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Study of Magnetohydrodynamic Fluid Flows and Their Applications

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ABSTRACT

In this paper a detailed study is presented on magnetohydrodynamic fluid flows with their basic governing equations. Basic concept of magnetohydrodynamic is discussed in detail. The results of various problems done by researchers are presented and addressed properly. The various applications of magnetohydrodynamic fluid flows have been presented.

KEYWORDS: *Fluid, Magnetohydrodynamic (MHD), Basic equations of magnetohydrodynamic, Magnetohydrodynamic fluid flow*

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INRODUCTION

Magnetohydrodynamics (MHD) is the study of the interaction of electrically conducting fluids and electromagnetic forces. MHD problems arise in a wide variety of situations. The description of MHD flows involves both the equations of fluid dynamics (Navier-Stokes equations) and the equations of electrodynamics (Maxwell's equations) which are mutually coupled through the Lorentz force and Ohm's law. In recent years various problems of magnetohydrodynamic (MHD) fluid flows have been solved by many researchers. Joseph et al. [1] considered the effect of variable suction on unsteady MHD oscillatory flow of Jeffrey fluid in a horizontal channel with heat and mass transfer has been studied. The temperature prescribed at plates is uniform and asymmetric. A perturbation method is employed to solve the momentum and energy equations. The effects of various dimensionless parameters on velocity and temperature profiles are considered and discussed in detail through graphs. The problem of MHD two dimensional flow over a permeable flat plate was studied by Chamkha and Issa [2] to investigate the effects of heat generation/absorption and thermophoresis on the flow. Maruf Hasan et al. [3] concentrated on the analysis of MHD free convection flow past an inclined stretching sheet. The viscous dissipation and radiation effects are assumed in the heat equation. Approximation solutions have been derived for velocity, temperature, concentration, Nusselt number, skin friction and Sherwood number using Nachtsheim-Swigert shooting iteration technique along with the six-order Runge-Kutta iteration scheme. Graphs are plotted to find out the characteristics of different physical parameters. The variations of physical parameters on skin friction coefficient, Nusselt number and Sherwood number are displayed via table. The unsteady hydromagnetic free convection flow of a Newtonian and polar fluid has been investigated by Helmy [4]. Misra et al. [5] considered the problem of oscillatory MHD flow of blood in a porous arteriole in presence of chemical reaction and an external magnetic field has been investigated. Heat and mass transfer during arterial blood flow is also studied. A mathematical model is developed and analyzed by using appropriate mathematical techniques. Expressions for the velocity profile, volumetric flow rate, wall shear stress and rates of heat and mass transfer have been obtained. Variations of the said quantities with different parameters are computed by using Mathematica software. The two dimensional MHD steady stagnation point flow towards a stretching surface was analyzed by Mahapatra *et. al* [6] and concluded that the velocity at a point decreases/increases with an increase in the applied magnetic field when the free stream velocity is less/greater than the stretching velocity. Raju et al. [7] investigated the problem a steady MHD forced convective flow of a viscous fluid of finite depth in a saturated porous medium over a fixed horizontal channel with thermally insulated and impermeable bottom wall in the presence of viscous dissipation and joule heating.

The governing equations are solved in the closed form and the exact solutions are obtained for velocity and temperature distributions when the temperatures on the fixed bottom and on the free surface are prescribed. The expressions for flow rate, mean velocity, temperature, mean temperature, mean mixed temperature in the flow region and the Nusselt number on the free surface have been obtained. The cases of large and small values of porosity coefficients have been obtained as limiting cases. Further, the cases of small depth (shallow fluid) and large depth (deep fluid) are also discussed. Seddeek [8] investigated the effects of magnetic field on the flow of micropolar fluids past a continuously moving plate by reducing the governing equations of motion in dimensionless form through a similarity transform. Priya et al. [9] discussed the combined effects of radiative heat transfer and a transverse magnetic field on steady rotating flow of an electrically conducting optically thin fluid through a porous medium in a parallel plate channel taking hall current into account and non-uniform temperatures at the walls. The analytical solutions of velocity, temperature, shear stresses and rate of heat transfer are obtained from coupled nonlinear partial differential equations for the problem. The computational results are discussed quantitatively with the different variations in dimensionless parameters entering in the solution. Raju et al. [10] discussed the problem of MHD free convective, dissipative boundary layer flow past vertical porous surface in the presence of thermal radiation, chemical reaction and constant suction, under the influence of uniform magnetic field which is applied normal to the surface is studied. The governing equations are solved analytically using a regular perturbation technique. The expressions for velocity, temperature and concentration fields are obtained. Falade et al. [11] investigated the effect of suction/injection on the unsteady oscillatory flow through a vertical channel with non-uniform wall temperature. The fluid is subjected to a transverse magnetic field and the velocity slip at the lower plate is taken into consideration. Exact solutions of the dimensionless equations governing the fluid flow are obtained and the effects of the flow parameters on temperature, velocity profiles, skin friction and rate of heat transfer are discussed and shown graphically. It is interesting to note that skin friction increases on both channel plates as injection increases on the heated plate.

Basic Equations For Electromagnetic Field

(1) Charge Conservation Equation (Charge Continuity Equation)

$$\nabla \cdot \vec{J} = -\frac{\partial \rho_e}{\partial t} \qquad (1)$$

(2) Maxwell's Equations

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad (2)$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \qquad (3)$$

$$\nabla \cdot \vec{D} = \rho_e \qquad (4)$$

(3) Constitutive Equations

$$\vec{D} = \varepsilon \vec{E} \qquad (5)$$

$$\vec{B} = \mu_e \vec{H} \qquad (6)$$

(4) Generalized Ohm's Law

$$\vec{J} = \sigma\left(\vec{E} + \vec{v} \times \vec{B})\right) + \rho_e \vec{v} \qquad (7)$$

where $\vec{J}$ is current density, $\vec{E}$ is electric field, $\vec{B}$ is magnetic induction, $\vec{H}$ is magnetic intensity, $\vec{D}$ is displacement vector, ρ_e is charge density, ε is electrical permittivity, μ_e is magnetic permeability, σ is electrical conductivity, $\vec{v}$ is velocity vector.

Basic Equations For Magnetohydrodynamic Fluid Flow

(1) Equation of State

$$\rho = \text{Constant} \qquad (8)$$

(2) Continuity Equation

$$\nabla \cdot \vec{v} = 0 \qquad (9)$$

(3) Equation of Motion

$$\rho \frac{D\vec{v}}{Dt} = -\nabla\left(p + \frac{\mu_e H^2}{2} \right) + \mu_e \left(\vec{H} \cdot \nabla\right)\vec{H} + \mu \nabla^2 \vec{v} \qquad (10)$$

(4) Equation of Energy

$$\rho C_v \frac{DT}{Dt} = k\nabla^2 T + \mu_e \nu_H \left(\nabla \times \vec{H}\right)^2 + \phi \qquad (11)$$

where $\phi = \mu\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right)\frac{\partial v_i}{\partial x_j}$

(5) Equation of Magnetic Field

$$\frac{\partial \vec{H}}{\partial t} + (\vec{v} \cdot \nabla)\vec{H} - \left(\vec{H} \cdot \nabla\right)\vec{v} = \nu_H \nabla^2 \vec{H} \qquad (12)$$

where $\frac{D}{Dt} = \frac{\partial}{\partial t} + v_j \frac{\partial}{\partial x_j}$ is material derivative, ρ is density, p is pressure, μ is viscosity, C_v is specific heat at constant volume, T is temperature, k is thermal conductivity, ν_H is magnetic diffusivity.

Applications

From a scientific point of view and by the proper application of the principles of the special theory of relativity, the interaction of electromagnetic fields and fluids can be described. The practical application of these principles, to actual physical phenomena of Astrophysics, Geo-physics, Engineering etc., have been increased in recent years. The study of this application to continuum has become known as magneto hydrodynamics or magneto fluid mechanics. The studies of magneto hydrodynamics of viscous conducting fluids have been played an important role during the recent times, owing to its practical interest and abundant applications in astro-physical and geo-physical fields. Astrophysicists and geo-physcists realized soon after the advent of special theory of relativity that electromagnetic fluid interactions were of great significance in astral and planetary processes. The main impetus to the Engineering approach to electromagnetic fluid interaction studies has come from the concept of the MHD direct conversion generation, propulsion studies of radio propagation in the ionosphere, and controlled nuclear fusion. Such studies have made for many years in connection with astro-physical and geo-physical such as sun spot theory, motion of the interstellar gas etc. MHD fluid flow in different geometries relevant to human body parts is an important scientific area due to its applications in medical sciences. Applications of MHD in medical sciences can be classified into four categories. Simple flow, peristaltic flow, pulsatile flow, and drag delivery are these categories. The results indicated that during a surgery when it is necessary to drop blood flow or reduce tissue temperature, it may be achieved by using a magnetic field. The study of MHD flow problems is currently receiving considerable interest and have a great future scope.

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