

**A STUDY ON UNSTEADY MHD FLUID FLOW OF AN
EXPONENTIALLY STRETCHING WITH AN
ANGULAR VELOCITY**

Submitted in partial fulfilment of the requirements for the award of
Master of Science degree in MATHEMATICS

by

Rakshambika S (40630007)



**DEPARTMENT OF MATHEMATICS
SCHOOL OF SCIENCE AND HUMANITIES**

SATHYABAMA

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

Accredited with Grade "A" by NAAC

JEEPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600 119

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of RAKSHAMBIKA.S(40630007) who carried out the project entitled "A STUDY OF UNSTEADY MHD FLUID FLOW OF AN EXPONENTIALLY STRETCHING WITH AN ANGULAR VELOCITY" under my supervision from November 2021 to May 2022.

Internal Guide

(Dr. A. Mohamed Ismail)

External Guide

Head of the Department **Dr. M. NIRMALA**, M.Sc., M.Phil., Ph.D.,

(Dr. M. Nirmala)

Head of the Department
Dept. of Mathematics

Sathyabama Institute of Science and Technology
(Deemed to be University), Chennai-600 119.

Submitter for Viva voce Examination held on 12.05.2022

R. Manohar =
Internal Examiner
(R. Manoharan)

S. Ganesh
External Examiner
(S. Ganesh)

DECLARATION

I (S. Rakshambika) hereby declare that the Project Report entitled " **A STUDY ON UNSTEADY MHD FLUID FLOW OF AN EXPONENTIALLY STRETCHING WITH AN ANGULAR VELOCITY** " done by me under the guidance of Dr. A. Mohamed Ismail at **Sathyabama Institute of Science and Technology** is submitted in partial fulfilment of the requirements for the award of Master of Science degree in Mathematics.

DATE: 12.05.2022

PLACE: CHENNAI



SIGNATURE OF THE CANDIDATE

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ABSTRACT:

The aim of the present paper is to investigate the unsteady MHD fluid flow of an exponentially stretching with an angular velocity. By using the similarity transformation, the governing partial differential equations, the higher-order differential equations are converted into ordinary differential equations. By solving these equations we get the Axial velocity, Transverse velocity and pressure distribution of the fluid is obtained. The flow features for different values of governing parameter viz density, initial entrance velocity, electromagnetic conductivity, permeability, porous medium, and angular velocity are analysed and discussed in detail.

KEYWORDS:

- Electromagnetic conductivity
- Permeability
- Porous medium
- Angular velocity
- Initial entrance velocity

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ABBREVIATION:

MHD - Magnetohydrodynamics

CHAPTER - I

INTRODUCTION

1.1 FLUID MECHANICS

Fluid Mechanics is a branch of science that 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 is called fluid kinematics when pressure forces are not considered and if the pressure forces are also considered for the fluids in motion that branch of science is called Fluid Dynamics.

Anything that flows is considered as a fluid which is usually a liquid or a gas, the latter being distinguished by its great relative compressibility. Fluids are treated as continuous media, and their motion and state can be specified in terms of the velocity $\mathbf{u}$, pressure p , density ρ , etc evaluated at every point in space $\mathbf{x}$ and time t . To define the density at a point, for example, suppose the point to be surrounded by a very small element (small compared with length scales of interest in experiments) which nevertheless contains a very large number of molecules. The density is then the total mass of all the molecules in the element divided by the volume of the element.

Considering the velocity, pressure, etc as functions of time and position in space is consistent with measurement techniques using fixed instruments in moving fluids. It is called the Eulerian specification. However, Newton's laws of motion are expressed in terms of individual particles, or fluid elements, that move about. Specifying a fluid motion in terms of the position $\mathbf{X}(t)$ of an individual particle is called the Lagrangian specification. The path followed by a fluid element is called a particle path, while a curve that, at any instant, is everywhere parallel to the local fluid velocity vector is called a streamline. Particle paths are coincident with streamlines in steady flows, for which the velocity $\mathbf{u}$ at any fixed point $\mathbf{x}$ does not vary with time t .

The fundamental principle of conservation of mass states that for any closed volume fixed in space in which the rate increase of mass within the volume is equal to the net rate at which fluid enters across the surface of the volume.

Newton's first two laws state that if a particle (or fluid element) has an acceleration then it must be experiencing a force (vector) equal to the product of the acceleration and the mass of the particle: $\text{force} = \text{mass} \times \text{acceleration}$. For any collection of particles, this becomes $\text{net force} = \text{rate of change of momentum}$, where the momentum of a particle is the product of its mass and its velocity.

Newton's third law states that, if two elements A and B exert forces on each other, the force exerted by A on B is the negative of the force exerted by B on A.

1.2 TYPES OF FLUID

Ideal fluid:

A fluid which is incompressible and has no viscosity or no friction is known as an ideal fluid. Ideal fluid is only an imaginary.

Real fluid:

Real fluids are fluids that have some viscosity and are compressible in nature. All the fluids in actuality are real fluids Example: Kerosene, petrol and castor oil.

Newtonian fluid:

Fluids which obey Newton's law in which the shear stress is directly proportional to the rate of the shear strain are known as Newtonian fluids. Example: Water, air emulsions, hydrogen.

Non-Newtonian fluid:

Fluid in which the shear stress is not proportional to the rate of the shear strain is known as Non-Newtonian fluid. Fluids in which the value of viscosity is not constant are known as non-Newtonian fluid.

Ideal plastic fluid:

A fluid in which the shear stress is more than the yield value and shear stress is proportional to the rate of shear strain is known as an ideal plastic fluid.

Incompressible fluid:

A fluid in which the density of the fluid does not change and changes to an external force or pressure is known as an incompressible fluid.

Compressible fluid:

A fluid in which the density of fluid changes while the change in external pressure or force is known as compressible fluid.

1.3 FLUID FLOW:

Nanigopal Datta and Saroj Kumar Mishra(1983) discussed unsteady couette flow and heat transfer in a dusty gas. Datta (1993) and Mishra (1993) discussed unsteady heat transfer to pulsate flow of a dusty viscous incompressible fluid in a channel. Ghosh (2000) discussed the hydromagnetic flow of a dusty visco-elastic fluid between two infinite parallel plates. Hazem Attia (2002) discussed unsteady MHD flow and heat transfer of dusty fluid between parallel plates with variable physical properties. Fathi et al (2004) analyzed a dusty gas model of flow through naturally occurring porous media. Ada, Weber and John Newman (2005) discussed modeling gas-phase flow in porous media. Allam and Hamdan (2006) analyzed the fluid particle model of flow through porous media, the case of uniform particle distribution and parallel velocity fields.

1.4 MAGNETOHYDRODYNAMICS

Magnetohydrodynamics (MHD) deals with the study of the motion of electrically conducting fluids in the presence of the magnetic field. The Magnetohydrodynamic flow between two parallel porous plates is a classical problem in Fluid Dynamics and it is known as the Hartmann flow. In such problems, the magnetic field induces motion. In the few cases of two- dimensional MHD channel flow found in literature, the cross-sections are considered rectangular or circular. Although other cross-sections, that is, elliptical, parabolic, etc., might be solved in special cases, the

rectangular and circular geometries have not been exhaustively studied.

In ordinary hydrodynamics, only one velocity profile exists for each kind of channel, provided that the flow is laminar and steady. When the fluid is an electrical conductor passing through a magnetic field, however, an infinity of velocity profiles is possible, each one resulting from a different return circuit for the electric current. The general MHD flow problem in a rectangular channel has walls of finite, non-zero conductivity that is a very difficult one in involving the magnetic field solutions not only in the conducting fluid but in the space outside the channel as well. For any given problem a numerical solution using finite differences can be obtained but it seems unlikely that an analytical solution is practical.

Magnetohydrodynamics (MHD) interactions have a wide range of applications in the fields of science and technology. The study of MHD flow plays an important role in agriculture, engineering magnetohydrodynamic power generators, magnetohydrodynamic pumps, accelerators, aerodynamic heating, electrostatic precipitation, polymer technology, purification of crude oil and fluid droplets, sprays and petroleum industries. The study of free convection under the influence of a magnetic field has attracted the interest of many researchers, in view of its application in geophysics and in astrophysics. The significance of this study in the fields of geological formations; aerodynamics and space sciences etc., is well recognized. In the field of power generation, MHD is receiving considerable attention due to the possibilities it offers for much higher efficiencies in power plants.

CHAPTER – II

LITERATURE SURVEY

Hazem A Attia(2002) studied the unsteady flow between two parallel plates with variable viscosity and electric conductivity. The fluid is driven by a constant pressure gradient and an external uniform magnetic field is applied perpendicular to the plates.

Gireesha, Bagewadi, and Prasannakumara(2007) discussed the flow of unsteady dusty fluid between two parallel plates under a constant pressure gradient is investigated using differential geometry techniques. Using the Laplace transformation the analytical expression for velocities of fluid and dust particles is obtained.

Abbas, Tabish Javed, Mehrab Hossen Sajid and Niaz Ali (2010) discussed the unsteady magnetohydrodynamic boundary layer flow and heat transfer analysis in an incompressible rotating viscous fluid over a stretching continuous sheet. The effects of the involved physical parameters on the velocity field, temperature distribution, local skin friction coefficients and the local Nusselt number are graphically discussed.

Pavitra and Gireesha(2013) made a numerical investigation to describe the boundary layer flow and the governing partial differential equations are reduced to nonlinear ordinary differential equations by transformation.

A.Mohamed Ismail and S.Ganesh(2014) studied the result of dust particles between two parallel plates through a porous medium with constant suction in the upper plate and constant injection in the lower plate. The result exposed that the velocity of dust particles is higher than that velocity of the fluid for all parameters considered.

Anand. V.W.J, Ganesh.S, Mohamed Ismail. A, Kirubhashankar. C.K (2015) were investigated the structure of an unsteady MDH flow of fluid accompanied through a parallel plate. The heat source parameter, Hartmann number, and Prandtl number are analyzed and discussed in detail. The results revealed that the velocity of the clean fluid is higher than the velocity of the dusty fluid.

Girija bai, Naidu, and Vasanth Kumar(2015) discussed the blood flow in the abdominal aortic artery which is affected by acute stenosis is simulated numerically. Computational analysis of variations in the blood flow due to antiplatelet drugs is

studied by applying different densities. The results of this study help us to visualize the consequences of acute stenosis before and after treatment.

Mahabaleshwar and Vinay Kumar(2016) investigated the effect of a mathematical model describing the aforementioned process. The flow is induced by an infinite elastic sheet that stretched along its plane. In that, the governing equations are converted into the nonlinear equation and also they (2019) discussed the viscous fluid flow past a semi-infinite porous solid, which is proportionally sheared at one boundary with the possibility of the fluid slipping according to Navier's slip or second-order slip and the flow through the porous solid is assumed to obey the Brinkman equation.

Latha and Kumar(2017) studied the heat and mass transfer effects on unsteady blood flow through a parallel plate channel in a saturated porous medium in the presence of a transverse magnetic field with thermal radiation. The governing highest order nonlinear PDEs are converted to the dimensionless equation using dimensionless variables.

Ganesh and Anand (2019) studied the flow of fluid in a porous channel in a Stenosis with the influence of an unsteady magnetic field which is uniform is considered. Their results related to velocity, pressure, and skin friction in this paper shows the presence of the magnetic field which in turn influences the flow field, and also they(2021) discussed unsteady magnetohydrodynamic incompressible viscous Couette flow along with the silver metallic parallel plates in which constant periodic suction takes place at the bottom porous silver metallic shield subjected to the magnetic field with inclination along with the rotation of the system.

Kirubhshankar, Immanuel, and Vaithysubramanian(2020) discussed the exact solution for the unsteady MHD fluid flow between the parallel plate is dependent on the Homotopy technique. In this study, the unsteady MHD, viscid condensed, and conducting fluid stream problem under a transverse magnetic field is discussed.

Ashraf Ali, Mohamed Ismail, and Vaithyasubramania(2021) discussed the composition of an unstable MHD with two parallel plates with heat and mass source transfer.

Sini Rahuman, Mohamed Ismail, Shyla Manavala Varghese(2020) were studied the wind flow around Pneumatophores Mangrove Roots of Avicennia Marina mangrove species to understand and visualize how the mangrove roots can reduce the speed of the heavy wind and thereby play a prominent role in protecting the coast from the effects of cyclone, typhoons or hurricanes, mudslides and storm surges.

Sini Rahuman, Mohamed Ismail, Shyla Manavalan Varghese(2021) discussed the wind and water flow patterns around stilt roots of Rhizophora mangrove species. Velocity and pressure at various locations are obtained to analyze the flow patterns. The simulation results show that the stilt roots of the Rhizophora mangrove tree steadily reduce the velocity of wind and wave flow.

Sini Rahuman, Mohamed Ismail, Shyla Manavalan Varghese(2021) analyzed the flow patterns around mangrove roots to understand their significance in coastal risk reduction. The simulation outcome confirms that the mangrove roots of mangrove species reduce the initial velocity of water flow. The flow patterns and flow structures around the root in the mangrove forest established precious data in increasing the effectiveness of the current breakwater model.

L.Prasanna Venkatesh(2021) studied the viscous oscillatory MHD inhomogeneous fluid flow through the rectangular channel with one wall being porous through which suction or injection is taken place at a constant rate and the other wall being rigid. The governing equation of motion in both cases is solved using similarity transformation and the graphical representation is analyzed and compared for velocity profiles.

Girija Bai, Prasanna Jeyanthi, Hemavathy, Premkumar and Mohamed Ismail investigated the three-dimensional unsteady blood flow in arteries with two axisymmetric stenoses of dilation of 25% was mathematically investigated in this work. Hemodynamic parameters such as velocity, pressure, and streamline pattern are examined using computational fluid dynamics methods. In the stenoses, low pressure and rapid velocity are noted. This is a sign that blood flow has been disrupted.

CHAPTER – III

AIM AND SCOPE OF THE PRESENT INVESTIGATION

3.1 AIM AND SCOPE:

- To study the unsteady MHD fluid flow of fluid flow of an exponentially stretching with an angular velocity
- To derive an analytical solution to axial, transverse velocities and pressure distribution
- To study the various parameters such as initial entrance velocity, electromagnetic conductivity, permeability, porous medium, angular velocity

3.2 FORMULATION OF THE PROBLEM

The flow of MHD fluid between two parallel porous plates $y = 0$ and $y = h$ are considered in the presence of a transverse magnetic field which is applied perpendicular to the walls in a parallel plate channel bounded by a loosely packed porous medium. The fluid is driven by a uniform pressure gradient parallel to the channel plates.

Hence the velocity vector and pressure are chosen as follows

$$\vec{q} = (u(x,y)\hat{i} + v(x,y)\hat{j})e^{-nt} \quad \text{and} \quad p(x,y) = p(x,y) e^{-nt}$$

where $u(x, y)$ and $v(x, y)$ are the velocity components of the flow along the coordinate directions of (x, y) respectively. Let x and y be the coordinate axes parallel and perpendicular to the channel walls.

The equation of continuity is $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$ (3.1)

Navier Stoke Equations are :

$$\rho \frac{\partial u}{\partial t} = \frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \sigma_e B_0^2 u - \frac{\mu u}{k} - \Omega u \quad (3.2)$$

$$\rho \frac{\partial v}{\partial t} = -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (3.3)$$

Let us choose the solutions of the equations (3.1) and (3.3) respectively as

$$\begin{aligned} u &= u(x, y)e^{-nt} \\ v &= v(x, y)e^{-nt} \\ p &= p(x, y)e^{-nt} \end{aligned} \quad (3.4)$$

With the boundary conditions

$$\begin{aligned} u(x, 0) &= 0 & u(x, h) &= 0 \\ v(x, 0) &= v_1 & v(x, h) &= v_2 \end{aligned} \quad (3.5)$$

where h is the distance between the two parallel plates.

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

$$u(x, y) = \frac{\partial \Psi}{\partial y} \quad \text{and} \quad v(x, y) = -\frac{\partial \Psi}{\partial x} \quad (3.6)$$

so that the equation of continuity (3.1) is satisfied. Equations (3.2) and (3.3) gives rise to

$$\begin{aligned} -n\rho u &= -\frac{\partial p}{\partial x} + \mu(\nabla^2 u) - \sigma_e B_0^2 u - \frac{\mu}{k} u - \Omega u \\ -n\rho \frac{\partial \Psi}{\partial y} &= -\frac{\partial p}{\partial x} + \mu \frac{\partial}{\partial y} (\nabla^2 \Psi) - \sigma_e B_0^2 \frac{\partial \Psi}{\partial y} - \frac{\mu}{k} \frac{\partial \Psi}{\partial y} - \Omega \frac{\partial \Psi}{\partial y} \end{aligned} \quad (3.7)$$

$$\text{and} \quad -n\rho v = -\frac{\partial p}{\partial y} + \mu(\nabla^2 v)$$

$$n\rho \frac{\partial \Psi}{\partial x} = -\frac{\partial p}{\partial y} + \mu(\nabla^2 \Psi) \quad (3.8)$$

Partially differentiating (3.7) w.r.t., 'y' give rise to

$$-n\rho \frac{\partial^2 \Psi}{\partial y^2} = -\frac{\partial^2 p}{\partial y \partial x} + \mu \frac{\partial^2}{\partial y^2} (\nabla^2 \Psi) - \sigma_e B_0^2 \frac{\partial^2 \Psi}{\partial y^2} - \frac{\mu}{k} \frac{\partial^2 \Psi}{\partial y^2} - \Omega \frac{\partial^2 \Psi}{\partial y^2}$$

$$(i.e) \quad \frac{\partial^2 p}{\partial y \partial x} = n\rho \frac{\partial^2 \Psi}{\partial y^2} + \mu \frac{\partial^2}{\partial y^2} (\nabla^2 \Psi) - \sigma_e B_0^2 \frac{\partial^2 \Psi}{\partial y^2} - \frac{\mu}{k} \frac{\partial^2 \Psi}{\partial y^2} - \Omega \frac{\partial^2 \Psi}{\partial y^2} \quad (3.9)$$

Partially differentiating (3.8) w.r.t., 'x' give rise to

$$n\rho \frac{\partial^2 \Psi}{\partial x^2} = \frac{\partial^2 p}{\partial x \partial y} - \mu \frac{\partial^2}{\partial y^2} (\nabla^2 \Psi)$$

$$\frac{\partial^2 p}{\partial y \partial x} = n\rho \frac{\partial^2 \Psi}{\partial x^2} + \mu \frac{\partial^2}{\partial y^2} (\nabla^2 \Psi) \quad (3.10)$$

The result obtained by eliminating the pressure p from the equations (3.9) and (3.10) is

$$\mu \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right) \nabla^2 \Psi + n\rho \left(\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} \right) - \sigma_e B_0^2 \frac{\partial^2 \Psi}{\partial y^2} - \frac{\mu}{k} \frac{\partial^2 \Psi}{\partial y^2} - \Omega \frac{\partial^2 \Psi}{\partial y^2} = 0 \quad (3.11)$$

$$\mu \mu (\nabla^2 + n\rho)(\nabla^2) \Psi + -\sigma_e B_0^2 \frac{\partial^2 \Psi}{\partial y^2} - \frac{\mu}{k} \frac{\partial^2 \Psi}{\partial y^2} - \Omega \frac{\partial^2 \Psi}{\partial y^2} = 0 \quad (3.12)$$

The function f(η) is introduced as follows:

$$\Psi = h \left(\frac{u_0}{a} - \frac{v_2}{h} \right) f(\eta) \quad (3.13)$$

where $\eta = \frac{y}{h}$, $a = 1 - \frac{v_1}{v_2}$, $0 \leq v_1 \leq v_2$

and u_0 is the average entrance velocity. And (3.12) implies

$$\left((\mu \nabla^2 + n\rho) \left(\frac{\partial}{\partial x^2} + \frac{\partial}{h^2 \partial^2} \right) \right) \left(h \left(\frac{u_0}{a} - \frac{v_{2x}}{h} \right) \right) f(\eta) -$$

$$\left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \left(\frac{\partial}{h^2 \partial^2} \right) h \left(\frac{u_0}{a} - \frac{v_2}{h} \right) f(\eta) = 0$$

$$\left((\mu \nabla^2 + n\rho) - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) \frac{1}{h} \frac{\partial}{\partial^2} \eta \left(\frac{u_0}{a} - \frac{v_{2x}}{h} \right) f(\eta) = 0$$

$$\left((\mu \nabla^2 + n\rho) - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) \frac{1}{h} \left(\frac{u_0}{a} - \frac{v_{2x}}{h} \right) f''(\eta) = 0$$

$$\frac{1}{h} \left(\frac{\partial}{\partial x^2} + \frac{1}{h^2} \frac{\partial}{\partial^2 \eta} \right) \left(\frac{u_0}{a} - \frac{v_2}{h} \right) f''(\eta) + \frac{1}{h} \left(\frac{u_0}{a} - \frac{v_{2x}}{h} \right) \left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) f''(\eta) = 0$$

$$\frac{\mu}{h^3} f''(\eta) + \frac{1}{h} \left(\frac{u_0}{a} - \frac{v_{2x}}{h} \right) \left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) f''(\eta) = 0$$

$$f''(\eta) - h^2 \left(\frac{(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega) - n\rho}{\mu} \right) f''(\eta) = 0$$

$$(D^4 - \alpha^2 h^2 D^2) f(\eta) = 0 \quad (3.14)$$

Where, $\alpha^2 = \frac{(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega) - n\rho}{\mu}$

$$m^4 - \alpha^2 h^2 m^2 = 0$$

$$m^2(m^2 - \alpha^2 h^2) = 0$$

$$m = 0, 0, \alpha h, -\alpha h$$

(i.e) $CF = C_1 + C_2 \eta + C_3 e^{\alpha h \eta} + C_4 e^{-\alpha h \eta}$

$$f(\eta) = C_1 + C_2 \eta + C_3 e^{\alpha h \eta} + C_4 e^{-\alpha h \eta} \quad (3.15)$$

Applying the boundary condition given by the equation (3.4) and (3.5)

$$u(x, y) = \frac{\partial \Psi}{\partial y} = h \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(\eta)$$

$$u(x, 0) = \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(0) = 0$$

$$\rightarrow f'(0) = 0$$

$$u(x, h) = \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f' \left(\frac{h}{h} \right) = 0$$

$$\rightarrow f'(1) = 0$$

$$v(x, y) = \frac{\partial \Psi}{\partial x} = -h \left(\frac{-v_2}{h} \right) f(\eta) = v_2 f(\eta)$$

$$v(x, 0) = v_2 f(0) = v_1$$

$$f(0) = \frac{v_1}{v_2} = - \left(1 - \frac{v_1}{v_2} \right) + 1$$

$$\rightarrow f(0) = 1 - a$$

$$\text{since } a = 1 - \frac{v_1}{v_2}$$

$$v(x, h) = v_2 f \left(\frac{h}{h} \right) = v_2$$

$$\rightarrow f(1) = 1$$

Boundary conditions on $f(\eta)$ are given by

$$f(0) = 1 - a; \quad f(1) = 1; \quad f'(0) = 0; \quad f'(1) = 0 \quad (3.16)$$

The results obtained by applying boundary condition on $f(\eta)$ are

$$f(0) = 1 - a = C_1 - C_2 + C_3 e^{-\alpha h} + C_4 e^{\alpha h} \quad (3.17)$$

$$f(1) = 1 = C_1 + C_2 + C_3 e^{\alpha h} + C_4 e^{-\alpha h} \quad (3.18)$$

$$\text{Since } f'(\eta) = C_2 + C_3 \alpha h e^{\alpha h \eta} - C_4 \alpha h e^{-\alpha h \eta}$$

$$f'(0) = 0 = C_2 + C_3 \alpha h e^{-\alpha h} - C_4 \alpha h e^{\alpha h} \quad (3.19)$$

$$f'(1) = 0 = C_2 + C_3 \alpha h e^{\alpha h} - C_4 \alpha h e^{-\alpha h} \quad (3.20)$$

Solving (3.17), (3.18), (3.19) & (3.20) by mathematically

$$(3.18) \times \alpha h + (3.20)$$

$$C_1 \alpha h + C_2 \alpha h + C_3 \alpha h e^{\alpha h} + \alpha h C_4 e^{-\alpha h} + C_2 + C_3 \alpha h e^{\alpha h} - C_4 \alpha h e^{-\alpha h} = \alpha h$$

$$C_1 \alpha h + C_2 (\alpha h + 1) + 2C_3 \alpha h e^{\alpha h} = \alpha h \quad (3.21)$$

$$(3.17) \times e^{\alpha h} - (3.18)$$

$$C_1 (e^{\alpha h} - 1) - C_2 + C_4 (e^{\alpha h} - e^{-\alpha h}) = e^{\alpha h} (1 - a) - 1 \quad (3.22)$$

$$(3.19) \times e^{\alpha h} - (3.20)$$

$$C_2 (\alpha h - 1) - \alpha h C_4 (e^{\alpha h} - e^{-\alpha h}) = 0$$

$$C_2 = \frac{\alpha h C_4}{e^{\alpha h}} (e^{\alpha h} - e^{-\alpha h}) \quad (3.23)$$

From equation (3.19)

$$\rightarrow C_2 + C_3 \alpha h - \alpha h C_4 = 0$$

$$\frac{\alpha h C_4}{e^{\alpha h}} (e^{\alpha h} - e^{-\alpha h}) + \alpha h C_3 - \alpha h C_4 = 0$$

$$\alpha h C_4 (e^{\alpha h} - e^{-\alpha h}) + \alpha h C_3 (e^{\alpha h} - 1) - \alpha h C_4 (e^{\alpha h} - 1) = 0$$

$$\alpha h C_4 (1 - e^{-\alpha h}) = -\alpha h C_3 (e^{\alpha h} - 1)$$

$$C_3 = \frac{C_4}{e^{\alpha h} - 1} (e^{-\alpha h} - 1) \quad (3.24)$$

From (3.17)

$$\rightarrow C_1 + C_3 + C_4 = 1 - a$$

$$C_1 = 1 - a - \frac{C_4}{e^{\alpha h} - 1} (e^{\alpha h} + e^{-\alpha h} - 2) \quad (3.25)$$

From (3.18)

$$C_1 + C_2 + C_3 e^{\alpha h} + C_4 e^{-\alpha h} = 1$$

$$1 - a - \frac{C_4}{e^{\alpha h} - 1} (e^{\alpha h} + e^{-\alpha h} - 2) + \frac{\alpha h C_4}{e^{\alpha h} - 1} (e^{\alpha h} - e^{-\alpha h}) + \frac{C_4}{e^{\alpha h} - 1} (1 - e^{\alpha h}) + C_4 e^{-\alpha h} = 1$$

$$\frac{C_4}{e^{\alpha h} - 1} (2 - e^{\alpha h} + e^{-\alpha h}) + \frac{\alpha h C_4}{e^{\alpha h} - 1} (e^{\alpha h} - e^{-\alpha h}) + \frac{C_4}{e^{\alpha h} - 1} (1 - e^{\alpha h}) + C_4 e^{-\alpha h} = 1$$

$$\frac{C_4}{e^{\alpha h} - 1} (e^{\alpha h} (\alpha h - 2) - e^{-\alpha h} (\alpha h + 2) + 4) = a$$

$$C_4 = \frac{a(e^{\alpha h} - 1)}{e^{\alpha h} (\alpha h - 2) - e^{-\alpha h} (\alpha h + 2) + 4} \quad (3.26)$$

The values of the constants are

$$C_1 = 1 - a - \frac{a(e^{\alpha h} + e^{-\alpha h} - 2)}{4 + e^{\alpha h} (\alpha h - 2) - e^{-\alpha h} (\alpha h + 2)}$$

$$C_1 = 1 - a - \frac{a(2\cos\alpha h - 2)}{4(1 - \cos\alpha h) + 2\alpha h \sin\alpha h}$$

$$C_2 = \frac{\alpha h a (e^{\alpha h} - e^{-\alpha h})}{4 + e^{\alpha h} (\alpha h - 2) - e^{-\alpha h} (\alpha h + 2)}$$

$$C_2 = \frac{\alpha h a (2\sin\alpha h)}{4(1 - \cos\alpha h) + 2\alpha h \sin\alpha h}$$

$$C_3 = \frac{a(e^{-\alpha h} - 1)}{4 + e^{\alpha h}(\alpha h - 2) - e^{-\alpha h}(\alpha h + 2)}$$

$$C_3 = \frac{a(e^{-\alpha h} - 1)}{4(1 - \cos \alpha h) + 2\alpha h \sin \alpha h}$$

$$C_4 = \frac{a(e^{\alpha h} - 1)}{4 + e^{\alpha h}(\alpha h - 2) - e^{-\alpha h}(\alpha h + 2)}$$

$$C_4 = \frac{a(e^{\alpha h} - 1)}{4(1 - \cos \alpha h) + 2\alpha h \sin \alpha h}$$

$$u = u(x, y)e^{-nt} = \frac{\partial \Psi}{\partial y} e^{-nt}$$

$$= \left(\frac{u_0}{a} - \frac{v_{2x}}{h} \right) \times \left[\frac{2\alpha h \sinh(\alpha h) + 2\alpha h \sin(\alpha(y-h)) - 2\alpha h \sinh(\alpha y)}{2\alpha h \sinh(\alpha h) + 4(1 - \cosh(\alpha h))} \right] e^{-nt} \quad (3.27)$$

$$v = v(x, y)e^{-nt} = -\frac{\partial \Psi}{\partial x}$$

$$= \frac{v_{2y} e^{-nt}}{2\alpha h \sinh(\alpha h) + 4(1 - \cosh(\alpha h))} \times \left[\begin{aligned} &4(1 - \cosh(\alpha h)) - 2a(1 - \cosh(\alpha h)) - \\ &2(1 - a)\alpha h \sinh(\alpha h) + 2a\alpha y \sinh(\alpha h) + \\ &2a \cosh(\alpha(y-h)) - 2a \cosh(\alpha y) \end{aligned} \right] \quad (3.28)$$

$$\text{Where } \alpha^2 = \frac{(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega) - n\rho}{\mu}$$

3.3 PRESSURE DISTRIBUTION:

The result obtained from equation (3.7), (3.8) & (3.13)

$$-n\rho \frac{\partial \Psi}{\partial y} = -\frac{\partial p}{\partial x} + \mu \frac{\partial}{\partial y} (\nabla^2 \Psi) - \frac{\partial \Psi}{\partial y} \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right)$$

$$\left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \frac{\partial \Psi}{\partial y} - n\rho \frac{\partial \Psi}{\partial y} = -\frac{\partial p}{\partial x} + \mu \frac{\partial}{\partial y} (\nabla^2 \Psi)$$

$$\frac{1}{h} \left(\left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) - n\rho \right) \frac{\partial \Psi}{\partial \eta} = -\frac{\partial p}{\partial x} + \frac{\mu}{h} \frac{\partial}{\partial \eta}$$

$$\frac{1}{h} \left(\left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) - n\rho \right) h \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(\eta) = -\frac{\partial p}{\partial x} + \frac{\mu}{h} \frac{\partial}{\partial \eta} \left(\frac{1}{h} \frac{\partial^2 \Psi}{\partial \eta^2} \right)$$

$$\left(\left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) - n\rho \right) \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(\eta) = -\frac{\partial p}{\partial x} + \frac{\mu}{h^3} \left(h \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'''(\eta) \right)$$

$$\frac{\partial p}{\partial x} = \left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(\eta) + \frac{\mu}{h^3} \left(h \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'''(\eta) \right) \quad (3.29)$$

$$n\rho v = \frac{\partial p}{\partial y} - \mu \frac{\partial}{\partial x} (\nabla^2 \Psi)$$

$$n\rho v_2 f(\eta) = \frac{\partial p}{\partial y} + \mu \frac{\partial}{\partial x} \frac{\partial^2 \Psi}{\partial y^2}$$

$$n\rho v_2 f(\eta) = \frac{\partial p}{\partial y} + \frac{\mu}{h^2} \frac{\partial}{\partial x} \left(\frac{\partial^2 \Psi}{\partial \eta^2} \right)$$

$$n\rho v_2 f(\eta) = \frac{\partial p}{\partial y} + \frac{\mu}{h^2} \frac{\partial}{\partial x} \left(h \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(\eta) \right)$$

$$n\rho v_2 f(\eta) = \frac{\partial p}{\partial y} - \frac{\mu}{h^2} v_2 x f''(\eta)$$

$$\frac{\partial p}{\partial y} = n\rho v_2 f(\eta) + \frac{\mu}{h^2} v_2 x f''(\eta) \quad (3.30)$$

By total derivation,

$$dp = \frac{\partial p}{\partial x} dx + \frac{\partial p}{\partial y} dy$$

$$dp = \left(\left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'(\eta) + \frac{\mu}{h^3} \left(h \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'''(\eta) \right) \right) dx \\ + \left(n\rho v_2 f(\eta) + \frac{\mu}{h^2} v_2 x f''(\eta) \right) dy$$

$$dp = \left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) \left(\left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) f'(\eta) + \frac{\mu}{h^2} f'''(\eta) \right) dx \\ + h \left(n\rho v_2 f(\eta) + \frac{\mu}{h^2} v_2 x f''(\eta) \right) d\eta$$

On integrating,

$$p(x, \eta) = \left(\frac{u_0}{a} - \frac{v_2 x^2}{h} \right) \left(\left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) f'(\eta) + \frac{\mu}{h^2} f'''(\eta) \right) + \\ h \left(n\rho v_2 \int_0^\eta f(\eta) + \frac{\mu}{h^2} v_2 x f''(\eta) \right)$$

$$p(x, \eta) = C_5 \left(\frac{u_0}{a} - \frac{v_2 x^2}{h} \right) + h \left(n\rho v_2 \int_0^\eta f(\eta) + \frac{\mu}{h^2} v_2 x f''(\eta) \right)$$

$$\text{where, } C_5 = \left(\left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) f'(\eta) + \frac{\mu}{h^2} \left(\left(\frac{u_0}{a} - \frac{v_2 x}{h} \right) f'''(\eta) \right) \right)$$

$$C_5 = \frac{\mu}{h^2} f'''(0) \text{ when } \eta = 0, f'(0) = 0$$

$$p(x, \eta) - p(0,0) = \left(\frac{u_0}{a} - \frac{v_2 x^2}{h} \right) \left(\left(n\rho - \left(\sigma_e B_0^2 + \frac{\mu}{k} + \Omega \right) \right) f'(\eta) + \frac{\mu}{h^2} f'''(\eta) \right) + \\ h \left(n\rho v_2 \int_0^\eta f(\eta) + \frac{\mu}{h^2} v_2 x f''(\eta) \right)$$

CHAPTER – IV

4 EXPERIMENT AND METHOD

4.1 METHOD:

- The above obtained Axial velocity and Transverse velocity of the fluid were graphically represented using the MATLAB.
- MATLAB is a programming platform designed specifically for students and scientists to analyze the graphical outputs of the given data.

4.2 MATLAB:

MATLAB is a software package in high performance language for technical computing. It integrates computation, visualization and programming in an easy to use environment where problems and solutions are expressed in familiar mathematical notion.

4.2.1 MATLAB WINDOWS:

There are three MATLAB windows which are as follows.

MATLAB Desktop:

This is the window which appears by default when MATLAB is launched. It consists of Command window, Current directory, Workspace and Command history.

Figure Window:

The output of all the commands written on the command window or executed by writing in M-file, whose output is a graph, appears on the window.

Editor Window:

This is where we can write, create, edit and save programs in a file. The file is known as M-file.

4.2.2 ALGORITHM:

Steps:

1. Save the opened file as mfile.
2. Give the command for clear screen which clears the
3. Define the list of syms (g,m,l,a,u0,v2,t,x,y,h,r) which are going to use in the program.
4. Assign the values for each syms declared above.
5. Define a while loop for which the process takes place until the given value attained.
6. Define the alpha value as r.
7. Construct the obtained Axial and Transverse velocity of the fluid flow as the variables w and j.
8. Give the command for the 2 dimensional graph plotting. For axial velocity as **plot(w,y)** and for Transverse velocity as **plot(j,y)**.
9. Then define the legend values which is represented in the graph.
10. Finally end the program and run to get the graphical output.

4.2.3 PROGRAM:

```
Clc;
syms g m l a u0 v2 t x y h r
u0=0.5;x=1;y=0:0.1:1;v2=0.5;h=2;a=1;g=0.4;m=0.75;l=0.5;k=0.1;r=0.5;t=0.5
;n=0.1;r1=0.2;r2=0.5;r3=0.6;r4=0.3;R=0.1;B0=0.2;mu=0.5;omega=0.3;i=0.1;
while i<=3.5
    r1=R;
    r2=B0;
    r3=mu;
    r4=omega;
    r=sqrt(((r1*r2^2+(r3/k)+r4)-n*i)/r3);
    g=r*h;
    m=r*y;
    l=r*(y-h);
    c1=((u0/a)-((v2*x)/h));
    c2=((2*a*g*sinh(g))+(2*a*g*sinh(l))-(2*a*g*sinh(m)));
    c3=((2*g*sinh(g))+(4*(1-cosh(g))));
    d1=v2;
    d2=((4*(1-cosh(g)))-(2*a*(1-cosh(g)))-
    (2*(1a)*g*sinh(g))+(2*a*m*sinh(g))+(2*a*cosh(l))-(2*a*cosh(m)));
    d3=((2*g*sinh(g))+(4*(1-cosh(g))));
    w=(c1*(c2/c3)*exp(-n*t));
    j=(d1*(d2/d3)*exp(-n*t));
```

```

plot(w,y);
%plot(j,y);
legend('t=0.5','t=1','t=1.5','t=2','t=2.5')
%legend('Ω=0.3','Ω=0.6','Ω=0.9','Ω=1.2','Ω=1.5')
%legend('k=0.1','k=0.6','k=1.1','k=1.6','k=2.1','k=2.6','k=3.1')
%legend('x=3.4','x=3','x=2.6','x=2.2','x=1.8','x=1.4','x=1')

%legend('u0=0.5','u0=1','u0=1.5','u0=2','u0=2.5','u0=3','u0=3.5','u0=4')
%legend('μ=0.5','μ=0.9','μ=1.3','μ=1.7','μ=2.1','μ=2.4')

%legend('B0=0.2','B0=0.5','B0=0.8','B0=1.1','B0=1.4','B0=1.7','B0=2','B0=2.3')
%legend('v2=0.5','v2=1','v2=1.5','v2=2','v2=2.5','v2=3','v2=3.5')
legend('i=0.1','i=0.7','i=1.3','i=1.9','i=2.5','i=3.1','i=3.7')
hold on;
t=t+0.5;
%k=k+0.5;
%mu=mu+0.3;
%omega=omega+0.3;
%x=x+0.4;
%u0=u0+0.5;
%B0=B0+0.3;
%v2=v2+0.5;
%r3=r3+0.5;
%i=i+0.6;

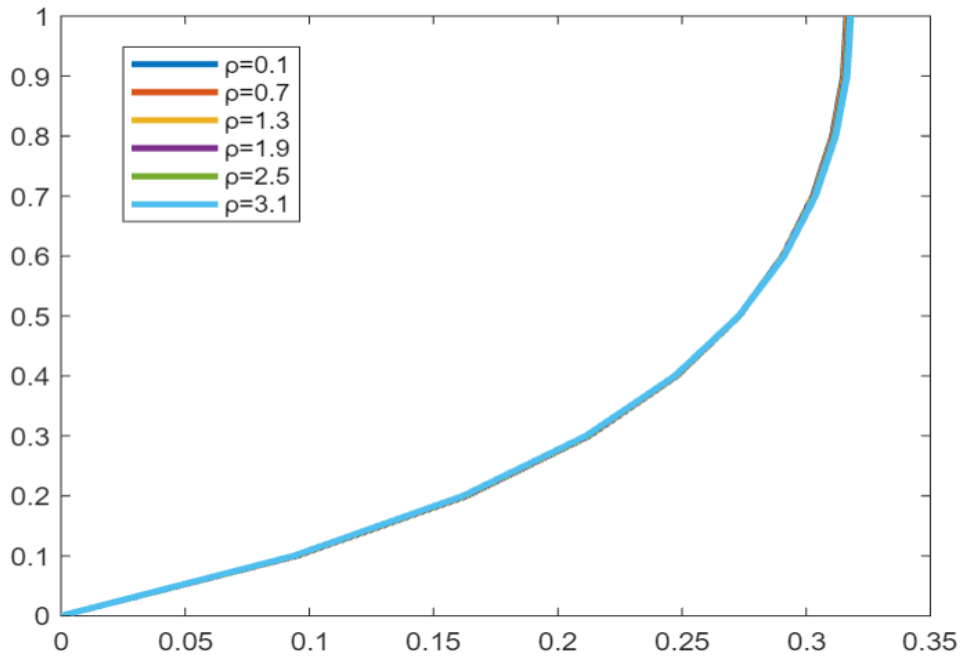
end

```

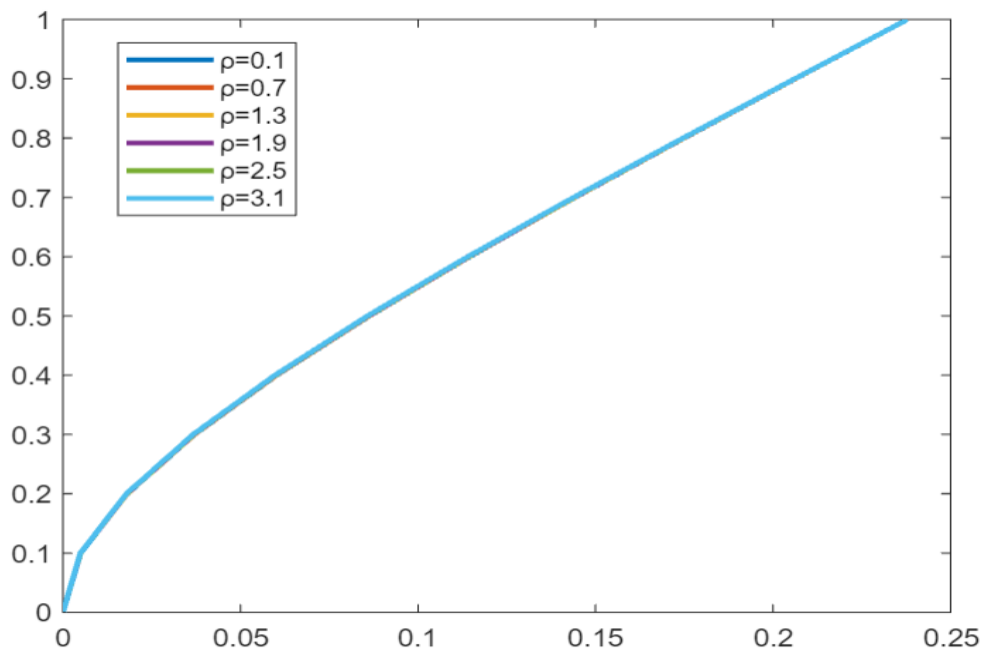
CHAPTER – V

5 RESULT AND DISCUSSION

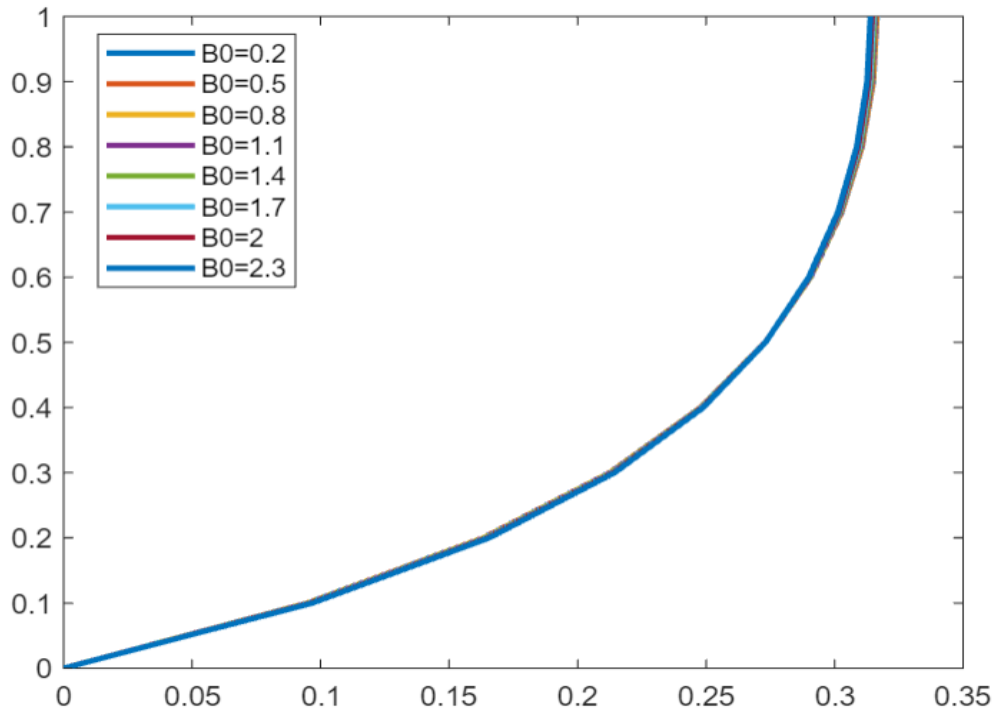
5.1 RESULT:



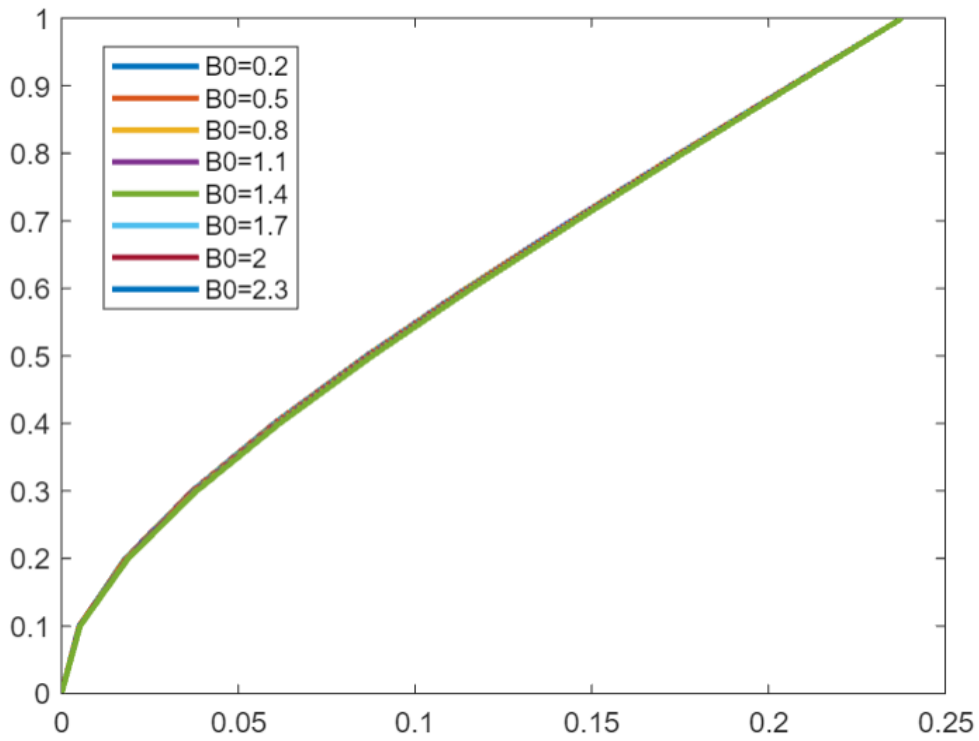
Fig(5.1) Axial velocity of the fluid when ρ increases



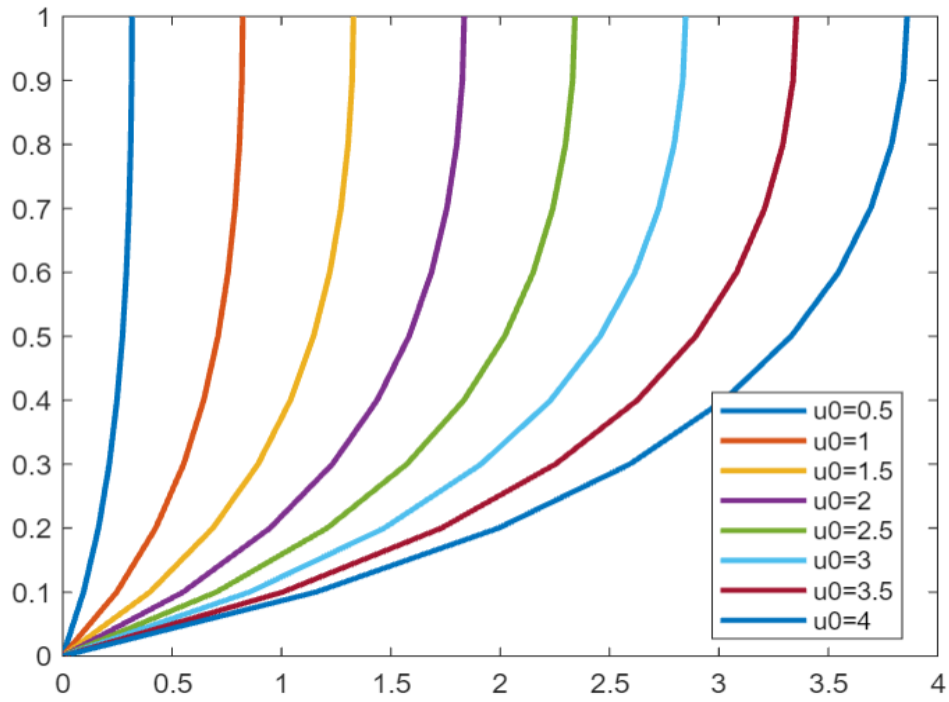
Fig(5.2) Transverse velocity of the fluid when ρ increases



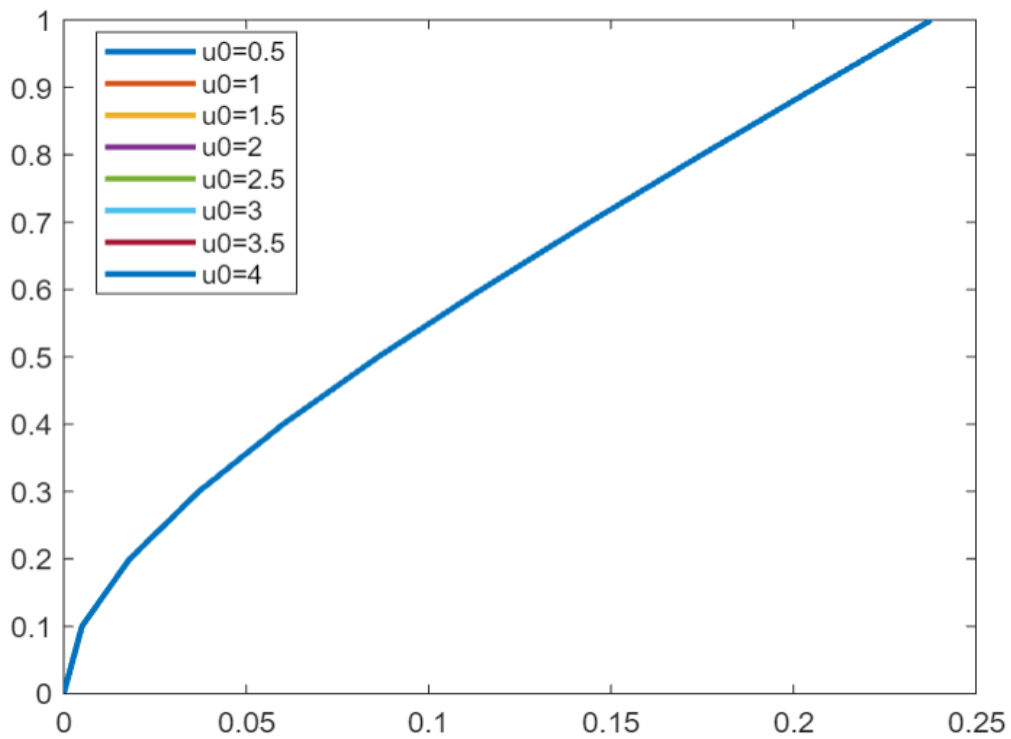
Fig(5.3) Axial velocity of the fluid when B_0 increases



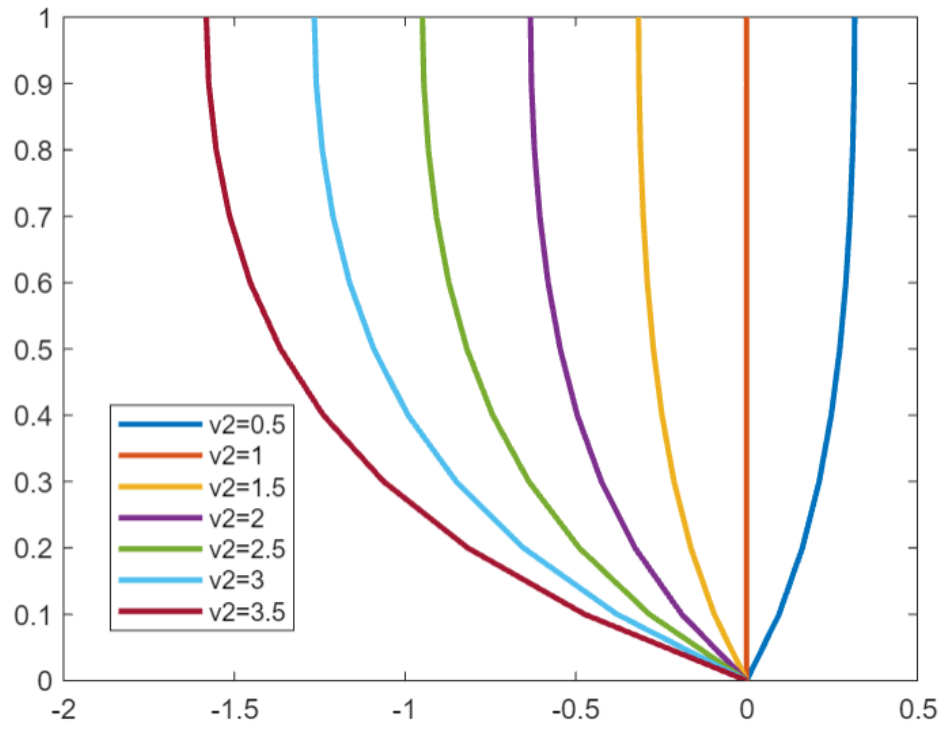
Fig(5.4) Transverse velocity of the fluid when B_0 increases



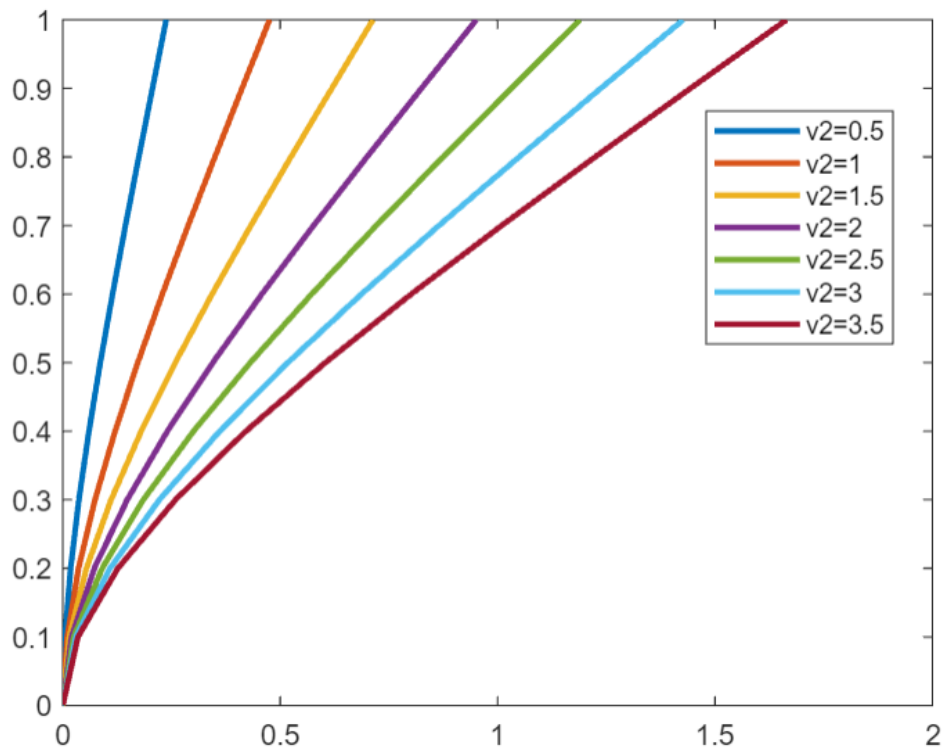
Fig(5.5) Axial velocity of the fluid when u_0 increases



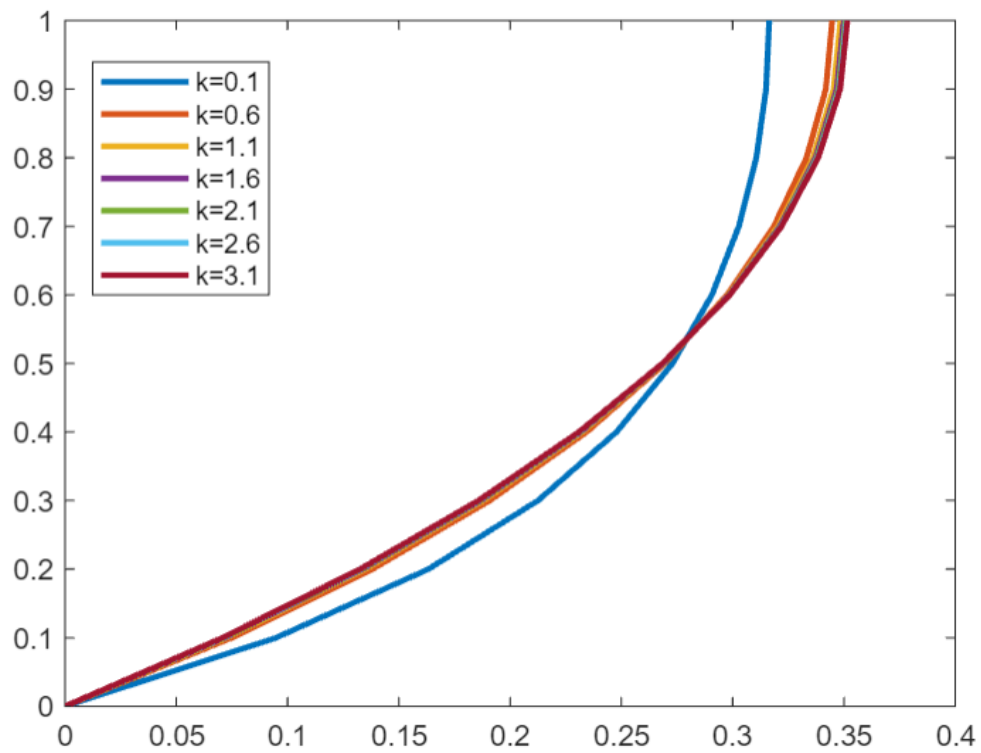
Fig(5.6) Transverse velocity of the fluid when u_0 increases



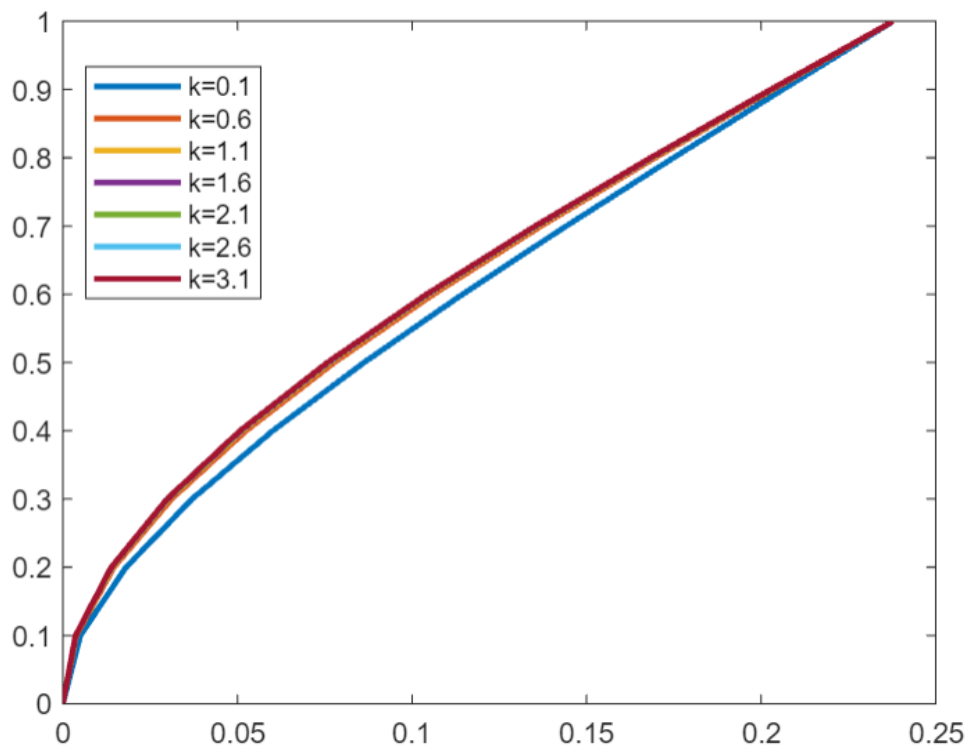
Fig(5.7) Axial velocity of the fluid when v_2 increases



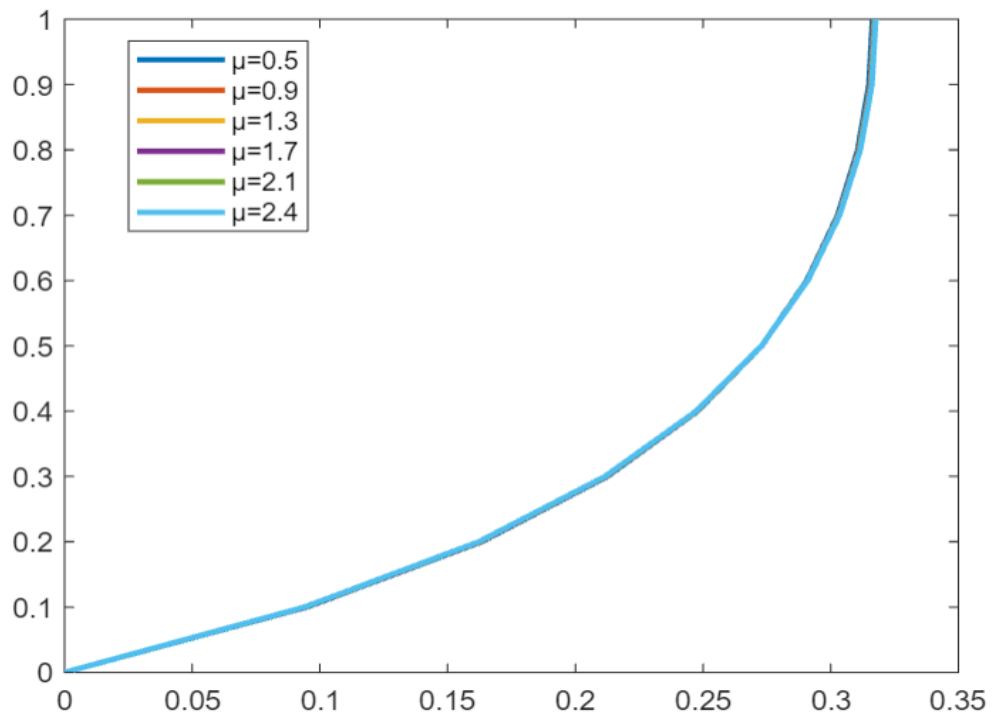
Fig(5.8) Transverse velocity of the fluid when v_2 increases



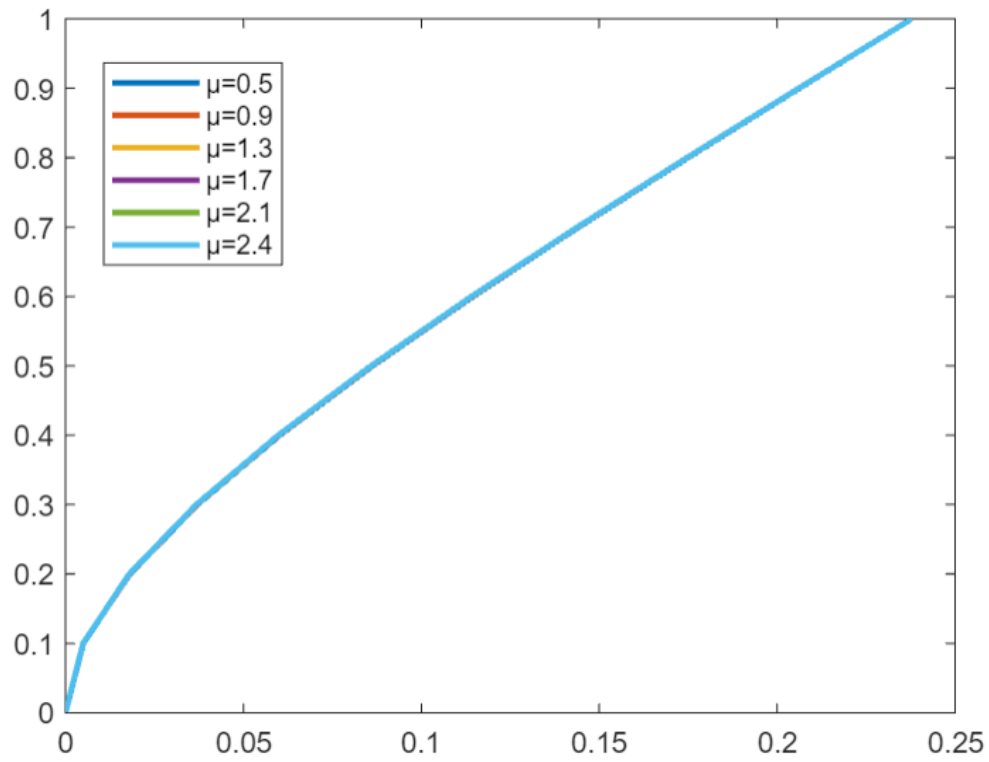
Fig(5.9) Axial velocity of the fluid when k increases



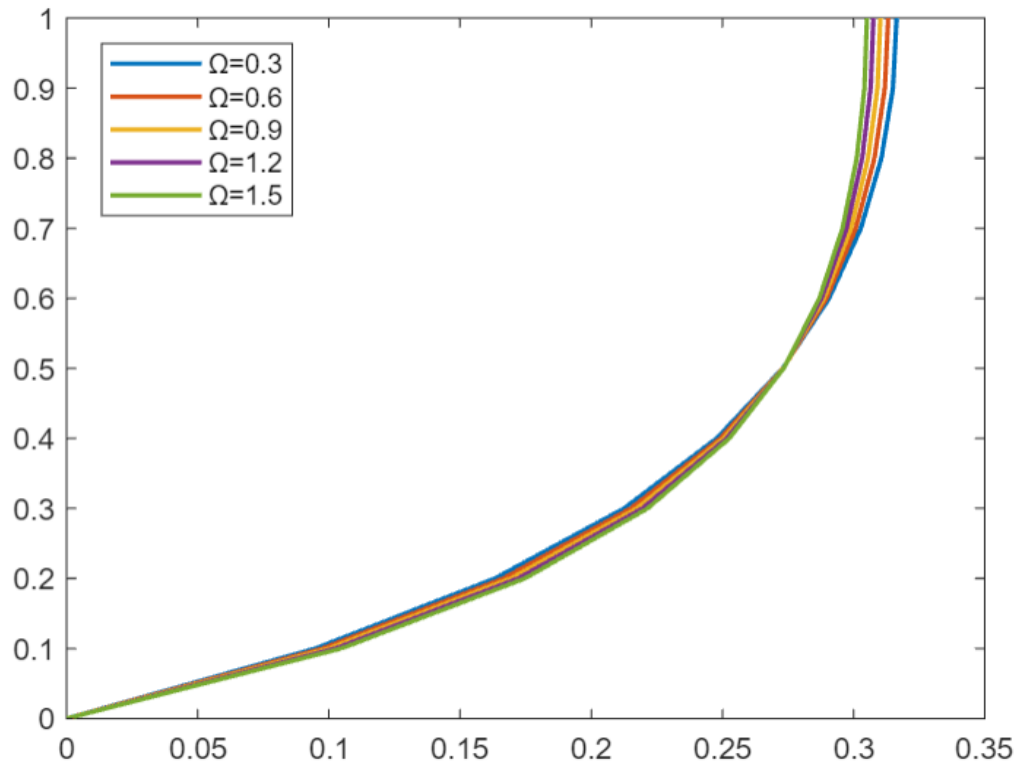
Fig(5.10) Transverse velocity of the fluid when k increases



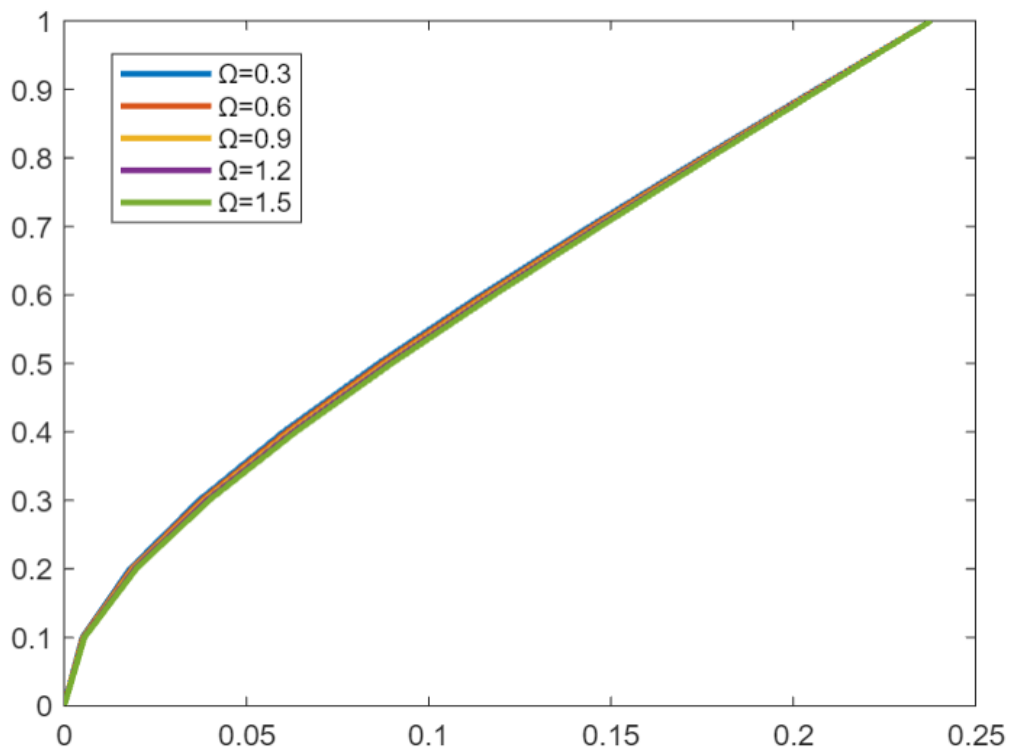
Fig(5.11) Axial velocity of the fluid when μ increases



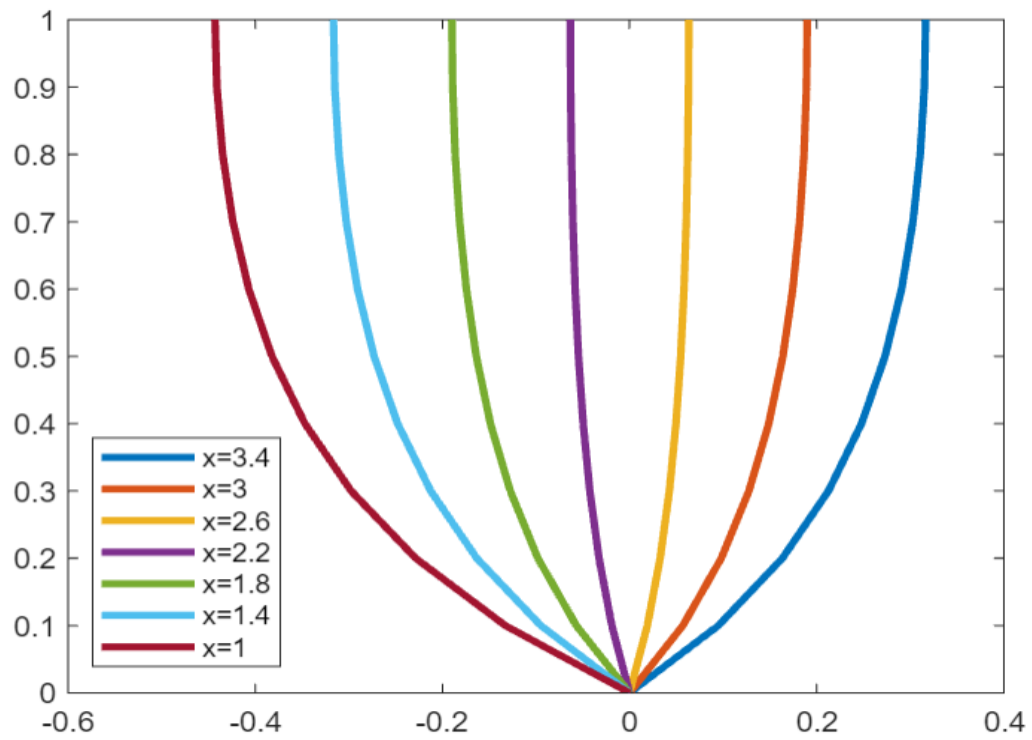
Fig(5.12) Transverse velocity of the fluid when μ increases



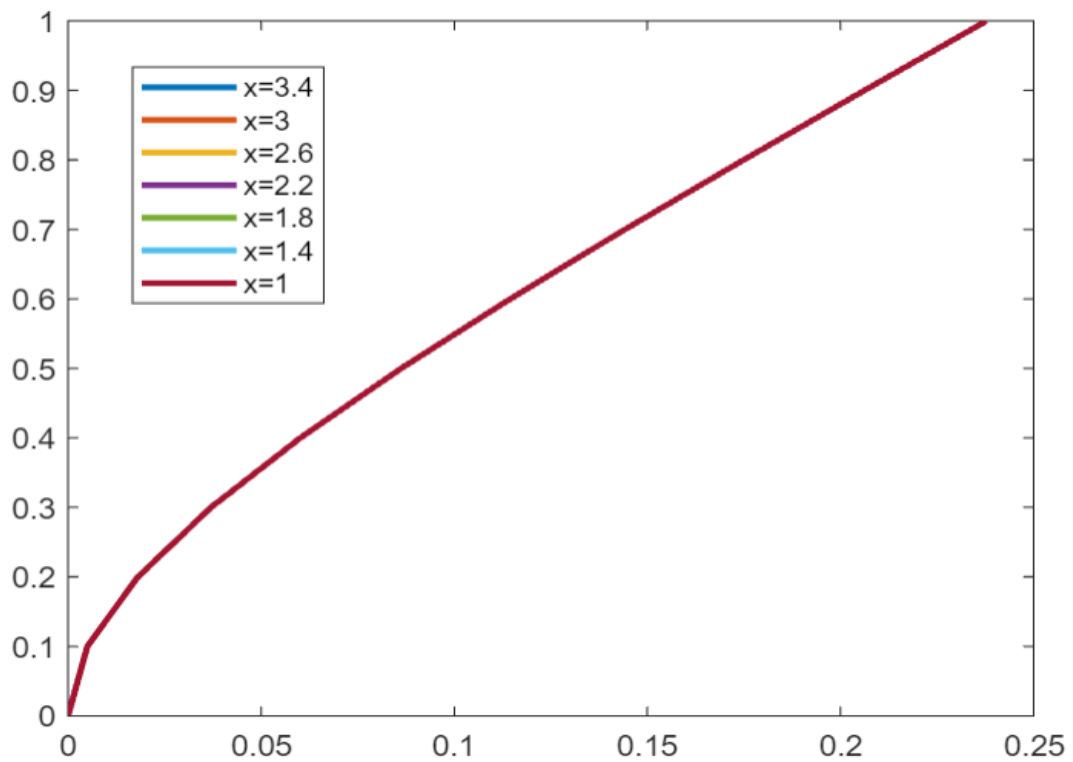
Fig(5.13) Axial velocity of the fluid when Ω increases



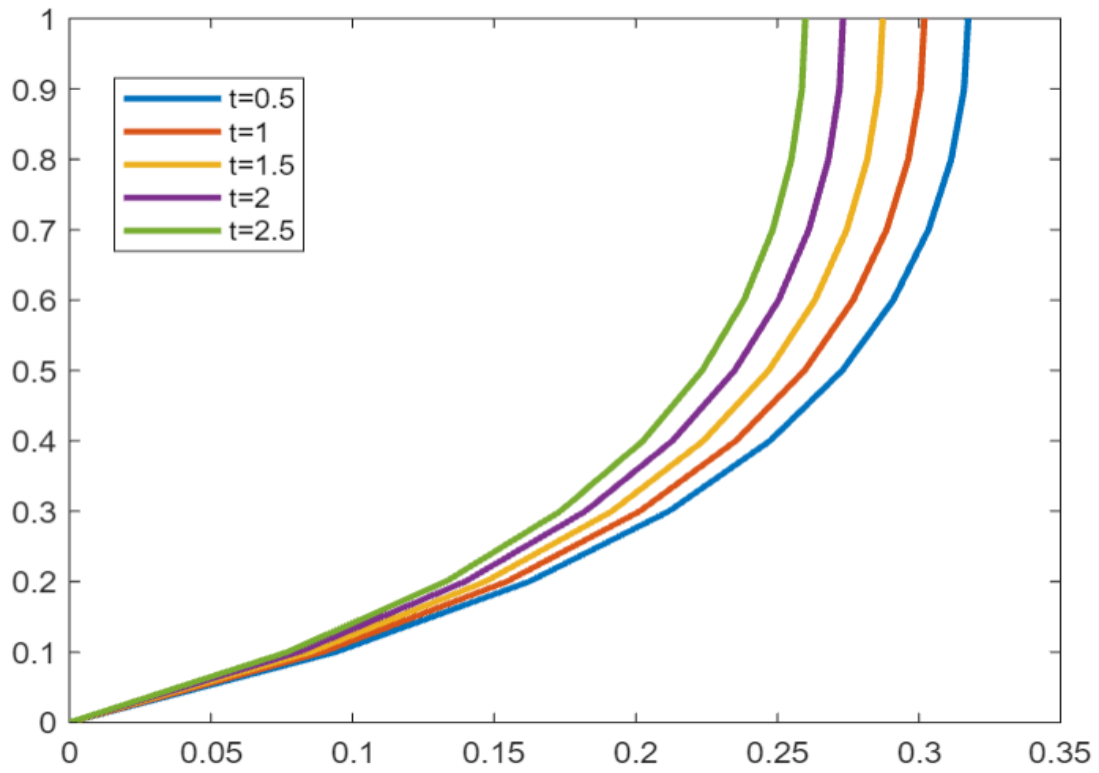
Fig(5.14) Transverse velocity of the fluid when Ω increases



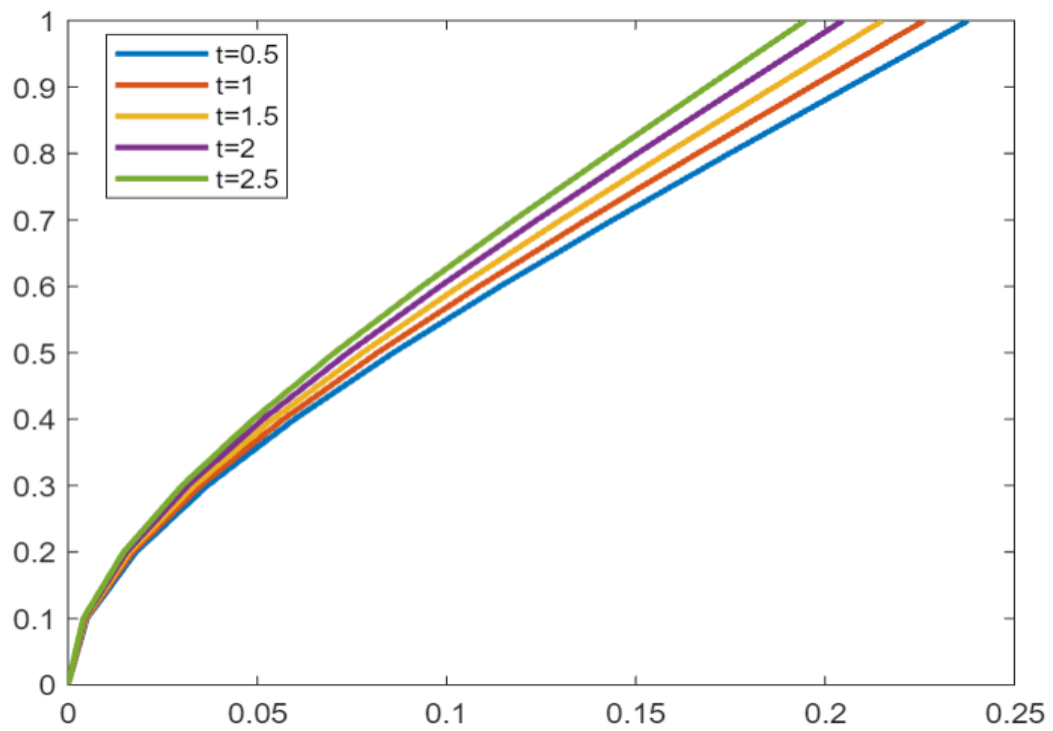
Fig(5.15) Axial velocity of the fluid when x increases



Fig(5.16) Transverse velocity of the fluid when x increases



Fig(5.17) Axial velocity of the fluid when t increases



Fig(5.18) Transverse velocity of the fluid when t increases

5.2 DISCUSSION:

In Fig 5.1,5.3 and 5.9 show the axial velocity of the fluid increases in the middle of the channel and decreases in the upper plate when the density, the permeability, electromagnetic conductivity of the fluid increase. Fig 5.2, 5.4, 5.6 and 5.10 show the transverse velocity of the fluid increases when the density, electromagnetic conductivity, average entrance velocity, permeability of the fluid increases. Fig 5.5 shows the transverse velocity of the fluid increases when the average entrance velocity of the fluid increases. Fig 5.7 shows the axial velocity of the fluid decreases when the v_2 of the fluid increases and in Fig 4.8 transverse velocity of the fluid increases when v_2 increases. Fig 5.11,5.13, 5.12,5.14 and 5.16 show the axial and transverse velocity of the fluid increase in the middle channel and decrease in the upper channel when the k increases. Fig 5.15 and 5.17 show the axial velocity of the fluid decreases when x and t increase. Fig 5.18 shows the transverse velocity of the fluid decreases when t increases.

CHAPTER – VI

6. SUMMARY AND CONCLUSION:

6.1 SUMMARY:

- The aim is to investigate the unsteady MHD fluid flow and to obtain the equation of velocities and pressure distribution.
- Taking the Navier stokes equation and equation of continuity, a problem is formed.
- By using the similarity transformation and defining the function Ψ , the higher order differential equation is converted into ordinary differential equation.
- By applying the boundary conditions in the function $f(\eta)$, the Axial and Transverse velocities are obtained.
- By substituting the pressure equation in the total derivation and on integrating, the pressure distribution of the fluid is obtained.
- By using the MATLAB software, the graphs were obtained and the results were discussed.

6.2 CONCLUSION:

The above analysis we discussed the Unsteady MHD Fluid Flow of an Exponentially Stretching with an Angular Velocity, the following conclusions are obtained from the current investigations.

- Axial velocity of the fluid increases in the middle of the channel and decreases in the upper plate when the density, the permeability, electromagnetic conductivity of the fluid increase.
- The transverse velocity of the fluid increases when the density, electromagnetic conductivity, average entrance velocity, permeability of the fluid increases.
- The transverse velocity of the fluid increases when the average entrance velocity of the fluid increases.
- The axial velocity of the fluid decreases when the v_2 of the fluid increases and transverse velocity of the fluid increases when v_2 increases.
- The axial and transverse velocity of the fluid increase in the middle channel and decrease in the upper channel when the k increases
- The axial velocity of the fluid decreases when x and t increase and the transverse velocity of the fluid decreases when t increases.

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