

UNSTEADY MAGNETOHYDRODYNAMIC STOKES FLOW OF VISCOUS FLUID BETWEEN TWO PARALLEL PLATES

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Science Degree in Mathematics

By

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **C.SHARUMATHI SINGH (38060010)** Who carried out the project entitled **"UNSTEADY MAGNETOHYDRODYNAMIC STOKES FLOW OF VISCOUS FLUID BETWEEN TWO POROUS PLATES"** under my supervision from **January 2021 to April 2021.**

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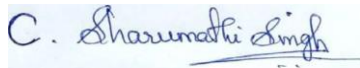
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DECLARATION

I **SHARUMATHI SINGH.C (38060010)** hereby declare that the Project Report entitled **“UNSTEADY MAGNETOHYDRODYNAMIC STOKES FLOW OF VISCOUS FLUID BETWEEN TWO POROUS PLATES”** done by me under the guidance of **Dr. R. DELHI BABU** (Internal) and _____(External) at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** submitted in partial fulfillment of the requirements for the award of Master of Science Degree in Mathematics

DATE:

PLACE: CHENNAI

A handwritten signature in blue ink, reading "C. Sharumathi Singh", is written over a light blue rectangular background.

SIGNATURE OF THE CANDIDATE

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ABSTRACT

The objective of this chapter is to analyze the Unsteady Magnetohydrodynamic Stokes flow of viscous fluid between two parallel porous plates when the fluid is being withdrawn through both the walls of the channel at the same rate. The problem is reduced to a third order nonlinear differential equation which depends on a Suction Reynolds number R and a Hartmann number M for which an exact solution is obtained.

KEYWORDS

Fluid flow

Parallel Plates

Magnetohydrodynamic flow

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CHAPTER-1

1. INTRODUCTION

FLUID DYNAMICS

Fluid Mechanics is that branch of Science which deals with the behaviour of fluids (liquids or gases) at rest as well as in motion. Thus this branch of Science deals with the static, kinematic and dynamic aspects of fluids. The study of fluids at rest is called fluid statics. The study of fluids in motion, where pressure forces are not considered, is called fluid kinematics and if the pressure forces are also considered for the fluids in motion, that branch of Science is called Fluid Dynamics. Fluid dynamics has a wide range of applications, including calculating forces and moments on aircraft, predicting weather patterns, the extraction of oils from underground reservoirs; influence of wind upon building structures, etc. Some of its principles are even used in traffic engineering, where traffic is treated as a continuous fluid.

1.1 IMPORTANCE OF FLUID FLOW

Fluids are divided into two categories. Those which undergo appreciable variations in density and volume under the impressed forces fall under the category of 'compressible fluids'. Then, there are those which undergo no noticeable changes in density and volume during motion. They are termed 'incompressible fluids'. Compressibility is thus a measure of the change in density and consequently, the change in volume of a fluid under the effect of external forces.

1.2 MAGNETOHYDRODYNAMIC FLOWS

MHD fluid flow in a parallel plate channel is an interesting area in the study of fluid mechanics because of its relevance to various engineering applications. The MHD flow in the planar channels leads to a startup process implying thereby a viscous layer at the boundary is suddenly set into motion and becomes important in the application of various branches of geophysics, astrophysics and fluid engineering. Magnetohydrodynamic flow has many applications in aerodynamic heating, electrostatic precipitation, polymer technology, petroleum industry, accelerators, fluid droplets, MHD pumps, power generators and purification of crude oil.

1.3 FLOW THROUGH POROUS MEDIUM

A medium which is a solid body containing pores is called a porous medium. Flow through porous media is also of interest in chemical engineering (adsorption, filtration, and flow in packed columns), petroleum engineering, hydrology, soil physics, biophysics and geophysics. Two macroscopic properties of porous media which may be used to describe fluid flow are porosity (ϵ) and permeability (k_1). The porosity of a porous medium describes how densely the material is packed. The porosity of a porous medium is defined as the fraction of the total volume of the medium that is occupied by the void space. Thus $1-\epsilon$ is the fraction that is occupied by solid. Porosity is a fraction between 0 and 1, typically ranging from less than 0.01 for solid granite to more than 0.5 for peat and clay. For manmade materials such as metallic frames, ϵ can approach to the value 1. For natural media, ϵ does not normally exceed 0.6.

The permeability is related to pore-size distribution since the distribution of the sizes of entrances, exits and lengths of the pore walls make up the major resistance to flow. The permeability is the single parameter that reflects the conductance of a given pore structure. The dimensions of the permeability are length squared.

1.4 NON-NEWTONIAN FLOWS

Fluids can be defined as substances that flow or deform under the application of shear stress and these include liquids and gases. They are part of engineering study in many tertiary institutions. Basically, in the study of science, fluids are divided into two broad groups. These divisions in this write-up are known as types of fluids which are Newtonian and non-Newtonian fluids. Newtonian fluids are those fluids that obey Newton Law of viscosity. The Newtonian viscosity is a physical property which is only a function of pressure and temperature. The flow properties of an incompressible Newtonian fluid can be characterized solely in terms of the density and viscosity.

CHAPTER-2

2. LITERATURE SURVEY:

Flow through porous media has many geophysical and engineering applications. Berman AS [1953] analyzed the Navier-Stokes equations have been solved to obtain a complete description of the fluid flow in a channel having a rectangular cross section and two equally porous walls. The scope has been limited to two-dimensional incompressible steady-state laminar flow. The solution of the flow equations leads to detailed expressions for the dependence of the velocity components and the pressure on position coordinates, channel dimensions, and fluid properties.

Hartmann and Lazarus [1937] investigated the effect of a transversely uniform MHD on the flow of conductive fluid between two infinitely parallel and fixed insulating plates. The equation describing MHD flow is a synthesis of the continuous equation and the Navier-Stokes equation. Governing equations are differential equations that require analytical or numerical solutions.

Hartmann J. [1937] considered the magnetic field in the laminar flow of conductive liquids.

Hassaninen I. A. and Mansour M.A. [1990] Analyzed the two-dimensional unsteady flow of a viscous, incompressible electrically- conducting fluid through a porous medium bounded by two infinite parallel plates under the action of a transverse magnetic field is presented. The lower plate is fixed while the other is oscillating in its own plane. Expressions for the transient velocity, the amplitude, the phase angle, and the skin-friction are derived. The effects of the magnetic parameters, permeability of the porous medium, and the frequency parameter are discussed.

Hamza E.A [1999], A similarity solution has been obtained for a flow between two parallel plates (rectangular or circular) approaching or receding from each other with suction or injection at the porous plate. Approximate analytic solutions based on the regular perturbation technique are given and a numerical solution of the resulting nonlinear differential equations is presented. The effects of injection and suction on the velocity profiles, pressure distribution and shearing stress on the wall are studied. In the case of the flow between circular plates the effects on load capacity due to mass transfer are investigated.

Soundalgekar V. and Uplekar [1986] investigated an exact analysis of a generalized MHD Couette flow, on taking into account the Hall current, is presented. Expressions for the axial and transverse components of velocity, the skin friction, are derived. These are shown in graphs. The exact solution to the energy equation, assuming the linear variation of the temperature along the plate, is also derived and this is shown graphically. The effects of different parameters are discussed.

Sing & Ram [1978] solved the differential equation by Laplace transform method, considering the laminar flow of conductive fluid laminar flow through a channel with a transverse magnetic field under a periodic pressure gradient.

Attia, H. A. and Kotb, N. A., (1996) studied the steady flow of an electrically conducting, viscous, incompressible fluid bounded by two parallel infinite insulated horizontal plates and the heat transfe through it are studied. The upper plate is given a constant velocity while the lower plate is kept stationary. The viscosity of the fluid is assumed to vary with temperature. The effect of an external uniform magnetic field as well as the action of an inflow perpendicular to the plates together with the influence of the pressure gradient on the flow and temperature distributions are reported. A numerical solution for the governing non-linear ordinary differential equations is developed.

Chiam T.C. (1993) investigated the boundary layer equations arising from the effects of a continuously moving flat plate under the action of a transverse applied magnetic field are converted into a system of ordinary differential equations subject to two-point boundary conditions by using the Local Nonsimilarity Method. An iterative method incorporating the shooting method is presented for solving both the two-equation and three-equation models.

R. Delhi Babu, S. Ganesh & C. K. Kirubhashankar (2020) studied the impact of unsteady magnetohydrodynamic flow of dust particles on the velocity of electrically directed viscous fluid between parallel porous plates with an angular velocity at the sight of a transverse magnetic field. The differential equations managing the flow are explained by similarity transformation. The velocity of the fluid, velocity of the dust particles and pressure distribution are obtained. The outcomes are the velocity of the dust particle is higher than that velocity of the fluid particles for each of the parameters examined.

CHAPTER-3

3. RESEARCH METHODOLOGY

3.1 AIM AND SCOPE

The main objectives of the work reported are:

- To study the effect of individual factors like Magnetic field, Hartmann number and Reynolds number.
- To study the solution for the unsteady MHD fluid flow through the parallel plate channel with heat source and external transverse magnetic field is presented.
- The effects of velocity are studied for the parameter magnetic field parameter.

The scope of the work reported is:

- It not only helps the people working in the field of Physiological fluid dynamics but also to the medical practitioners.

3.2 DESCRIPTION OF RESEARCH WORK

This research work focuses on the MATLAB implementation of interpretation of analytical solutions obtained for various fluid flow problems.

Research Problem

The main objective of the research work is to analyze the flow of fluids through parallel porous plates in the presence/absence of magnetic effects.

Research Methodologies

Analytical solutions are obtained by transforming the partial differential equation concerning the flow into an ordinary linear differential equation with constant coefficients by using similarity transformation. The arbitrary constant is then calculated by using boundary condition of the respective problem and the results are interpreted by using MATLAB applications

CHAPTER-4

4. MATHEMATICAL FORMULATION

The unsteady laminar flow of an incompressible viscous fluid between two parallel porous plates is considered in the presence of a transverse magnetic field H_0 applied perpendicular to the walls. The origin is taken at the centre of the channel and let x and y be the coordinate axes parallel and perpendicular to the channel walls.

The length of the channel is assumed to be L and $2h$ is the distance between the two plates. Let u and v be the velocity components in the x and y directions respectively.

The equation of continuity is
$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

Equations of momentum are

$$\rho \frac{\partial u}{\partial t} = -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \sigma_e B_0^2 u \quad (2)$$

$$\rho \frac{\partial v}{\partial t} = -\frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (3)$$

4.1 NOTATIONS

σ_e - electrical conductivity

$B_0 = \mu_e H_0$

B_0 - electromagnetic induction,

μ - Coefficient of viscosity

μ_e - magnetic permeability

ψ - Stream function

η - Dimensionless Variable

H_0 - Transverse magnetic field

4.2 BOUNDARY CONDITION :

The boundary conditions are $u = 0$ on $y = h$ and $y = -h$; $v = v_0 e^{i\omega t}$ on $y = h$ and $v = -v_0 e^{i\omega t}$ on $y = -h$ where v_0 is the velocity of suction at the walls of the channel.

Let dimensionless variable be $\eta = \frac{y}{h}$, $u = u(x, y)e^{i\omega t}$,
 $v = v(x, y)e^{i\omega t}$, $p = p(x, y)e^{i\omega t}$ where ω is the frequency.

The equations (1), (2) and (3) becomes

$$\frac{\partial u}{\partial x} + \frac{1}{h} \frac{\partial v}{\partial \eta} = 0 \quad (4)$$

$$\rho i \omega u = -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{1}{h^2} \frac{\partial^2 u}{\partial \eta^2} \right) - \sigma_e B_0^2 u \quad (5)$$

$$\rho i \omega v = -\frac{\partial p}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{1}{h^2} \frac{\partial^2 v}{\partial \eta^2} \right) \quad (6)$$

Let $\nu = \frac{\mu}{\rho}$ = Kinematic Viscosity, ρ the density of the fluid, μ the coefficient of viscosity and p the pressure.

Comment [c1]:

The boundary conditions are converted into

$$u(x, 1) = 0, \quad u(x, -1) = 0 \quad (7)$$

$$v(x, 1) = v_0, \quad v(x, -1) = -v_0 \quad (8)$$

Let ψ be the stream function such that

$$u = \frac{1}{h} \frac{\partial \psi}{\partial \eta} \quad (9)$$

$$v = -\frac{\partial \psi}{\partial x} \quad (10)$$

The equation of continuity can be satisfied by a stream function of the form

$$\psi(x, \eta) = (hU(0) - v_0 x) f(\eta) \quad (11)$$

where $U(0)$ is the average entrance velocity at $x = 0$. From equation(11), the velocity components (9) and (10) are given by

$$u = \frac{1}{h} (hU(0) - v_0 x) f'(\eta) \quad (12)$$

$$v = v_0 f(\eta) \quad (13)$$

where the prime denotes the differentiation with respect to the dimensionless

variable $\eta = \frac{y}{h}$. Since the fluid is being withdrawn at constant rate from both the walls, v_0 is independent of x .

Using (12) and (13) in (5) and (6), the equations of momentum reduce to

$$-\frac{1}{\rho} \frac{\partial p}{\partial x} = \left(U(0) - \frac{v_0 x}{h} \right) \cdot \left(i\omega f'(\eta) - \frac{v}{h^2} f'''(\eta) + \frac{\sigma_e B_0^2}{\rho} f'(\eta) \right) \quad (14)$$

$$-\frac{1}{h\rho} \frac{\partial p}{\partial \eta} = i\omega v_0 f(\eta) - \frac{v \cdot v_0 f''(\eta)}{h^2} \quad (15)$$

Now differentiating (15) w.r.t. 'x', the following equation is obtained.

$$\frac{\partial^2 p}{\partial x \partial \eta} = 0 \quad (16)$$

Differentiating (14) w.r.t. 'η', it follows that

$$\frac{-1}{\rho} \frac{\partial^2 p}{\partial x \partial \eta} = \left(U(0) - \frac{v_0 x}{h} \right) \cdot \frac{d}{d\eta} \left(i\omega f'(\eta) - \frac{v}{h^2} f'''(\eta) + \frac{\sigma_e B_0^2}{\rho} f'(\eta) \right) \quad (17)$$

From (16), equation (17) can be written as

$$\frac{d}{d\eta} \left(i\omega f'(\eta) - \frac{v}{h^2} f'''(\eta) + \frac{\sigma_e B_0^2}{\rho} f'(\eta) \right) = 0 \quad (18)$$

Let $R = \text{Suction Reynolds number} = \frac{h v_0}{\nu}$

$$M = \text{Hartmann number} = B_0 h \left(\frac{\sigma_e}{\nu \rho} \right)^{\frac{1}{2}}$$

Integrating (18) w.r.t. 'η' and substituting the above expressions, we get

$$\begin{aligned} f'''(\eta) - \frac{i\omega h^2}{\nu} f'(\eta) - \frac{\sigma_e B_0^2 h^2}{\rho \nu} f'(\eta) &= K \\ \Rightarrow f'''(\eta) - \alpha^2 h^2 f'(\eta) - a_1 R f'(\eta) &= K \end{aligned} \quad (19)$$

where $R = \frac{h v_0}{\nu}$ and $a_1 = \frac{\sigma_e h B_0^2}{\rho \nu}$ and K is an arbitrary constant.

Boundary conditions on f(η) are

$$f(1) = 1, f(-1) = -1, f'(1) = 0 \text{ and } f'(-1) = 0 \quad (20)$$

4.3 GENERAL SOLUTION OF EQUATION OF MOTION AND CONTINUITY

Hence the solution of the equations of motion and continuity is given by a nonlinear third order differential equation (19) subject to the boundary conditions (20).

∴ Equation (19) can be rewritten as

$$f'''(\eta) - (\alpha^2 h^2 + M^2)f'(\eta) = K \quad \text{where } \alpha^2 h^2 = M^2 \quad \text{and} \quad \alpha^2 = \frac{i\rho\omega}{\mu}$$

$$\text{i.e. } (D^3 - (\alpha^2 h^2 + M^2)D)f(\eta) = K \quad \text{where} \quad D = \frac{d}{d\eta} \quad \text{and} \quad D^2 = \frac{d^2}{d\eta^2}$$

The roots of the auxiliary equation for the above equation are $m=0$,

$$m = \pm \sqrt{\alpha^2 h^2 + M^2}$$

$$\therefore f(\eta) = A + Be^{\sqrt{\alpha^2 h^2 + M^2}\eta} + Ce^{-\sqrt{\alpha^2 h^2 + M^2}\eta} - \frac{K\eta}{\alpha^2 h^2 + M^2} \quad (21)$$

Applying the boundary conditions, we get,

$$f(\eta) = \frac{1}{(1 - \sqrt{\alpha^2 h^2 + M^2} \coth \sqrt{\alpha^2 h^2 + M^2})} \cdot \left(\frac{\sinh \sqrt{\alpha^2 h^2 + M^2} \eta}{\sinh \sqrt{\alpha^2 h^2 + M^2}} - \eta \sqrt{\alpha^2 h^2 + M^2} \coth \sqrt{\alpha^2 h^2 + M^2} \right) \quad (22)$$

4.4 EXPRESSION OF VELOCITY COMPONENTS

Hence the expressions for the velocity components are

$$u = \frac{1}{h} [hU(0) - v_0 x] f'(\eta) e^{i\omega t}$$

$$= \left(U(0) - \frac{v_0 x}{h} \right) \cdot \left(\frac{\sqrt{\alpha^2 h^2 + M^2}}{(1 - \sqrt{\alpha^2 h^2 + M^2} \coth \sqrt{\alpha^2 h^2 + M^2})} \right) \cdot \left(\frac{\cosh \sqrt{\alpha^2 h^2 + M^2} \eta}{\sinh \sqrt{\alpha^2 h^2 + M^2}} - \coth \sqrt{\alpha^2 h^2 + M^2} \right) e^{i\omega t}$$

$$v = v_0 f(\eta) e^{i\omega t}$$

$$= v_0 \left(\frac{1}{1 - \sqrt{\alpha^2 h^2 + M^2} \coth \sqrt{\alpha^2 h^2 + M^2}} \right) \cdot \left(\frac{\sinh \sqrt{\alpha^2 h^2 + M^2} \eta}{\sinh \sqrt{\alpha^2 h^2 + M^2}} - \eta \sqrt{\alpha^2 h^2 + M^2} \coth \sqrt{\alpha^2 h^2 + M^2} \right) e^{i\omega t}$$

CHAPTER-5

5. PERFORMANCE ANALYSIS

5.1 FIGURES AND DISCUSSION

The graphs of the axial velocity and radial velocity profiles have been drawn for different values of M . Figures 5.1 and 5.2 represents the axial velocity profiles at different cross sections of the channel at $x = 0$, $x = 5$ when the average entrance velocity is $u_0 = 0.5$ and $h = 1.0$. The magnitude of the axial velocity increases as x increases from $x = 0$ to $x = 5$ for different values of ωt , namely $\omega t = 0, \pi/4, \pi/2, 3\pi/4$, and π respectively. When the Hartmann number M is increased, we see that the magnitude of the axial velocity profiles decreases as seen in Figure 5.3. The Figure 5.4 represent the radial velocity profiles of v at $v_0 = 0.5$, $h = 1.0$, $\alpha = 1.0$ and for different values of M . As M increases from $M = 1.0$ to $M = 5.0$, it is seen that there is a marginal increase in the magnitude of the radial velocity. The Figure 5.5 represent the axial velocity profiles of u at $x = 0$, $h = 1.0$, $u_0 = 0.5$, $\omega t = 0$ and for different values of M . Here we see that the profiles are parabolic.

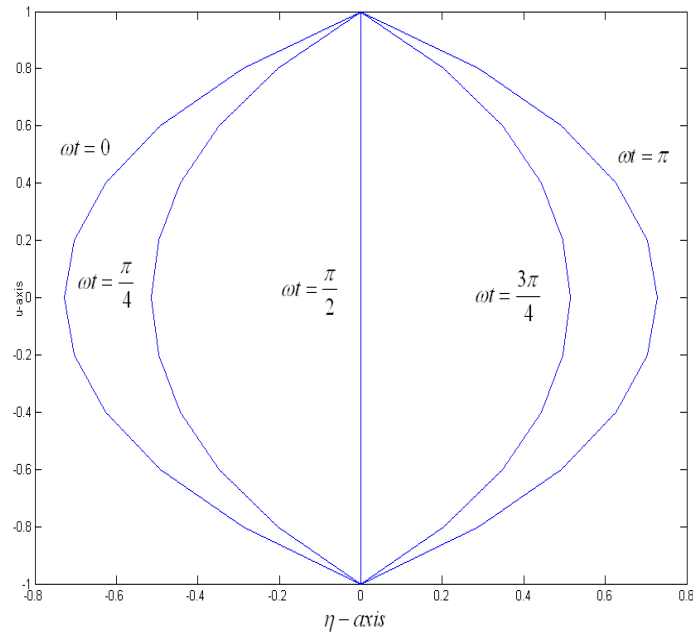


Figure 5.1 Axial velocity profiles when $u_0=0.5$, $v_0=0.5$, $h=1.0$, $M=1.0$, $\alpha=1.0$, $x=0$ and for different values of ωt

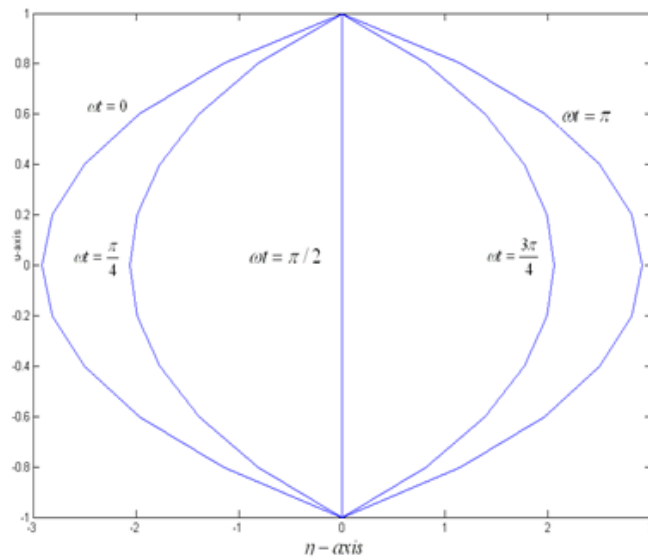


Figure 5.2 Axial velocity profiles when $u_0=0.5$, $v_0=0.5$, $h=1.0$, $M=1.0$, $\alpha=1.0$, $x=5$ and for different values of ωt

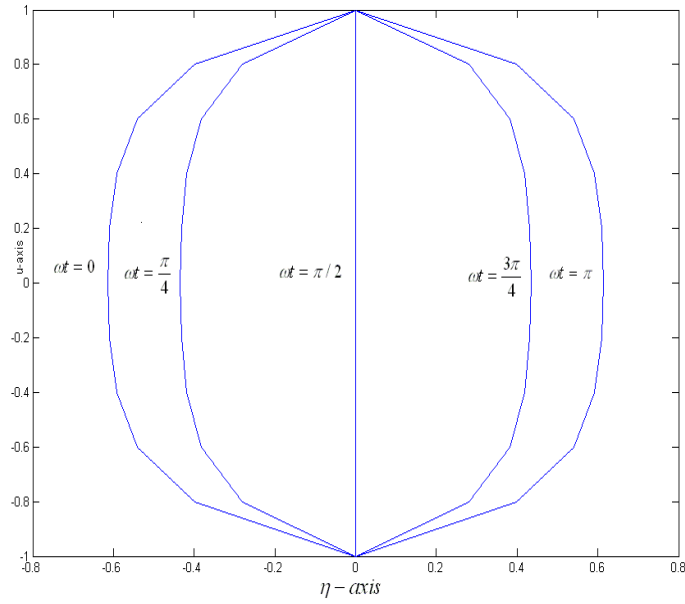


Figure 5.3 Axial velocity profiles when $u_0=0.5$, $v_0=0.5$, $h=1.0$, $M=5.0$, $\alpha=1.0$, $x=0$ and for different values of ωt

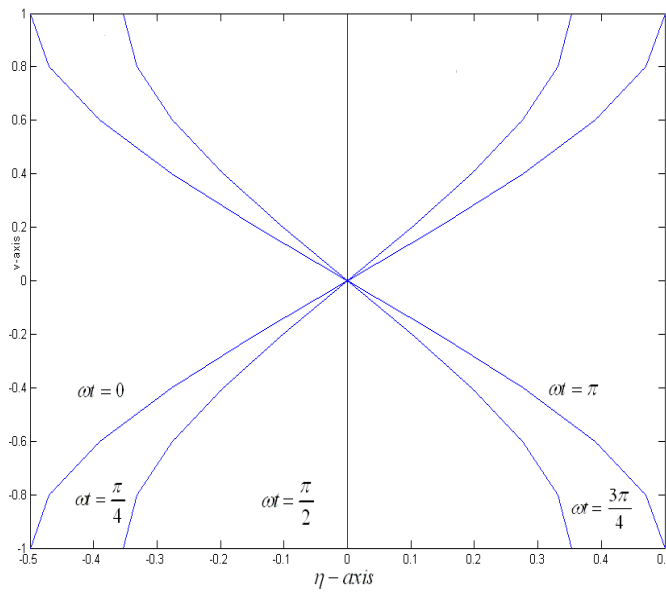


Figure 5.4 Radial velocity profiles when $v_0=0.5$, $h=1.0$, $M=1.0$, $\alpha=1.0$, $x=0$ and for different values of ωt

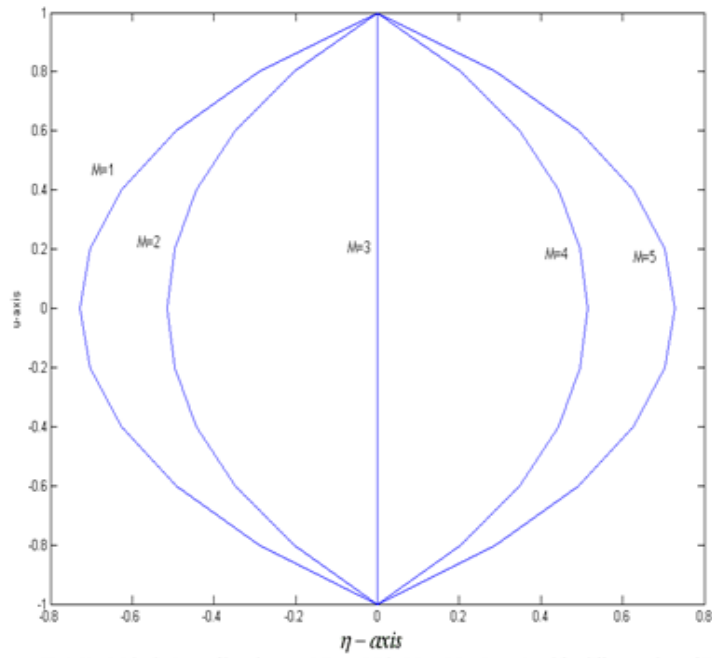


Figure 5.5 Axial velocity profiles when $u_0 = 0.5$, $v_0 = 0.5$, $h=1.0$, $\alpha=1.0$, $x=0$, $\omega t=0$ and for different values of M

CHAPTER-6

6. SUMMARY AND CONCLUSIONS

6.1 CONCLUSION

In the above analysis a class of solutions of unsteady magnetohydrodynamics stokes flow of viscous fluid between two parallel porous plates is presented, in the presence of a transverse magnetic field when the fluid is being withdrawn through both the walls of the channel at the same rate.

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