

Steady Laminar Flow of Viscous MHD Liquid in Constantly Moving Channel

Submitted in partial fulfillment of the requirement for the award of
Master of Science Degree in Mathematics

By

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**DEPARTMENT OF MATHEMATICS
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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade “A++” by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of SUVETHA.V (42630008). Who carried out the project entitled "**STEADY LAMINAR FLOW OF VISCOUS MHD LIQUID IN CONSTANTLY MOVING CHANNEL**" under my supervision from December 2023 to April 2024.

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DECLARATION

I SUVETHA.V (42630008) hereby declare that the Project Report entitled **“STEADY LAMINAR FLOW OF VISCOUS MHD LIQUID IN CONSTANTLY MOVING CHANNELS”** done by me under the guidance of Dr.C.K.KIRUBHASHANKAR, at **Sathyabama Institute of Science and Technology** is submitted in fulfillment of the requirements for the award of Master of science degree in Mathematics

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ABSTRACT

This paper investigates the steady two-dimensional laminar flow of an incompressible viscous liquid between two parallel plates under the influence of a transverse magnetic field. It assumes equal normal wall velocities and examines the velocity profile, pressure gradient, and the effects of velocity potential graphically, considering various parameters. Additionally, it explores the steady MHD flow between moving parallel plates with small uniform suction at the lower stationary plate.

Keywords: Fluid Flow, Parallel Plates, MHD Flow.

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CHAPTER 1

INTRODUCTION

1.1 FLUID DYNAMICS

Fluid Mechanics is that branch of science which deals with the behavior 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.

1.2 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.

1.3 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. Magneto hydrodynamic 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.

1.4 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. In oil industry it is measured in 'darcy' with $1\text{darcy} = 9.87 \times 10^{-9} \text{ cm}^2$. The permeability and porosity are related since if the porosity is zero the permeability is zero.

1.5 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

LITERATURE SURVEY

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 [2].

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 [3].

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 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.

Cox.S.M [1991] considered the flow of a viscous incompressible fluid in a parallel-walled channel, driven by steady uniform suction through the porous channel walls. A similarity transformation reduces the Navier-Stokes equations to a single partial differential equation (PDE) for the stream function, with two-point boundary conditions. We discuss the bifurcations of the steady solutions first, and show how a pitchfork bifurcation is unfolded when a symmetry of the problem is broken.

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.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 AIM AND SCOPER

The main objectives of the work reported are:

- To study the effect of individual factors like Magnetic field and Reynolds number.
- To study the solution for the steady 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

FORMULATION

4. MODEL FORMULATION

The flow of an incompressible viscous liquid between two parallel porous plates $y = 0$ and $y = h$ is considered in the presence of a transverse magnetic field which is applied perpendicular to the walls. Let u and v be the velocity components in the x and y directions respectively in the flow field at time t .

The equation of continuity is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$ (4.1)

Equations of momentum are:

$$u \frac{\partial u}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\mu}{\rho} \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \frac{\sigma B_0^2 u}{\rho} \quad (4.2)$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\mu}{\rho} \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (4.3)$$

4.1 ASSUMPTIONS

1. Flow between non conducting two parallel plates.
2. Viscosity of the fluid is considered as constant.
3. One plate is in uniform motion and the other plate (stationary plate) at rest with uniform suction.

4.2 NOTATIONS

- ρ - Density of the liquid
- P - Pressure of the liquid
- μ - Coefficient of viscosity
- ψ - Stream function

- η - Dimensionless distance
- σ - Electrical conductivity of the liquid
- ν - Kinematic viscosity ($\nu = \mu/\rho$)
- B_0 - Electromagnetic induction
- H_0 - Transverse magnetic field
- R - Reynolds number $\left(\frac{h\nu_0}{\nu}\right)$
- M – Hartmann number $\left(M = \sqrt{\frac{\sigma B_0^2 h^2}{\rho \nu}} = B_0 h \sqrt{\frac{\sigma}{\mu}}\right)$

4.3 GENERAL SOLUTION OF ANALYTICAL PROBLEM

With the help of discussions in the previous sections, let us choose the solutions of the equations (4.1)-(4.3) respectively as

$$\begin{aligned} u &= u(x, y)e^{-i\omega t} \\ v &= v(x, y)e^{-i\omega t} \\ p &= p(x, y)e^{-i\omega t} \end{aligned} \tag{4.4}$$

Let $\eta = \frac{y}{h}$ be the dimensionless distance and let $\nu = \frac{\mu}{\rho}$ be the kinematic viscosity and the equations (4.1), (4.2) and (4.3) become

$$\frac{\partial u}{\partial x} + \frac{1}{h} \frac{\partial u}{\partial \eta} = 0 \tag{4.5}$$

$$u \frac{\partial u}{\partial x} + \frac{\nu}{h} \frac{\partial v}{\partial \eta} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\mu}{\rho} \frac{\partial^2 u}{\partial \eta^2} - \frac{\sigma B_0^2 u}{\rho} \tag{4.6}$$

$$\nu \frac{\partial v}{\partial \eta} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\mu}{\rho} \frac{\partial^2 u}{\partial \eta^2} \tag{4.7}$$

The boundary conditions are converted into

$$\begin{aligned} u(x, 0) &= 0, & u(x, 1) &= U \\ v(x, 0) &= -v_0, & v(x, 1) &= 0 \end{aligned} \quad (4.8)$$

The stream function $\psi(x, y)$ is defined as

$$\psi(x, \eta) = (hu(0) - v_0x)f(\eta) \quad (4.9)$$

$$u(x, y) = \frac{\partial \psi}{\partial y} \quad \& \quad v(x, y) = \frac{\partial \psi}{\partial x} \quad (4.10)$$

From equations (4.2), (4.3), (4.9) and (4.10), we have

$$-\frac{1}{\rho} \frac{\partial p}{\partial x} = \frac{1}{h} (hu(0) - v_0x) v_0 f f'' - \frac{v}{h^2} f'''(\eta) + \frac{\sigma B_0^2}{\rho} f' - \frac{v_0}{h} f'^2 \quad (4.11)$$

$$-\frac{1}{\rho h} \frac{\partial p}{\partial \eta} = -\frac{v}{h^2} v_0 f'' + \frac{v_0^2}{h} f f' \quad (4.12)$$

Partially differentiation of equations (4.11) & (4.12) with respect to 'η' & 'x' respectively

$$\frac{\partial^2 p}{\partial \eta \partial x} = \frac{1}{h} (hu(0) - v_0x) - \frac{v}{h^2} f'''(\eta) + \frac{\sigma B_0^2}{\rho} f' + \frac{v_0}{h} (f f'' - f'^2) \quad (4.13)$$

$$\frac{\partial^2 p}{\partial \eta \partial x} = 0 \quad (4.14)$$

From equations (4.13) & (4.14), we get,

$$\text{i.e., } \frac{d}{d\eta} - \frac{v}{h^2} f'''(\eta) + \frac{\sigma B_0^2}{\rho} f' + \frac{v_0}{h} (f f'' - f'^2) = 0 \quad (4.15)$$

Integrating equation (4.15), we have

$$f'''(\eta) - R(f f'' - f'^2) - M^2 f' = K \quad (4.16)$$

with the boundary conditions

$$\begin{aligned} f(0) &= -1, & f(-1) &= -1 \\ f'(1) &= 0, & f'(-1) &= 0 \end{aligned}$$

4.4 SOLUTION OF ANALYTICAL PROBLEM

Equation (4.16) reduces to the form

$$f'''(\eta) - R(ff'' - f'^2) - M^2 f' = K \quad (4.17)$$

with the boundary conditions

$$\begin{aligned} f(1) &= 0, & f(-1) &= -1 \\ f'(1) &= 0, & f'(-1) &= 0 \end{aligned} \quad (4.18)$$

Hence the solution of (4.17) subject to the boundary condition (4.18) is

$$f(\eta) = \frac{(1-\eta)\phi \cosh \phi + \sinh(\phi\eta) - \sinh \phi}{2(\sinh \phi - \phi \cosh \phi)},$$

where $\phi = \sqrt{\alpha^2 h^2 + M^2}$

Substituting the value of $f(\eta)$ in the stream function $\psi(x, \eta) = (hu(0) - v_0 x)f(\eta)$

Using the stream function ψ and equation (4.9)

$$\begin{aligned} u &= u(x, y)e^{i\omega t} \\ &= \frac{1}{h} \frac{\partial \psi}{\partial y} e^{i\omega t} \\ &= \frac{1}{h} (hu(0) - v_0 x) f'(\eta) e^{i\omega t} \\ &= u(0) - \frac{v_0 x}{h} e^{i\omega t} \frac{\cosh(\phi y/h) - \phi \cosh \phi}{2(\sinh \phi - \phi \cosh \phi)} \\ v &= v(x, y)e^{i\omega t} \\ &= -\frac{\partial \psi}{\partial x} e^{i\omega t} \\ &= v_0 e^{i\omega t} \frac{(1-(y/h))\phi \cosh \phi + \sinh(\phi\eta) - \sinh \phi}{2(\sinh \phi - \phi \cosh \phi)} \end{aligned}$$

CHAPTER 5

PERFORMANCE ANALYSIS

5.1 SENSITIVE ANALYSIS AND DISCUSSION

From the above discussions, we have analyzed the liquid flow between two parallel porous plates, where the upper plate is moving uniformly. Liquid suction is through the lower fixed plate. Here the effects of velocity profiles and pressure distribution are studied. The axial and radial velocity profiles have been drawn for various cross section of the channel at $x = 0, x = 4$ when the average entrance velocity is $u_0 = 0.5$ with suction $v_0 = 0.5$ and $h = 1$. The magnitude of the axial velocity increases from $x = 0$ to $x = 4$ for different values of ωt . The Figures 3 & 4 represent the radial velocity profiles at $v_0 = 0.5, h = 1$ for different values of ωt . It is also seen from the figures that radial velocity vanishes for $\omega t = \pi/2$ and radial velocity profiles are non-linear for the other values of ωt . From the figures we see that axial velocity profiles for different values of ωt are parabolic.

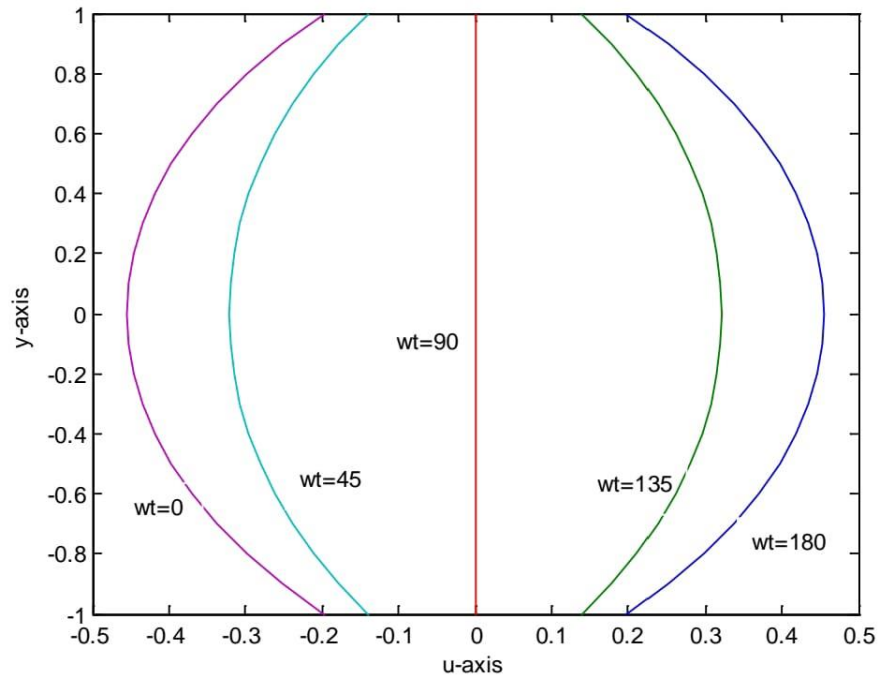


Fig 5.1: Axial Velocity Profiles when $u_0 = 0.5$, $v_0 = 0.5$, $h=1$, $\alpha = 1$, $x = 0$ and for Different Values of ωt

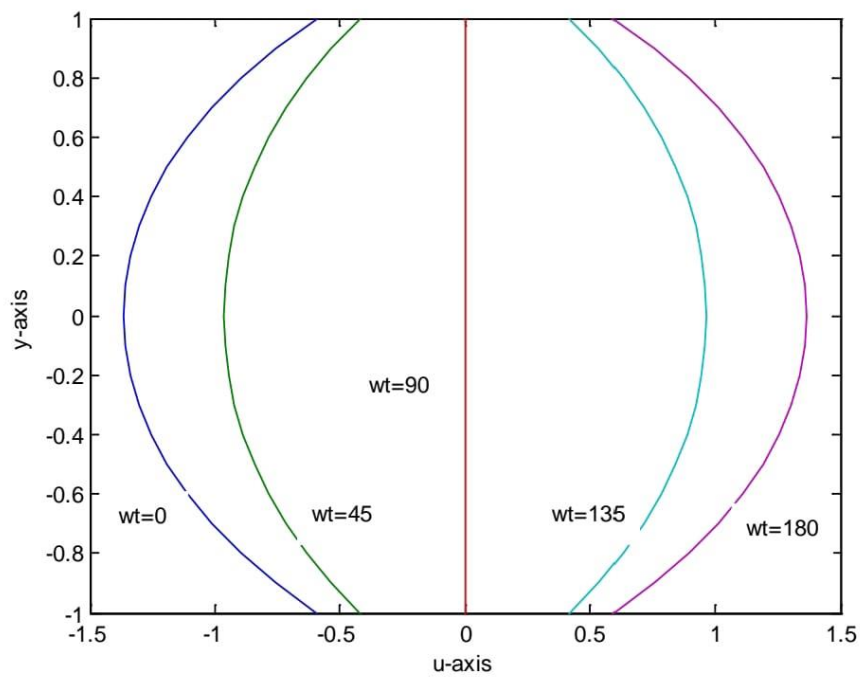


Fig 5.2: Axial Velocity Profiles when $u_0 = 0.5$, $v_0 = 0.5$, $h=1$, $\alpha = 1$, $x = 4$ and for Different Values of wt

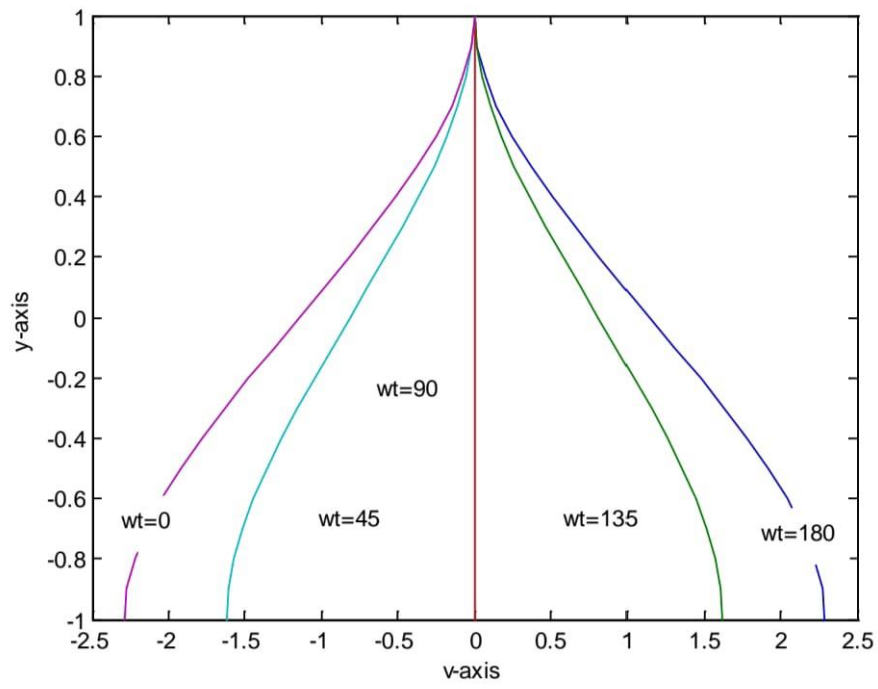


Fig 5.3: Radial Velocity Profiles when $u_0 = 0.5$, $v_0 = 0.5$, $h=1$, $\alpha = 1$, $x = 0$ and for Different Values of ωt

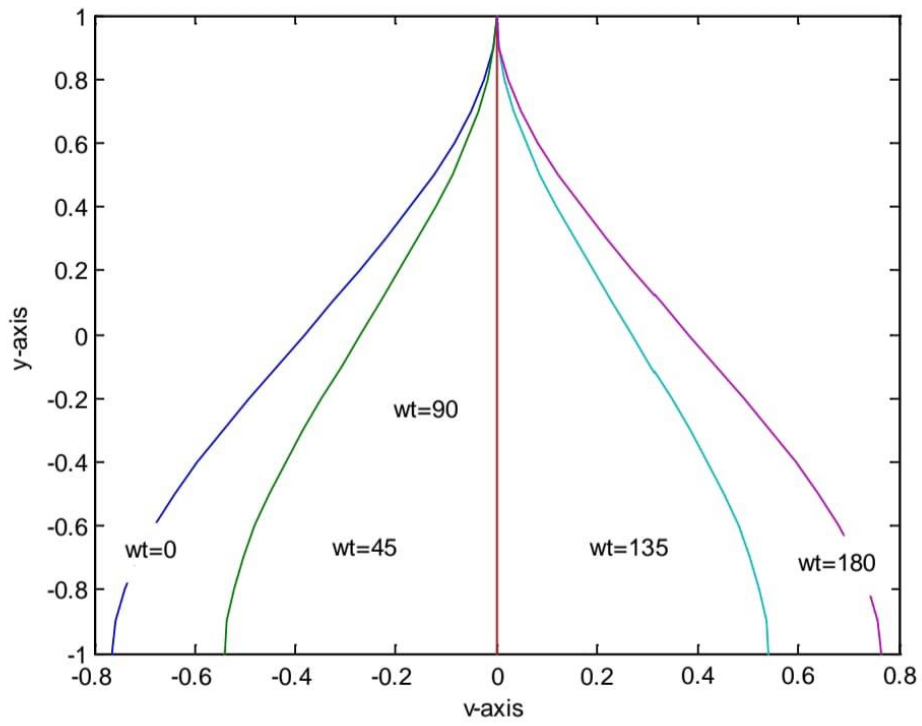


Fig 5.4: Radial Velocity Profiles when $u_0 = 0.5$, $v_0 = 0.5$, $h=1$, $\alpha = 1$, $x = 4$ and for Different Values of wt

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 CONCLUSION

Analytical solutions were derived for velocity profiles at various ωt values. Figures 1 & 2 indicate an increase in axial velocity magnitude at $x = 0$ and $x = 4$. Additionally, the radial velocity stresses are notably higher at the lower plate compared to the upper plate. The velocity profiles and pressure gradient for liquid flow were analyzed across different ωt values, with the results presented graphically.

6.2 FUTURE RESEARCH

Future research may explore three-dimensional laminar flow, variable wall velocities, and magnetic field strength effects. Additionally, investigations into the impact of the magnetic Reynolds number, heat transfer, and non-Newtonian fluids are crucial. Numerical simulations and experimental validations can provide deeper insights, informing potential engineering applications in microfluidics and power generation. Optimization strategies for flow control and efficiency improvement are also promising avenues for exploration.

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