



STUDY OF MAGNETIC FIELD ON FLUID CHANNEL

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ABSTRACT:

The study of magnetic fields on fluid channels has garnered significant attention due to its applications in engineering, biomedical systems, and industrial processes. This paper investigates the influence of an inclined magnetic field on fluid flow within a channel, with a particular focus on the impact of heat and mass transfer.

The behavior of the fluid under the combined effects of magnetic fields, thermal gradients, and mass diffusion is analyzed using mathematical modeling and numerical simulations. The results highlight the interplay between magnetic forces, buoyancy effects, and fluid dynamics, providing insights into optimizing systems such as cooling devices, magnetic drug targeting, and energy-efficient industrial processes.

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1. INTRODUCTION

The interaction between magnetic fields and fluid flow has been a subject of extensive research due to its relevance in various scientific and engineering applications. Magnetohydrodynamics (MHD), the study of electrically conducting fluids in the presence of magnetic fields, plays a crucial role in understanding phenomena such as plasma confinement, liquid metal cooling, and biomedical fluid dynamics (Davidson, 2001). In recent years, the impact of inclined magnetic fields on fluid channels has gained prominence due to their ability to alter flow patterns, heat transfer rates, and mass diffusion processes.

This paper explores the behavior of fluid flow in a channel subjected to an inclined magnetic field, with a focus on the combined effects of heat and mass transfer. The inclination of the magnetic field introduces additional complexity, as it influences the Lorentz force acting on the fluid, thereby modifying velocity profiles, temperature distributions, and concentration gradients. The study aims to provide a comprehensive understanding of these phenomena and their implications for practical applications.

2. MATHEMATICAL FORMULATION

The governing equations for the fluid flow in the presence of an inclined magnetic field are derived from the principles of conservation of mass, momentum, energy, and species concentration. The following assumptions are

made:

1. The fluid is incompressible and Newtonian.
2. The magnetic field is uniform and inclined at an angle θ to the horizontal axis.
3. The induced magnetic field is negligible compared to the applied magnetic field (low magnetic Reynolds number approximation).
4. The Boussinesq approximation is valid for buoyancy-driven flows.

The continuity, momentum, energy, and concentration equations are given by:

$$\begin{aligned} \nabla \cdot \mathbf{u} &= 0 \\ \rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) &= -\nabla p + \mu \nabla^2 \mathbf{u} + \mathbf{J} \times \mathbf{B} + \rho \mathbf{g} \\ \rho c_p \left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) &= k \nabla^2 T + \Phi \\ \frac{\partial C}{\partial t} + \mathbf{u} \cdot \nabla C &= D \nabla^2 C \end{aligned}$$

where \mathbf{u} is the velocity vector, p is the pressure, ρ is the fluid density, μ is the dynamic viscosity, \mathbf{J} is the current density, \mathbf{B} is the magnetic field, \mathbf{g} is the gravitational acceleration, T is the temperature, c_p is the specific heat, k is the thermal conductivity, Φ is the viscous dissipation, C is the concentration, and D is the mass diffusivity.

The Lorentz force term $\mathbf{J} \times \mathbf{B}$ is expressed as:

$$\mathbf{J} \times \mathbf{B} = \sigma (\mathbf{u} \times \mathbf{B}) \times \mathbf{B}$$

where σ is the electrical conductivity of the fluid.

3. IMPACT OF HEAT AND MASS TRANSFER

The presence of an inclined magnetic field significantly influences heat and mass transfer in the fluid channel. The Lorentz force generated by the magnetic field alters the velocity profile, which in turn affects the temperature and concentration distributions. The inclination angle θ plays a critical role in determining the magnitude and direction of the Lorentz force, thereby influencing the flow behavior.

3.1 HEAT TRANSFER

The application of a magnetic field enhances heat transfer by modifying the flow structure. The inclined magnetic field induces secondary flows, which increase the mixing of fluid layers and improve thermal convection. However, the suppression of turbulence due to the magnetic damping effect can reduce heat transfer rates in certain configurations (Sarkar et al., 2018). The balance between these competing effects depends on the Hartmann number (Ha), which represents the ratio of electromagnetic forces to viscous forces:

$$Ha = BL\sqrt{\frac{\sigma}{\mu}}$$

where L is the characteristic length of the channel.

3.2 MASS TRANSFER

Mass transfer in the presence of a magnetic field is influenced by the interaction between the Lorentz force and concentration gradients. The inclined magnetic field can enhance or suppress mass diffusion depending on the orientation and strength of the field. Studies have shown that the Sherwood number (Sh), which characterizes mass transfer rates, increases with the Hartmann number for certain inclination angles (Sheikholeslami et al., 2019).

4. NUMERICAL SIMULATIONS AND RESULTS

Numerical simulations were conducted using finite element analysis to solve the governing equations. The results demonstrate the following key findings:

1. The velocity profile exhibits a parabolic shape, with the maximum velocity shifting toward the channel walls due to the Lorentz force.

2. The temperature distribution shows enhanced thermal gradients near the walls, indicating improved heat transfer.

3. The concentration profile indicates increased mass diffusion in the presence of an inclined magnetic field.

4. The inclination angle θ significantly affects the flow behavior, with optimal heat and mass transfer observed at intermediate angles.

5. Applications

The findings of this study have practical implications for various applications, including:

- Cooling Systems: Enhanced heat transfer in magnetic cooling systems for electronic devices.

- Biomedical Engineering: Targeted drug delivery using magnetic nanoparticles.

- Industrial Processes: Optimization of heat exchangers and reactors in chemical industries.

6. CONCLUSION

This study provides a detailed analysis of the impact of an inclined magnetic field on fluid flow in a channel, with a focus on heat and mass transfer. The results highlight the importance of the magnetic field inclination angle in determining flow behavior and transport phenomena. Future work will explore the effects of non-Newtonian fluids and transient magnetic fields on fluid dynamics.

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