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Inclined Magnetic Unsteady MHD Non-Newtonian Fluid Flow between Parallel Plates

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Abstract

The study investigates the dynamic and magnetic characteristics of unsteady magnetohydrodynamic (MHD) non-Newtonian fluid flow between parallel plates when the fluid flow is inclined. This research explores the complex interaction between magnetic forces, non-Newtonian fluid behavior, and the inclination of the flow within confined geometries. Non-Newtonian fluids, exhibiting viscosity characteristics deviating from classical Newtonian fluids, are frequently encountered in industrial processes and biological systems. Understanding their behavior in the presence of magnetic fields, especially under unsteady flow conditions, is crucial for optimizing various engineering applications. The presence of a magnetic field, commonly known as magnetohydrodynamics, introduces an additional dimension to the study. Magnetic forces interact with the fluid flow, leading to intricate flow patterns and behaviors. When the fluid flow is inclined, it adds an extra layer of complexity, influencing the direction and velocity of the flow.As research in this area progresses, the potential for advancements in industrial processes and environmental applications becomes increasingly evident. The synthesis of magnetic forces, non-Newtonian fluid behavior, and inclined flow dynamics opens new avenues for technological breakthroughs and sustainable engineering solutions.

Introduction

The study of fluid dynamics in confined geometries is a fundamental field of research with diverse applications in science and engineering. When one introduces magnetohydrodynamics (MHD) and non-Newtonian fluid behavior into this context, the complexity of the phenomenon increases significantly. In this introduction, we delve into the intriguing realm of inclined magnetic unsteady MHD non-Newtonian fluid flow between parallel plates.MHD deals with the interaction between magnetic fields and electrically conducting fluids. When such fluids are set into motion, the interplay between magnetic forces and fluid dynamics results in a rich tapestry of phenomena. Understanding unsteady MHD flows is essential for applications ranging from nuclear fusion research to space propulsion systems.

Non-Newtonian fluids are a class of complex fluids whose viscosity doesn't conform to the linear relationship between shear stress and shear rate observed in Newtonian fluids. These fluids, which include substances like polymers, sludges, and biological fluids, often exhibit shear-thinning or shear-thickening behavior. They are prevalent in various industrial processes, from food production to pharmaceutical manufacturing.The scenario of fluid flow between parallel plates is a classic configuration used to investigate fundamental flow characteristics. When the flow is inclined, it introduces an additional variable that profoundly affects the fluid dynamics. This inclination can be encountered in practical engineering situations, such as the cooling of electronic components or the flow of fluids in pipelines with varying orientations.

In this research, the primary focus lies in comprehending the intricate interactions between unsteady flow, magnetic forces, and non-Newtonian fluid behavior within the confined space between parallel plates. The study aims to elucidate how the inclination of the flow influences these interactions and their resulting effects on flow profiles, heat transfer, and fluid behavior.This research involves a multidisciplinary approach that combines computational simulations, mathematical modeling, and potentially experimental investigations. These methods are instrumental in unraveling the complex dynamics of this multifaceted fluid flow scenario.

As we delve deeper into this captivating field of study, we anticipate not only a deeper understanding of fundamental fluid dynamics but also innovative solutions to engineering challenges. The synthesis of magnetic effects, non-Newtonian fluid behavior, and inclined flow dynamics holds great promise for advancing technological solutions and furthering our understanding of complex fluid systems.

Formulation of the Problem

As illustrated in Figure 1, we studied the unsteady MHD flow of a viscous, incompressible, and non-Newtonian fluid between two horizontal, infinitely parallel plates under the influence of a changing magnetic field. The top plate moves with a constant velocity Uo, while the bottom plate remains stationary. It is decided to use a Cartesian coordinate system (x, y) with the x-axis running parallel to the plates and the y-axis perpendicular to them. The flow is subjected to an obliquely applied magnetic field He, whose intensity is modulated by a constant H. α (0 < α < π 2) a plate's worth of. In the past t = 0, The plates are immobile and temporally t > 0, the upper plate (located at y = h) begins forward motion at a constant rate along the positive x-axis U0 > 0.

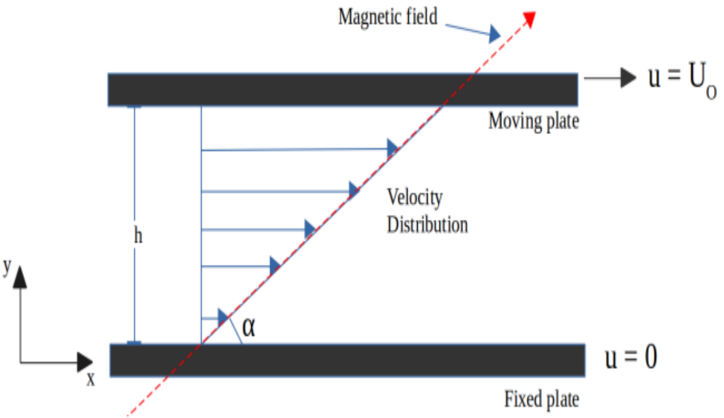

Figure 4.14: Geometry of the Research Problem

The flow variables in this research are functions of y and t solely because the plates are infinite in the x direction and the flow is turbulent and two-dimensional. The magnitude (H) of the applied magnetic field is a function of both y and t, since its intensity (B) varies with both variables.

Governing Equations

Equation of continuity

The concept of conservation of mass, which asserts that under normal circumstances, mass can neither be generated nor destroyed, provides the basis for the equation of continuity. Fluid entering and exiting a volume element in the flow field is mass balanced, giving rise to this quantity. In its most basic form, the continuity equation looks like this:

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot (\rho \vec{q}) = 0.$$

where $\vec{q}$ is the velocity vector and ρ refers to the density of the fluid. Whether or not fluid flow is feasible is largely determined by the solution to the continuity equation. When the velocity field agrees with the continuity equation, we say that flow is feasible. If we assume that the fluid is incompressible (i.e., that) we get ∂ ρ ∂t = 0. Since this is the case, the continuity equation (5.1) simplifies to the following form.

$$\vec{\nabla} \cdot \vec{q} = 0.$$

The whole speed profile, as measured in Cartesian coordinates, (⃗q) is given as $\vec{q} = u\hat{\mathbf{i}} + v\hat{\mathbf{j}} + w\hat{\mathbf{k}}$ and the gradient operator $(\vec{\nabla})$ is expressed as $\vec{\nabla} = \frac{\partial}{\partial x}\hat{\mathbf{i}} + \frac{\partial}{\partial y}\hat{\mathbf{j}} + \frac{\partial}{\partial z}\hat{\mathbf{k}}.$ for this reason, we may rewrite as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0.$$

The y-direction velocity is considered to be constant, and the flow is assumed to be two-dimensional (the flow variables are assumed to be z-independent). Therefore, we may simplify equation to the following

$$\frac{\partial u}{\partial x} = 0.$$

For this investigation, we use the continuity equation in Cartesian coordinates.

Equation of conservation of momentum

The momentum equation is based on Newton's second law of motion. According to the law, the rate of change in fluid momentum within a control volume must be equal to the total of the forces acting on the volume. For an incompressible fluid, the universal momentum equation is

$$\rho\left[\frac{\partial \vec{q}}{\partial t} + \vec{q}\cdot\left(\vec{\nabla}\vec{q}\right)\right] = -\vec{\nabla}p + \vec{\nabla}\cdot\left(\mu\vec{\nabla}\vec{q}\right) + \rho\vec{F}.$$

The term $\frac{\partial \vec{q}}{\partial t}$ is the temporal acceleration $\vec{q}\cdot\left(\vec{\nabla}\vec{q}\right)$ is the convective acceleration, ⃗∇p is the pressure gradient, $\vec{\nabla}\cdot\left(\mu\vec{\nabla}\vec{q}\right)$ is the viscous term, and ρ⃗F stands in for the body's forces. In this analysis, we assume that the only body force acting on the fluid is the Lorentz force. Force of Lorentz (J⃗×⃗B) is added to the right-hand side of the momentum equation (5.5) to get

$$\rho\left[\frac{\partial \vec{q}}{\partial t} + \vec{q}\cdot\left(\vec{\nabla}\vec{q}\right)\right] = -\vec{\nabla}p + \vec{\nabla}\cdot\left(\mu\vec{\nabla}\vec{q}\right) + \vec{J}\times\vec{B}.$$

We point out that since this is a non-Newtonian fluid, the dynamic viscosity (μ) varies over time. Below, we examine the Lorentz force and the power law model (used to characterize the fluid's non-Newtonian behavior).

Power law model

The shear stress (τ) for a power-law fluid, a special case of the more general Newtonian fluid, is given by

$$\tau = \mu_0\left(\frac{\partial u}{\partial y}\right)^{n-1}\frac{\partial u}{\partial y},$$

where $\frac{\partial u}{\partial y}$ is the fluid consistency coefficient, μ0 is the shear rate (or velocity gradient) perpendicular to the shear plane, and n is the flow behavior index. Although Equation is helpful due to its simplicity, it only gives a rough idea of how a true non-Newtonian fluid might behave. The total amount

$$\mu = \mu_0\left(\frac{\partial u}{\partial y}\right)^{n-1}$$

a function of shear rate (in Pa s), which indicates an apparent viscosity. In the case of power-law fluids, the value of the flow behavior index (n) determines whether the fluid is Newtonian or non-Newtonian. Since the viscosity is always the same when n = 1, we say that the fluid is Newtonian in this case. If this is not the case, we say that the fluid is non-Newtonian. There are two subtypes of non-Newtonian fluids: pseudoplastic and dilatant. When n is less than one, the fluid is termed pseudoplastic because it has shear-thinning qualities (like blood and milk) and when n is more than one, the fluid is called dilatant because it has shear-thickening behavior (like a sugar solution). The dilatant is the subject of the current investigation.

Maxwell's equations of electromagnetism

The mathematical formulation of the MHD phenomena requires Maxwell's equations of electromagnetism. The electric field (E), magnetic field (B), and electric current density (J) are all described by a set of four equations known as Maxwell's equations. In (5), the equations are written as:

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla} \times \vec{B} = \mu_e \vec{J} + \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t}$$

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho_e}{\varepsilon_0}$$

$$\vec{\nabla} \cdot \vec{B} = 0$$

where ρe is the electric charge density (or charge per unit volume). The electric permittivity of free space (ε0) and the magnetic permeability of free space (μe) are related to the speed of light (c) by the equation c 2 = 1/(μeε0). Faraday's law, represented by the equation (5.9a), asserts that an electric field is generated whenever a magnetic field undergoes a time-dependent change. Ampere's law, represented by the equation (5.9b), asserts that a magnetic field may be generated by either a current or an unstable electric field. Gauss's equation for electric field, given by (5.9c), asserts that the total electric charge density within a closed surface has a direct proportionality to the net electric flux passing through that surface. Gauss's law for magnetism, given by (5.9d), asserts that magnetic monopoles do not exist. Current density in an electrical circuit (J⃗) illustrates the interaction between charged particles and their fluid environment. Complete magnetic field (⃗B) is given by the sum of the induced magnetic field (H⃗) and the applied magnetic field eH⃗ , i.e.,

$$\vec{B} = \mu_e \left(\vec{H} + \tilde{\vec{H}}\right)$$

Non- Dimensionalization

Dimensional analysis is a mathematical method for comparing systems of varying sizes. It guarantees that the study's findings may be applied to different configurations with the same geometry and the same flow conditions. Choosing an appropriate scale against which to measure all physical model parameters is the first step in dimensional analysis. The dimensionless numbers that control the flow, heat, and mass transfer characteristics can only be determined by non-dimensional zing the particular governing equations. Since these equations are dimensionless, their solutions must be constrained to lie inside the range [0,1]. For the sake of this analysis, we will refer to the characteristic length h and the characteristic velocity U0. Thus, h/U0 is the typical time.

$$\bar{y} = \frac{y}{h}, \bar{t} = \frac{t}{h/U_0}, \bar{u} = \frac{u}{U_0}, \Theta = \frac{T - T_\infty}{T_{\text{wall}} - T_\infty}, \phi = \frac{H_x}{H_0}.$$

Following are the partial derivatives of the dimensionless independent variables with regard to the dimensional independent variables obtained in this way.

$$\frac{\partial \bar{y}}{\partial y} = \frac{1}{h}, \quad \frac{\partial \bar{y}}{\partial t} = 0$$

$$\frac{\partial \bar{t}}{\partial y} = 0, \quad \frac{\partial \bar{t}}{\partial t} = \frac{U_0}{h}$$

First partial derivatives are transformed as follows by using the chain rule of differentiation to equations.

$$\frac{\partial}{\partial y} = \frac{\partial \bar{y}}{\partial y}\frac{\partial}{\partial \bar{y}} + \frac{\partial \bar{t}}{\partial y}\frac{\partial}{\partial \bar{t}} = \frac{1}{h}\frac{\partial}{\partial \bar{y}}$$

$$\frac{\partial}{\partial t} = \frac{\partial \bar{y}}{\partial t}\frac{\partial}{\partial \bar{y}} + \frac{\partial \bar{t}}{\partial t}\frac{\partial}{\partial \bar{t}} = \frac{U_0}{h}\frac{\partial}{\partial \bar{t}}$$

The second partial derivatives of the specified governing equations are also transformed in a similar fashion, as shown below.

$$\frac{\partial^2}{\partial y^2} = \frac{\partial}{\partial y}\left(\frac{\partial}{\partial y}\right) = \frac{\partial}{\partial y}\left(\frac{1}{h}\frac{\partial}{\partial \bar{y}}\right)$$
$$= \frac{\partial \bar{y}}{\partial y}\frac{\partial}{\partial \bar{y}}\left(\frac{1}{h}\frac{\partial}{\partial \bar{y}}\right) + \frac{\partial \bar{t}}{\partial y}\frac{\partial}{\partial \bar{t}}\left(\frac{1}{h}\frac{\partial}{\partial \bar{y}}\right) = \frac{1}{h}\frac{\partial}{\partial \bar{y}}\left(\frac{1}{h}\frac{\partial}{\partial \bar{y}}\right)$$
$$= \frac{1}{h^2}\frac{\partial^2}{\partial \bar{y}^2}$$

Equations and Equation stated in terms of the dimensionless variables provided in Equation express the derivatives involved in the particular governing equations.

$$\frac{\partial u}{\partial y} = \frac{1}{h}\frac{\partial (U_0\bar{u})}{\partial \bar{y}} = \frac{U_0}{h}\frac{\partial \bar{u}}{\partial \bar{y}}$$

$$\frac{\partial u}{\partial t} = \frac{U_0}{h}\frac{\partial (U_0\bar{u})}{\partial \bar{t}} = \frac{U_0^2}{h}\frac{\partial \bar{u}}{\partial \bar{t}}$$

$$\frac{\partial^2 u}{\partial y^2} = \frac{1}{h^2}\frac{\partial^2 (U_0\bar{u})}{\partial \bar{y}^2} = \frac{U_0}{h^2}\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}$$

$$\frac{\partial T}{\partial y} = \frac{1}{h}\frac{\partial [(T_{\text{wall}} - T_\infty)\Theta + T_\infty]}{\partial \bar{y}} = \frac{(T_{\text{wall}} - T_\infty)}{h}\frac{\partial}{\partial}$$

$$\frac{\partial T}{\partial t} = \frac{U_0}{h}\frac{\partial [(T_{\text{wall}} - T_\infty)\Theta + T_\infty]}{\partial \bar{t}} = \frac{U_0 (T_{\text{wall}} - T_\infty)}{h}$$

$$\frac{\partial^2 T}{\partial y^2} = \frac{1}{h^2}\frac{\partial^2 [(T_{\text{wall}} - T_\infty)\alpha + T_\infty]}{\partial \bar{y}^2} = \frac{(T_{\text{wall}} - T_\infty)}{h^2}\frac{\partial^2 \alpha}{\partial \bar{y}^2}$$

$$\frac{\partial H_x}{\partial y} = \frac{1}{h}\frac{\partial (H_0\phi)}{\partial \bar{y}} = \frac{H_0}{h}\frac{\partial \phi}{\partial \bar{y}}$$

$$\frac{\partial H_x}{\partial t} = \frac{U_0}{h}\frac{\partial (H_0\phi)}{\partial \bar{t}} = \frac{U_0 H_0}{h}\frac{\partial \phi}{\partial \bar{t}}$$

$$\frac{\partial^2 H_x}{\partial y^2} = \frac{1}{h^2}\frac{\partial^2 (H_0\phi)}{\partial \bar{y}^2} = \frac{H_0}{h^2}\frac{\partial^2 \phi}{\partial \bar{y}^2}$$

Magneto hydro dynamic Flow of Viscous Fluid between Two Parallel Porous Plates with Bottom Injection and Top Suction Subjected To an Inclined Magnetic Field:

Flow of magneto hydro dynamic fluid between two parallel plates is known as the Hartmann flow, and it is a classic problem in the field of Fluid Dynamics. The aforementioned issue has several practical applications, including magneto hydrodynamic pumps, fluid droplet and spray generation, crude oil purification, the petroleum industry, and electrostatic precipitation. Research into the effects of solid particles on the functioning of such devices has led to several publications, including analyses of particulate suspensions in a conducting fluid in the presence of an externally produced magnetic field. Hall currents in MHD viscous flows have important technological applications in MHD generators and Hall accelerators, as well as MHD in aircraft. With the assumption of equal normal wall velocities, Berman (1953) solved the problem of constant laminar flow of an incompressible viscous fluid through a porous channel with a rectangular cross section when the Reynolds number is small. Sellars (1955) extended the issue first explored by Berman for cases when the Reynolds number is big. The topic of two-dimensional steady-state laminar flow in porous-walled tubes was later extended to a wider range of Reynolds numbers by Yuan (1956). Between two permeable parallel plates, Krishnambal and Ganesh S. (2004) investigated the unsteady stokes flow of a viscous fluid.Hazeem Ali Attia (2005a) looked into the unsteady laminar flow of an incompressible viscous fluid and heat transfer between two parallel plates when there was a constant suction and injection. Hazeem Ali Attia (2005b) looked at the inhomogeneous flow of a dusty conducting fluid between parallel porous plates with temperature-dependent viscosity. Between two parallel porous plates, Ganesh and Krishnambal (2006) studied the magnetohydrodynamic motion of a viscous fluid. Here, we explore the effects of a transverse magnetic field on the flow of an incompressible viscous fluid between two parallel porous plates using bottom injection and top suction. This chapter addresses the issue of continual laminar flow of an electrically conducting viscous incompressible fluid between two parallel porous plates of a channel with bottom injection and top suction in the presence of a transverse magnetic field. The difference in pressure. $\frac{\partial p}{\partial x}$ is something that's been spoken about in the field flow, where the vertical velocity is always the same.

Model Formulation

Laminar flow of an incompressible viscous fluid is investigated between two parallel porous plates with bottom injection, top suction at walls, and a uniform -flow velocity in a transverse magnetic field of intensity H0 applied perpendicular to the walls. The center of the channel will serve as the origin for the x and y axes, which will be parallel and perpendicular to the channel walls, respectively. L is assumed to represent the length of the channel, and h is the assumed separation between the plates. These are the flow-controlling equations:

The equation of continuity is $\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0$

Equations of momentum are

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{\sigma_e B_0{}^2 u\sin^2\alpha}{\rho}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\mu}{\rho}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)$$

where σe is the electrical conductivity and B0 = μeHo is the magnetic permeability multiplied by the electromagnetic induction. Conditions at the problem's edges are u (x , h) = 0, u (x, -h) = 0, v (x, h) = V and v (x, -h) = - V, where V is the velocity of suction at the walls of the channel.

Let $\nu=\frac{\mu}{\rho}=$ kinematic viscosity.

Consideration is given to the flow between two parallel porous plates located at y=h and y=-h.

A pressure difference propels the flow. $\frac{\partial p}{\partial x}$. It is assumed that a uniform There is a rise in vertical flow. That is, the component of the velocity vector pointing upwards is the same everywhere in the flow field.

Conclusion

The study of inclined magnetic unsteady magnetohydrodynamic (MHD) non-Newtonian fluid flow between parallel plates represents a complex and multifaceted field of research with wide-ranging implications in science and engineering. This investigation delves into the intricate interplay between magnetic forces, the rheological properties of non-Newtonian fluids, and the influence of inclined flow within confined geometries.he synergy of magnetic forces, unsteady flow dynamics, and non-Newtonian fluid behavior creates a highly complex and dynamic system. Understanding these interactions is pivotal for predicting and optimizing fluid behavior in various applications.Non-Newtonian fluids, characterized by their variable viscosity, significantly impact flow profiles, shear stress distributions, and velocity gradients within the confined space between parallel plates. These properties have profound implications for industrial processes involving such fluids.The presence of a magnetic field further complicates the fluid flow dynamics. Magnetic forces induce Lorentz forces, which can lead to flow stabilization, enhancement, or suppression, depending on the field strength and fluid conductivity.

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