1}$$

$$\frac{\partial \vec{V}}{\partial t} + (\vec{V}.\nabla)\vec{V} = -\left(\frac{1}{\rho}\right)\nabla p + \mu \nabla^2 \vec{V} + \frac{1}{\rho}\left(\vec{J} \times \vec{B}\right) + \vec{Z} - \frac{\mu}{K}\vec{V} \tag{2}$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + \vec{V}.\nabla T\right) = k\nabla^2 T + \rho \upsilon\, \Phi + \frac{J^2}{\sigma} \tag{3}$$

Where Φ is dissipation function, stated as

$$\Phi = 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y} + \frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 - \frac{3}{2}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)^2$$

Eq. (1) is continuity equation and eq. (2) is addressing motion with the third term in the right-hand side is the magnetic body force and $\vec{J}$ is the current density due to the magnetic field defined by

$$\vec{J} = \sigma(\vec{E} + \vec{V} \times \vec{B}) \tag{4}$$

$\vec{Z}$ is the force due to buoyancy

$$Z = \beta g(T_0 - T) \tag{5}$$

The gravitational body force $\vec{Z}$ has been neglected in the Eq. (2)

Using the velocity and magnetic field distribution as stated above, the Eq. (1) to Eq. (3) are as follows:

The equation of motion and energy for the both the phases becomes

$$P + \mu\frac{d^2u}{dy^2} - \sigma(E_z + uB_0)B_0 - \frac{\mu}{K}u \tag{6}$$

$$\rho C_p u\frac{\partial T}{\partial x} = k\frac{\partial^2 T}{\partial y^2} + \mu\left(\frac{\partial u}{\partial y}\right)^2 + \sigma(E_z + uB_0)^2 \tag{7}$$

Two walls of the flow channels are kept at equal temperature which is constant. As a result, temperature gradient $\frac{\partial T}{\partial x}$ becomes zero. Thus, the Eq. (7) reduce to

$$k\frac{\partial^2 T}{\partial y^2} + \mu\left(\frac{\partial u}{\partial y}\right)^2 + \sigma(E_z + uB_0)^2 = 0 \tag{8}$$

Considering the certain conditions equations of motion, energy and respective interface and boundary conditions for both the phases reduce to;

Phase-I

$$P + \mu_1\frac{d^2u_1}{dy_1^2} - \sigma_1(E_z + u_1B_0)B_0 - \frac{\mu_1}{K_1}u_1 = 0 \tag{9}$$

$$k_1\frac{d^2T_1}{dy_1^2} + \mu_1\left(\frac{du_1}{dy_1}\right)^2 + \sigma_1(E_z + u_1B_0)^2 = 0 \tag{10}$$

Phase-II

$$P + \mu_2\frac{d^2u_2}{dy_2^2} - \sigma_2(E_z + u_2B_0)B_0 - \frac{\mu_2}{K_2}u_2 = 0 \tag{11}$$

$$k_2\frac{d^2T_2}{dy_2^2} + \mu_2\left(\frac{du_2}{dy_2}\right)^2 + \sigma_2(E_z + u_2B_0)^2 = 0 \tag{12}$$

The Boundary and interface conditions on u_1 and u_2 are

$$\left.\begin{aligned} &u_1(+h_1) = 0, \quad u_2(-h_2) = 0, \quad u_1(0) = u_2(0) \\ &\mu_1\frac{du_1}{dy_1} = \mu_2\frac{du_2}{dy_2} \qquad \text{at} \qquad y = 0 \end{aligned}\right\} \tag{13}$$

If both the walls are kept at constant temperature then, the boundary conditions for T_1 and T_2 becomes,

$$\left.\begin{array}{lll} T_1(+h_1) = T_{w_1}, & T_2(-h_2) = T_{w_2}, & T_1(0) = T_2(0) \\ k_1 \frac{dT_1}{dy_1} = k_2 \frac{dT_2}{dy_2} & \text{at} & y = 0 \end{array}\right\} \tag{14}$$

Considering the non-dimensional terms:

$$u_1^* = \left(\frac{u_1}{\bar{u}_1}\right), \quad y_1^* = \left(\frac{y_1}{h_1}\right), \quad u_2^* = \left(\frac{u_2}{\bar{u}_2}\right), \quad y_2^* = \left(\frac{y_2}{h_2}\right), \quad G = \frac{P}{(\mu_1 \bar{u}_1 / h_1^2)}$$

$$R_e = \frac{E_z}{\bar{u}_1 B_0}, \qquad \theta_1 = \frac{T_1 - T_w}{\bar{u}_1^2 \mu_1 / k_1}, \qquad \theta_2 = \frac{T_2 - T_w}{\bar{u}_1^2 \mu_1 / k_1}, \tag{15}$$

Temperature considered common for both the wall is T_w. Eq. (9) to Eq. (12) reduces to,

$$\frac{d^2 u_1}{dy_1^2} + G - M_1^2 (R_e + u_1) - \frac{1}{K_1} u_1 = 0 \tag{16}$$

$$\frac{d^2 \theta_1}{dy_1^2} + \left(\frac{du_1}{dy_1}\right)^2 + M_1^2 (R_e + u_1)^2 = 0 \tag{17}$$

$$\frac{d^2 u_2}{dy_2^2} + \frac{\alpha}{\beta^2} G - M_1^2 (R_e + u_2) - \frac{1}{K_2} u_2 = 0 \tag{18}$$

$$\frac{d^2 \theta_2}{dy_2^2} + \frac{\gamma}{\alpha}\left(\frac{du_2}{dy_2}\right)^2 + \frac{\gamma}{\alpha} M_2^2 (R_e + u_2)^2 = 0 \tag{19}$$

In the equations notation 1 is for upper phase where 2 represents lower phase. M_1, M_2 represents the intensity of applied magnetic field in both the fluid phases I and II, where K_1, K_2 is used to the permeability of the porous medium for the two phases, respectively.

In phase I,

$$M_1 = B_0 h_1 \sqrt{\frac{\sigma_1}{\mu_1}}, \qquad K_1^* = \frac{K_1}{h_1^2}$$

In phase-II,

$$M_2 = B_0 h_2 \sqrt{\frac{\sigma_2}{\mu_2}}, \qquad K_2^* = \frac{K_2}{h_2^2}$$

R_e: Electric field loading parameter, *G:* Pressure gradient.

$$\alpha = \frac{\mu_1}{\mu_2}, \quad \beta = \frac{h_1}{h_2}, \quad \gamma = \frac{k_1}{k_2}, \qquad \delta = \frac{\sigma_1}{\sigma_2},$$

Where *α, β, γ, δ* are representing ratio of viscosities, heights, thermal conductivities, and electrical conductivities of two immiscible fluids, respectively.

Boundary conditions represented by eq. (13) and eq. (14) becomes,

$$\left.\begin{array}{lll} u_1(+1) = 0, & u_2(-1) = 0, & u_1(0) = u_2(0) \\ \frac{du_1}{dy_1} = \left(\frac{\beta}{\alpha}\right) \frac{du_2}{dy_2} & \text{at} & y = 0 \end{array}\right\} \tag{20}$$

$$\left.\begin{array}{lll} \theta_1(+1) = 0, & \theta_2(-1) = 0, & \theta_1(0) = \theta_2(0) \\ \frac{d\theta_1}{dy_1} = \frac{\beta}{\gamma}\frac{d\theta_2}{dy_2} & \text{at} & y = 0 \end{array}\right\} \quad (21)$$

Reduced boundary Conditions eq. (20) and eq. (21) are showing continuity of velocity and shear stress as well as continuity of temperature and heat flux at the interface $y = 0$ respectively.

4 Solution

Detailed exact solutions for the velocities u_1 and u_2 under the condition (20) for both the two-phases are obtained using perturbation technique, given by:

$$u_1(y_1) = C_1\, cosh(N_1 y_1) + \frac{C_3\, sinh(N_1 y_1)}{N_1} - \frac{G_1}{N_1^2} \quad (22)$$

$$u_2(y_2) = C_2\, cosh(N_2 y_2) + \frac{C_4\, sinh(N_2 y_2)}{N_2} - \frac{G_2}{N_2^2} \quad (23)$$

Where $G_1 = M_1^2 R_e - G$, $G_2 = M_2^2 R_e - G\frac{\alpha}{\beta^2}$, $N_1 = \sqrt{M_1^2 + \frac{1}{K_1}}$, $N_2 = \sqrt{M_2^2 + \frac{1}{K_2}}$

Using the values of u_1 and u_2 in Eq. (10), and Eq. (12) under the boundary condition (21), the temperature distributions for both the phases are;

$$\theta_1[y_1] = -\frac{1}{4M_1^2}(cosh[2N_1 y_1]C_3^2 + 4\, sinh[N_1 y_1]C_3(cosh[N_1 y_1]C_1 + 2k_5)N_1 + M_1^2(-4C_5 - 4C_7 y_1 + cosh[2N_1 y_1]C_1^2 + 8\, cosh[N_1 y_1]C_1 k_5 + 2k_5^2 M_1^2 y_1^2)) \quad (24)$$

$$\theta_2[y_2] = -\frac{1}{4\alpha M_2^2}(\gamma\, cosh[2N_2 y_2]C_4^2 + 4\gamma\, sinh[N_2 y_2]C_4(cosh[N_2 y_2]C_2 + 2k_6)N_2 + M_2^2(-4\alpha C_6 - 4\alpha C_8 y_2 + \gamma\, cosh[2N_2 y_2]C_2^2 + 8\gamma\, cosh[N_2 y_2]C_2 k_6 + 2\gamma k_6^2 M_2^2 y_2^2)) \quad (25)$$

Where $k_5 = R_e - \frac{G_1}{M_1^2}$, $k_6 = R_e - \frac{G_2}{M_2^2}$, $k_7 = \frac{1}{4\alpha(\beta+\gamma)M_1^2 M_2^2}$

The values of u_1 and u_2 as well as θ_1 and θ_2 are obtained from eq. (22) to eq. (25) with different values of various parameter. Analysis is done on behalf of trends of the plots for both the phases.

5 Results and Discussion

Here figures are plotted for fluid velocity distribution and temperature profile for different parameters. Pressure gradient is kept constant. Fig. 1 and Fig. 2 are plotted for both the velocity of fluid and temperature profile at different values of magnetic field parameter. We observe from Fig. 1 that flow is accelerated highly with increasing values of M (1.5 to 1.7) in presence of constant values of porosity parameter. Fig. 2 is representing an increasing trend of temperature profile for increasing values of M with other parameters are constant.

We evaluated numerical value of fluid velocity for both the phases and temperature for varying porosity parameter (2 to 2.5 and 2 to 3) keeping all other parameter constant. These are shown by Fig. 3 an Fig. 4 and observed that velocity and temperature is increasing. Temperature decreasing after travelling some distances which satisfies physical nature of temperature field.

As the study is done for two fluids of different viscosities. The effect of ratio of fluid viscosities α (0.1 to 0.3) on velocity and temperature is observed through Fig. 5 and Fig 6. Fluid velocity showing slow decreasing trend where temperature getting rapid increasing trend.

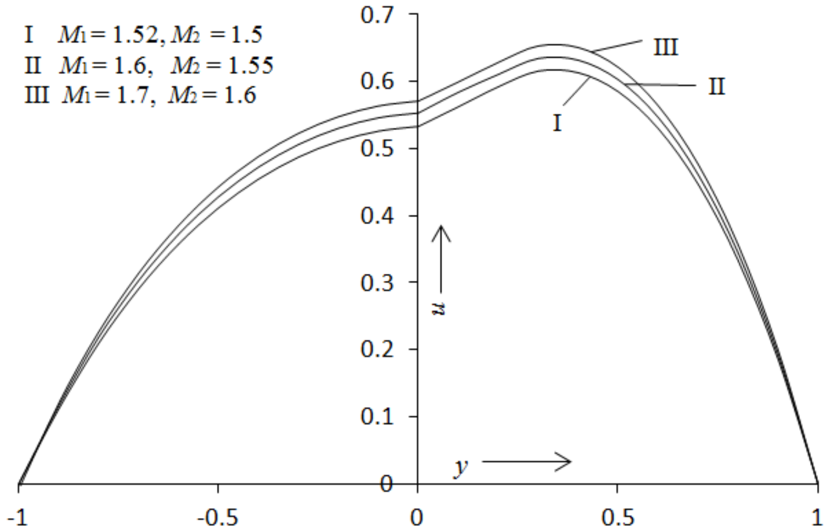

Fig. 1. Velocity profile for different value of *M*1 and *M*2

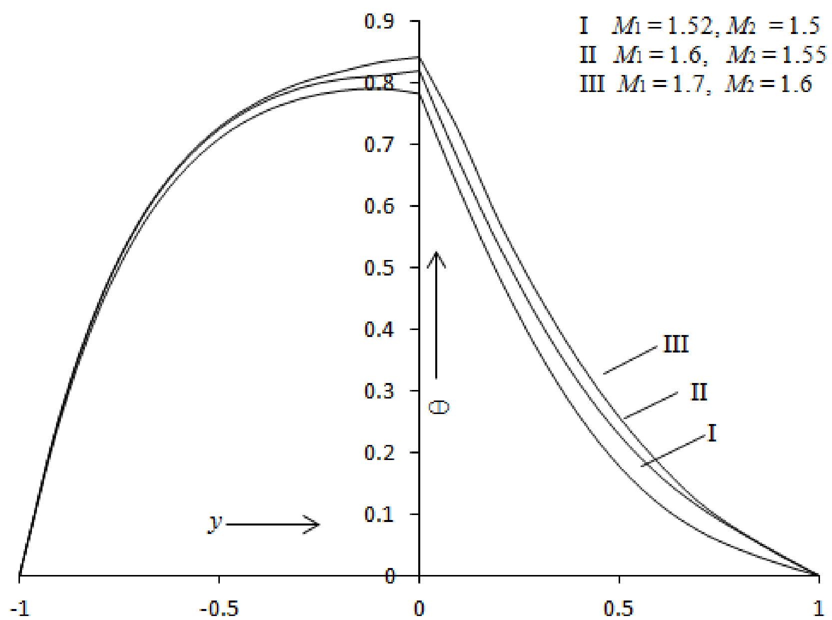

Fig. 2. Temperature profile for different value of *M*1 and *M*2

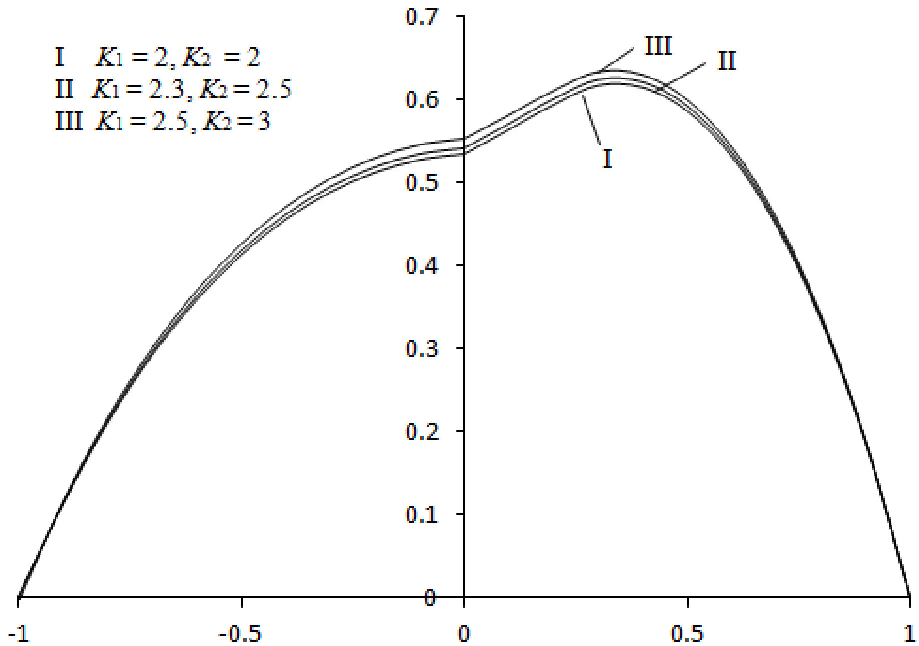

Fig. 3. Velocity profile for different value of *K*1 and *K*2

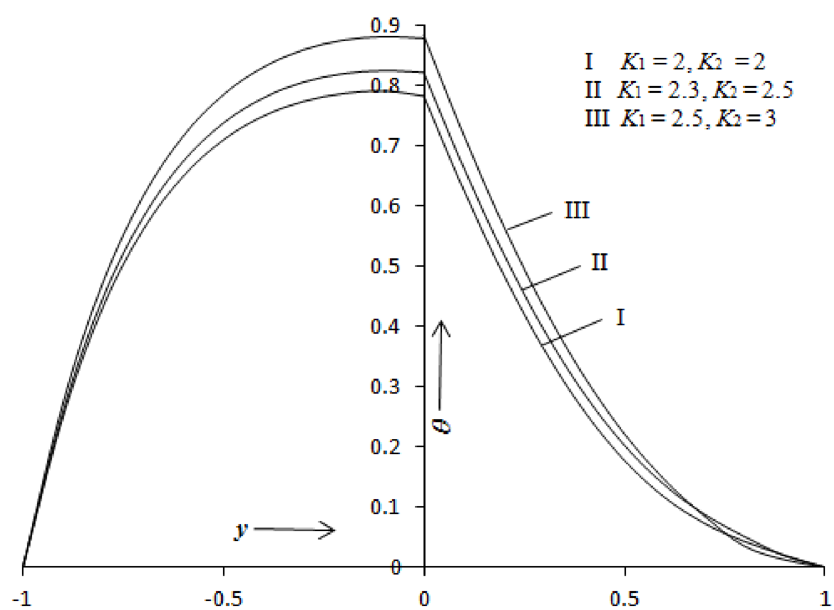

Fig. 4. Temperature profile for different value of *K*1 and *K*2

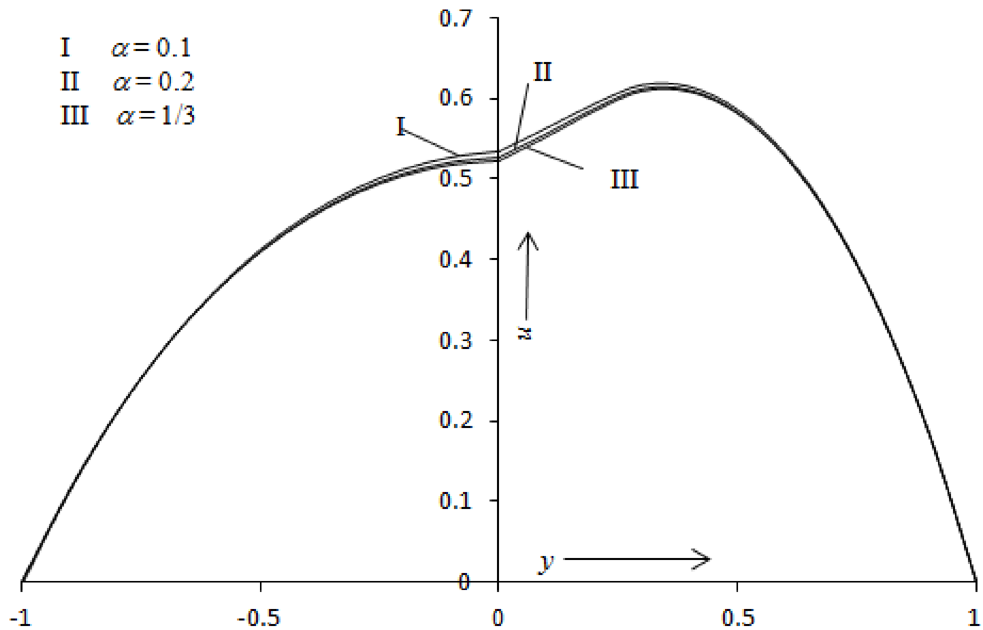

Fig. 5. Velocity profile for different value of α

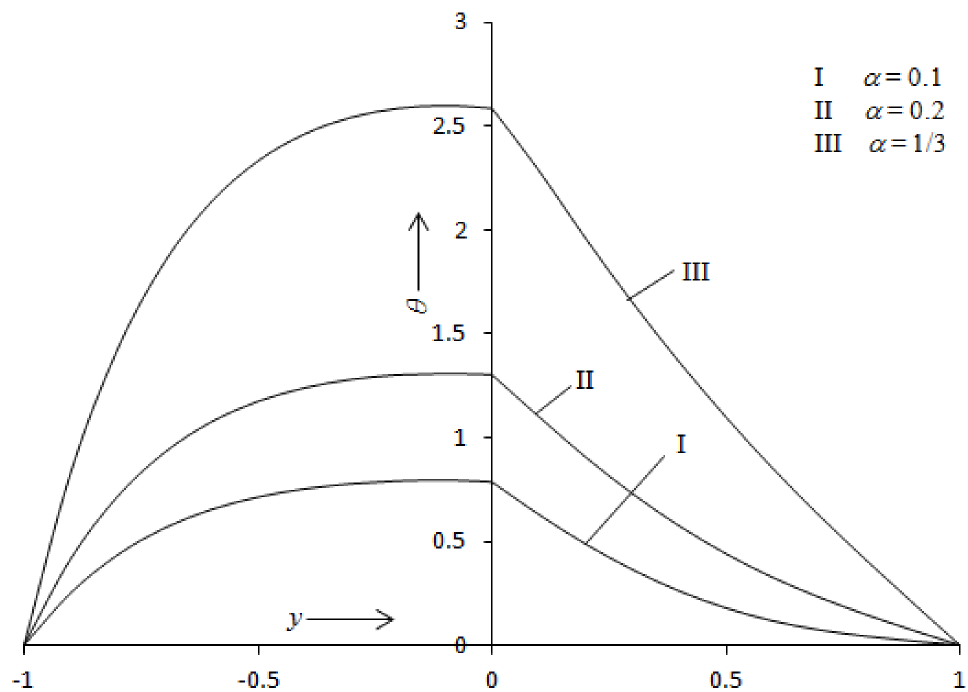

Fig. 6. Temperature profile for different value of α

6 Conclusion

The present study Two-phase flow MHD fluid through porous medium with heat transfer in a rectangular horizontal channel is concluded as,

- Study of two fluids of different viscosities are considered and showing accelerated flow with increasing magnetic field parameter and porosity parameter.
- Temperature is actively increasing with increasing permeability, which adds the energy of fluids which can be used in pumping of oils, water etc.
- Viscosity ratios with constant permeability giving rapid increments in internal energy of fluid. Slow decreasing variations are seen in velocity with increasing ratios of fluid viscosities.
- Industry controlling mechanism can be benefitted in purification of oils, pumping, pollution control, extraction of oil from oil wells.
- This application is helpful in the field of medical science where pulsatile and peristaltic multiphase flow are governed.

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Competing Interests

Authors have declared that no competing interests exist.

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