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ANALYSIS OF FLOW WITHIN A VERTICAL CHANNEL INFLUENCED BY A MAGNETIC FIELD

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Abstract:

Influence of magnetic field on two immiscible fluids within vertical channel has been examined. The study involves electrically conducting fluids, with channel walls assumed to be electrically insulated. The coupled governing equations have been solved using an analytical approach. It was found that Hartmann number and pressure significantly influence flow: an increase in Hartmann number leads to suppression of fluid motion, while higher pressure enhances fluid flow. The outcomes have been presented through graphical illustrations.

INTRODUCTION

In subsurface environments, immiscible fluids—both liquid and gas—move as distinct phases. Common examples of immiscible, or multiphase, flow include the behavior of substances like gasoline or dry cleaning chemicals within groundwater, the interaction between air and water in unsaturated soil zones, and the coexistence of oil, gas, and water in petroleum reservoirs. Geothermal systems also often exhibit multiphase flow, such as water and steam moving in tandem. The study of convection in immiscible fluids under magnetic influences has been explored, including notable work by J. Prathapkumar [1].

Magnetofluid dynamics, or hydromagnetics, examines the behavior of electrically conductive fluids when influenced by magnetic fields. These fluids encompass liquid metals, plasmas, and electrolyte solutions like saltwater. The term "magnetohydrodynamics" (MHD) combines "magneto-" (magnetic field), "hydro-" (fluid), and "-dynamics" (movement). Hannes Alfvén, who initiated the field of MHD, received a Nobel Prize in Physics for his pioneering contributions.

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0$$

Research by Umavathi [2], as well as by Chamkha and Ahmed [3], has investigated effect of magnetic fields on fluid flow dynamics. Magnetohydrodynamics (MHD) is based on principle that magnetic fields can generate currents within moving conductive fluid, which then produces forces that influence the fluid motion and alter the magnetic field itself. Studies by Prathap Kumar [4], Umavathi [5], and Zoran Boričić [6] have explored mixed convection behavior of MHD along with viscous fluids in vertical channels.

The equations governing MHD combine Navier–Stokes equations from fluid mechanics with Maxwell's equations from electromagnetism. These equations are differential and must be solved simultaneously, either through analytical or numerical methods.

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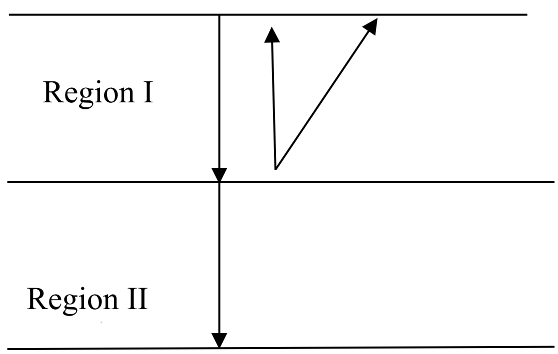
Heat transfer, unlike functions of state, depends on the specific path taken during a thermodynamic process; thus, the heat exchanged during a process that alters a system's state is determined by how the process unfolds rather than merely the difference between the initial and final states.

Several works, including those by Xu et al. [8], Nikodijevic et al. [9], Umavathi, and Liu [10], have examined MHD flow and associated heat transfer within fluid dynamics. In current investigation, we analyze fluid flow properties under influence of magnetic fields.

MATHEMATICAL MODULATION:

MHD flow involving 2 immiscible fluids in horizontal channel with isothermal boundaries under effect of external magnetic field has been studied. Setup includes two regions filled with immiscible, incompressible fluids, assuming a steady, one-dimensional (1D), and fully developed flow. Fluids differ in their viscosities (μ_1 and μ_2) and densities (ρ_1 and ρ_2). Exact analytical expressions for velocity and temperature distributions have been obtained and evaluated for distinct parameter settings.

Physical configuration, depicted in Figure 1, comprises 2 infinitely extended parallel plates aligned along iii and kkk axes. In region I ($h \leq y \leq 2h$), the fluid has viscosity μ_1 , electrical conductivity σ_1, thermal conductivity k_1, as well as specific heat capacity c_{p1}. In region II ($0 \leq y \leq h$), second fluid has viscosity μ_2 , thermal conductivity k_2, electrical conductivity σ_2, and specific heat capacity c_{p2}.



Uniform magnetic field with strength b is applied perpendicular to fluid flow, directed along the $\vec{J}$-axis, while the flow itself is considered one-dimensional.

$$\vec{U} = \overrightarrow{U_\iota}$$

$$\vec{B} = \overrightarrow{B_J}$$

Here $\vec{B}$ denotes magnetic field vector. Upper and lower plates are kept at 2 constant temperature $T_{w1}$and T_{w2}, respectively, and plates are electrically insulated. Stationary problem is being examined.

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Mathematical formulation of described MHD three-fluid flow problem begins with continuity equation:

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0\text{, because of }\frac{\partial V}{\partial y}=0$$

We have $U=U,(y)$,

- Momentum equation(for two fluid layers)
- $\mu_i\frac{d^2U_i}{dy^2}-\sigma_i B^2U_i-\frac{\partial p}{\partial x}=0, i=1,2,3$ ……………..(1)
- Energy equation
- $\rho c_p(\frac{\partial T}{\partial t}+\vec{U}\nabla T)=k\nabla T+\mu\phi+\frac{\overrightarrow{J^2}}{\sigma}$ ………………(2)
- Here current density vector J is $\vec{J}=\sigma(\vec{E}+\vec{U}X\vec{B})$

E represents vector of applied electric field, which I neglected in current investigation.

Energy equation has following form: $K\frac{d^2T}{dy^2}+\left(\frac{dU}{dy}\right)^2+\sigma B^2U^2=0$ …………(3)

Boundary interface conditions:

$$U_1*(-h_1)=0, U_2*(-h_2)=0, U_1*(0)=U_2*(0), \alpha_1\frac{dU_1*}{dy}(0)=\frac{dU_2*}{dy}(0)$$

$T_1(2h_1)=Tw_1$, $T_1(h)=T_2(h)$, $T_2(0)=T_3(0)$, $T_3(-h)=Tw_2$ …………..(4)

Non-dimensional transformations:

$$u_1^*=\frac{u_1}{u_1}\; u_2^*=\frac{u_2}{u_1}\; y_1^*=\frac{y_1}{h_1}\; y_2^*=\frac{y_2}{h_2}, p_i=-\frac{h^2}{\mu_i u_1}\frac{\partial p}{\partial x}$$ ……………………(5)

Now, substituting these non-dimensional transformations in 1, 2, and 3

$$\frac{d^2u_i*}{dy*^2}-Ha_i^2 u_i^*+p_i=0$$ ……………………(6)

$$\frac{d^2\theta_i}{dy*^2}+E_{ci}P_r\left(\frac{du_1*}{dy*}\right)^2+p_{ri}E_{ci}\,Ha_i^2\,u_i*^2=0$$ ……………………….(7)

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It is evident that temperature varies solely along j direction, since it remains constant along i direction on channel walls.

Fluid flow and thermal boundary conditions corresponding to this scenario are defined by following equations:

$$u_1{*}(2) = 0, u_1{*}(1) = u_2{*}(1), u_3{*}(-1) = 0, \alpha_1 \frac{du_1{*}}{dy{*}}(1) = \frac{du_2{*}}{dy{*}}$$

$$\theta_1(-1) = 1, \theta_2(1) = 0, \theta_1(0) = \theta_2(0), \frac{d\theta_1}{dy}(0) = \beta_1 \frac{d\theta_2}{dy}(0) \ldots\ldots\ldots\ldots..(8)$$

Solution: Solutions of equations 6 and 7 are given below

$$u_1 = A_1 Cosh(Ha_1) - B_1 Sinh(Ha_1) + C_1$$

$$u_2 = A_2 Cosh(Ha_2) + B_2 Sinh(Ha_2) + C_2$$

$$\theta_1 = -P_r E_c \{\frac{1}{4}(A_1^2 + B_1^2) Cosh(2Ha_1 y) + \frac{1}{2} A_1 B_1 Sinh(2Ha_1 y) + 2C_1[A_1 Cosh(Ha_1 y) + B_1 Sinh(Ha_1 y) + \frac{1}{2} C_1^2 Ha_1^2 y^2] + D_1 y + E_1$$

$$\theta_2 = -P_r E_c \{\frac{1}{4}(A_2^2 + B_2^2) Cosh(2Ha_2 y) + \frac{1}{2} A_2 B_2 Sinh(2Ha_2 y) + 2C_2[A_2 Cosh(Ha_2 y) + B_2 Sinh(Ha_2 y) + \frac{1}{2} C_2^2 Ha_2^2 y^2] + D_2 y + E_2$$

Results and discussion

In preceding section, mathematical formulation for flow and heat transfer of 2 immiscible fluids under a uniform magnetic field was established.

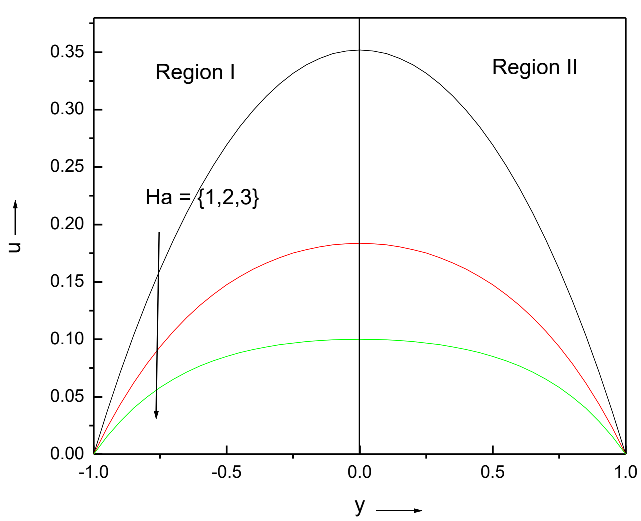

Fig 1 Velocity profile for different values of Hartmann number

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Figure 1 illustrates the effect of the Hartmann number on Velocity profiles.

It was observed that with rising Hartmann number, velocity decreases in both physical regions. This is due to Lorent force, which retards the velocity nature, result matches with Kalyan et al.[19].

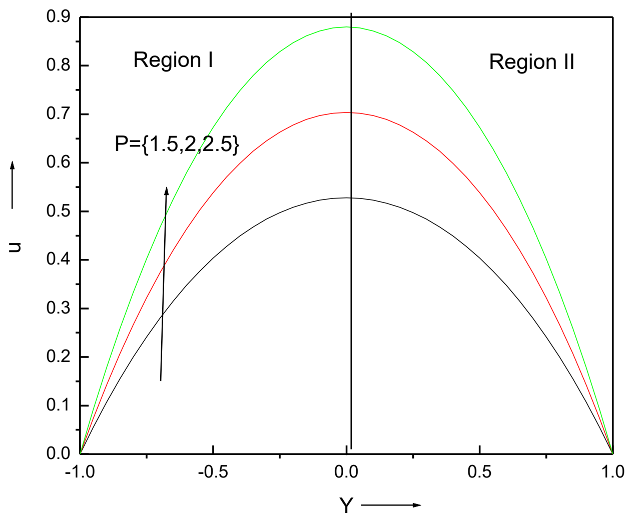

Fig 2:Velocity profile for different values of pressure

Effect of pressure gradient on fluid flow nature enhances speed in both regions that practically exist, as shown in the fig.2.

Conclusion:

MHD flow as well as heat transfer problem, involving 2 immiscible fluids, confined between parallel plates under an external magnetic field has been analytically examined. Exact solutions for dimensionless velocity as well as temperature profiles of each fluid were derived by applying appropriate interface matching and boundary conditions. Analysis shows that Hartmann number and pressure significantly influence flow: an increase in Hartmann number reduces flow rate, while a rise in pressure enhances it.

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