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Analysis of Oscillatory Flow for Tangent Hyperbolic Fluid

A Thesis

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Master in Science of Mathematics

By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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الى من علمني العطاء دون انتظار.. الى من أحمل أسمه بكل افتخار..

الى من أفتقد حرارة تصفيقه فرحا بإنجازي في هذه اللحظة..

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الى ملاكي في الحياة.. الى معنى الحب والحنان.. الى بسمه الحياة وسر الوجود

الى من كان دعاءها سر نجاحي وحنانها بلسم جراحي الى أغلى الحبايب

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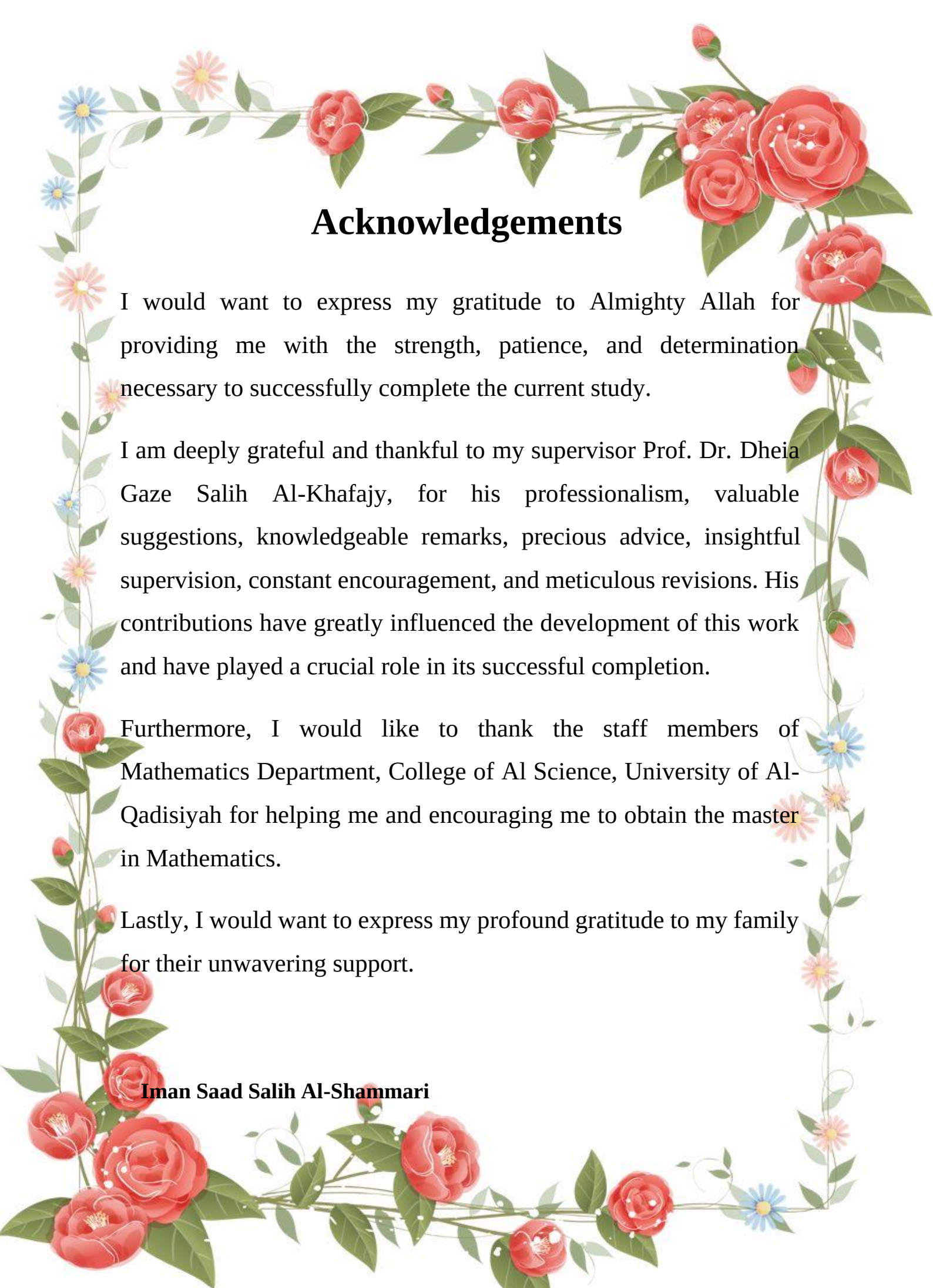
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الى زوجي

الى الذين هم ملاذي ورمز فخري واعتزازي فأنا منهم وهم مني

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List of Symbols

Symbols	Meaning
MHD	Magnetohydrodynamic
$\rho, \bar{p}$	Density, Pressure
$\bar{\delta}$	Shear stress
(We)	Dimensionless Tangent Hyperbolic fluid parameters.
μ	Dynamic viscosity
ν	Kinematics viscosity
μ_c	Zero shear rate viscosity
(u, v, w)	The velocity components in the (x, y, z) directions
t	Time
(X, Y, Z)	The body forces in the (x, y, z) directions
σ	Electrical conductivity
$\bar{J}$	Ohm's law
$\bar{u}$	The axial velocity
T	Fluid temperature
ω	The frequency of the oscillation
λ	The real constant
D	The coefficient of mass diffusivity
C	The concentration
K_r	Chemical reaction parameter
Sc, Sr	The Schmidt number, The Sort number
T_m	The mean temperature
B_0	Magnetic field strength

Symbols	Meaning
k	Permeability
g	Hastening due to gravity
C_T	Specific heat at constant pressure
K_T	Thermal conductivity
Q	Radioactive heat flux
η	The radiation absorption
$\bar{V}$	The fluid velocity in the cartesian coordinates system (x, y, z)
U	The mean flow velocity
Da, Re	Darcy number, Reynolds number
M	Magnetic parameter
Pe, N	Peclet number, Radiation parameter

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Abstract

This thesis aims to examine and analyze a specific kind of fluid that cannot be compressed, known as a non-Newtonian tangent hyperbolic fluid. The unstable oscillating flow of a tangent hyperbolic fluid presents three issues for two types of flow, namely Poiseuille and Couette. Various techniques are employed to solve the system of nonlinear partial differential equations that regulate this problem, and subsequently, the outcomes are achieved using the "Mathematica 13" software.

In the first problem, challenge focused on analyzing the mass transport in the oscillatory flow of a tangent hyperbolic fluid along a horizontal channel. We observed the impact of altering the velocity of the fluid on its temperature.

The second challenge focused on analyzing the heat transfer in the oscillatory flow of magnetohydrodynamics (MHD) and its impact on the temperature and concentration of the tangent hyperbolic fluid through a regular permeable channel.

In the last problem, we determined how temperature impacts the concentration and subsequently affects the oscillatory flow of a tangent hyperbolic fluid with magnetohydrodynamics through a regular permeable channel.

Introduction

Fluid mechanics is a branch of mathematics science (theoretical and applied), it is interested in studying the motion of fluids (liquids, gases, and plasma) and the forces acting on them. It has applications in various disciplines, including mechanical, aerospace, civil, chemical, and biomedical engineering, geophysics, oceanography, meteorology, astrophysics, and biology. Fluid mechanics is used to investigate liquids in motion and at rest. The study of fluid mechanics goes back at least to the days of ancient Greece, when Archimedes investigated the stillness of fluids and buoyancy and formulated his famous law now known as Archimedes' Principle, which was published in his book *On Floating Bodies* – generally considered the first major work in fluid mechanics [17].

Because of its wide variety of applications in nuclear engineering and industry, the oscillator flow has gotten a lot of attention in recent years, many researchers studied the oscillator flow to transfer liquids between two surfaces under the impact of the magnetic field in different locations. the amongst the first researcher in this field, Raptis et al [43], also see [19], [51], [37], [34], [35], and [49].

Fluids are functions of viscosity that vary with shear rate and their distinguishing nature is imperative in biomedical flows, polymer and food processing, petroleum production, lubrication process and more. Hence the approximation of Newtonian fluid is not sufficient to achieve the best results [14]. since such fluids have complex rheological characteristics. Here we are considering the tangent hyperbolic fluid model which is a subclass of non-Newtonian model. These fluids include blood flow, ketchup, tooth paste, paints, nail polish, whipped cream etc. Experimental

studies supports that such a flow model predicts the shear-thinning phenomenon precisely. Also due to its simplicity in computation and physical robustness this rheological model has some advantages over the other non-Newtonian model. Also instead of empirical relation, the constitutive equations are derived from kinetic theory of liquids. Consequently, the scientists showed their keen interest for the flow of tangent hyperbolic fluid under different physical conditions [29]. Akbar et al. [1] numerically studied the effect of magnetic field on the flow of tangent hyperbolic fluid towards an elastic surface, they have shown that the magnetic field (M) resists the flow whereas the skin friction coefficient increases with increasing M , it was also concluded that with the increasing values of both power-law-index (n) and Weissenberg number (We), skin friction coefficient also increases, also see [20], [30], [46], and [50].

Porous media can be distinguished through its spatial properties such as permeability, porosity, hardness and so many other properties, but one of the most recognized characteristics is permeability and porosity [5]. There are many materials in porous media such as man-made materials like cement, natural materials such as rocks, and biological tissues such as bones. Porous media is used in many applications in science and engineering fields. Al-Khafajy and Al-Kaabi. [6] studied the legitimacy of the local thermal equilibrium hypothesis in porous media. Alawee et al. [2] studied Thompson's numerical analysis of non-Dacian mixed convection flows in a ventilated enclosure filled with a fluid-saturated porous medium. Mohammed et al. [37] studied Thompson, Heat transfer enhancement with pressure drop optimization in a horizontal porous channel locally heated from below, also see [2], and [23].

Interest began to study the effect of temperature and concentration on the movement of fluids through a channel, as most researchers agreed that

increasing the temperature increases the velocity of the fluid while the velocity of the fluid changes in an unclear way with the difference in concentration. Depending on the location of the fluid in the channel. Al-Khafajy and Al-Kaabi. [5]. They studied the effect of heat transfer on the oscillating flow of the hydrodynamics magnetizing Prandtl-Eyring fluid through a porous medium under the influence of temperature and concentration, also see [23], and [24]

In astronomical, geophysical, and engineering mechanics, the influence of the magnetic field on the electrical movement of the conductive fluid is crucial. In food engineering, petroleum processing, power engineering, and polymer solutions, as well as polymer melt in the plastic manufacturing sectors, heat transfer of non-Newtonian fluids is a top priority. In different divisions of magnetohydrodynamic power generation, nanotechnological production, and groundwater flow, heat transfer in the presence of intense magnetic fields is crucial. The magnetic and mechanical properties that follow, and this science is also looking at specifically producing electricity from hot gases evaporated ionizing generators that depend on this magnetic movement. It's still looking at ways to simulate nuclear fusion in the lab by adding strong electromagnetic energy to a combination of deuterium and tritium, similar to what happens in the sun and nuclear reactors using molten sodium metal [21], also see [26], [36], [39],[46], and [44].

The work embodied in the present thesis is divided into four chapters:

Chapter One

Review of important definitions and concepts that will be addressed later.

Chapter Two

This chapter aims to discuss the oscillatory flow effect on the temperature of tangent hyperbolic fluid through a horizontal channel, we examined the influences of certain parameters that are active on fluid velocity by analyzing the graphs obtained after we reached the momentum equation solution and used the MATHEMATICA program for plot the velocity and temperature of the fluid for two types of flow (Poiseuille and Couette).

Chapter Three

This chapter aims to discuss the oscillatory flow for tangent hyperbolic fluid through a regular permeable channel with magneto field its effect on the temperature and concentration, we examined the influences of certain parameters that are active on fluid velocity by analyzing the graphs obtained after we reached the momentum equation solution, and used the MATHEMATICA program for plot the velocity and temperature of the fluid for two types of flow (Poiseuille and Couette).

Chapter Four

The aim is to study a mathematical model explaining the impacts influence of temperature on the concentration and thus on the MHD oscillatory flow of a tangent hyperbolic fluid through a regular permeable channel. We used the perturbation method to obtain a clear formula for fluid motion. The results obtained are illustrated by graphs after we reached the momentum equation solution, and used the MATHEMATICA program for plotting the velocity and temperature of the fluid.

Chapter One

Elementary Concepts and Basic Definitions

1.1 Introduction

In this chapter, some simple concepts and basic definitions are given be used in this study.

1.2 Fluid Mechanics: [42]

Fluid mechanics may be defined as that the branch of engineering science which deal with the behavior of fluid under the conditions of rest and motion. The fluid mechanics may be divided into three parts: Statics, Kinematics, Dynamics.

1. **Statics:** The study of incompressible fluids under static conditions is called hydrostatic and that dealing with the compressible static gases is termed as aero statics.
2. **Kinematics:** It deal with the velocities, accelerations and the patterns of flow only. Forces or energy causing velocity and acceleration are not dealt under this heading.
3. **Dynamics:** It deal with the relations between velocities, accelerations of fluid with the forces or energy causing them.

1.3 Basic Definitions of Fluid Mechanics:

In this part, we show some of the necessary definitions related to fluid mechanics. They are:

1.3.1 Fluid: [18]

It is defined as a substance that deforms continuously under the action of shear stress, regardless of its magnitude.

1.3.2 Density: [18]

Density is defined as mass per unit volume. It usually denoted by ρ (rho).

Its units are Kg/m^3 , i.e., $\rho = \frac{m}{V}$ (1.1)

where m and V represent the mass and the volume, respectively.

1.3.3 Pressure: [18]

Pressure is defined as a normal force exerted by a fluid per unit area,

$$p = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} = \frac{ma}{A} \quad (1.2)$$

So that force means acceleration(a) in times of mass.

1.3.4 Shear Stress: [40]

Shear stress is defined as the force per unit area and is denoted by the symbol τ , i.e.

$$\tau = \frac{F}{A} \quad (1.3)$$

Where, F = the applied force.

A = the cross-sectional area of material with an area parallel to the applied force vector.

1.3.5 Shear Strain: [33]

Shear strain or shear a deformation of the solid body is displaced parallel plane in the body, quantitatively it is the displacement of any plane relative to a second plan divided by the perpendicular distance between planes the force causing such deformation.

1.3.6 Viscosity: [12]

Viscosity is defined as the resistance of a fluid to motion and its internal friction. A fluid, in a static state, is by definition unable to resist even the slightest amount of shear stress. Application of shear stress results in a continual and permanent distortion known as flow.

1.3.7 Dynamitic Viscosity: [12], [30]

Dynamitic Viscosity defined as the tangentiality force required per unit area to sustain a unit velocity of gradient.

$$\mu = \frac{\tau}{du/dy} \quad (1.4)$$

Where, μ viscosity of fluid, and du/dy is the rate of deformation (shear rate). In the SI system the units of viscosity are $kg/(m.s)$

1.3.8 Kinematics Viscosity: [12]

Kinematic viscosity is defined as the ratio of dynamic viscosity to a density of the fluid and is denoted by the symbol ν , i.e.

$$\nu = \frac{\mu}{\rho} \quad (1.5)$$

where, μ = the dynamic viscosity, ρ = the density.

1.4 Newton's Law of Viscosity: [42]

This law states that the shear stress τ on a fluid element layer is directly proportionality to the rate of shear strain. The constant of proportionality is called the co-efficient of viscosity. Mathematically,

$$\tau \propto \frac{\partial u}{\partial y} \quad (1.6)$$

which may be written as:

$$\tau = \mu \frac{\partial u}{\partial y} \quad (1.7)$$

where μ is a constant of proportionality, called dynamic viscosity.

The dimensions may be found as follows:

$$\mu = \frac{\text{Stress}}{\text{Velocity}/\text{Distance}} = \frac{\tau}{\partial u/\partial y} = \frac{\text{Force}}{\text{Area}} \times \frac{\text{Distance}}{\text{Velocity}} \quad (1.8)$$

This fluid which follows this law are known as Newtonian fluids.

1.5 Classification of Fluid: [15], [33], [42]

Fluids may be classified into the following type:

1. Ideal Fluids: A ideal fluid is one which is incompressible and has zero viscosity or (in other words shear stress is always zero regardless of the motion of the fluid). Thus, an ideal fluid is represented by the horizontal axis ($\tau = 0$).

2. Real Fluids: Exert shearing stress and offers resistance to the body

Moving through it as well as, between the particles of the fluid itself. For

Example: oil and blood. Also, fluids may be classified according to the relation between the stress and the rate of strain as follows:

i-Newtonian Fluids: A real fluid in which the shear stress is directed

Proportional to the rate of shear strain. (Linear relation), i.e., obeys the Newton's law of viscosity. For example: water, or are considered of a Newtonian fluid.

ii- Non-Newtonian Fluids: A real fluid in which shear stress is not Directly proportional to the rate of shear strain. (Nonlinear relation), i.e., does not obey the Newton's law of viscosity. For example: honey, blood, processing of food is considering of non-Newtonian fluid.

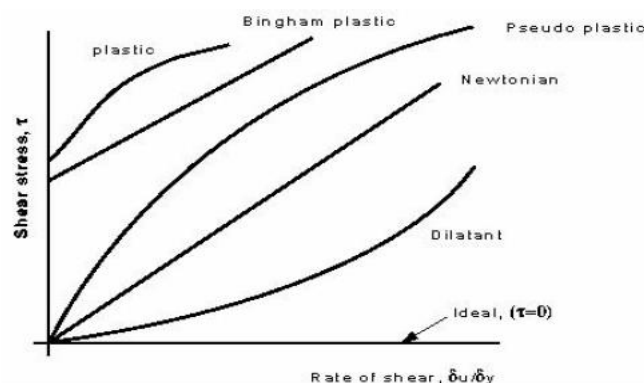


Figure 1.1 Graph of the Shear stress vs. Rate of shear strain $\frac{du}{dy}$ [34]

1.6 Types of Fluid Flow: [33], [42]

A fluid flow consists of a number of small particles grouped together. These particles may group themselves in a variety of ways and type of flow depends on how these groups behave. Fluid flow may be classified as follows.

- **Steady and unsteady flows:** Steady flow is the type of flow in which the fluid characteristics like velocity, pressure, density, etc. at a point do not change with time is called steady flow. Mathematically, we have:

$$\left(\frac{\partial u}{\partial t}\right)_{x_0, y_0, z_0} = 0; \left(\frac{\partial v}{\partial t}\right)_{x_0, y_0, z_0} = 0; \left(\frac{\partial w}{\partial t}\right)_{x_0, y_0, z_0} = 0 \quad (1.9)$$

$$\left(\frac{\partial p}{\partial t}\right)_{x_0, y_0, z_0} = 0; \left(\frac{\partial \rho}{\partial t}\right)_{x_0, y_0, z_0} = 0; \text{ and so, on}$$

where (x_0, y_0, z_0) is a fixed point in a fluid field where these variables are measured w.r.t. time.

Unsteady flow is that type of flow in which the velocity, pressure or density at a point change w.r.t. time. Mathematically, we have:

$$\left(\frac{\partial u}{\partial t}\right)_{x_0, y_0, z_0} \neq 0; \left(\frac{\partial v}{\partial t}\right)_{x_0, y_0, z_0} \neq 0; \left(\frac{\partial w}{\partial t}\right)_{x_0, y_0, z_0} \neq 0 \quad (1.10)$$

$$\left(\frac{\partial p}{\partial t}\right)_{x_0, y_0, z_0} \neq 0; \left(\frac{\partial \rho}{\partial t}\right)_{x_0, y_0, z_0} \neq 0. \text{ and so, on}$$

- **Uniform and Non-uniform flows:** The type of flow, in which the velocity at any given time does not change with respect to space is called uniform flow. Mathematically, we have

$$\left(\frac{\partial V}{\partial s}\right)_{t=\text{constant}} = 0.$$

Where, ∂V = Change in velocity, and ∂s = Displacement in any direction. While Non-uniform flow is the type of flow in which the velocity at any given time changes with respect to space. Mathematically,

$$\left(\frac{\partial V}{\partial s}\right)_{t=\text{constant}} \neq 0.$$

- **Rotational and Irrotational flows:** A flow is said to be rotational if the fluid particles while moving in the direction of flow rotate about their

mass centers. Flow near the solid boundaries is rotational. A flow is said to be irrotational if the fluid particles while moving in the direction of flow do not rotate about their mass centers. Flow outside the boundary layer is generally considered irrotational.

- **Compressible and Incompressible Flow:** Compressible flow is that type of flow in which the density ρ of the fluid changes from point to point (or in other words density is not constant for this flow). Mathematically: $\rho \neq \text{constant}$. Incompressible flow is Although there is no such thing in reality as an incompressible fluid, this term is applied where the change in density with pressure is so small as to be negligible. Liquids are generally considered flowing incompressible.
- **Laminar and Turbulent Flows:** A laminar flow is one in which paths taken by individual particles do not cross one another and move along well-defined paths; this type of flow is also called stream-line flow. A turbulent flow is that flow in which fluid particles move zig zag way.

1.7 Continuity Equation: [42]

The continuity equation is based on the principle of conservation of mass. It states as follows: “If no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be same.” so that the general equation of continuity in three dimensions, and is applicable to any type of flow and for any fluid whether compressible or incompressible.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \quad (1.11)$$

where, ρ is the density and (u, v, w) are the velocity components in (x, y, z) directions, respectively. If the fluid is incompressible, then $\rho = \text{constant}$, and the continuity equation may be written as:

In three-directions:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (1.12)$$

In two-directions:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1.13)$$

In one-directions:

$$\frac{\partial u}{\partial x} = 0 \quad (1.14)$$

1.8 The Momentum Equations (The Navier–Stokes Equation):[13],[54]

It is based on the law of conservation of momentum or on the momentum principle, which states that the net force acting on a fluid mass is equal to the change in momentum of flow per unit time in that direction. The momentum equations (Navier-Stokes equation) are the system of non-linear partial differential equations that describe the fluid motion. Mathematically, in three dimensions as:

$$\left. \begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} &= X - \frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \nabla^2 u \\ \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} &= Y - \frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \nabla^2 v \\ \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} &= Z - \frac{1}{\rho} \frac{\partial p}{\partial z} + \nu \nabla^2 w \end{aligned} \right\} \quad (1.15)$$

where (u, v, w) are the components in the x, y and z directions, respectively, (X, Y, Z) are the body forces in the x, y and z directions, respectively, ν is the kinematic viscosity, and $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ is the Laplacian operator.

1.9 Basic Definitions of The Electrostatic Field:

Through this section, the most important definitions, which will be used in our work, later on, will be introduced.

1.9.1 Electrostatic Field: [21]

The electrostatic field, denoted by E , is defined as the force that is exerted on a unit charge, in the field and its vector in the same directions as the force.

$$\bar{E} = \lim_{\Delta q \rightarrow 0} \frac{F}{\Delta q} \quad (1.16)$$

where Δq is the charge, and F is the force.

1.9.2 Current Density: [21]

The current density, denoted by $\bar{J}$, is defined as the flow of charges across a unit cross-sectional area per second.

$$J = \frac{I}{A} = \frac{\text{Amps}}{\text{m}^2} \quad (1.17)$$

Where A is the cross-sectional area, and I is the current flowing through the conductor, respectively

1.9.3 Electrical Conductivity: [21]

It is denoted by σ and is defined by the ratio of current density $\bar{J}$ in the electrostatic field E .

$$\sigma = \frac{\bar{J}}{E} \quad (1.18)$$

and its unit is $(\frac{\text{Volt}}{\text{amp}})$.

1.9.4 Ohm's Law: [28]

The Ohm's law describes the conduction current and is given by:

$$\bar{J} = \sigma(\bar{E} + \bar{V} \times \bar{B}) \quad (1.19)$$

where σ is electrical conductivity, $\bar{E}$ is the electrostatic field, $\bar{V}$ is velocity and $\bar{B}$ Is a magnetic field.

1.9.5 Lorentz Force: [10]

The force due to a magnetic field $\bar{B}$, acting on a charge q moving at a velocity $\bar{U}_m$, which denoted by $\bar{F}_m$, and given by:

$$\bar{F}_m = q(\bar{U}_m) \cdot \bar{B} \quad (1.20)$$

Where q is the charge, if $J = q(\bar{U}_m)$, then the Lorentz force bcome as

$$\bar{F}_m = J \cdot \bar{B} \quad (1.21)$$

where $(J \cdot \bar{B})$ is the component of Lorentz force, J is the current density.

1.10 The Magnetohydrodynamics (MHD): [18], [48]

Magnetohydrodynamics (MHD) concerns the interaction between magnetic fields and conducting fluids. The motion of an electrically conducting fluid in the presence of a magnetic field is the subject of magnetohydrodynamics (MHD), a branch of continuum mechanics. Potential differences are created when conducting material moves across magnetic lines of force, causing electric currents to flow. The magnetic fields associated with these currents modulate the magnetic field that causes them to exist. The flow of electric current across a magnetic field, on the other hand, is connected with a body force, known as the Lorentz force, which influences fluid flow, which really defines characterizes of (MHD), by close coupling between the hydrodynamics and electrodynamics.

The Navier-Stokes equation represented by a nonlinear partial differential equation and is given by:

In x -direction is

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + X\rho + \mu \nabla^2 u + (\bar{J} \times \bar{B})_x \quad (1.22)$$

In the y -direction:

$$\rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = -\frac{\partial p}{\partial y} + Y\rho + \mu \nabla^2 v + (\bar{J} \times \bar{B})_y \quad (1.23)$$

In the z-direction:

$$\rho \left(\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = - \frac{\partial p}{\partial z} + Z\rho + \mu \nabla^2 w + (\bar{J} \times \bar{B})_z \quad (1.24)$$

where u , v , and w are the velocity vectors, $\bar{B}$ is the magnetic field, J is the current density. $(J \times \bar{B})_x$, $(J \times \bar{B})_y$, and $(J \times \bar{B})_z$ are component of Lorentz force.

1.11 Dimensional Analysis: [53], [20]

The method of dimensional analysis aims at deriving similarity parameters, which can be used to apply data measured with a model configuration to the geometrically similar full-scale configuration. Thereby the number of necessary experiments can be reduced, which depends on the number the physical quantities influencing the problem. The dimensional analysis also offers the advantage, that the physical quantities can be combined in such a way and that the results are independent of the measuring units. The physical quantities are combined in a product such that dimensionless combinations result.

1.12 Dimensionless Numbers: [53], [55]

In fluid mechanics, dimensionless numbers or non-dimensional numbers are those which are useful to determine the flow characteristics of a fluid. Depending on experience and judgment, less important traits may be left out. The most important factors are thus still present and have a far greater influence on the phenomena than those that were removed. This section will define a few of the dimensionless integers that are important to our inquiry.

1.12.1 Reynolds Number:

The Reynolds number, denoted by (Re) , is the most common dimensionless number in fluid mechanics. Low (Re) flows involve small sizes, low speeds, and high kinematic viscosity such as bacteria swimming through mucus. High (Re) flows involve large sizes, high speeds, and low

kinematic viscosity such as an ocean liner steaming at full speed, and represents the ratio of inertia force to the viscous force, and given by:

$$Re = \frac{\rho h U}{\mu_c} \quad (1.25)$$

where ρ is the flow density, U is uniform velocity, h is dimension of the channel and μ_c is dynamic viscosity respectively.

1.12.2 Darcy Number:

In fluid dynamics through porous media, the Darcy number, denoted by Da , represents the relative effect of the permeability of the medium versus it is cross-sectional commonly the diameter squared. The number is named after Henry Darcy and is found from non-dimensionalizing the differential form of Darcy's law. This number should not be confused with the Darcy friction factor which applies to pressure drop in a pipe. It is defined as:

$$Da = \frac{k}{h^2} \quad (1.26)$$

where (k) is the permeability of the medium and (h) is the diameter of the particle.

1.12.3 Peclet Number:

The Peclet number, denoted by (Pe) , is a dimensionless group representing the ratio of heat transfer by motion of a fluid to heat transfer by thermal conduction.

$$Pe = \frac{c_T \rho h U}{K_T} \quad (1.27)$$

where U is the fluid velocity h is a characteristic dimension, c_T specific heat at constant pressure and K_T is the thermal diffusivity the fluid.

1.12.4 Magnetic Parameter:

The Magnetic parameter, denoted by (M), equal to the product of the square of the magnetic permeability, the square of the magnetic field strength, the electrical conductivity, and a characteristic length, divided by the product of the mass density and the fluid velocity.

1.12.5 Weissenberg number:

White interpreted the group of elastic forces to viscous forces as representing the recoverable strain in the fluid and quotes Weissenberg's paper from the First International Rheological Congress held in 1948

“As a dimensionless quantity of tensorial character, we may quote here the recoverable strain. Just as the Reynolds Number coordinates the rheological states with respect to the similitude in the relative proportions of the forces of inertia and of internal friction, so the recoverable strain does with respect to similitude in anisotropy in the sheared states...”. As a consequence, he termed the group $\Gamma \frac{U}{h}$ the “Weissenberg number”.

$$We = \Gamma \frac{U}{h}, \quad (1.28)$$

where Γ is time constant, h is the dimensional constant, U is mean flow viscosity.

1.12.9 Prandtl Number

The Prandtl number is a dimensionless number, it is the ratio of kinematic viscosity ν to thermal diffusivity α . It is defined as:

$$Pr = \frac{\mu c_T}{K_T} \quad (1.29)$$

Where K_T is the heat transport (thermal conductivity) and c_T is the specific heat.

1.12.7 Grashof's Number

The Grashof's number is a measure of buoyancy or free-convection effects in a flow. The Grashof's number denoted by G_r and given by:

$$G_r = \frac{\rho g \beta_T h^2 (T_1 - T_0)}{\mu_c U} \quad (1.30)$$

where β_T is the coefficient of thermal expansion, U is mean flow velocity, h is the average radius of the tube, g is an acceleration due gravity, and T_0 and T_1 is the temperature at the lower and upper wall.

1.12.8 Soret's Number

Soret number is the ratio of temperature difference to the concentration. Mathematically,

$$S_r = \frac{DK_H(T_1 - T_0)}{T_m U h (C_1 - C_2)} \quad (1.31)$$

Where T_m is the mean fluid temperature, D is the mass diffusivity, and K_H is the thermal diffusion ratio.

1.12.9 Brinkman number:

The Brinkman number Br is a dimensionless number related to heat conduction from a wall to a flowing viscous fluid, commonly used in polymer processing, where the polymer are the giant molecules of chemistry, such as starch and DNA. There are several definitions; one is, it is the ratio between heat produced by viscous dissipation and heat transported by molecular conduction:

$$Br = \frac{\mu_c U^2}{K_T \Delta T} = Pr Ec, \quad (1.32)$$

where μ_c is the dynamic viscosity, U is the flow velocity, K_T is the thermal conductivity, ΔT fluid temperature, Pr is the Prandtl number and Ec is the Eckert number.

1.12.10 Schmidt's Number

Schmidt's number, denoted by S_c , relates "viscous diffusion to mass diffusion", and is given by:

$$S_c = \frac{U h}{D} \quad (1.33)$$

Where D is the coefficient of mass diffusivity.

1.13 Perturbation Technique: [28]

The Perturbation technique is a mathematical method for finding an approximate solution to a problem, by starting from the exact solution of a related, simpler problem. A critical feature of the technique is a middle step that breaks the problem into "solvable" and "perturbation". Perturbation technique is applicable if the problem at hand cannot be solved exactly, but can be formulated by adding a "small" term in the mathematical description of the exactly solvable problem. We have for the approximation to the full solution A , a series of the small parameter (here called ε), like the following:

$$A = A_0 + \varepsilon^1 A_1 + \varepsilon^2 A_2 + \dots \quad (1.34)$$

An approximate "perturbation solution" is obtained by truncating the series, usually by keeping only the first two terms, the initial solution and the "first-order" perturbation correction.

$$A \approx A_0 + \varepsilon A_1 \quad (1.35)$$

1.14 Steady Unidirectional Flow: [53], [56]

1.14.1 Poiseuille Flow:

The flow between the two parallel lines separated by $2h$ distance, with both the upper and lower plate fixed, and the degree of pressure forced gradient flow command as shown in (Fig. 1.2). The flow is constant, non-

compressible, and two-dimensional in the xy -plane. As the entire flow has been developed, this means that the speed profile does not change with the x . Because nature is fully developed for flow, there are no inertial effects and density does not enter the problem. It turns out that u , the velocity component in the x -direction, is a function of the distance $2h$, the pressure level of the fluid viscosity μ , and the vertical coordinates y .

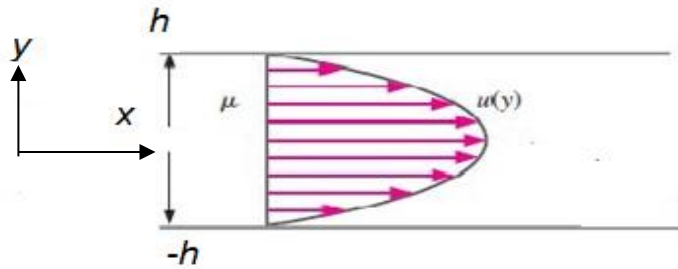


Figure 1.2 Graph of the Poiseuille flow.

1.14.2 Couette Flow:

The flow between two infinite parallel plates separated by distance h , with the top plate moving at speed V_{top} and the bottom plate fixed as illustrated in (Fig 1.3). The flow is steady, incompressible, and two-dimensional in the xy -plane. Generate a dimensionless relationship for the x -component of fluid velocity u as a function of fluid viscosity μ , plate speeds V_{top} , distance $2h$, fluid density ρ , and distance y .

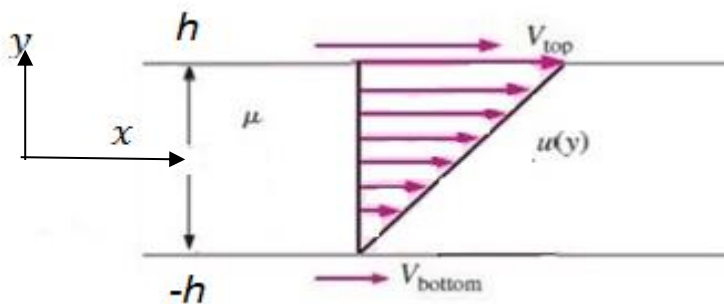


Figure 1.3 Graph of the Couette flow.

Chapter two

Analyze of Oscillatory Flow Its Effect on the Temperature of Tangent Hyperbolic Fluid Through a Horizontal Channel

Analyze of oscillatory flow its effect on the temperature of tangent hyperbolic fluid through a horizontal channel

2.1 Introduction

The utilization of non-Newtonian in many manufacturing industries as a primary cooling component is extensive. Moreover, it is utilized in thermal extrusion systems, biomedical engineering, cancer treatment, and other fields.

Thermal technology applications, such as crude oil refineries, heat exchangers, geothermal processes, and isolation processes, rely on the reliable transfer of heat and mass in liquids within a well-defined system, they are frequently seen in many applications such as the generation of emulsion sheets like imaging films, the extraction of polymeric sheets, and the transportation of blood and plasma [16]. Non-Newtonian fluids are also employed to enhance the quality of printing technologies. Because of their complex structure, there are no individual equations that can fully describe the physical and mathematical properties of non-Newtonian fluids [7], one concrete example of this concept is the tangent hyperbolic fluid. Several writers have investigated the wide range of industrial uses of tangent hyperbolic fluid, which is a non-Newtonian fluid, where the flow of this fluid has been studied in different conditions, different channels and at different times for several researchers, including [20], [30], and [47].

This chapter aims to discuss the oscillatory flow effect on the temperature of tangent hyperbolic fluid through a horizontal channel, we examined the influences of certain parameters that are active on fluid velocity by analyzing the graphs obtained after we reached the momentum equation solution, and used the MATHEMATICA program for plot the velocity and temperature of the fluid for two types of flow (Poiseuille and Couette).

Analyze of oscillatory flow its effect on the temperature of tangent hyperbolic fluid through a horizontal channel

2.2 Mathematical Formulation:

A mathematical model has been created for the oscillatory flow of a tangent hyperbolic fluid through a regular horizontal flat channel. We start by adopting a regular horizontal flow channel with a width of $2h$. The channel wall is exposed to a difference in temperature, where the fixed lower wall has a temperature of T_0 while the upper wall has a temperature of T_1 and takes two states: the first is stationary (Poiseuille flow), and the second is moving at a constant speed (Couette flow). We adopted Cartesian coordinates, where x represents the horizontal axis while the vertical axis is y and represents the flow field $(u(y, t), 0, 0)$, which fulfills the continuity equation.

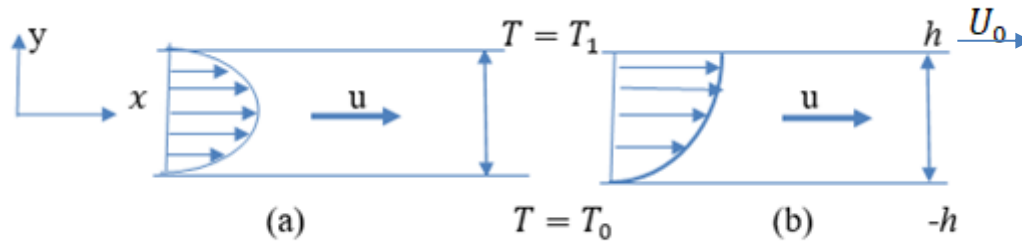


Figure 2-1: Channel format: (a) Poiseuille flow and (b) Couette flow [23]

2.3 Basic Equations:

The basic equations governing for the problem are given by:[23]

The continuity equation:

$$\text{div } \bar{V} = 0. \quad (2.1)$$

The momentum equation:

$$\rho(\bar{V} \cdot \nabla) \bar{V} = -\nabla \bar{p} + \text{div } \bar{S}. \quad (2.2)$$

The temperature equation:

$$c_T \rho(\bar{V} \cdot \nabla) T = K_T \nabla^2 T + \bar{S} \cdot (\text{grad } \bar{V}) - \nabla Q. \quad (2.3)$$

where $V \equiv (u(y, t), 0, 0)$ is the velocity field, $T(y, t)$ "fluid temperature", $\bar{p}$ "the pressure", $\bar{S}$ "extra stress tensor", ρ "fluid density", c_T "specific heat at constant pressure", K_T "thermal conductivity" and Q "radioactive heat flux".

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2.4 Constitutive Equation:

The fundamental equation for the tangent hyperbolic fluid given by: [22], [37]

$$\bar{\mathcal{S}} = [\mu_{\infty} + (\mu_c + \mu_{\infty})\tanh(\Gamma\bar{\dot{\gamma}})^n]\bar{\dot{\gamma}}. \quad (2.4)$$

where μ_c "constant viscosity", $\bar{\dot{\gamma}}$ "shear rate", μ_{∞} "infinity shear rate viscosity", Γ "time constant", n "dimensionless power law index".

In this study the constitutive equation considered when $\mu_{\infty}=0$. It has been considered the tangent hyperbolic fluid which represent shear thinning characteristics when $\Gamma\bar{\dot{\gamma}} < 1$. Therefore Eq (2.4) becomes:

$$\begin{aligned} \bar{\mathcal{S}} &= \mu_c[(\Gamma\bar{\dot{\gamma}})^n]\bar{\dot{\gamma}}, \\ \bar{\mathcal{S}} &= \mu_c[(1 + \Gamma\bar{\dot{\gamma}} - 1)^n]\bar{\dot{\gamma}}, \\ \bar{\mathcal{S}} &= \mu_c[1 + n(\Gamma\bar{\dot{\gamma}} - 1)]\bar{\dot{\gamma}}. \end{aligned} \quad (2.5)$$

and $\bar{\dot{\gamma}}$ the Rivlin-Ericksen [37] tensors which is defined by:

$$\bar{\dot{\gamma}} = \nabla\bar{V} + (\nabla\bar{V})^T. \quad (2.6)$$

where $\bar{V} = (\bar{u}, \bar{v}, \bar{w})$ is the velocity field in Cartesian coordinates system (x, y, z) , $\nabla\bar{V}$ "gradient of velocity", and $(\nabla\bar{V})^T$ "transpose of the velocity gradient", which is given by:

$$\nabla\bar{V} = \begin{bmatrix} \bar{u}_{\bar{x}} & \bar{u}_{\bar{y}} & \bar{u}_{\bar{z}} \\ \bar{v}_{\bar{x}} & \bar{v}_{\bar{y}} & \bar{v}_{\bar{z}} \\ \bar{w}_{\bar{x}} & \bar{w}_{\bar{y}} & \bar{w}_{\bar{z}} \end{bmatrix}, \quad (\nabla\bar{V})^T = \begin{bmatrix} \bar{u}_{\bar{x}} & \bar{v}_{\bar{x}} & \bar{w}_{\bar{x}} \\ \bar{u}_{\bar{y}} & \bar{v}_{\bar{y}} & \bar{w}_{\bar{y}} \\ \bar{u}_{\bar{z}} & \bar{v}_{\bar{z}} & \bar{w}_{\bar{z}} \end{bmatrix}.$$

Then

$$\bar{\dot{\gamma}} = \begin{bmatrix} 2\bar{u}_{\bar{x}} & \bar{v}_{\bar{x}} + \bar{u}_{\bar{y}} & \bar{w}_{\bar{x}} + \bar{u}_{\bar{z}} \\ \bar{v}_{\bar{x}} + \bar{u}_{\bar{y}} & 2\bar{v}_{\bar{y}} & \bar{v}_{\bar{z}} + \bar{w}_{\bar{y}} \\ \bar{w}_{\bar{x}} + \bar{u}_{\bar{z}} & \bar{v}_{\bar{z}} + \bar{w}_{\bar{y}} & 2\bar{w}_{\bar{z}} \end{bmatrix}, \quad (2.7)$$

and $\dot{\gamma}$ is defined by;

$$\begin{aligned} \dot{\gamma} &= \sqrt{\frac{1}{2}\sum_i \sum_j \dot{\gamma}_{ij}\dot{\gamma}_{ji}} \\ &= \sqrt{\frac{1}{2}(\dot{\gamma}_{11}^2 + \dot{\gamma}_{12}\dot{\gamma}_{21} + \dot{\gamma}_{13}\dot{\gamma}_{31}) + \frac{1}{2}(\dot{\gamma}_{12}\dot{\gamma}_{21} + \dot{\gamma}_{22}^2 + \dot{\gamma}_{23}\dot{\gamma}_{32}) + \frac{1}{2}(\dot{\gamma}_{13}\dot{\gamma}_{31} + \dot{\gamma}_{23}\dot{\gamma}_{32} + \dot{\gamma}_{33}^2)} \end{aligned}$$

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$$= \sqrt{\frac{1}{2}[(\dot{\gamma}_{11}^2 + \dot{\gamma}_{22}^2 + \dot{\gamma}_{33}^2) + 2(\dot{\gamma}_{12}^2 + \dot{\gamma}_{13}^2 + \dot{\gamma}_{23}^2)]}$$

$$= \sqrt{\frac{1}{2}\left[4(u_x^2 + v_y^2 + w_z^2) + 2\left((u_y + v_x)^2 + (u_z + w_x)^2 + (v_z + w_y)^2\right)\right]},$$

hence

$$\dot{\gamma} = \sqrt{2\left\{\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right\} + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)^2}.$$

Since $(u(y, t), 0, 0)$ is the velocity field, then

$$\bar{\dot{\gamma}} = \left(\frac{\partial \bar{u}}{\partial \bar{y}}\right). \quad (2.8)$$

Substituting equations (2.7) and (2.8) into equation (2.5), we have

$$\bar{\mathcal{S}} = \mu_c \left[1 + n\left(\Gamma \frac{\partial \bar{u}}{\partial \bar{y}} - 1\right)\right] \frac{\partial \bar{u}}{\partial \bar{y}}. \quad (2.9)$$

The stress components are given by:

$$\bar{\mathcal{S}}_{\bar{x}\bar{x}} = \bar{\mathcal{S}}_{\bar{y}\bar{y}} = 0, \quad (2.10)$$

$$\bar{\mathcal{S}}_{\bar{x}\bar{y}} = \bar{\mathcal{S}}_{\bar{y}\bar{x}} = \mu_c \left[(1 - n) \frac{\partial \bar{u}}{\partial \bar{y}} + n\Gamma \left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2\right], \quad (2.11)$$

and

$$\bar{\mathcal{S}} \cdot (\text{grad } \bar{V}) = \begin{bmatrix} \bar{\mathcal{S}}_{\bar{x}\bar{x}} & \bar{\mathcal{S}}_{\bar{x}\bar{y}} \\ \bar{\mathcal{S}}_{\bar{y}\bar{x}} & \bar{\mathcal{S}}_{\bar{y}\bar{y}} \end{bmatrix} \begin{bmatrix} \bar{u}_{\bar{x}} & \bar{u}_{\bar{y}} \\ \bar{v}_{\bar{x}} & \bar{v}_{\bar{y}} \end{bmatrix} = \bar{\mathcal{S}}_{\bar{x}\bar{x}}\bar{u}_{\bar{x}} + \bar{\mathcal{S}}_{\bar{x}\bar{y}}\bar{u}_{\bar{y}} + \bar{\mathcal{S}}_{\bar{y}\bar{x}}\bar{v}_{\bar{x}} + \bar{\mathcal{S}}_{\bar{y}\bar{y}}\bar{v}_{\bar{y}}$$

$$\Rightarrow \bar{\mathcal{S}} \cdot (\text{grad } \bar{V}) = \bar{\mathcal{S}}_{\bar{x}\bar{y}}\bar{u}_{\bar{y}}. \quad (2.12)$$

The radioactive heat flux is given by [50]:

$$\nabla Q = 4\eta^2(T_0 - T). \quad (2.13)$$

where Q is a radioactive heat flux, η is a radiation absorption. Substituting equations (2.4) and (2.10)- (2.13), into equations (2.2) and (2.3), we have the following equations;

The continuity equation is given by:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0. \quad (2.14)$$

The momentum equations are:

$$\text{In the } x - \text{direction: } \rho \left(\frac{\partial \bar{u}}{\partial \bar{t}} + \bar{u} \frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v} \frac{\partial \bar{u}}{\partial \bar{y}} \right) = -\frac{\partial \bar{p}}{\partial \bar{x}} + \frac{\partial \bar{\mathcal{S}}_{\bar{x}\bar{y}}}{\partial \bar{y}}, \quad (2.15)$$

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In the y - direction: $\rho \left(\frac{\partial \bar{v}}{\partial \bar{t}} + \bar{u} \frac{\partial \bar{v}}{\partial \bar{x}} + \bar{v} \frac{\partial \bar{v}}{\partial \bar{y}} \right) = -\frac{\partial \bar{p}}{\partial \bar{y}} + \frac{\partial \bar{S}_{y\bar{x}}}{\partial \bar{x}}.$ (2.16)

The temperature equation is given be:

$$c_T \rho \left(\frac{\partial T}{\partial \bar{t}} + \bar{u} \frac{\partial T}{\partial \bar{x}} + \bar{v} \frac{\partial T}{\partial \bar{y}} \right) = K_T \left(\frac{\partial^2 T}{\partial \bar{x}^2} + \frac{\partial^2 T}{\partial \bar{y}^2} \right) + \bar{S}_{x\bar{y}} \bar{u}_{\bar{y}} - 4\eta^2 (T_0 - T). \quad (2.17)$$

The temperatures at the walls of the channel are given as:

$$T = T_0 \text{ at } \bar{y} = -h, \text{ and } T = T_1 \text{ at } \bar{y} = h. \quad (2.18)$$

2.5 Method of Solution:

In order to simplify the governing equations of the problem, we may introduce the following dimensionless transformations as follows:

$$\left. \begin{aligned} x &= \frac{\bar{x}}{h}, y = \frac{\bar{y}}{h}, u = \frac{\bar{u}}{U}, v = \frac{\bar{v}}{U}, t = \frac{\bar{t}U}{h}, p = \frac{\bar{p}h}{\mu_c U}, \\ \theta &= \frac{T-T_0}{\Delta T}, \Delta T = T_1 - T_0, \mathcal{S}_{xy} = \frac{h}{\mu_c U} \bar{S}_{x\bar{y}} \end{aligned} \right\} \quad (2.19)$$

where U is the mean flow velocity.

Substituting Eq. (2.19) into equations (2.14)- (2.17), we have the following of non-dimensional equations:

$$\begin{aligned} \frac{\partial(Uu)}{\partial(xh)} + \frac{\partial(Uv)}{\partial(yh)} &= 0, \\ \rho \left(\frac{U\partial u}{\frac{h}{U}\partial t} + Uu \frac{U\partial u}{h\partial x} + Uv \frac{U\partial u}{h\partial y} \right) &= -\frac{\frac{\mu_c U}{h}\partial p}{h\partial x} + \frac{\frac{\mu_c U}{h}\partial \mathcal{S}_{xy}}{h\partial y}, \\ \rho \left(\frac{U\partial v}{\frac{h}{U}\partial t} + Uu \frac{U\partial v}{h\partial x} + Uv \frac{U\partial v}{h\partial y} \right) &= -\frac{\frac{\mu_0 U}{h}dp}{h\partial y} + \frac{\frac{\mu_0 U}{h}\partial \mathcal{S}_{xy}}{h\partial x}, \\ c_T \rho \frac{\partial(\theta(T_1-T_0)+T_0)}{\frac{h}{U}\partial t} &= K_T \left(\frac{\partial^2(\theta(T_1-T_0)+T_0)}{h^2\partial x^2} + \frac{\partial^2(\theta(T_1-T_0)+T_0)}{h^2\partial y^2} \right) + \\ &\quad \frac{\mu_c U}{h} \mathcal{S}_{xy} \frac{U\partial u}{h\partial y} + 4\eta^2 \theta (T_1 - T_0), \end{aligned}$$

implies that

$$\frac{U}{h} \left(\frac{\partial(u)}{\partial(x)} + \frac{\partial(v)}{\partial(y)} \right) = 0, \quad (2.20)$$

$$\rho \frac{U^2}{h} \frac{\partial u}{\partial t} = -\frac{\mu_c U}{h^2} \frac{\partial p}{\partial x} + \frac{\mu_c U}{h^2} \frac{\partial \mathcal{S}_{xy}}{\partial y}, \quad (2.21)$$

$$\rho(0) = -\frac{\mu_c U}{h^2} \frac{\partial p}{\partial y} + 0, \quad (2.22)$$

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$$\frac{c_T \rho U}{h} \frac{\partial(\theta(T_1 - T_0) + T_0)}{\partial t} = \frac{K_T}{h^2} \left(\frac{\partial^2(\theta(T_1 - T_0) + T_0)}{\partial y^2} \right) + 4\eta^2 \theta(T_1 - T_0) + \frac{\mu_c U^2}{h^2} \mathcal{S}_{xy} \frac{\partial u}{\partial y}, \quad (2.23)$$

$$\text{and } \frac{\mu_c U}{h} \mathcal{S}_{yx} = \mu_c \left[\frac{U \partial u}{h \partial y} + n \left(\Gamma \left(\frac{U \partial u}{h \partial y} \right)^2 - \frac{U \partial u}{h \partial y} \right) \right].$$

Dividing by $\frac{h}{\mu_c U}$, and after simplification, we have

$$\Rightarrow \mathcal{S}_{xy} = \left[(1 - n) \frac{\partial u}{\partial y} + n \Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2 \right], \quad (2.24)$$

with the boundary conditions of the temperature equation

$$\theta \Delta T + T_0 = T_0 \text{ at } hy = -h, \text{ and } \theta \Delta T + T_0 = T_1 \text{ at } hy = h. \quad (2.25)$$

Substituting the equation (2.24) in to the equations (2.21) - (2.23), after that simplify the equations, we obtain;

$$\rho \frac{Uh}{\mu_c} \frac{\partial u}{\partial t} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial y} \left(\frac{\partial u}{\partial y} + n \left(\Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2 - \frac{\partial u}{\partial y} \right) \right), \quad (2.26)$$

$$\frac{\partial p}{\partial y} = 0, \quad (2.27)$$

$$\frac{c_T \rho U h}{K_T} \frac{\partial(\theta(T_1 - T_0) + T_0)}{\partial t} = \left(\frac{\partial^2(\theta(T_1 - T_0) + T_0)}{\partial y^2} \right) + \frac{h^2}{K_T} (4\eta^2 \theta(T_1 - T_0)) + \frac{\mu_c U^2}{K_T} \left(\frac{\partial u}{\partial y} + n \left(\Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2 - \frac{\partial u}{\partial y} \right) \right) \frac{\partial u}{\partial y}. \quad (2.28)$$

with the non-dimensional boundary conditions of the temperature equation

$$\theta = 0 \text{ at } y = -1 \text{ and } \theta = 1 \text{ at } y = 1. \quad (2.29)$$

This from equation (2.27), the pressure p depended on x only. Now the last form of the system of equations governing the flow of the tangent hyperbolic fluid is as follows [10];

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (2.30)$$

$$\frac{\partial p}{\partial x} = -Re \frac{\partial u}{\partial t} + (1 - n) \frac{\partial^2 u}{\partial y^2} + 2nWe \frac{\partial u}{\partial y} \frac{\partial^2 u}{\partial y^2}, \quad (2.31)$$

$$Pe \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + N^2 \theta + Br(1 - n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3, \quad (2.32)$$

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where $Re = \frac{\rho h U}{\mu_c}$ "Reynolds number", $Pe = \frac{c_T \rho h U}{K_T}$ "Peclet number", $N = \sqrt{\frac{4\eta^2 h^2}{K_T}}$ "radiation parameter", $Pr = \frac{\mu_c c_T}{K_T}$ "Prandtl number", $Ec = \frac{U^2}{c_T \Delta T}$ "Eckert number", $Br = Pr Ec$ "Brinkman number", and $We = \Gamma \frac{U}{h}$ "Weissenberg number".

The solution of equations (2.31)- (2.32) has been computed in the next section for two types of flows (Poiseuille flow and Couette flow).

2.6 Solution of the Problem:

This section contains three parts: solving the motion equation, solving the shear stress equation, and solving the heat equation

2.6.1 Solution of the motion equation

i- Poiseuille flow:

Suppose that the no-slip condition, Figure 2-1 (a), that is;

$$\bar{u} = 0 \text{ at } \bar{y} = -h, \text{ and } \bar{u} = 0 \text{ at } \bar{y} = h.$$

To solve the momentum equation (2.31), hence let

$$-\frac{\partial p}{\partial x} = \lambda e^{i\omega t}, \quad (2.33)$$

$$u(y, t) = u_0(y) e^{i\omega t}, \quad (2.34)$$

where λ "real constant" and ω "oscillation of frequency".

The non-dimensional boundary conditions are as follows:

$$\left. \begin{aligned} 0 &= u(1, t) = u_0(1) e^{i\omega t} \\ \Rightarrow u_0(1) &= 0 \end{aligned} \right\}$$

$$\left. \begin{aligned} 0 &= u(-1, t) = u_0(-1) e^{i\omega t} \\ \Rightarrow u_0(-1) &= 0 \end{aligned} \right\}$$

By substituting equations (2.33) and (2.34) into equation (2.31), we have;

$$-\lambda e^{i\omega t} = -Re \frac{\partial}{\partial t} (u_0(y) e^{i\omega t}) + (1-n) \frac{\partial^2}{\partial y^2} (u_0(y) e^{i\omega t}) +$$

$$2nWe \frac{\partial}{\partial y} (u_0(y) e^{i\omega t}) \frac{\partial^2}{\partial y^2} (u_0(y) e^{i\omega t}),$$

Implied that

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$$-\lambda e^{i\omega t} = -i\omega Re e^{i\omega t} u_0 + (1-n)e^{i\omega t} \frac{\partial^2 u_0}{\partial y^2} + 2nWe e^{2i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2}.$$

Dividing by $e^{i\omega t}$, and after simplification, we have

$$(n-1) \frac{\partial^2 u_0}{\partial y^2} + i\omega Re u_0 = \lambda + 2nWe e^{i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2}.$$

Dividing by $(n-1)$, and after simplification, we have

$$\frac{\partial^2 u_0}{\partial y^2} + \frac{i\omega Re}{(n-1)} u_0 = \frac{\lambda}{(n-1)} + \frac{2n}{(n-1)} We e^{i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2}. \quad (2.35)$$

So will use the perturbation technique to find the solution of problem as follows:

$$u_0 = u_{00} + We u_{01} + O(We^2). \quad (2.36)$$

Now, by substituting equation (2.36) in equation (2.35), we obtain:

$$\begin{aligned} \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial^2 u_{01}}{\partial y^2} + \frac{i\omega Re}{(n-1)} u_{00} + We \frac{i\omega Re}{(n-1)} u_{01} - \\ We \frac{2n}{(n-1)} e^{i\omega t} \left(\frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial u_{01}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} + \right. \\ \left. We \frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{01}}{\partial y^2} + (We)^2 \frac{\partial u_{01}}{\partial y} \frac{\partial^2 u_{01}}{\partial y^2} \right) = \frac{\lambda}{(n-1)}. \end{aligned}$$

We can find the equation as following by boundary conditions are:

$$\begin{aligned} 0 = u_0(1) = u_{00}(1) + we u_{01}(1) \\ \Rightarrow u_{00}(1) = 0, u_{01}(1) = 0 \\ 0 = u_0(-1) = u_{00}(-1) + we u_{01}(-1) \\ \Rightarrow u_{00}(-1) = 0, u_{01}(-1) = 0 \end{aligned} \quad \left. \begin{array}{l} \\ \\ \end{array} \right\}$$

then equating the like powers of we obtain the following results presented in the forthcoming subsections:

i - Zeros-order system (we^0)

$$\frac{\partial^2 u_{00}}{\partial y^2} + \frac{i\omega Re}{(n-1)} u_{00} = \frac{\lambda}{(n-1)}. \quad (2.37)$$

The solution of the equation (2.37) is non-homogenies diffraction equation, so that the general solution of this equation is $u_{00} = u_{00h} + u_{00p}$, where u_{00h} is solution of the homogeneies part of the equation (2.37), and u_{00p}

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is a particular solution of the non-homogeneous equation (2.37), now the general solution of equation (2.37) is

$$u_{00} = \frac{B}{A} + C_1 \cos[\sqrt{A}y] + C_2 \sin[\sqrt{A}y],$$

$$u_{00h} = C_1 \cos[\sqrt{A}y] + C_2 \sin[\sqrt{A}y], \text{ and } u_{00p} = \frac{B}{A}$$

Where $A = \frac{i\omega Re}{(n-1)}$ and $B = \frac{\lambda}{(n-1)}$

and the constant C_1 and C_2 , can be found by as boundary conditions are:

$$u_{00}(-1) = u_{00}(1) = 0.$$

Hence, the final form of the solution of the equation (2.37) is

$$u_{00} = \frac{B}{A} + \left(-\frac{B \sec[\sqrt{A}h]}{A} \right) \cos[\sqrt{A}y]. \quad (2.38)$$

ii – First - order system (We^1)

$$\frac{\partial^2 u_{01}}{\partial y^2} + \frac{i\omega Re}{(n-1)} u_{01} = \frac{2n}{(n-1)} e^{i\omega t} \frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2}. \quad (2.39)$$

The general solution of the equation (2.39) $u_{01} = u_{01h} + u_{01p}$ and we found that $u_{01h} = C_3 \cos[\sqrt{A}y] + C_4 \sin[\sqrt{A}y]$, and $u_{01p} = -\frac{B^2 e^{i\omega t} n \sec[\sqrt{A}]^2 \sin[2\sqrt{A}y]}{3A^{3/2}(-1+n)}$

By The associated boundary conditions are:

$$u_{01}(-1) = u_{01}(1) = 0.$$

we found $C_3 = 0$ and $C_4 = \frac{B^2 e^{i\omega t} n \csc[\sqrt{A}] \sec[\sqrt{A}]^2 \sin[2\sqrt{A}]}{3A^{3/2}(-1+n)}$,

Hence, the final form of the solution of the equation (2.39) is

$$u_{01} = \left(\frac{B^2 e^{i\omega t} n \csc[\sqrt{A}] \sec[\sqrt{A}]^2 \sin[2\sqrt{A}]}{3A^{3/2}(-1+n)} \right) \sin[\sqrt{A}y] - \frac{B^2 e^{i\omega t} n \sec[\sqrt{A}]^2 \sin[2\sqrt{A}y]}{3A^{3/2}(-1+n)}. \quad (2.40)$$

From the solution of equations (2.38) and (2.40), the resulting substitution in equation (2.34) after substitution in equation (2.36), we obtain the solution of the equation of motion in the case of Poiseuille flow

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$$\begin{aligned}
 u(y, t) = & \left(\frac{B}{A} + \left(-\frac{B \operatorname{Sec}[\sqrt{A}h]}{A} \right) \cos[\sqrt{A}y] + \right. \\
 & We \left(\left(\frac{B^2 e^{i\omega} n \operatorname{Csc}[\sqrt{A}] \operatorname{Sec}[\sqrt{A}]^2 \sin[2\sqrt{A}]}{3A^{3/2}(-1+n)} \right) \sin[\sqrt{A}y] - \right. \\
 & \left. \left. \frac{B^2 e^{i\omega} n \operatorname{Sec}[\sqrt{A}]^2 \sin[2\sqrt{A}y]}{3A^{3/2}(-1+n)} \right) \right) e^{i\omega t}
 \end{aligned} \tag{2.41}$$

ii-Couette flow:

Assume here that the flow channel is two parallel plates, the lower plate is at rest and the upper plate is moving with the velocity U_0 . The boundary conditions for the problem in the non-dimensional form are:

$$\begin{aligned}
 u(-1) &= 0, \quad u(1) = U_0. \\
 \left. \begin{aligned} 0 &= u(-1, t) = u_0(-1)e^{i\omega t} \\ &\Rightarrow u_0(-1) = 0 \end{aligned} \right\} \\
 \left. \begin{aligned} U_0 &= u(1, t) = u_0(1)e^{i\omega t} \\ &\Rightarrow u_0(1) = U_0 e^{-i\omega t} \end{aligned} \right\}
 \end{aligned}$$

So will use the perturbation technique to find the solution of problem as follows:

$$\begin{aligned}
 u_0 &= u_{00} + We u_{01} + O(We^2) \\
 \left. \begin{aligned} 0 &= u_0(-1) = u_{00}(-1) + We u_{01}(-1) \\ &\Rightarrow u_{00}(-1) = 0, u_{01}(-1) = 0 \end{aligned} \right\} \\
 \left. \begin{aligned} U_0 e^{-i\omega t} &= u_0(1) = u_{00}(1) + We u_{01}(1) \\ &\Rightarrow u_{00}(1) = U_0 e^{-i\omega t}, u_{01}(1) = 0 \end{aligned} \right\}
 \end{aligned}$$

The velocity equation appears as a very long function. Therefore, we limited ourselves to explaining its effect through graphs of the velocity function in the case of Couette flow

2.6.2 Solutions of the shear stress

To solve the shear stress equation (2.24) in two cases "Poiseuille flow and Couette flow".

I-**The shear stress of the tangent hyperbolic fluid for Poiseuille flow**

By deriving equation (2.41) and putting it in the equation (2.24), we obtain;

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$$\begin{aligned}
 \mathcal{S}_{xy} = & (1 - n) \left(e^{i\omega t} \left(\frac{B \operatorname{Sec}[\sqrt{A}] \operatorname{Sin}[\sqrt{A}y]}{\sqrt{A}} + \right. \right. \\
 & We \left(- \frac{2B^2 e^{i\omega t} n \operatorname{Cos}[2\sqrt{A}y] \operatorname{Sec}[\sqrt{A}]^2}{3A(-1+n)} + \right. \\
 & \left. \left. \frac{B^2 e^{i\omega t} n \operatorname{Cos}[\sqrt{A}y] \operatorname{Csc}[\sqrt{A}] \operatorname{Sec}[\sqrt{A}]^2 \operatorname{Sin}[2\sqrt{A}]}{3A(-1+n)} \right) \right) \left. \right) + \\
 & nWe \left(e^{i\omega t} \left(\frac{B \operatorname{Sec}[\sqrt{A}] \operatorname{Sin}[\sqrt{A}y]}{\sqrt{A}} + \right. \right. \\
 & We \left(- \frac{2B^2 e^{i\omega t} n \operatorname{Cos}[2\sqrt{A}y] \operatorname{Sec}[\sqrt{A}]^2}{3A(-1+n)} + \right. \\
 & \left. \left. \frac{B^2 e^{i\omega t} n \operatorname{Cos}[\sqrt{A}y] \operatorname{Csc}[\sqrt{A}] \operatorname{Sec}[\sqrt{A}]^2 \operatorname{Sin}[2\sqrt{A}]}{3A(-1+n)} \right) \right) \left. \right)^2 \quad (2.42)
 \end{aligned}$$

II- The shear stress of the tangent hyperbolic fluid for Couette flow

By compensation the equation (2.42) into the equation (2.24), and by using "MATHEMATICA 13" program, where obtain too long results, so we confined ourselves to the interpretation of the illustrations only.

Where $A = \frac{i\omega Re}{(n-1)}$ and $B = \frac{\lambda}{(n-1)}$ in two cases "Poiseuille flow and Couette flow".

2.6.3 Solutions of the Temperature

To solve the temperature equation (2.32) with boundary conditions. $\theta(-1) = 0$, $\theta(1) = 1$.

$$\text{Let } \theta(y, t) = \theta_0(y) e^{i\omega t} \quad (2.45)$$

$$\theta(-1) = 0 \Rightarrow \theta_0(-1) e^{i\omega t} = 0 \Rightarrow \theta_0(-1) = 0,$$

$$\theta(1) = 1 \Rightarrow \theta_0(1) e^{i\omega t} = 1 \Rightarrow \theta_0(1) = e^{-i\omega t}.$$

Substituting the equation (2.45) into the equation (2.32), we have;

$$\begin{aligned}
 Pe \frac{\partial}{\partial t} (\theta_0(y) e^{i\omega t}) &= \frac{\partial^2}{\partial y^2} (\theta_0(y) e^{i\omega t}) + N^2 (\theta_0(y) e^{i\omega t}) + Br(1 - \\
 & n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3.
 \end{aligned}$$

By dividing by $e^{i\omega t}$, and after simplification, we have

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$$\Rightarrow \frac{\partial^2 \theta_0}{\partial y^2} + (N^2 - i\omega Pe)\theta_0 = -e^{-i\omega t} \left(Br(1-n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3 \right). \quad (2.46)$$

The solution of equation (2.46) is non-homogeneous diffraction equation, so that the general solution of this equation is $\theta_0(y) = \theta_{0h}(y) + \theta_{0p}(y)$, where θ_{0h} is solution of the homogeneous part of the equation (2.46), where $\theta_{0p}(y)$ is a particular solution of equation (2.46), now the general solution of equation (2.46), is

$$\theta_0 = \frac{D}{S} + C_1 \cos[\sqrt{S}y] + C_2 \sin[\sqrt{S}y].$$

$$\theta_{0h}(y) = C_1 \cos[\sqrt{S}y] + C_2 \sin[\sqrt{S}y], \theta_{0p}(y) = \frac{D}{S}$$

and the constant C_1 and C_2 , can be found by boundary conditions are:

$$\theta_0(-1) = 0, \theta_0(1) = e^{-i\omega t}.$$

Now dividing the solution of the equation (2.46) into two types of boundary conditions for motion flow, Poiseuille flow condition and Couette flow condition, respectively;

$$\text{Where } S = N^2 - i\omega Pe, \text{ and } D = -e^{-i\omega t} \left(Br(1-n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3 \right).$$

Hence, the final form of the solution of the equation (2.46) is

I-The temperature of the tangent hyperbolic fluid for Poiseuille flow

$$\theta_0 = \frac{D}{S} + \left(-\frac{e^{-i\omega t}(2De^{it\omega} - S)\sec[\sqrt{S}]}{2S} \right) \cos[\sqrt{S}y] + \left(\frac{1}{2}e^{-i\omega t} \csc[\sqrt{S}] \right) \sin[\sqrt{S}y] \quad (2-47)$$

$$\text{where } D = -e^{-i\omega t} \left(Br(1-n) \left(e^{it\omega} \left(\frac{B\sec[\sqrt{A}]\sin[\sqrt{A}y]}{\sqrt{A}} + We \left(-\frac{2B^2e^{it\omega}n\cos[2\sqrt{A}y]\sec[\sqrt{A}]}{3A(-1+n)} + \frac{1}{3A(-1+n)} B^2e^{it\omega}n\cos[\sqrt{A}y]\csc[\sqrt{A}]\sec[\sqrt{A}]^2\sin[2\sqrt{A}y] \right) \right) \right)^2 + n * Br * We \left(e^{it\omega} \left(\frac{B\sec[\sqrt{A}]\sin[\sqrt{A}y]}{\sqrt{A}} + \right. \right.$$

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$$We \left(-\frac{2B^2 e^{it\omega} n \cos[2\sqrt{A}y] \sec[\sqrt{A}]^2}{3A(-1+n)} + \frac{1}{3A(-1+n)} B^2 e^{it\omega} n \cos[\sqrt{A}y] \csc[\sqrt{A}] \sec[\sqrt{A}]^2 \sin[2\sqrt{A}y] \right)^3 \Bigg),$$

where $S = N^2 - i\omega Pe$, $A = \frac{i\omega Re}{n-1}$, $B = \frac{\lambda}{n-1}$

II-The temperature of the tangent hyperbolic fluid for Couette flow

The temperature equation appears as a very long function. Therefore, we limited ourselves to explaining its effect through graphs of the temperature function in the case of Couette flow.

2.7- Numerical Results and Discussion

In this section, we discuss graphically oscillatory flow and its effect on the temperature of tangent hyperbolic fluid through a horizontal channel medium for Poiseuille flow and Couette flow. Through the MATHEMATICA-13 program, we discuss all the solutions we obtain graphically. Under the influence of different parameters related to the fluid (velocity, shear stress and temperature), important results are displayed in the figure (2.2) - (2.22), width of the flow channel area $-1 \leq y \leq 1$.

1-Figures (2.2) - (2.7), show the effect of parameters with ω, n, Re, t, We, i , and λ on fluid velocity, each figure compares two types of flow, (a) represent Poiseuille flow, and (b) represent Couette flow. Figure (2.2) shows the velocity profile u decreases with ω rise. Figure (2.3) shows the velocity profile u increases and more clearly in the middle of the channel when n increases. The velocity profile u decreases when Re increases, as see in Figure (2.4). Figure (2.5) Shows the velocity in flow Poiseuille increases in the upper wall while it decreases in the lower wall of the channel when the parameter We increases, while in flow Couette the velocity increases along the channel as We increases. Figure (2.6 illustrates that as the parameters λ increases, the velocity profile u rise. Figure (2.7)

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shows that u increases with increases t . We noticed from drawings (2.2) - (2.7) that the fluid flow velocity in the case of (Couette flow) is more than that of (Poiseuille flow) due to the movement of the upper wall of the channel at a constant velocity ($U_0 = 0.3$).

2-Figures (2.8) – (2.13) show the effect of parameters with ω, Re, n, t, W_e, i , and λ on the shear stress, each figure compares two types of flow, (a) representing shear stress when the flow is Poiseuille, and (b) representing shear stress when the flow is Couette. Figure (2.8)- (2.10) show us that with the increasing of the parameters ω , n and Re the shear stress increases when $0 < y \leq 1$, and decreases when $-1 \leq y < 0$ in two flows. Figure (2.11) show us that with the increasing of W_e the shear stress increases in Poiseuille flow, while in Couette flow the shear stress decreasing. Figures (2.12) and (2.13) illustrations the influence of the parameters λ and t on the shear stress increases when $-1 < y \leq 0$ while decreases when $0 \leq y < 1$ in two flows.

3-Figures (2.14) - (2.22) show the effect of parameters with $\omega, n, N, Re, W_e, Pe, \beta_r, t, i$, and λ on the temperature profile appears, each figure compares two types of flow, (a) representing Poiseuille flow, and (b) representing Couette flow. Figure (2.14) indicates that as ω increases, the temperature lowers. Figure (2.15) show us that with the increasing of n the temperature decreases in Poiseuille flow, while in Couette flow the temperature increasing. The temperature rises as N increases, as seen in Figure (2.16). As seen in Figure (2.17), the temperature lowers as Re increases. As for the We parameter, it decreases the fluid temperature near the upper channel wall and vice versa at the lower wall of the flow channel, where the fluid temperature increases with the increase of the We parameter in Poiseuille flow, while in Couette flow temperature decreasing, which is clear in Figure (2.18). As seen in Figure (2.19), the temperature rises as λ increases. Figure (2.20) we can observe that as Pe

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increases, the temperature lowers in Poiseuille flow, and Couette flow. As seen in Figure (2.21), the temperature rises as β_r increases. In Figure (2.22) we can observe that as t increases, the temperature profile lowers in Poiseuille flow, and Couette flow.

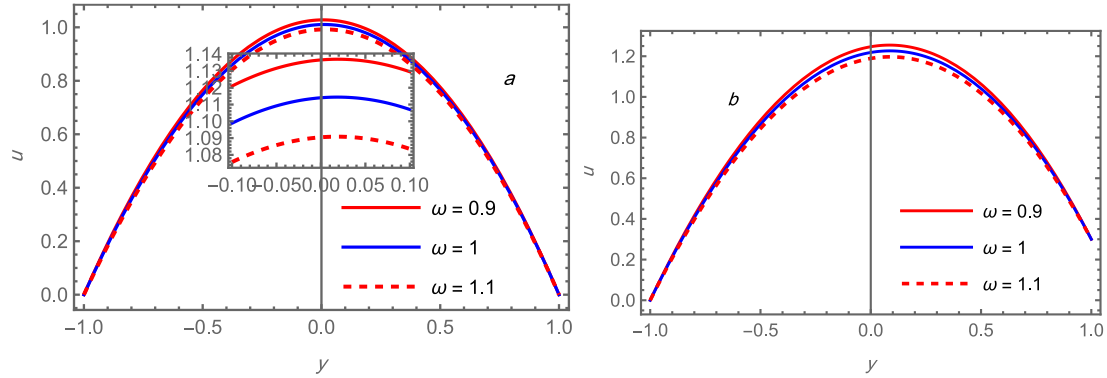


Figure 2.2 Velocity profile with different values ω for (a) Poiseuille flow and (b) Couette flow, with $n = 0.2$, $Re = 1$, $We = 0.1$, $\lambda = 2$, $t = 0.5$, $U_0 = 0.3$.

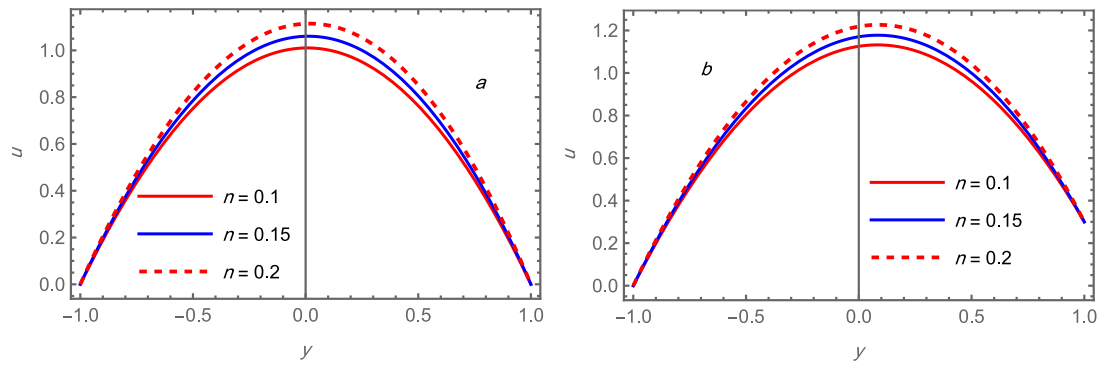


Figure 2.3 Velocity profile with different values n for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1$, $Re = 1$, $We = 0.1$, $\lambda = 2$, $t = 0.5$, $U_0 = 0.3$.

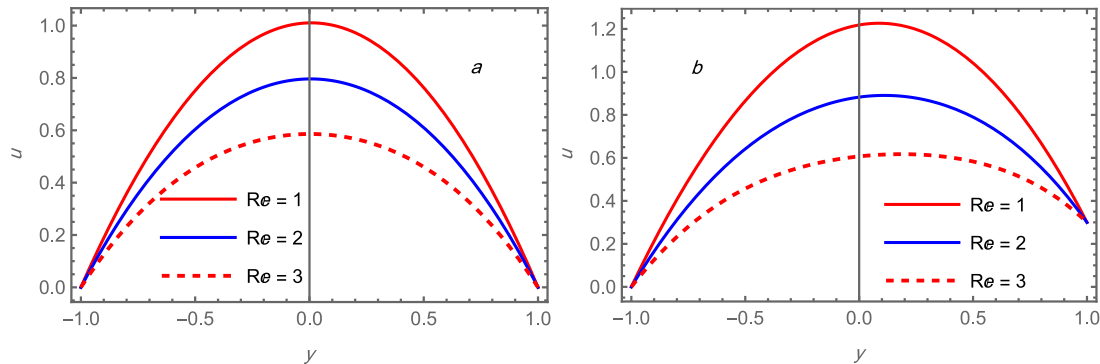


Figure 2.4 Velocity profile with different values Re for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1$, $n = 0.2$, $We = 0.1$, $\lambda = 2$, $t = 0.5$, $U_0 = 0.3$.

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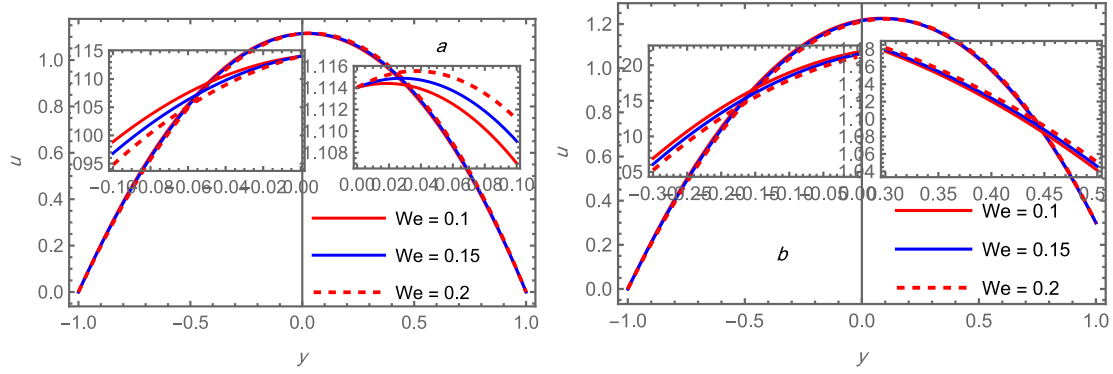


Figure 2.5 Velocity profile with different values We for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, \lambda = 2, t = 0.5, U_0 = 0.3$.

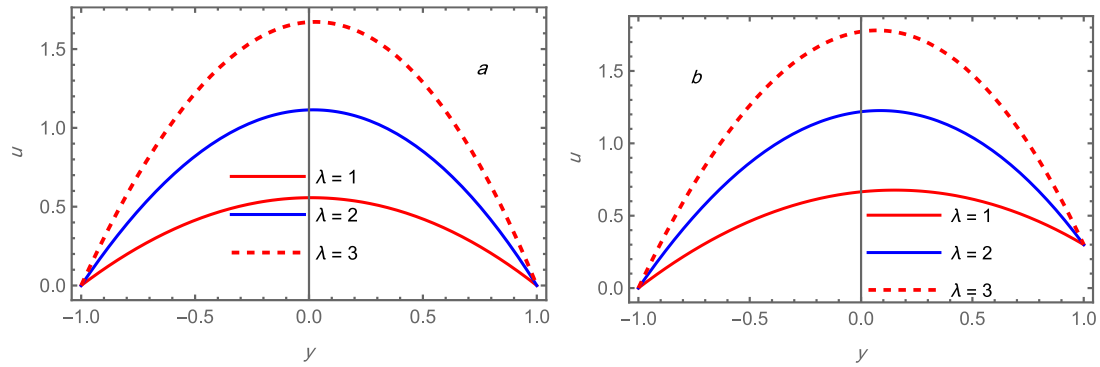


Figure 2.6 Velocity profile with different values λ for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, We = 0.1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

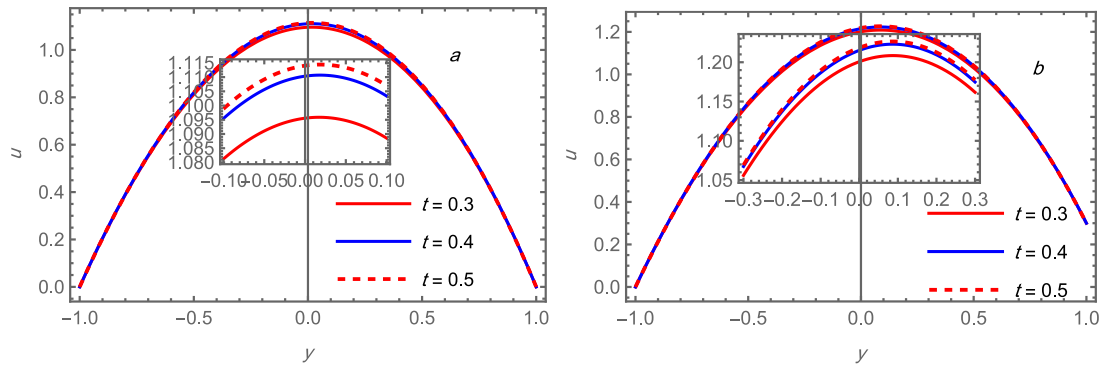


Figure 2.7 Velocity profile with different values t for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, We = 0.1, \lambda = 2, U_0 = 0.3$.

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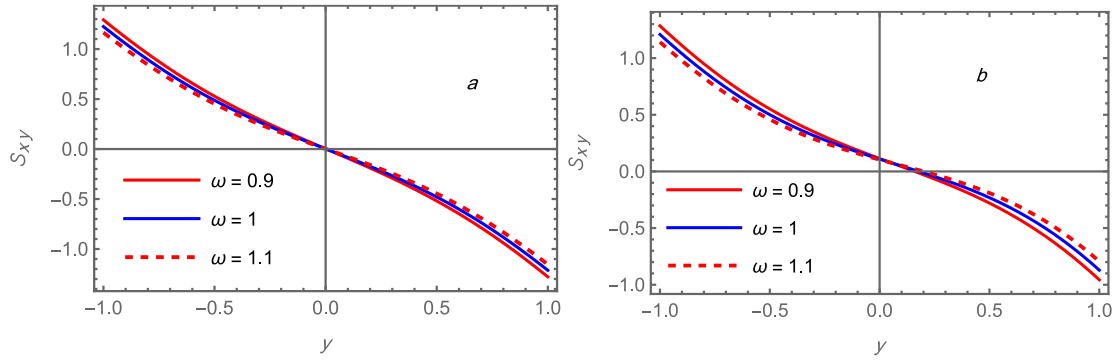


Figure 2.8 Shear stress profile with different values ω for (a) Poiseuille flow and (b) Couette flow, with $n = 0.2, Re = 3, We = 0.1, \lambda = 2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

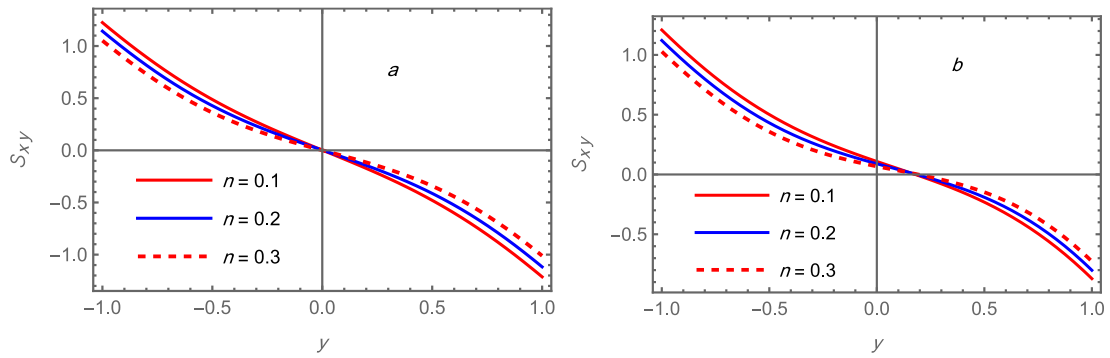


Figure 2.9 Shear stress profile with different values n for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, Re = 3, We = 0.1, \lambda = 2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

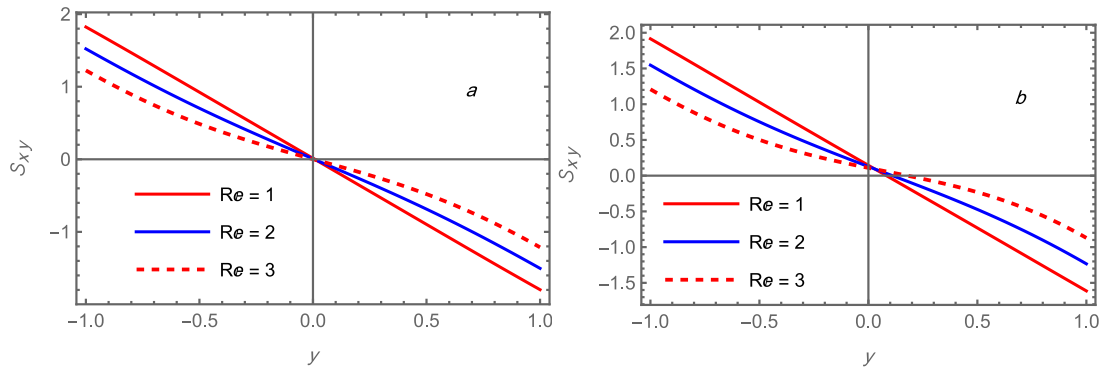


Figure 2.10 Shear stress profile with different values Re for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, We = 0.1, \lambda = 2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

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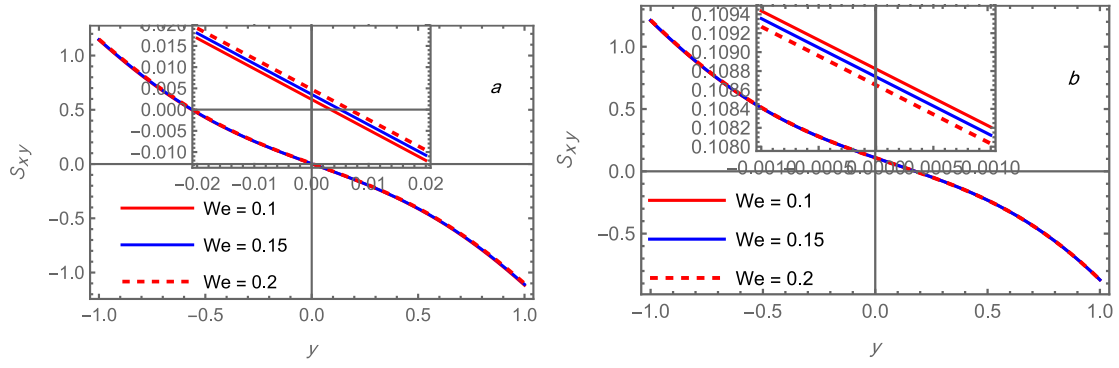


Figure 2.11 Shear stress profile with different values We for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 3, \lambda = 2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

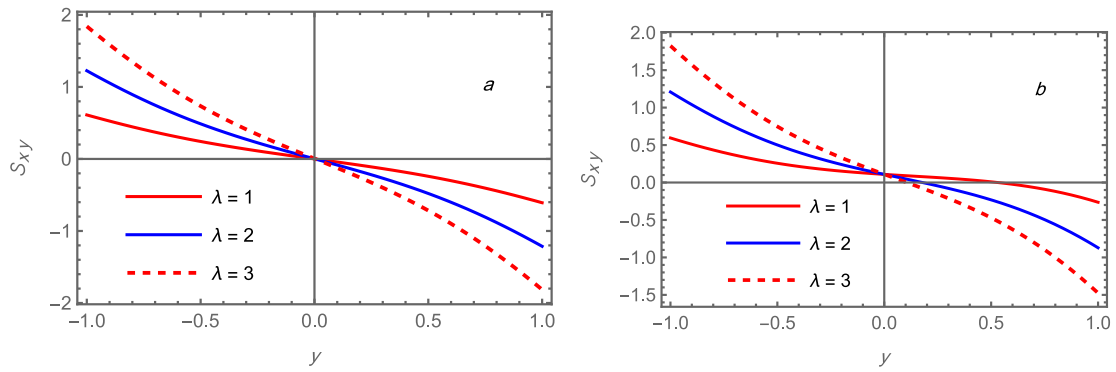


Figure 2.12 Shear stress profile with different values λ for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 3, We = 0.1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

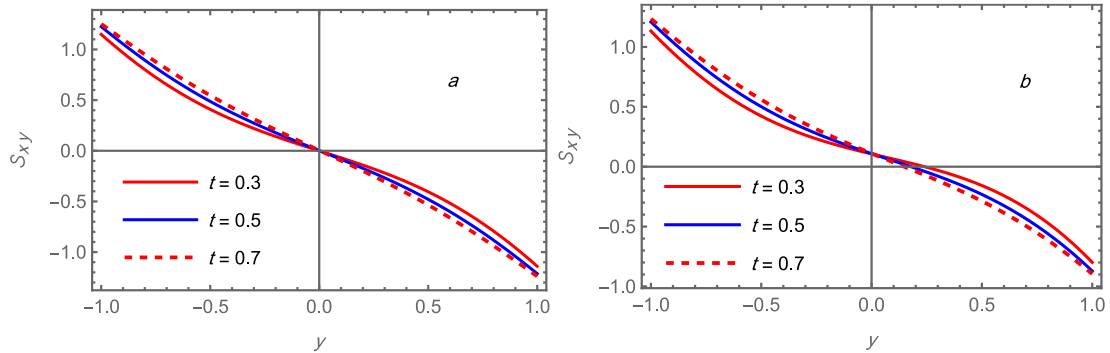


Figure 2.13 Shear stress profile with different values t for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 3, We = 0.1, \lambda = 2, i = \sqrt{-1}, U_0 = 0.3$.

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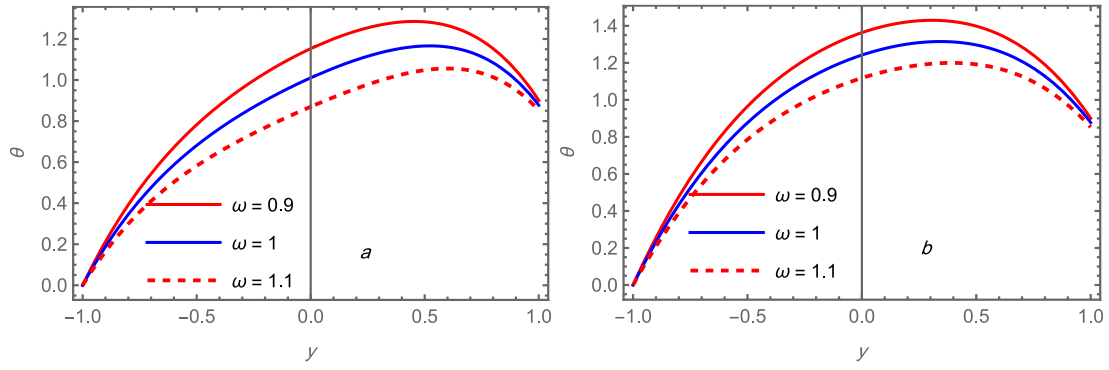


Figure 2.14 Temperature profile with different values ω for (a) Poiseuille flow and (b) Couette flow, with $N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

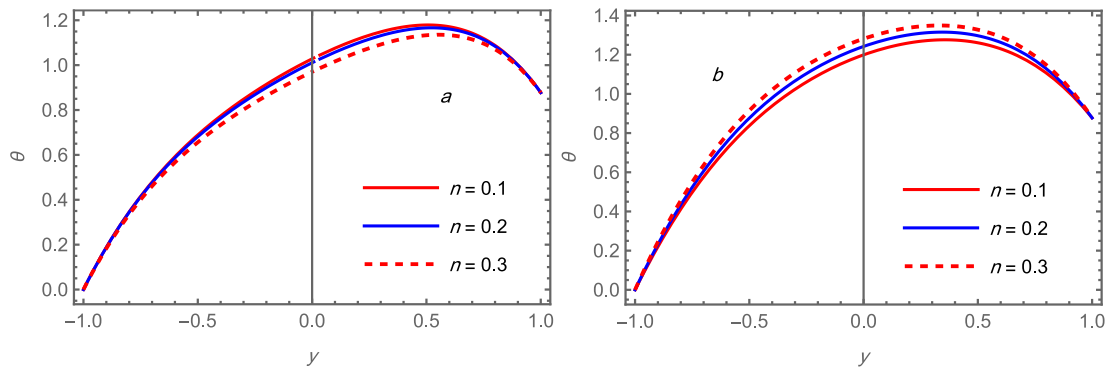


Figure 2.15 Temperature profile with different values n for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, R_e = 1, W_e = 0.1, \lambda = 2, Pe = 0.5, Br = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

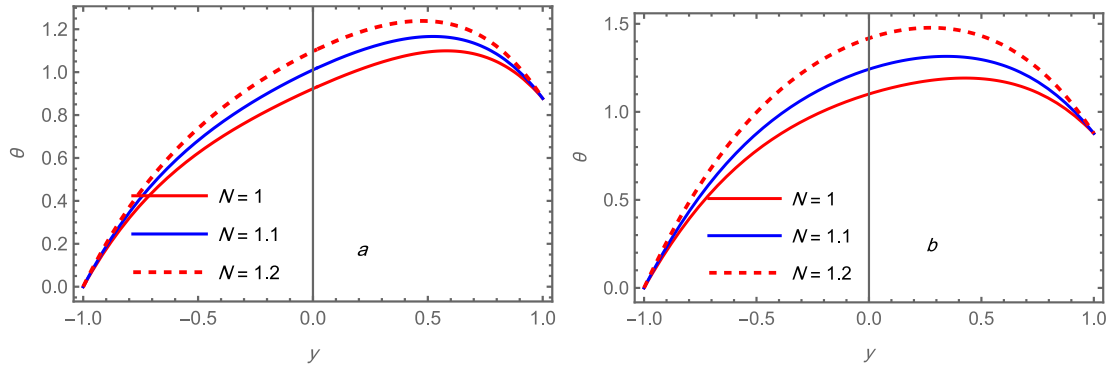


Figure 2.16 Temperature profile with different values N for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, Pe = 0.5, Br = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

Analyze of oscillatory flow its effect on the temperature of tangent hyperbolic fluid through a horizontal channel

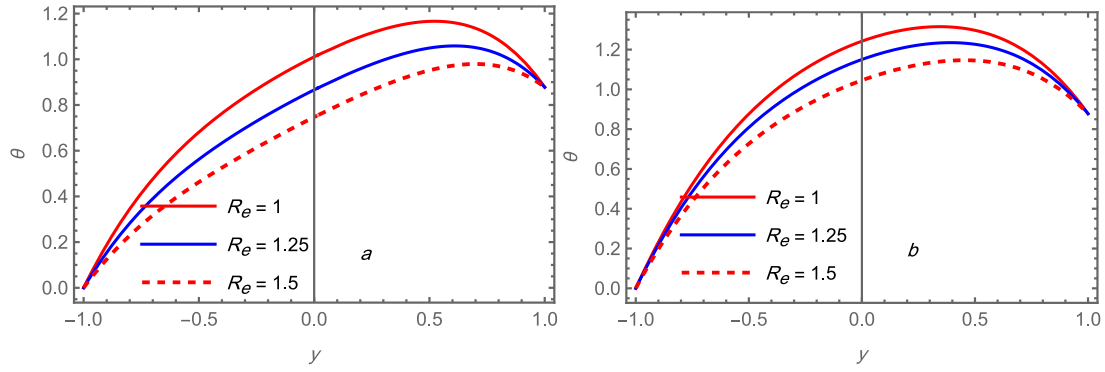


Figure 2.17 Temperature profile with different values R_e for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, W_e = 0.1, \lambda = 2, Pe = 0.5, Br = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

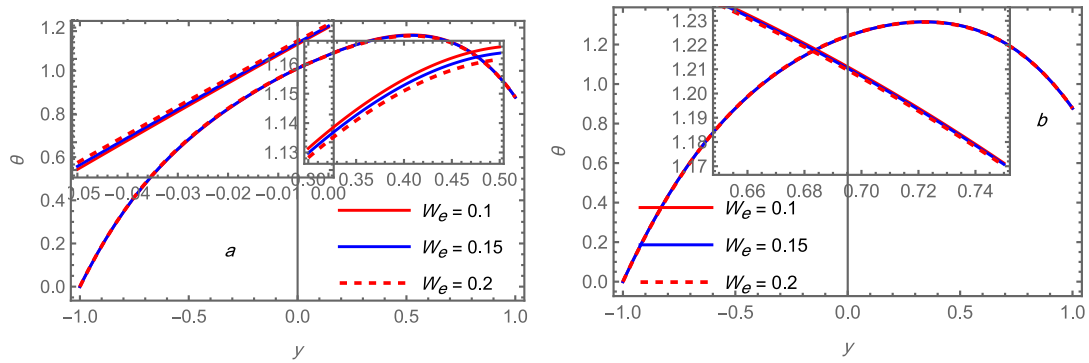


Figure 2.18 Temperature profile with different values W_e for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, \lambda = 2, Pe = 0.5, Br = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

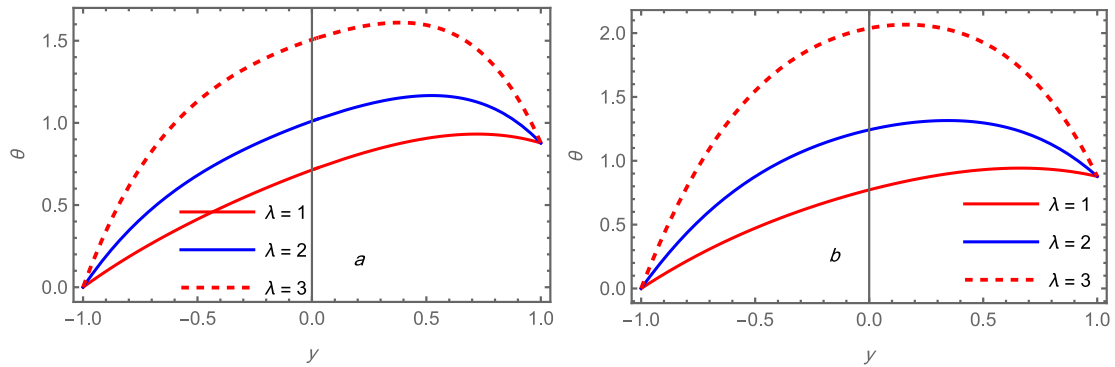


Figure 2.19 Temperature profile with different values λ for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, Pe = 0.5, Br = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

Analyze of oscillatory flow its effect on the temperature of tangent hyperbolic fluid through a horizontal channel

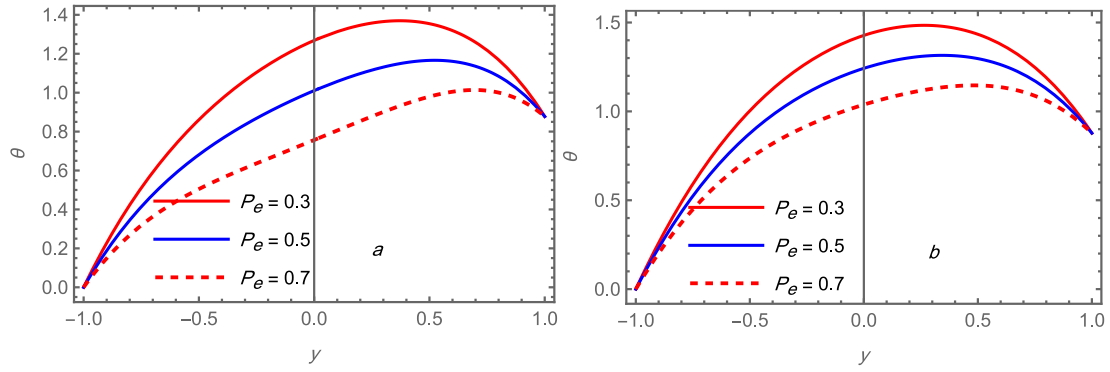


Figure 2.20 Temperature profile with different values Pe for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, Br = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

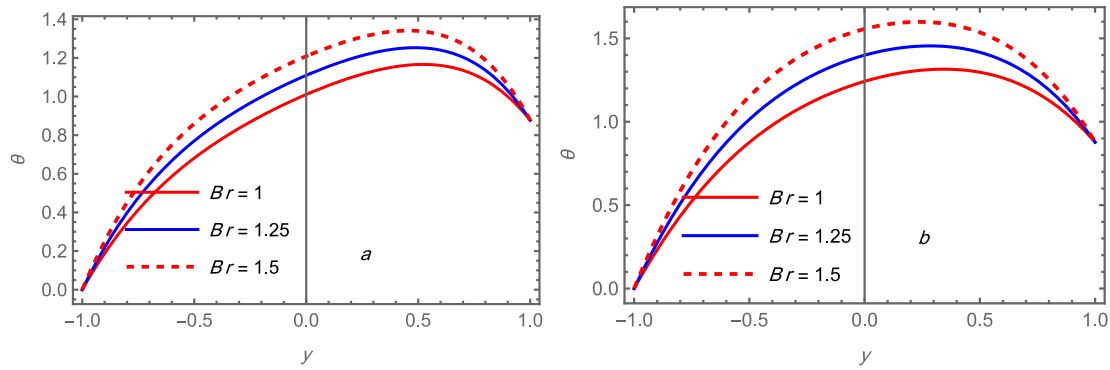


Figure 2.21 Temperature profile with different values Br for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, Pe = 0.5, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

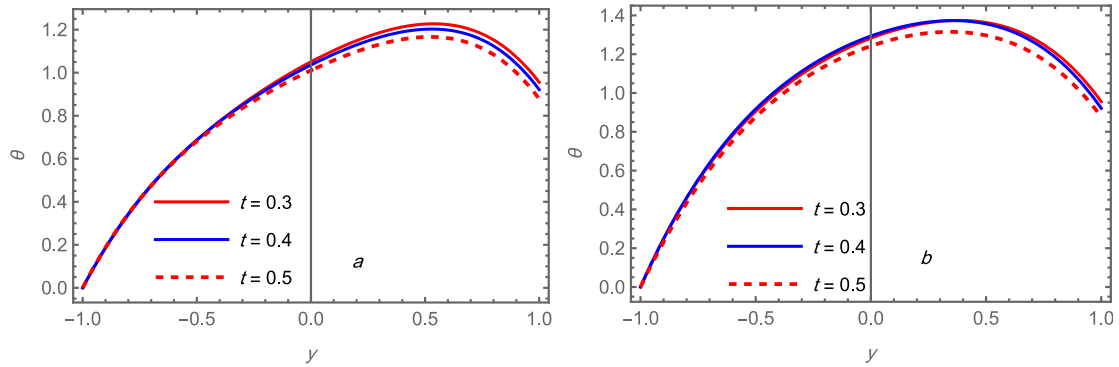


Figure 2.22 Temperature profile with different values t for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, Pe = 0.5, Br = 1, i = \sqrt{-1}, U_0 = 0.3$.

Analyze of oscillatory flow its effect on the temperature of tangent hyperbolic fluid through a horizontal channel

2.8- Conclusion Remarks

Here, we investigate the oscillatory flow and temperature of tangent hyperbolic fluid through a regular channel. We used the Mathematica"13" program to discuss the effect of parameters on the movement of liquids by explaining the graphs obtained, and we will highlight some of the key findings:

1. The movement of the upper wall of the channel at a constant speed ($U_0 = 0.3$) in the case of Couette flow caused the speed of the fluid flow inside the channel to be higher than its speed in the case of Poiseuille flow.
2. The velocity in Poiseuille flow and Couette flow increase by the increase n , t , and λ while in W_e increasing when $0 \leq y \leq 1$,and decreases when $-1 \leq y \leq 0$.
3. The velocity in the Poiseuille flow and Couette flow decreases by the increasing R_e and ω .
4. The temperature in the Poiseuille flow and Couette flow decreases by the increase R_e and while the temperature was increased by the increase N , λ and β_r .
5. When the parameter n and ω is increased, the temperature decreases in Poiseuille flow while it increases in Couette flow.
6. When the parameter W_e is increased, the temperature decreases over time $0 \leq y \leq 1$, while it increases at $-1 \leq y \leq 0$.

Chapter Three

Analysis of the MHD Oscillatory
Flow and Its Effect on The
Temperature and Concentration of
Tangent Hyperbolic Fluid Through
a Regular Permeable Channel

3.1 Introduction

There is a lot of research studying the effect of magnetic fields and channel permeability on the flow characteristics of various fluids. In their study, Migtaa and Al-Khafajy [36] examine the impact of heat transfer on the oscillatory flow of Carreau-Yasuda fluid through a porous media in the context of magnetohydrodynamics (MHD). They specifically investigate two types of geometries, Poiseuille and Couette.

This chapter aim to discuss the oscillatory flow for hyperbolic tangent fluid through a regular permeable channel with a magneto field and its effect on the temperature and concentration, we examined the influences of certain parameters that are active on fluid velocity by analyzing the graphs obtained after we reached the momentum equation solution, and used the MATHEMATICA program for plot the velocity and temperature of the fluid for two types of flow (Poiseuille and Couette).

3.2 Mathematical Formulation:

Adopted a magnetic field with the effect of a simple electric current on a fluid stream through a horizontal channel with small holes in its wall to build a mathematical model that controls the oscillating flow of a tangential hyperbolic fluid. the channel has a width of $2h$, and the upper channel wall is affected by a temperature of T_1 , so the fluid concentration is C_1 while the lower channel wall temperature is T_0 and the fluid concentration is C_0 , and takes two states: the first is stationary (Poiseuille flow), and the second is moving at a constant speed (Couette flow). We adopted Cartesian coordinates, where x represents the horizontal axis while the vertical axis is y and represents the flow field $(u(y, t), 0, 0)$, which fulfills the continuity equation.

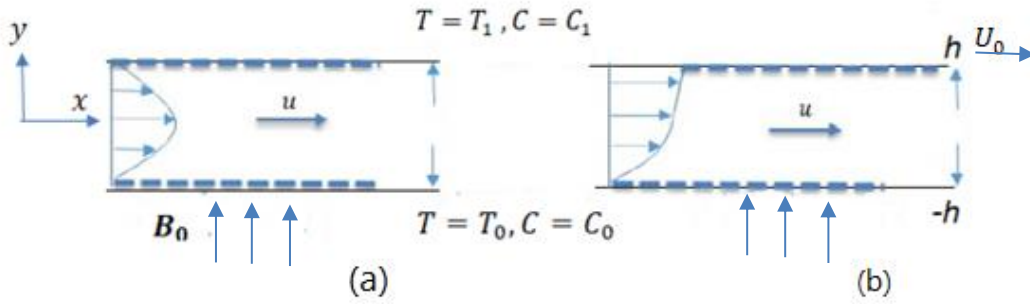


Figure 3-1: Channel format: (a) Poiseuille flow and (b) Couette flow [23].

3.3 Basic Equations [23]

The basic equations governing for the problem are given by:

The continuity equation:

$$\text{div } \bar{V} = 0. \quad (3.1)$$

The momentum equation:

$$\rho(\bar{V} \cdot \nabla) \bar{V} = -\nabla \bar{p} + \text{div } \bar{S} + \bar{J} \times \bar{B} - \frac{\mu_c}{k} \bar{V}. \quad (3.2)$$

The temperature equation:

$$c_T \rho(\bar{V} \cdot \nabla) T = K_T \nabla^2 T + \bar{S} \cdot (\text{grad } \bar{V}) - \nabla Q. \quad (3.3)$$

The concentration equation:

$$(\bar{V} \cdot \nabla)C = D \nabla^2 C - K_r^*(C - C_0) + \frac{DK_H}{T_m} \nabla^2 T. \quad (3.4)$$

where $V \equiv (u(y, t), 0, 0)$ is the velocity field, $T(y, t)$ is a fluid temperature, $C(y, t)$ is a fluid concentration, $\bar{p}$ "pressure", $\bar{\mathcal{S}}$ "extra stress tensor", $\bar{J}$ "induced current", $\bar{B} = (0, B_0, 0)$ the field of magnetic, μ_c "constant viscosity", ρ "fluid density", k "permeability", c_T "specific heat at constant pressure", K_T "thermal conductivity", Q "radioactive heat flux", D "coefficient of mass diffusivity", K_r^* "chemical reaction coefficient", K_H "thermal diffusion ratio" and T_m "the mean fluid temperature".

3.4 Calculation of Lorentz force:

To calculate the Lorentz force will be applied a magnetic field only in y - direction $(0, B_0, 0)$ and then, we study the effect of it on the fluid flow as follows:

$$V \times B = \begin{vmatrix} i & j & k \\ u & 0 & 0 \\ 0 & B_0 & 0 \end{vmatrix} = B_0 u k.$$

By definition of Ohm's low getting:

$$J = \sigma(E + V \times B) = \sigma B_0 u k.$$

So,

$$J \times B = \begin{vmatrix} i & j & k \\ 0 & 0 & \sigma B_0 u \\ 0 & B_0 & 0 \end{vmatrix} = -\sigma B_0^2 u i, \quad (3.5)$$

when u, v and w it's the velocity components in the directions x, y and z , i, j and k are unit vectors, E the field of electric, σ the electrical conductivity, J current density (or conduction current).

3.5 Constitutive Equation:

The fundamental equation for the tangent hyperbolic fluid given by: [22], [37]

$$\bar{\mathcal{S}} = [\mu_\infty + (\mu_c + \mu_\infty) \tanh(\Gamma \bar{\dot{\gamma}})^n] \bar{\dot{\gamma}} \quad (3.6)$$

where μ_c is the constant viscosity, $\bar{\dot{\gamma}}$ is the shear rate, μ_∞ infinity shear rate viscosity, Γ time constant, n the dimensionless power law index

In this study the constitutive equation considered when $\mu_\infty=0$. It has been considered the tangent hyperbolic fluid which represent shear thinning characteristics when $\Gamma\bar{\dot{\gamma}} < 1$. Therefore Eq (3.5) becomes:

$$\begin{aligned}\bar{\mathcal{S}} &= \mu_c[(\Gamma\bar{\dot{\gamma}})^n]\bar{\dot{\gamma}} \\ \bar{\mathcal{S}} &= \mu_c[1 + n(\Gamma\bar{\dot{\gamma}} - 1)]\bar{\dot{\gamma}}\end{aligned}\quad (3.7)$$

and $\bar{\dot{\gamma}}$ the Rivlin-Ericksen [22] tensors which is defined by:

$$\bar{\dot{\gamma}} = \nabla\bar{V} + (\nabla\bar{V})^T \quad (3.8)$$

where $\bar{V} = (\bar{u}, \bar{v}, \bar{w})$ is the velocity field in Cartesian coordinates system (x, y, z) , $\nabla\bar{V}$ is the gradient of velocity, and $(\nabla\bar{V})^T$ is the transpose of the velocity gradient, which is given by:

$$\nabla\bar{V} = \begin{bmatrix} \bar{u}_{\bar{x}} & \bar{u}_{\bar{y}} & \bar{u}_{\bar{z}} \\ \bar{v}_{\bar{x}} & \bar{v}_{\bar{y}} & \bar{v}_{\bar{z}} \\ \bar{w}_{\bar{x}} & \bar{w}_{\bar{y}} & \bar{w}_{\bar{z}} \end{bmatrix}, \quad (\nabla\bar{V})^T = \begin{bmatrix} \bar{u}_{\bar{x}} & \bar{v}_{\bar{x}} & \bar{w}_{\bar{x}} \\ \bar{u}_{\bar{y}} & \bar{v}_{\bar{y}} & \bar{w}_{\bar{y}} \\ \bar{u}_{\bar{z}} & \bar{v}_{\bar{z}} & \bar{w}_{\bar{z}} \end{bmatrix}.$$

Then

$$\bar{\dot{\gamma}} = \begin{bmatrix} 2\bar{u}_{\bar{x}} & \bar{v}_{\bar{x}} + \bar{u}_{\bar{y}} & \bar{w}_{\bar{x}} + \bar{u}_{\bar{z}} \\ \bar{v}_{\bar{x}} + \bar{u}_{\bar{y}} & 2\bar{v}_{\bar{y}} & \bar{v}_{\bar{z}} + \bar{w}_{\bar{y}} \\ \bar{w}_{\bar{x}} + \bar{u}_{\bar{z}} & \bar{v}_{\bar{z}} + \bar{w}_{\bar{y}} & 2\bar{w}_{\bar{z}} \end{bmatrix}, \quad (3.9)$$

and $\dot{\gamma}$ is defined by;

$$\dot{\gamma} = \sqrt{\frac{1}{2} \sum_i \sum_j \dot{\gamma}_{ij} \dot{\gamma}_{ji}}.$$

Since $(u(y, t), 0, 0)$ is the velocity field, then

$$\bar{\dot{\gamma}} = \left(\frac{\partial \bar{u}}{\partial \bar{y}} \right). \quad (3.10)$$

Substituting equations (3.10) into equation (3.7), we have

$$\bar{\mathcal{S}} = \mu_c \left[1 + n \left(\Gamma \frac{\partial \bar{u}}{\partial \bar{y}} - 1 \right) \right] \frac{\partial \bar{u}}{\partial \bar{y}}. \quad (3.11)$$

The stress components are given by:

Analysis of the MHD oscillatory flow and its effect on the temperature and concentration of tangent hyperbolic fluid through a regular permeable channel

$$\begin{aligned}\bar{\mathcal{S}}_{\bar{x}\bar{x}} &= \bar{\mathcal{S}}_{\bar{y}\bar{y}} = 0, \\ \bar{\mathcal{S}}_{\bar{x}\bar{y}} &= \bar{\mathcal{S}}_{\bar{y}\bar{x}} = \mu_c \left[(1 - n) \frac{\partial \bar{u}}{\partial \bar{y}} + n \Gamma \left(\frac{\partial \bar{u}}{\partial \bar{y}} \right)^2 \right],\end{aligned}\quad (3.12)$$

and

$$\begin{aligned}\bar{\mathcal{S}} \cdot (\text{grad } \bar{V}) &= \begin{bmatrix} \bar{\mathcal{S}}_{\bar{x}\bar{x}} & \bar{\mathcal{S}}_{\bar{x}\bar{y}} \\ \bar{\mathcal{S}}_{\bar{y}\bar{x}} & \bar{\mathcal{S}}_{\bar{y}\bar{y}} \end{bmatrix} \begin{bmatrix} \bar{u}_{\bar{x}} & \bar{u}_{\bar{y}} \\ \bar{v}_{\bar{x}} & \bar{v}_{\bar{y}} \end{bmatrix} = \bar{\mathcal{S}}_{\bar{x}\bar{x}} \bar{u}_{\bar{x}} + \bar{\mathcal{S}}_{\bar{x}\bar{y}} \bar{u}_{\bar{y}} + \bar{\mathcal{S}}_{\bar{y}\bar{x}} \bar{v}_{\bar{x}} + \bar{\mathcal{S}}_{\bar{y}\bar{y}} \bar{v}_{\bar{y}} \\ \Rightarrow \bar{\mathcal{S}} \cdot (\text{grad } \bar{V}) &= \bar{\mathcal{S}}_{\bar{x}\bar{y}} \bar{u}_{\bar{y}}.\end{aligned}\quad (3.13)$$

The radioactive heat flux [50] is given by:

$$\nabla Q = 4\eta^2 (T_0 - T), \quad (3.14)$$

where Q is a radioactive heat flux, η is a radiation absorption.

Substituting equations (3.5) and (3.12) - (3.14), into equations (3.2) - (3.4), we have the following equations;

The continuity equation:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0. \quad (3.15)$$

The momentum equation in the x - direction:

$$\rho \left(\frac{\partial \bar{u}}{\partial \bar{t}} + \bar{u} \frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v} \frac{\partial \bar{u}}{\partial \bar{y}} \right) = -\frac{\partial \bar{p}}{\partial \bar{x}} + \frac{\partial \bar{\mathcal{S}}_{\bar{x}\bar{y}}}{\partial \bar{y}} - \sigma B_0^2 \bar{u} - \frac{\mu_c}{k} \bar{u}. \quad (3.16)$$

The momentum equation in the y - direction:

$$\rho \left(\frac{\partial \bar{v}}{\partial \bar{t}} + \bar{u} \frac{\partial \bar{v}}{\partial \bar{x}} + \bar{v} \frac{\partial \bar{v}}{\partial \bar{y}} \right) = -\frac{\partial \bar{p}}{\partial \bar{y}} + \frac{\partial \bar{\mathcal{S}}_{\bar{y}\bar{x}}}{\partial \bar{x}} - \sigma B_0^2 \bar{v} - \frac{\mu_c}{k} \bar{v}. \quad (3.17)$$

The temperature equation:

$$c_T \rho \left(\frac{\partial T}{\partial \bar{t}} + \bar{u} \frac{\partial T}{\partial \bar{x}} + \bar{v} \frac{\partial T}{\partial \bar{y}} \right) = K_T \left(\frac{\partial^2 T}{\partial \bar{x}^2} + \frac{\partial^2 T}{\partial \bar{y}^2} \right) + \bar{\mathcal{S}}_{\bar{x}\bar{y}} \bar{u}_{\bar{y}} - 4\eta^2 (T_0 - T). \quad (3.18)$$

The concentration equation:

$$\frac{\partial C}{\partial \bar{t}} = D \frac{\partial^2 C}{\partial \bar{y}^2} - K_r^* (C - C_0) + \frac{DK_H}{T_m} \frac{\partial^2 T}{\partial \bar{y}^2}. \quad (3.19)$$

The temperatures and concentration at the walls of the channel are given as:

$$T = T_1, C = C_1 \text{ at } \bar{y} = h, \text{ and } T = T_0, C = C_0 \text{ at } \bar{y} = -h. \quad (3.20)$$

3.6 Method of Solution:

Analysis of the MHD oscillatory flow and its effect on the temperature and concentration of tangent hyperbolic fluid through a regular permeable channel

In order to simplify the governing equations of the problem, we may introduce the following dimensionless transformations as follows:

$$\left. \begin{aligned} x = \frac{\bar{x}}{h}, y = \frac{\bar{y}}{h}, u = \frac{\bar{u}}{U}, v = \frac{\bar{v}}{U}, t = \frac{\bar{t}U}{h}, p = \frac{\bar{p}h}{\mu_c U}, \Delta T = T_1 - T_0, \\ \theta = \frac{T-T_0}{\Delta T}, \mathcal{S}_{xy} = \frac{h}{\mu_c U} \bar{\mathcal{S}}_{\bar{x}\bar{y}}, \Delta \Phi = C_1 - C_0, \Phi = \frac{C-C_0}{\Delta \Phi} \end{aligned} \right\} \quad (3.21)$$

where U "mean flow velocity".

Substituting equations (3.21) into equations (3.12) and (3.15) - (3.20), we have the following of non-dimensional equations:

$$\begin{aligned} \frac{\partial(Uu)}{\partial(xh)} + \frac{\partial(Uv)}{\partial(yh)} &= 0, \\ \rho \left(\frac{U \partial u}{\frac{h}{U} \partial t} + Uu \frac{U \partial u}{h \partial x} + Uv \frac{U \partial u}{h \partial y} \right) &= -\frac{\mu_c U}{h} \frac{\partial p}{\partial x} + \frac{\mu_c U}{h} \frac{\partial \mathcal{S}_{xy}}{\partial y} - \sigma B_0^2 Uu - \frac{\mu_c U}{k} u, \\ \rho \left(\frac{U \partial v}{\frac{h}{U} \partial t} + Uu \frac{U \partial v}{h \partial x} + Uv \frac{U \partial v}{h \partial y} \right) &= -\frac{\mu_c U}{h} \frac{\partial p}{\partial y} + \frac{\mu_c U}{h} \frac{\partial \mathcal{S}_{xy}}{\partial x} - \sigma B_0^2 Uv - \frac{\mu_c U}{k} v, \\ c_T \rho \frac{\partial(\theta(T_1-T_0)+T_0)}{\frac{h}{U} \partial t} &= K_T \left(\frac{\partial^2(\theta(T_1-T_0)+T_0)}{h^2 \partial y^2} \right) + \frac{\mu_c U}{h} \mathcal{S}_{xy} \frac{U \partial u}{h \partial y} + 4\eta^2 \theta \Delta T, \\ \frac{\partial(\Phi(C_1-C_0)+C_0)}{\frac{h}{U} \partial t} &= D \frac{\partial^2(\Phi(C_1-C_0)+C_0)}{h^2 \partial y^2} - K_r^*(\Phi(C_1 - C_0)) + \\ &\quad \frac{DK_H}{T_m} \frac{\partial^2(\theta(T_1-T_0)+T_0)}{h^2 \partial y^2}. \end{aligned}$$

implies that

$$\frac{U}{h} \left(\frac{\partial(u)}{\partial(x)} + \frac{\partial(v)}{\partial(y)} \right) = 0, \quad (3.21)$$

$$\rho \frac{U^2}{h} \frac{\partial u}{\partial t} = -\frac{\mu_c U}{h^2} \frac{\partial p}{\partial x} + \frac{\mu_c U}{h^2} \frac{\partial \mathcal{S}_{xy}}{\partial y} - \sigma B_0^2 Uu - \frac{\mu_c U}{k} u, \quad (3.22)$$

$$\rho(0) = -\frac{\mu_c U}{h^2} \frac{\partial p}{\partial y} + 0 + 0 - 0, \quad (3.23)$$

$$\begin{aligned} \frac{c_T \rho U(T_1-T_0)}{h} \frac{\partial \theta}{\partial t} &= \frac{K_T}{h^2} (T_1 - T_0) \left(\frac{\partial^2 \theta}{\partial y^2} \right) + 4\eta^2 \theta (T_1 - T_0) + \\ &\quad \frac{\mu_c U^2}{h^2} \mathcal{S}_{xy} \frac{\partial u}{\partial y}, \end{aligned} \quad (3.24)$$

$$\frac{U}{h} (C_1 - C_0) \frac{\partial \Phi}{\partial t} = \frac{D}{h^2} (C_1 - C_0) \frac{\partial^2 \Phi}{\partial y^2} - K_r^*(C_1 - C_0) \Phi + \frac{DK_H}{T_m} \frac{(T_1-T_0)}{h^2} \frac{\partial^2 \theta}{\partial y^2}. \quad (3.25)$$

$$\text{and } \frac{\mu_c U}{h} \mathcal{S}_{yx} = \mu_c \left[(1-n) \frac{U \partial u}{h \partial y} + n \Gamma \left(\frac{U \partial u}{h \partial y} \right)^2 \right]$$

$$\Rightarrow \mathcal{S}_{xy} = (1-n) \frac{\partial u}{\partial y} + n \Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2. \quad (3.26)$$

with the boundary conditions of the temperature equation and concentration equation

$$\left. \begin{aligned} \theta \Delta T + T_0 &= T_1, \Phi(C_1 - C_0) + C_0 = C_1 \text{ at } hy = h \\ \theta \Delta T + T_0 &= T_0, \Phi(C_1 - C_0) + C_0 = C_0 \text{ at } hy = -h \end{aligned} \right\} \quad (3.27)$$

Substituting the equation (3.26) into the equations (3.22) - (3.25), after that simplify the equations, we obtain;

$$\rho \frac{U h \partial u}{\mu_c \partial t} = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial y} \left((1-n) \frac{\partial u}{\partial y} + n \Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2 \right) - \frac{\sigma B_0^2 h^2}{\mu_c} u - \frac{h^2}{k} u, \quad (3.28)$$

$$\frac{\partial p}{\partial y} = 0, \quad (3.29)$$

$$\frac{c_T \rho U (T_1 - T_0)}{h} \frac{\partial \theta}{\partial t} = \frac{K_T}{h^2} (T_1 - T_0) \left(\frac{\partial^2 \theta}{\partial y^2} \right) + 4\eta^2 \theta (T_1 - T_0) + \frac{\mu_c U^2}{K_T} \left((1-n) \frac{\partial u}{\partial y} + n \Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2 \right) \frac{\partial u}{\partial y}, \quad (3.30)$$

$$\frac{\partial \Phi}{\partial t} = \frac{D}{U h} \frac{\partial^2 \Phi}{\partial y^2} - \frac{h K_r^*}{U} \Phi + \frac{D K_H}{T_m U h} \frac{(T_1 - T_0)}{(C_1 - C_2)} \frac{\partial^2 \theta}{\partial y^2}. \quad (3.31)$$

with the non-dimensional boundary conditions of the temperature equation and the concentration equation.

$$\theta = 1, \Phi = 1 \text{ at } y = 1 \text{ and } \theta = 0, \Phi = 0 \text{ at } y = -1. \quad (3.32)$$

Thus, from equation (3.28), the pressure p depended on x only.

Now the last form of the system of equations governing the flow of the tangent hyperbolic fluid is as follows;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (3.33)$$

$$\frac{\partial p}{\partial x} = -Re \frac{\partial u}{\partial t} + (1-n) \frac{\partial^2 u}{\partial y^2} + 2nWe \frac{\partial u}{\partial y} \frac{\partial^2 u}{\partial y^2} - \left(M^2 + \frac{1}{Da} \right) u, \quad (3.34)$$

$$Pe \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + N^2 \theta + Br(1-n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3, \quad (3.35)$$

$$\frac{\partial \Phi}{\partial t} = \frac{1}{S_c} \frac{\partial^2 \Phi}{\partial y^2} - K_r \Phi + S_r \frac{\partial^2 \theta}{\partial y^2}. \quad (3.36)$$

$$\mathcal{S}_{xy} = (1 - n) \frac{\partial u}{\partial y} + nWe \left(\frac{\partial u}{\partial y} \right)^2, \quad (3.37)$$

where $Re = \frac{\rho h U}{\mu_c}$ "Reynolds number", $Da = \frac{k}{h^2}$ "Darcy number", $M =$

$\sqrt{\frac{\sigma B_0^2 h^2}{\mu_c}}$ "magnetic parameter", $Pe = \frac{c_T \rho h U}{K_T}$ "Peclet number", $N = \sqrt{\frac{4\eta^2 h^2}{K_T}}$

"radiation parameter", $Pr = \frac{\mu_c c_T}{K_T}$ "Prandtl number", $Ec = \frac{U^2}{c_T \Delta T}$ "Eckert

number", $Br = Pr Ec = \frac{\mu_c c_T U^2}{K_T c_T \Delta T}$ "Brinkman number", $We = \Gamma \frac{U}{h}$

"Weissenberg number", $K_r = \frac{h K_r^*}{U}$ is the Chemical reaction parameter, $S_c =$

$\frac{U h}{D}$ is the Schmidt number, and $S_r = \frac{DK_H(T_1 - T_0)}{T_m U h (C_1 - C_2)}$ "Sort number.

The solution of equations (3.34) - (3.37) has been computed in the next section for two types of flows (Poiseuille flow and Couette flow).

3.7 Solution of the Problem:

This section contains three parts: solving the motion equation, solving the shear stress equation, solving the heat equation and solving concentration.

3.7.1 Solution of the motion equation

To solve the motion equation (3.34) in two cases "Poiseuille flow and Couette flow".

I- Poiseuille flow

Suppose that the nonslip condition, Figure 3-1 (a), that is;

$$\bar{u} = 0 \text{ at } \bar{y} = h, \text{ and } \bar{u} = 0 \text{ at } \bar{y} = -h.$$

To solve the momentum equation (3.34), let

$$-\frac{\partial p}{\partial x} = \lambda e^{i\omega t}, \quad (3.38)$$

$$u(y, t) = u_0(y) e^{i\omega t}, \quad (3.39)$$

where ω be an oscillation of frequency and λ is a real constant.

The non-dimensional boundary conditions are as follows:

$$u(1, t) = 0, \quad u(-1, t) = 0,$$

$$0 = u(1, t) = u_0(1)e^{i\omega t} \Rightarrow u_0(1) = 0,$$

$$0 = u(-1, t) = u_0(-1)e^{i\omega t} \Rightarrow u_0(-1) = 0.$$

By substituting equations (3.38) and (3.39) into equation (3.34), we have;

$$\begin{aligned} -\lambda e^{i\omega t} = & -Re \frac{\partial}{\partial t} (u_0(y)e^{i\omega t}) + (1-n) \frac{\partial^2}{\partial y^2} (u_0(y)e^{i\omega t}) + \\ & 2nWe \frac{\partial}{\partial y} (u_0(y)e^{i\omega t}) \frac{\partial^2}{\partial y^2} (u_0(y)e^{i\omega t}) - \left(M^2 + \right. \\ & \left. \frac{1}{Da} \right) u_0(y)e^{i\omega t}, \end{aligned}$$

By dividing by $e^{i\omega t}$, and after simplification, we have

$$\begin{aligned} -\lambda = & -(i\omega Re + M^2 + \frac{1}{Da})u_0 + (1-n) \frac{\partial^2 u_0}{\partial y^2} + \\ & 2nWe e^{i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2}, \end{aligned}$$

By dividing by $(n-1)$, and after simplification, we have

$$\frac{\partial^2 u_0}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_0 - \frac{2n}{n-1} We e^{i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2} = \frac{\lambda}{n-1}, \quad (3.40)$$

So will use the perturbation technique to find the solution of problem as follows:

$$u_0 = u_{00} + We u_{01} + O(We^2), \quad (3.41)$$

Now, by substituting equation (3.40) in equation (3.39), we obtain:

$$\begin{aligned} \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial^2 u_{01}}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{00} + We \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{01} - \\ \frac{2n}{1-n} We e^{i\omega t} \left(\frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial u_{01}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} + \right. \\ \left. We \frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{01}}{\partial y^2} + (We)^2 \frac{\partial u_{01}}{\partial y} \frac{\partial^2 u_{01}}{\partial y^2} \right) = \frac{\lambda}{n-1}. \end{aligned} \quad (3.42)$$

We can find the equation as following by boundary conditions are:

$$0 = u_0(1) = u_{00}(1) + We u_{01}(1) \Rightarrow u_{00}(1) = 0, u_{01}(1) = 0$$

$$0 = u_0(-1) = u_{00}(-1) + We u_{01}(-1) \Rightarrow u_{00}(-1) = 0, u_{01}(-1) = 0$$

then equating the like powers of we obtain the following results presented in the forthcoming subsections:

I - Zeros-order system (we^0)

$$\frac{\partial^2 u_{00}}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{00} = \frac{\lambda}{n-1}. \quad (3.43)$$

The associated boundary conditions are:

$$u_{00}(1) = u_{00}(-1) = 0 \quad (3.44)$$

II – First-order system (we^1)

$$\frac{\partial^2 u_{01}}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{01} = \frac{2n}{n-1} e^{i\omega t} \frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2}. \quad (3.45)$$

The associated boundary condition is:

$$u_{01}(1) = u_{01}(-1) = 0 \quad (3.46)$$

III - Zeros-order solution

Solution of Eq. (3.43) subset to the associate boundary conditions (3.44)

$$u_{00} = \frac{B}{A} + \left(-\frac{B \text{Sec}[\sqrt{A}]}{A} \right) \text{Cos}[\sqrt{A}y]. \quad (3.47)$$

IV - First-order solution

Solution of Eq. (3.45) subset to the associate boundary conditions (3.46)

$$u_{01} = \left(\frac{B^2 D \text{Csc}[\sqrt{A}] \text{Sec}[\sqrt{A}]^2 \text{Sin}[2\sqrt{A}]}{6A^{3/2}} \right) \text{Sin}[\sqrt{A}y] - \frac{B^2 D \text{Sec}[\sqrt{A}]^2 \text{Sin}[2\sqrt{A}y]}{6A^{3/2}}. \quad (3.48)$$

From the solution of equations (3.47) and (3.48), and substitution in equation (3.41), we obtain the solution of the equation of motion in the case of Poiseuille flow.

$$u_0 = \frac{B}{A} + \left(-\frac{B \text{Sec}[\sqrt{A}]}{A} \right) \text{Cos}[\sqrt{A}y] + W_e \left(\left(\frac{B^2 D \text{Csc}[\sqrt{A}] \text{Sec}[\sqrt{A}]^2 \text{Sin}[2\sqrt{A}]}{6A^{3/2}} \right) \text{Sin}[\sqrt{A}y] - \frac{B^2 D \text{Sec}[\sqrt{A}]^2 \text{Sin}[2\sqrt{A}y]}{6A^{3/2}} \right). \quad (3.49)$$

where $A = \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right)$, $D = \left(\frac{2n}{n-1} e^{i\omega t} \right)$ and $B = \left(\frac{\lambda}{n-1} \right)$

II- Couette flow:

In this case, the flow channel is two parallel plates, the lower plate is at rest and the upper plate is moving with the velocity U_0 . The boundary conditions for the problem in the non-dimensional form are:

$$u(1) = U_0, \quad u(-1) = 0.$$

$$U_0 = u(1, t) = u_0(1)e^{i\omega t} \Rightarrow u_0(1) = U_0 e^{-i\omega t}$$

$$0 = u(-1, t) = u_0(-1)e^{i\omega t} \Rightarrow u_0(-1) = 0$$

$$U_0 e^{-i\omega t} = u_0(1) = u_{00}(1) + We u_{01}(1) \Rightarrow u_{00}(1) = U_0 e^{-i\omega t}, u_{01}(1) = 0$$

$$0 = u_0(-1) = u_{00}(-1) + We u_{01}(-1) \Rightarrow u_{00}(-1) = 0, u_{01}(-1) = 0$$

The velocity equation appears as a very long function. Therefore, we limited ourselves to explaining its effect through graphs of the velocity function in the case of Couette flow

3.7.2 Solutions of the shear stress

To solve the shear stress equation (3.37) in two cases "Poiseuille flow and Couette flow".

i- The shear stress of the Tangent hyperbolic fluid for Poiseuille flow

By using the equation (3.49) into the equation (3.37), we obtain;

$$\begin{aligned} \mathcal{S}_{xy} = (1 - n) & \left(e^{it\omega} \left(\frac{B \text{Sec}[\sqrt{A}] \text{Sin}[\sqrt{A}y]}{\sqrt{A}} + \left(-\frac{B^2 D \text{Cos}[2\sqrt{A}y] \text{Sec}[\sqrt{A}]^2}{3A} + \right. \right. \right. \\ & \left. \left. \left. \frac{B^2 D \text{Cos}[\sqrt{A}y] \text{Csc}[\sqrt{A}] \text{Sec}[\sqrt{A}]^2 \text{Sin}[2\sqrt{A}]}{6A} \right) W_e \right) \right) + n * \\ & W_e \left(e^{it\omega} \left(\frac{B \text{Sec}[\sqrt{A}] \text{Sin}[\sqrt{A}y]}{\sqrt{A}} + \left(-\frac{B^2 D \text{Cos}[2\sqrt{A}y] \text{Sec}[\sqrt{A}]^2}{3A} + \right. \right. \right. \\ & \left. \left. \left. \frac{B^2 D \text{Cos}[\sqrt{A}y] \text{Csc}[\sqrt{A}] \text{Sec}[\sqrt{A}]^2 \text{Sin}[2\sqrt{A}]}{6A} \right) W_e \right) \right)^2 \end{aligned}$$

ii- The shear stress of the Tangent hyperbolic fluid for Couette flow

By using the motion equation in Couette flow into the equation (3.37), The value of the solution is very large and we will discuss it in the drawings.

3.7.3 Solutions of the Temperature

To solve the temperature equation (3.35) with boundary conditions.

$$\theta(-1) = 0, \theta(1) = 1.$$

$$\text{Let } \theta(y, t) = \theta_0(y)e^{i\omega t} \quad (3.50)$$

$$\theta(-1) = 0 \Rightarrow \theta_0(-1)e^{i\omega t} = 0 \Rightarrow \theta_0(-1) = 0$$

$$\theta(1) = 1 \Rightarrow \theta_0(1)e^{i\omega t} = 1 \Rightarrow \theta_0(1) = e^{-i\omega t}.$$

Substituting the equation (3.50) into the equation (3.35), we have;

$$Pe \frac{\partial}{\partial t} (\theta_0(y)e^{i\omega t}) = \frac{\partial^2}{\partial y^2} (\theta_0(y)e^{i\omega t}) + N^2 (\theta_0(y)e^{i\omega t}) + Br(1 - n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3$$

By dividing by $e^{i\omega t}$, and after simplification, we have

$$\frac{\partial^2 \theta_0}{\partial y^2} + (N^2 - i\omega Pe)\theta_0 = -e^{-i\omega t} \left(Br(1 - n) \left(\frac{\partial u}{\partial y} \right)^2 + nBrWe \left(\frac{\partial u}{\partial y} \right)^3 \right). \quad (3.51)$$

The solution of equation (3.51) with boundary conditions $\theta_0(1) = e^{-i\omega t}$, $\theta_0(-1) = 0$, is divided into two parts according to the type of flow "Poiseuille flow or Couette flow" and thus we get the solution.

The value of the solution is very large and we will discuss it in the drawings.

3.7.4 Solutions of the concentration

To solve the concentration equation (3.36) with boundary conditions:

$$\theta = \Phi = 1 \text{ at } y = 1 \text{ and } \theta = \Phi = 0 \text{ at } y = -1.$$

$$\Phi(-1) = 0, \Phi(1) = 1$$

$$\text{Let } \Phi(y, t) = \Phi_0(y)e^{i\omega t} \quad (3.52)$$

$$\Phi(-1) = 0 \Rightarrow \Phi_0(-1)e^{i\omega t} = 0 \Rightarrow \Phi_0(-1) = 0$$

$$\Phi(1) = 1 \Rightarrow \Phi_0(1)e^{i\omega t} = 1 \Rightarrow \Phi_0(1) = e^{-i\omega t}$$

Substituting equations (3.50) and (3.52) by equation (3.36), results in

$$\frac{\partial}{\partial t} (\Phi_0(y)e^{i\omega t}) = \frac{1}{Sc} \frac{\partial^2}{\partial y^2} (\Phi_0(y)e^{i\omega t}) - Kr(\Phi_0(y)e^{i\omega t}) + Sr \frac{\partial^2}{\partial y^2} (\theta_0(y)e^{i\omega t})$$

Implies that

$$\frac{\partial^2 \Phi_0}{\partial y^2} - S_c(K_r + i\omega)\Phi_0 + S_c S_r \frac{\partial^2 \theta_0}{\partial y^2} = 0 \quad (3.53)$$

The solution of equation (3.53) with boundary conditions $\Phi_0(-1) = 0$, $\Phi_0(1) = e^{-i\omega t}$, is divided into two parts according to the type of flow "Poiseuille flow " and thus we get the solution.

The value of the solution is very large and we will discuss it in the drawings.

3.8- Numerical Results and Discussion

In this section, we discuss graphically oscillatory flow and its effect on the temperature and the concentration of tangent hyperbolic fluid through a horizontal channel medium for Poiseuille flow and Couette flow. Through the MATHEMATICA-13 program, we discuss all the solutions we obtain graphically. Under the influence of different parameters related to the fluid (velocity, shear stress, temperature and concentration), important results are displayed in the figure (3.2) - (3.42), width of the flow channel area $-1 \leq y \leq 1$.

1. Figures (3.2) - (3.9), show the effect of parameters with $\omega, n, Re, t, We, M, Da, i$ and λ on fluid velocity, each figure compares two types of flow, (a) represent Poiseuille flow, and (b) represent Couette flow. Figure (3.2) shows the velocity profile u decreases with ω increases. Figure (3.3) shows the velocity profile u increases when n increases. Figure (3.4) shows that u decreases when Re increases. Figure (3.5) Shows the velocity in Poiseuille flow increases in the upper wall while it decreases in the lower wall of the channel when the parameter We increase, while in Couette flow the velocity increases along the channel as We increase. Figure (3.6) shows that u increases with increases λ . Figure (3.7) shows that u decreases with increases M . Figure (3.8) shows that u increases with increases Da . Figure (3.9) shows that u decreases with increases t .

2. Figures (3.10) – (3.17) show the effect of parameters with $\omega, R_e, n, t, W_e, M, Da, i$, and λ on the shear stress, each figure compares two types of flow, (a) representing shear stress when the flow is Poiseuille, and (b) representing shear stress when the flow is Couette. Figure (3.10)-(3.12) show us that with the increasing of the parameters ω , n and R_e the shear stress increases when $0 < y \leq 1$, and decreases when $-1 \leq y < 0$ in two flows. Figure (3.13) show us that with the increasing of W_e the shear stress increases. Figures (3.14) - (3.16) and (3.17) illustrations the influence of the parameters Da, λ and t on the shear stress increases when $-1 < y \leq 0$ while decreases when $0 \leq y < 1$ in two flows. Figure (3.15) show us that with the increasing of the parameter M the shear stress increases when $0 < y \leq 1$, and decreases when $-1 \leq y < 0$ in two flows.
3. Figures (3.18) - (3.28) show the effect of parameters with $\omega, n, N, R_e, W_e, Pe, \beta_r, t, M, Da, i$, and λ on the temperature profile appears, each figure compares two types of flow, (a) representing Poiseuille flow, and (b) representing Couette flow. Figure (3.18) shows the temperature profile decreases with the increasing ω . Figure (3.19) show us that with the increase of n the temperature decreases. Figure (3.20) show us that with the increase of R_e the temperature decreases. Figures (3.21) - (3.24) show us that with the increasing of W_e, λ, β_r and N the temperature increases in Poiseuille flow, and Couette flow. Figure (3.25), (3.26) and (3.28) show us that with the increasing of Pe and M and t the temperature decreases in Poiseuille flow, and Couette flow. Figure (3.27) show us that with the increasing of Da the temperature increases.
4. Figures (3.29) - (3.42) show the effect of parameters with $\omega, n, N, R_e, W_e, Pe, \beta_r, t, M, Da, K_r, S_c, S_r, i$, and λ on the concentration profile appears, each figure compares two types of flow, (a) representing Poiseuille flow, and (b) representing Couette flow. Figure (3.29) shows the

concentration profile decreases with the increasing ω . Figure (3.30) show us that with the increasing of N the concentration decreases. Figure (3.31) and (3.32) show us that with the increasing of n and Re the concentration increases. Figure (3.33) show us that with the increase of λ the concentration decreases. Figure (3.34) show us that with the increase of Pe the concentration increase. Figures (3.35) - (3.41) show us that with the increasing of $We, t, \beta_r, Da, K_r, S_c$ and S_r the concentration decreases. Figure (3.42) show us that with the increasing of M the concentration increases.

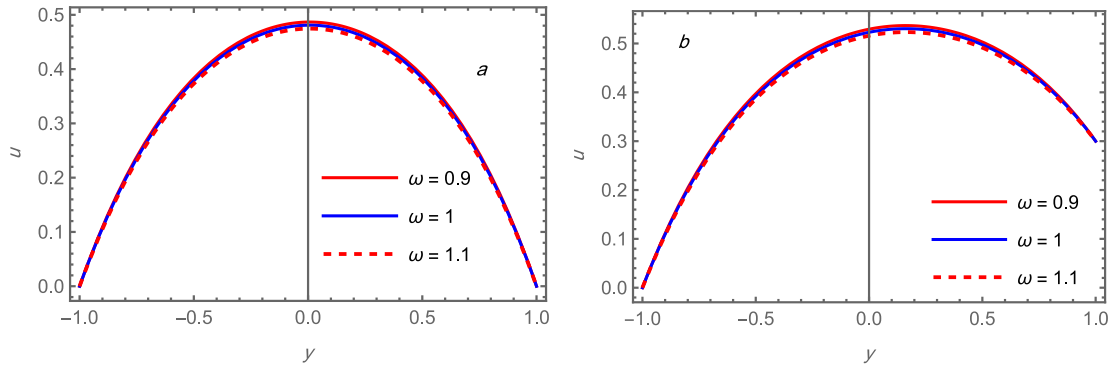


Figure 3.2 Velocity profile with different values ω for (a) Poiseuille flow and (b) Couette flow, with $n = 0.2, Re = 1, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

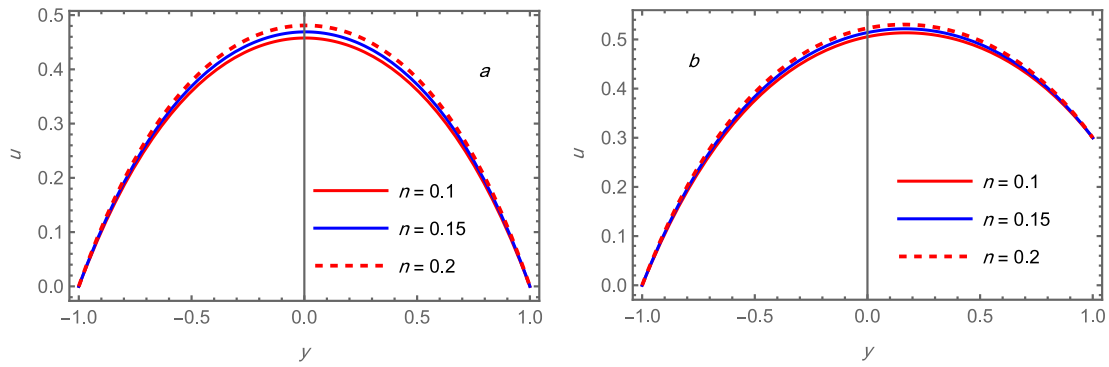


Figure 3.3 Velocity profile with different values n for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, Re = 1, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

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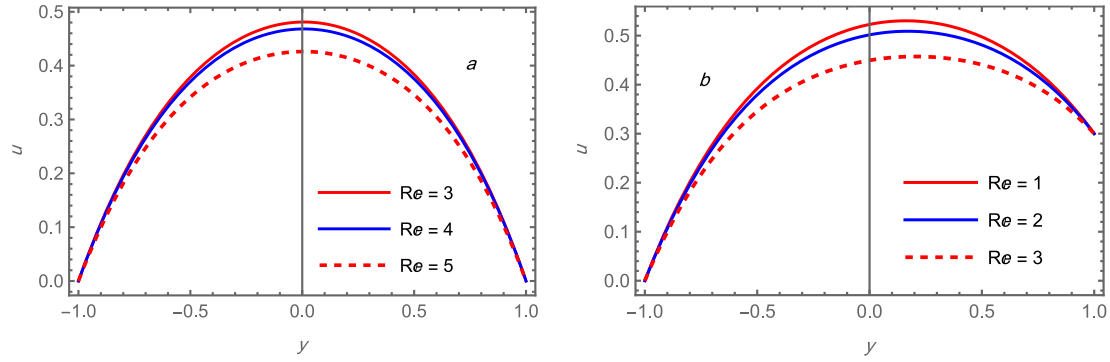


Figure 3.4 Velocity profile with different values Re for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

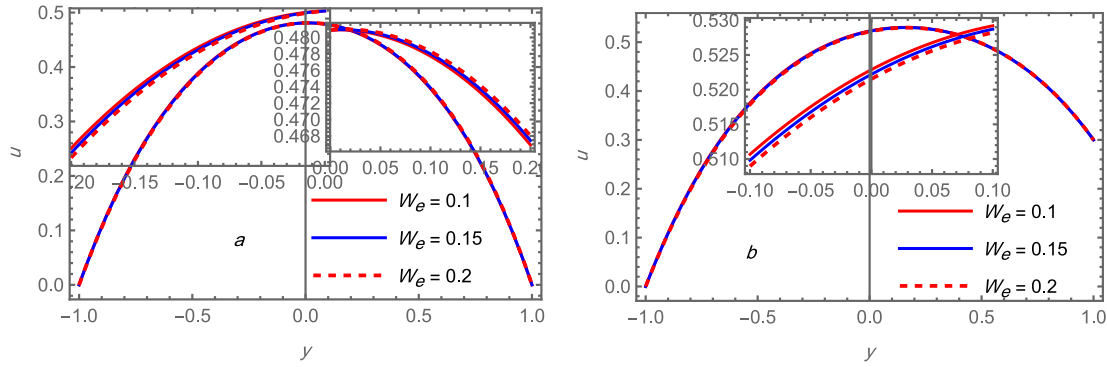


Figure 3.5 Velocity profile with different values We for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

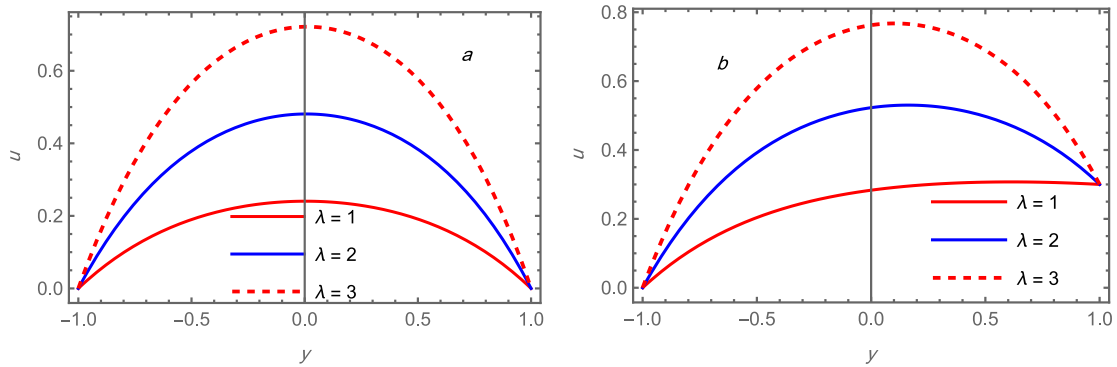


Figure 3.6 Velocity profile with different values λ for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, We = 0.1, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

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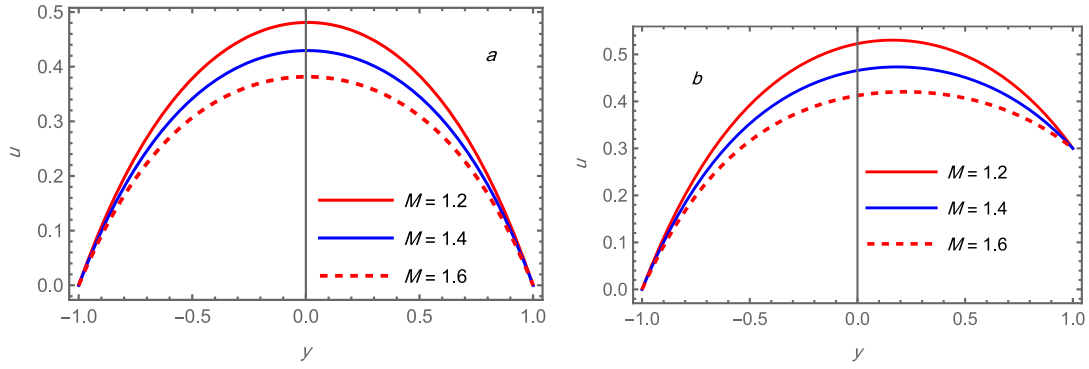


Figure 3.7 Velocity profile with different values M for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, We = 0.1, \lambda = 2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

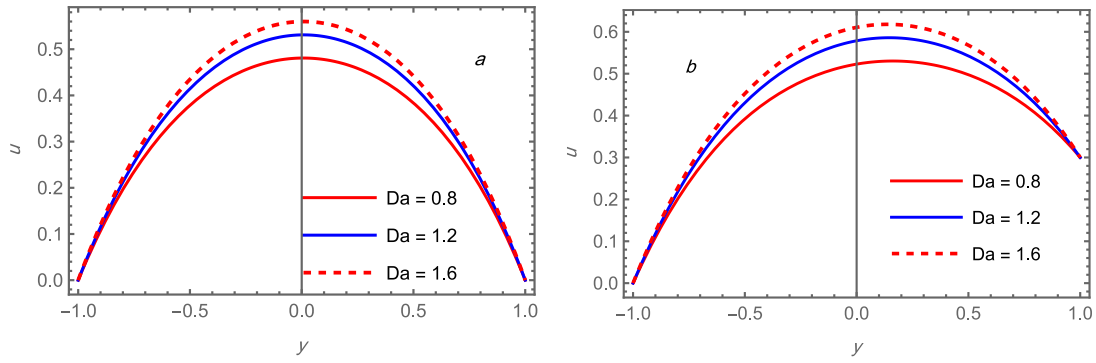


Figure 3.8 Velocity profile with different values Da for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, We = 0.1, \lambda = 2, M = 1.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

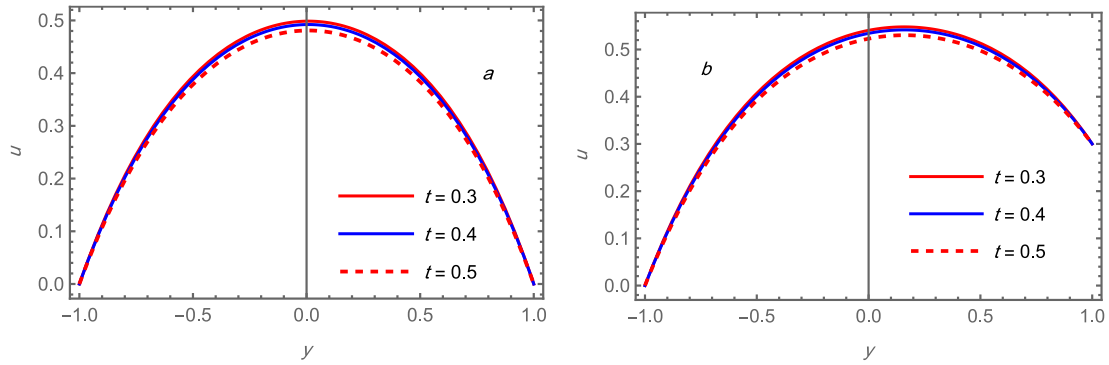


Figure 3.9 Velocity profile with different values t for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, Re = 1, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, U_0 = 0.3$.

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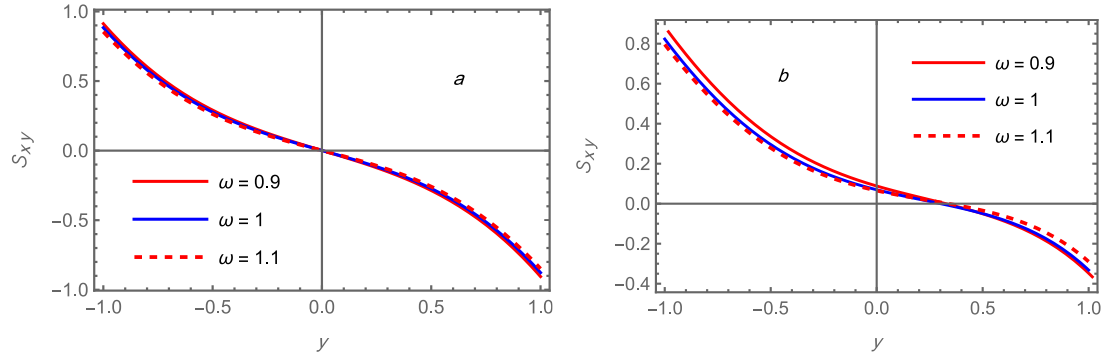


Figure 3.10 Shear stress profile with different values ω for (a) Poiseuille flow and (b) Couette flow, with $n = 0.1, Re = 4, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

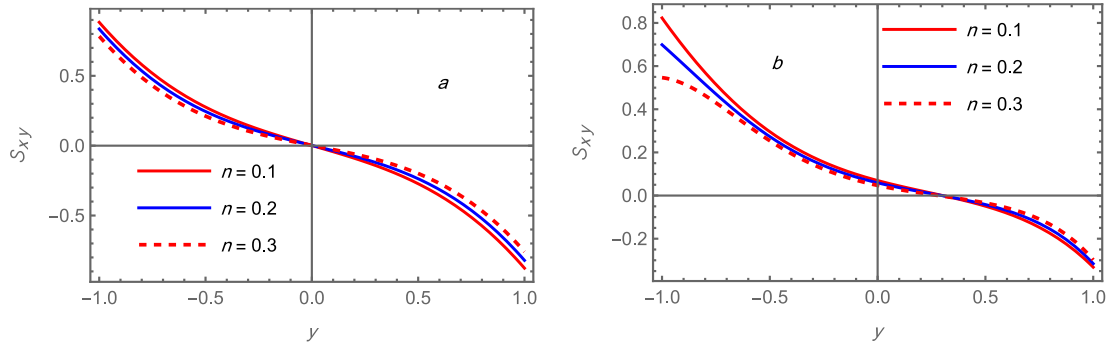


Figure 3.11 Shear stress profile with different values n for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, Re = 4, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, t = 0.5, U_0 = 0.3$.

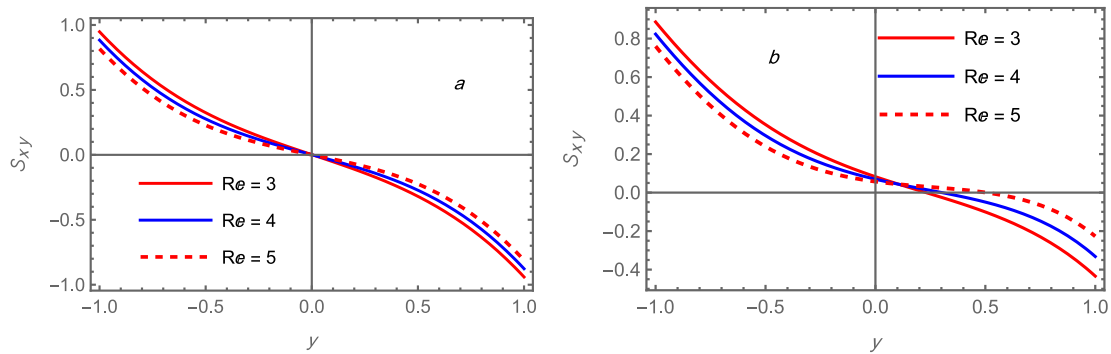


Figure 3.12 Shear stress profile with different values Re for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.1, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

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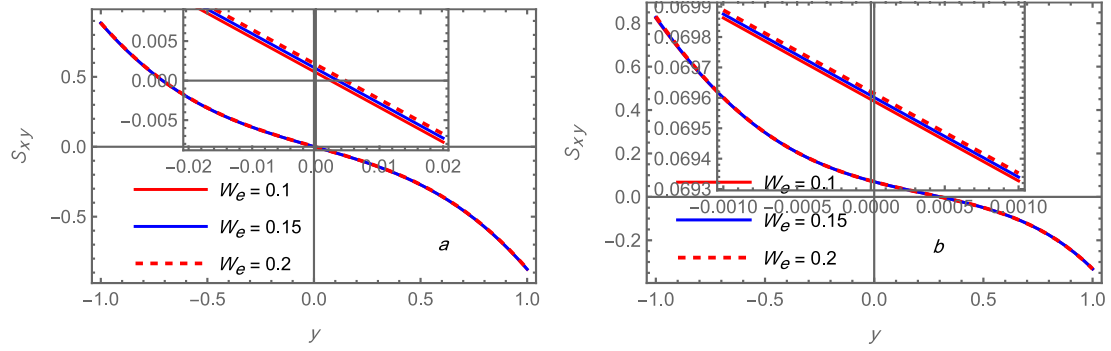


Figure 3.13 Shear stress profile with different values We for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.1, Re = 4, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

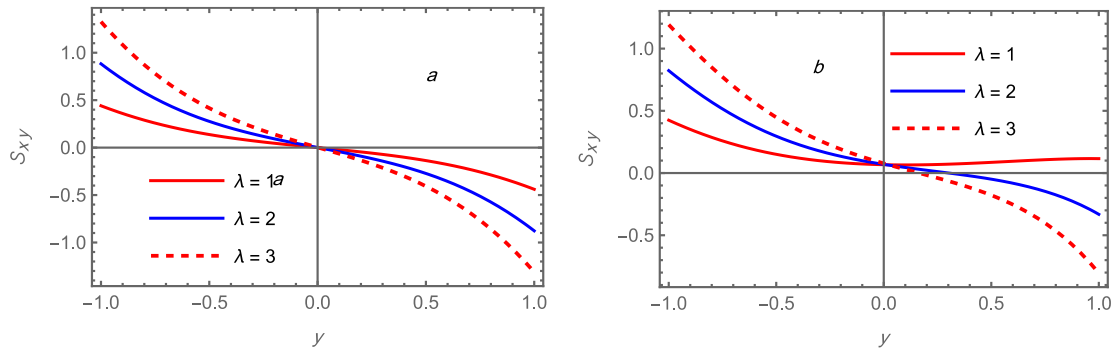


Figure 3.14 Shear stress profile with different values λ for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.1, Re = 4, We = 0.1, M = 1.2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

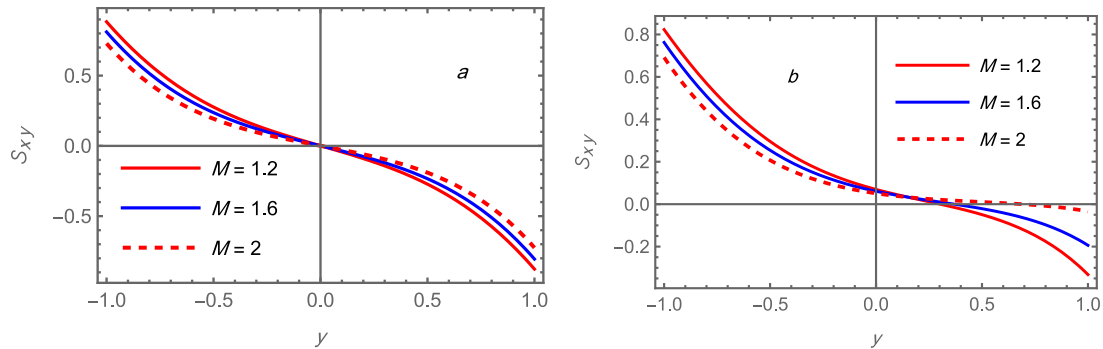


Figure 3.15 Shear stress profile with different values M for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.1, Re = 4, We = 0.1, \lambda = 2, Da = 0.8, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

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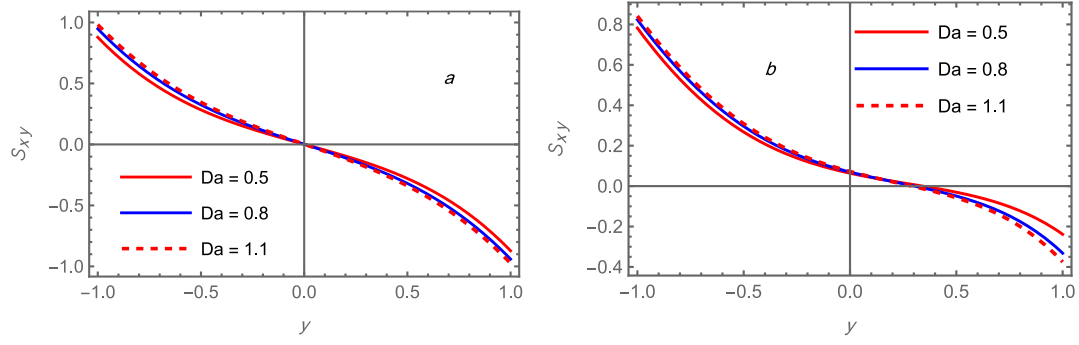


Figure 3.16 Shear stress profile with different values Da for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.1, Re = 4, We = 0.1, \lambda = 2, M = 1.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

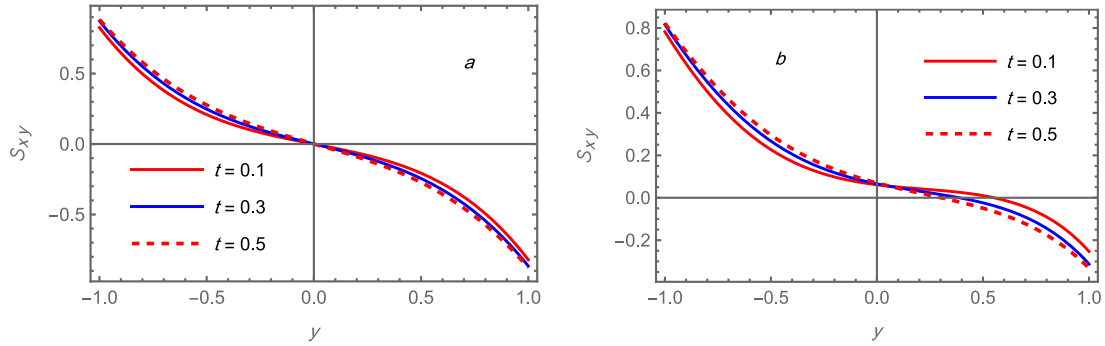


Figure 3.17 Shear stress profile with different values t for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.1, Re = 3, We = 0.1, \lambda = 2, M = 1.2, Da = 0.8, i = \sqrt{-1}, U_0 = 0.3$.

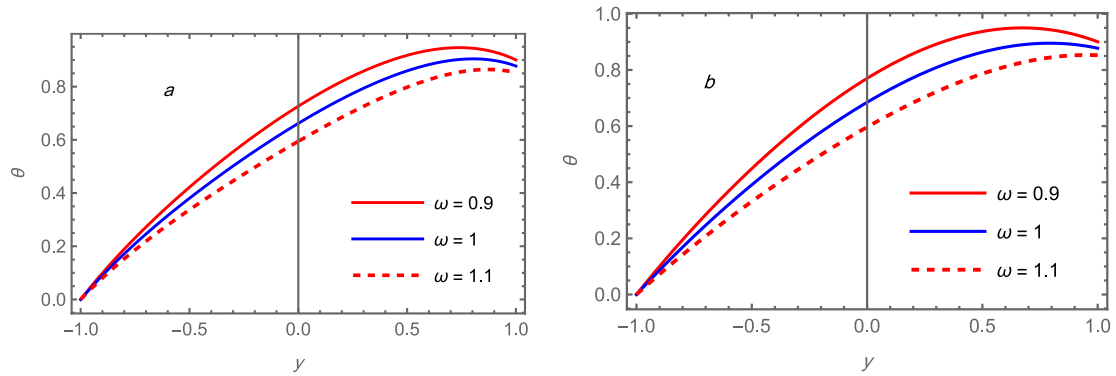


Figure 3.18 Temperature profile with *different* values ω for (a) Poiseuille flow and (b) Couette flow, with $N = 1.1, n = 0.2, Re = 1, We = 0.1, \lambda = 2, M = 1.2, Da =$

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$0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

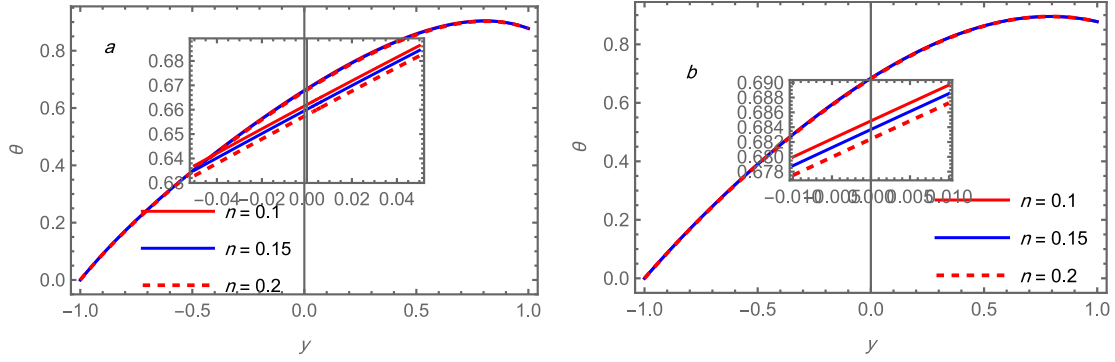


Figure 3.19 Temperature profile with different values n for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

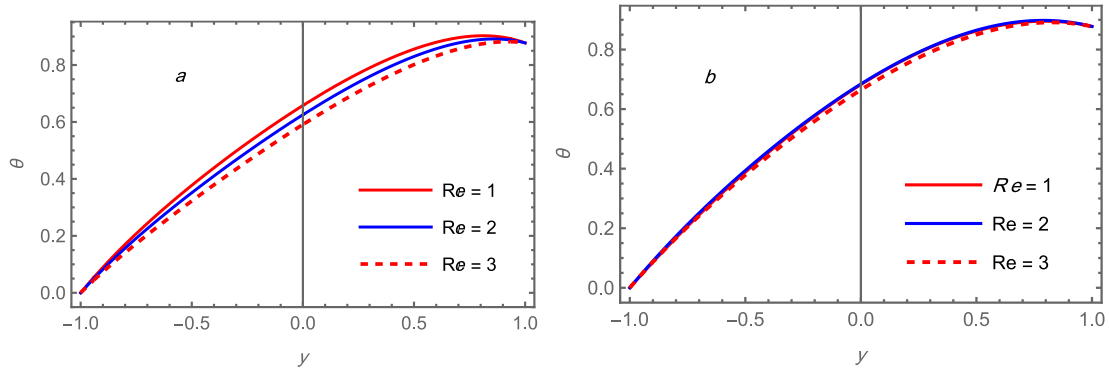


Figure 3.20 Temperature profile with different values R_e for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

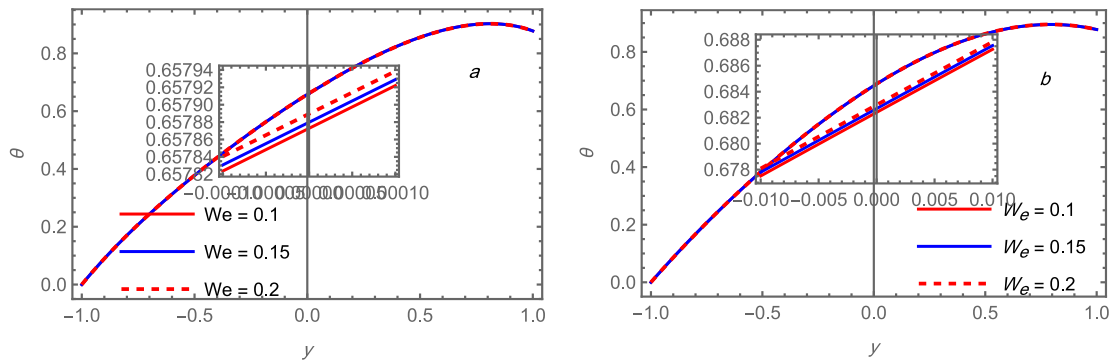


Figure 3.21 Temperature profile with different values W_e for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

Analysis of the MHD oscillatory flow and its effect on the temperature and concentration of tangent hyperbolic fluid through a regular permeable channel

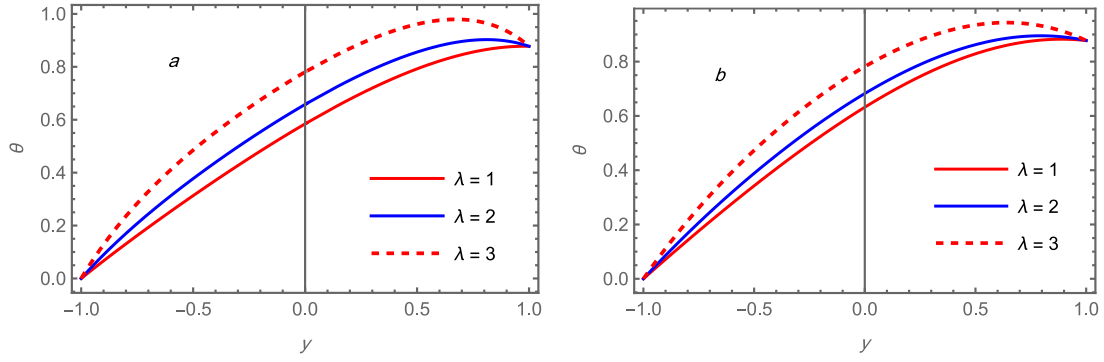


Figure 3.22 Temperature profile with different values λ for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

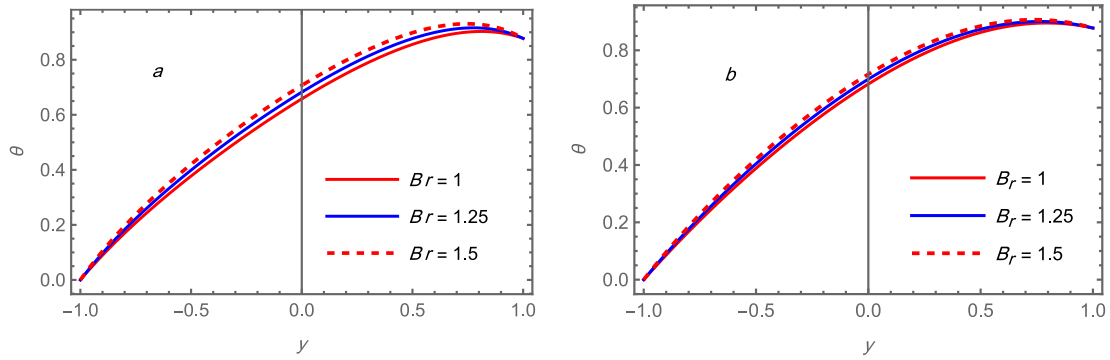


Figure 3.23 Temperature profile with different values β_r for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

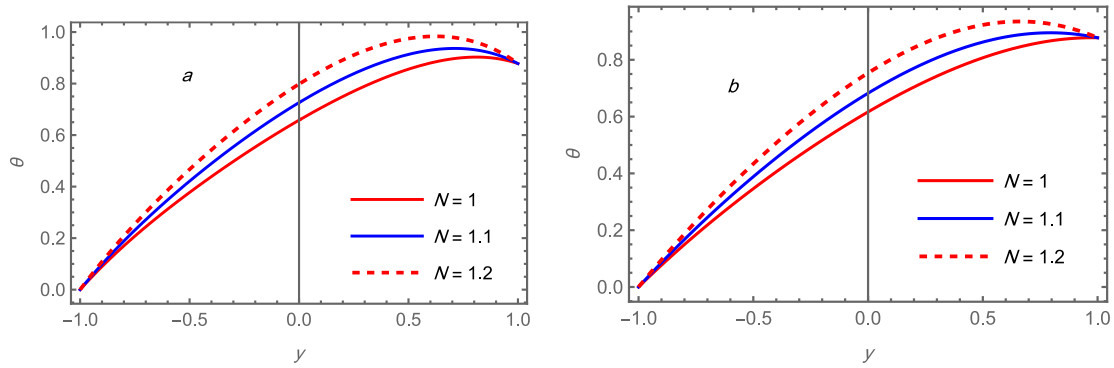


Figure 3.24 Temperature profile with different values N for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

Analysis of the MHD oscillatory flow and its effect on the temperature and concentration of tangent hyperbolic fluid through a regular permeable channel

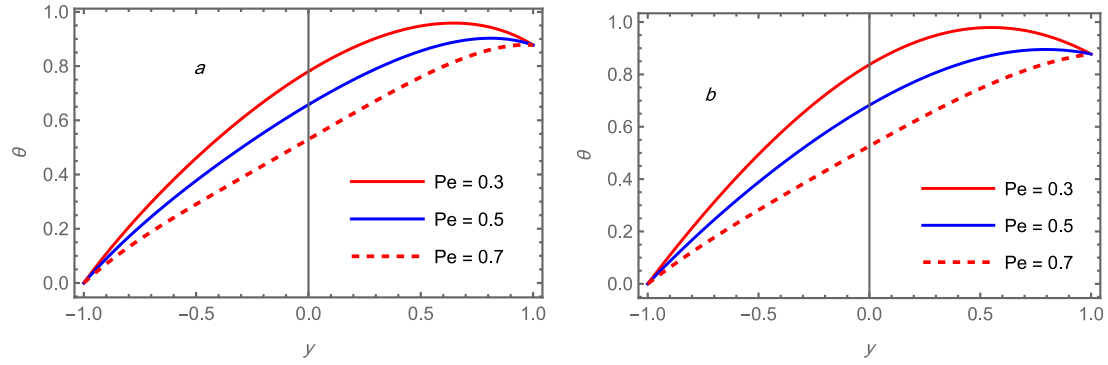


Figure 3.25 Temperature profile with different values Pe for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

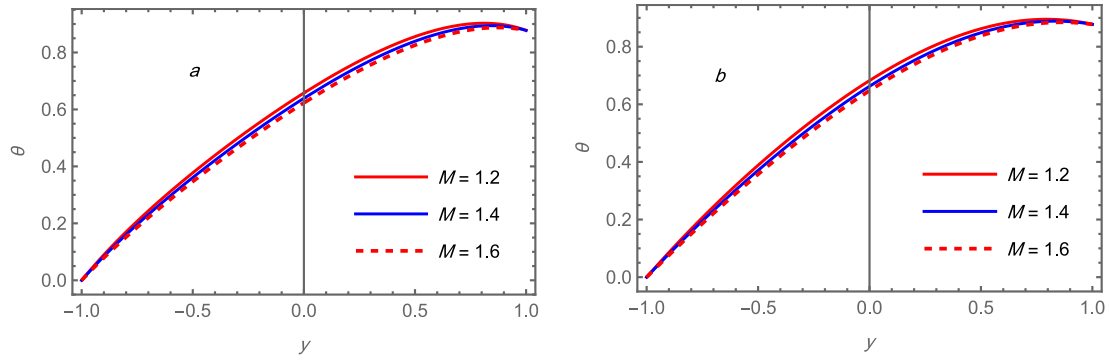


Figure 3.26 Temperature profile with different values M for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

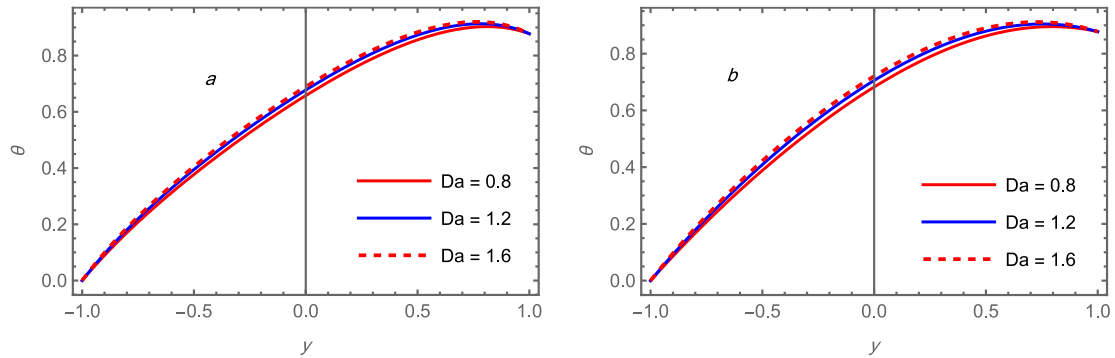


Figure 3.27 Temperature profile with different values Da for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0$.

Analysis of the MHD oscillatory flow and its effect on the temperature and concentration of tangent hyperbolic fluid through a regular permeable channel

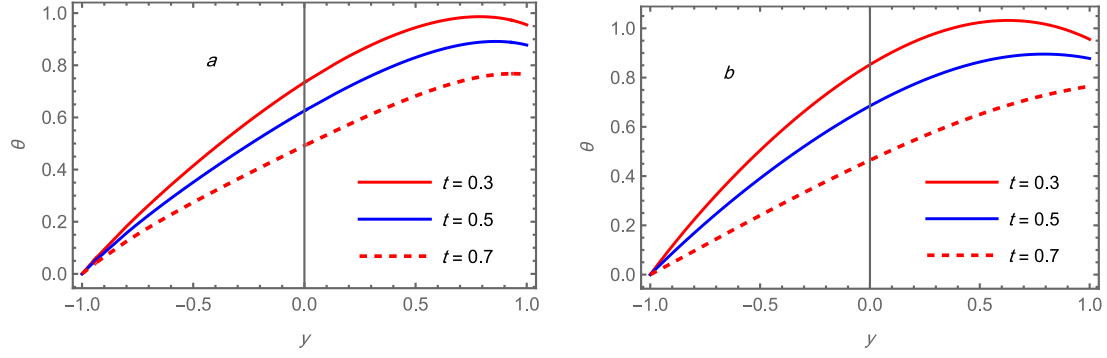


Figure 3.28 Temperature profile with different values t for (a) Poiseuille flow and (b) Couette flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, i = \sqrt{-1}, U_0 = 0.3$

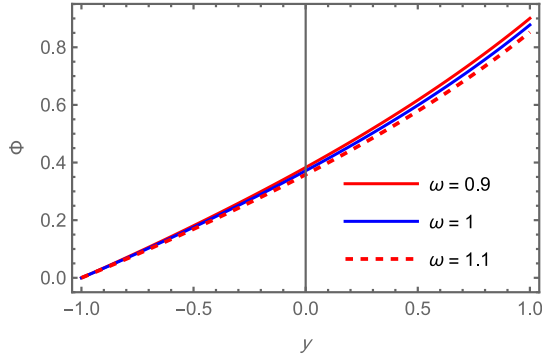


Figure 3.29 concentration profile with different values ω for Poiseuille flow, with $N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 3$.

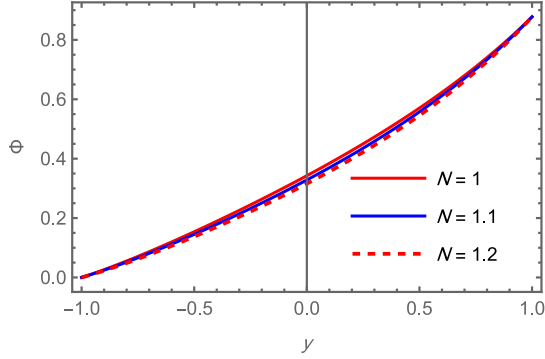


Figure 3.30 concentration profile with different values N for Poiseuille flow, with $\omega = 1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

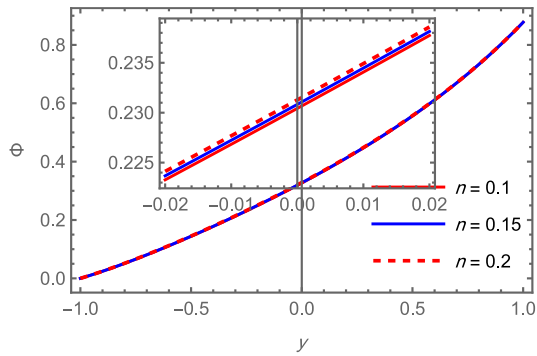


Figure 3.31 concentration profile with different values n for Poiseuille flow, with $\omega = 1, N = 1.1, R_e = 1, W_e =$

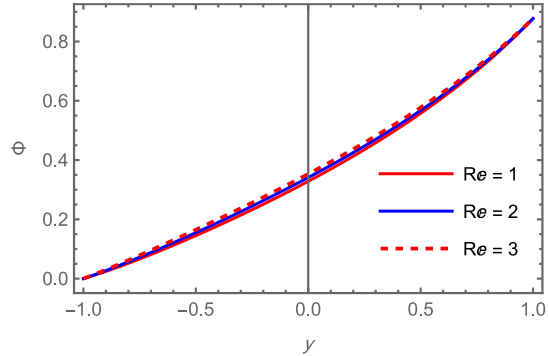


Figure 3.32 concentration profile with different values R_e for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, W_e =$

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$0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da =$ $0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c =$ $1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3.$	$0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da =$ $0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c =$ $1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$
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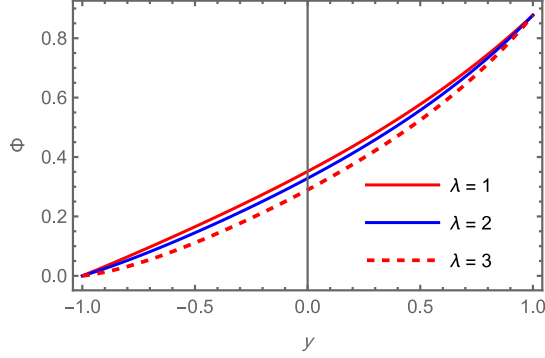


Figure 3.33 concentration profile with different values λ for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

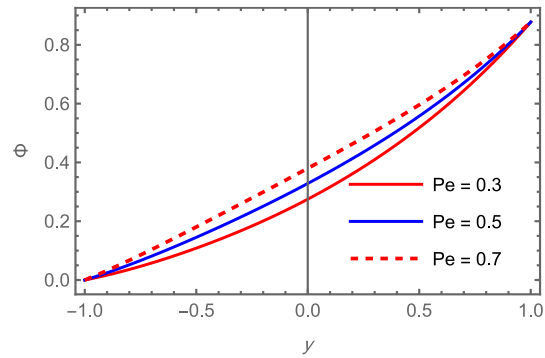


Figure 3.34 concentration profile with different values Pe for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

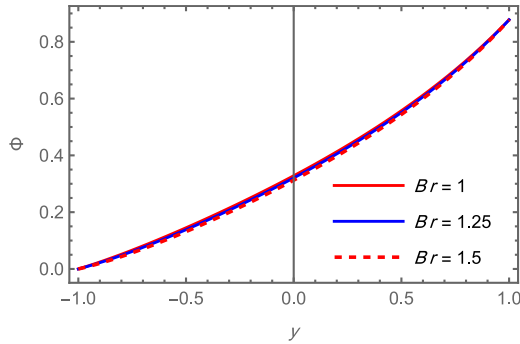


Figure 3.35 concentration profile with different values β_r for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3.$

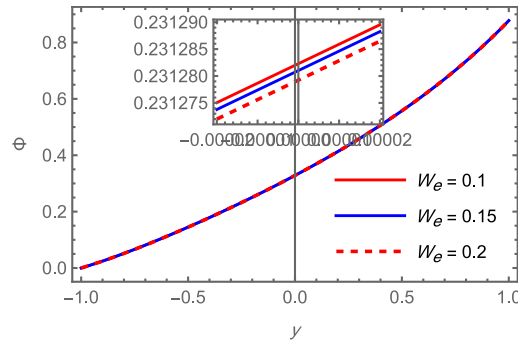


Figure 3.36 concentration profile with different values W_e for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

Analysis of the MHD oscillatory flow and its effect on the temperature and concentration of tangent hyperbolic fluid through a regular permeable channel

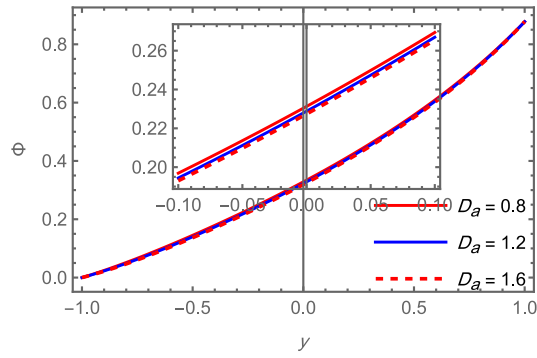


Figure 3.37 concentration profile with different values Da for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

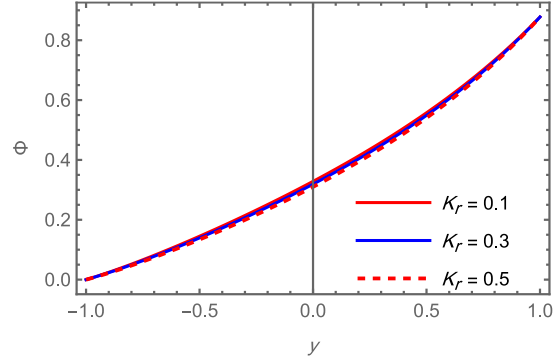


Figure 3.38 concentration profile with different values K_r for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

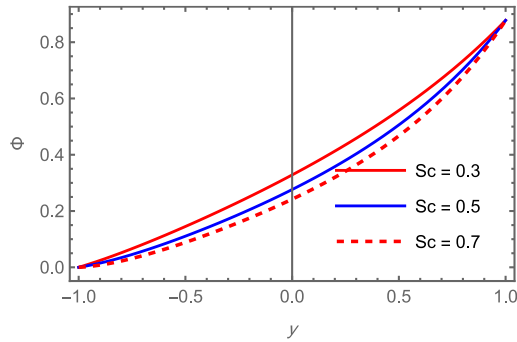


Figure 3.39 concentration profile with different values S_c for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

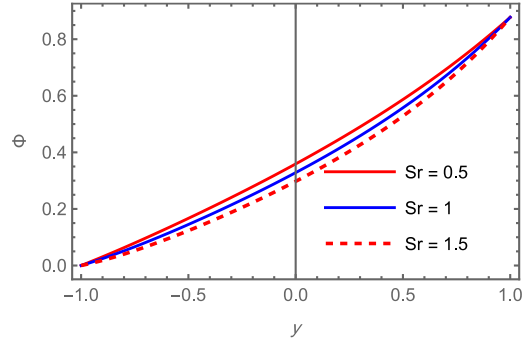


Figure 3.40 concentration profile with different values S_r for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$.

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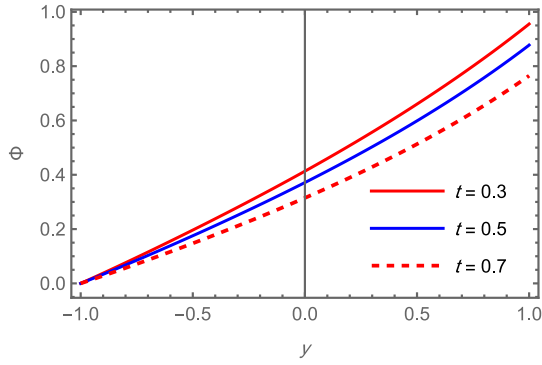


Figure 3.41 concentration profile with different values t for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, M = 1.2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, U_0 = 3.$

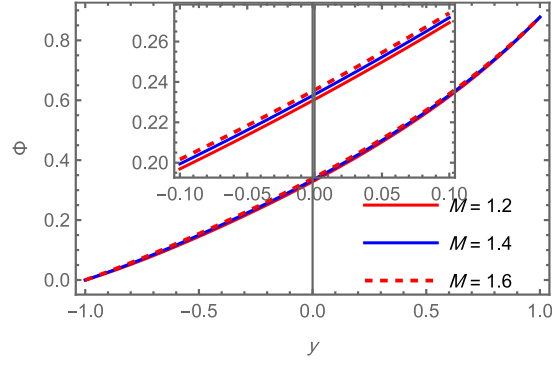


Figure 3.42 concentration profile with different values M for Poiseuille flow, with $\omega = 1, N = 1.1, n = 0.2, R_e = 1, W_e = 0.1, \beta_r = 1, \lambda = 2, Da = 0.8, Pe = 0.5, \beta_r = 1, K_r = 0.3, S_c = 1, S_r = 0.2, i = \sqrt{-1}, t = 0.5, U_0 = 0.3$

3.9- Conclusion Remarks

Here, we investigate the effect of magnetic field and permeability on temperature of tangent hyperbolic fluid through a regular channel. We used the Mathematica"13" program to discuss the effect of parameters on the movement of liquids by explaining the graphs obtained, and we will highlight some of the key findings:

7. The movement of the upper wall of the channel at a constant speed ($U_0 = 0.3$) in the case of Couette flow caused the speed of the fluid flow inside the channel to be higher than its speed in the case of Poiseuille flow.
8. The velocity in Poiseuille flow and Couette flow increase by the increase n , t , and λ while in W_e increasing when $0 \leq y \leq 1$, and decreases when $-1 \leq y \leq 0$ only at P-flow.
9. The velocity in the Poiseuille flow and Couette flow decreases by the increasing R_e and ω , while W_e decreases only at Couette flow.

10. The velocity in the Poiseuille flow decreases by the increase M while the temperature was increased by the increase Da while Couette flow the temperature was increased by the increase M and Da .
11. The temperature in the Poiseuille flow and Couette flow decreases by the increase Re, Pe, ω and n while the temperature was increased by the increase N, λ and β_r .
12. When the parameter We increases, the temperature increases during the period at $-1 \leq y \leq 0$, while it decreases $0 \leq y \leq 1$.
13. The temperature in the Poiseuille flow and Couette flow decreases by the increase M while the temperature was increased by the increase Da .
14. The concentration in Poiseuille flow increase by the increase M, Re, Pe, n while the concentration was decreases by the increase $\omega, N, \beta_r, t, i, We, Da, Kr, Sc, Sr$ and λ
15. In the concentration equation, we contented ourselves with drawing it in P-flow only. Because they have the same effect. The only difference is that in Couette flow the movement of concentration is higher than its movement in Poiseuille flow due to the movement of the upper wall of the channel.
16. In the concentration equation, we contented ourselves with drawing it in Poiseuille flow only. Because they have the same effect. The only difference is that in Couette flow the movement of concentration is higher than its movement in Poiseuille flow, this is due to the movement of the upper wall of the channel in Couette flow.

Chapter Four

Influence of temperature on the concentration and thus on the MHD oscillatory flow of a tangent hyperbolic fluid through a regular permeable channel

4.1 Introduction

Interest began to study the effect of temperature and focus on the movement of fluids through a channel, as most researchers agreed that increasing the temperature increases the velocity of the fluid while the velocity of the fluid changes in an unclear way with the difference in concentration, depending on the location of the fluid in the channel. Nigam and Singh [38] examined the impact of heat transfer on the oscillatory flow of magnetohydrodynamics via a porous medium between parallel plates, considering the role of temperature and concentration. The dynamics governing the flow of non-Newtonian fluids are highly intricate, and their behavior in permeable media is contingent upon the specific model employed, also see [3].

This chapter aim to discuss the impact influence of temperature on the concentration and thus on the MHD oscillatory flow of a tangent hyperbolic fluid through a regular permeable channel. We used the perturbation method to obtain a clear formula for fluid motion. The results obtained are illustrated by graphs after we reached the momentum equation solution, and used the MATHEMATICA program to plot the velocity and temperature of the fluid.

4.2 Mathematical Formulation:

Adopted a with the effect of a simple electric current on a fluid stream through a horizontal channel with small holes in its wall magnetic field to build a mathematical model that controls the oscillating flow of a tangential hyperbolic fluid. the channel has a width of $2h$, and the upper channel wall is affected by a temperature of T_1 , so the fluid concentration is C_1 while the lower channel wall temperature is T_0 and the fluid concentration is C_0 . We adopted Cartesian coordinates to study the mathematical model, where x represents the horizontal axis and the vertical axis is y and represents the flow field $(u(y, t), 0, 0)$, which achieves the continuity equation.

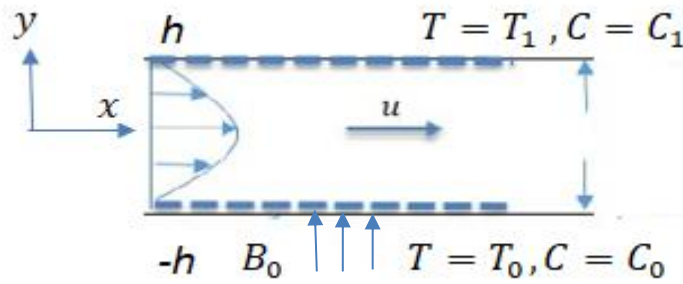


Figure 4-1: Channel format [23].

4.3 Basic Equations: [23]

The basic equations governing for the problem are given by:

The continuity equation:

$$\text{div } \bar{V} = 0. \quad (4.1)$$

The momentum equation:

$$\begin{aligned} \rho(\bar{V} \cdot \nabla) \bar{V} = & -\nabla \bar{p} + \text{div } \bar{S} + \rho g \beta_T (T - T_0) + \rho g \beta_C (C - C_1) + \\ & \bar{J} \times \bar{B} - \frac{\mu_c}{k} \bar{V}. \end{aligned} \quad (4.2)$$

The temperature equation:

$$c_T \rho (\bar{V} \cdot \nabla) T = K_T \nabla^2 T + Q_H (T - T_0) - \nabla Q. \quad (4.3)$$

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The concentration equation:

$$(\bar{V} \cdot \nabla)C = D\nabla^2 C - K_r^*(C - C_0) + \frac{DK_H}{T_m} \nabla^2 T. \quad (4.4)$$

where $V \equiv (u(y, t), 0, 0)$ is the velocity field, $T(y, t)$ is a fluid temperature, $C(y, t)$ is a fluid concentration, $\bar{p}$ "pressure", $\bar{\mathcal{S}}$ "extra stress tensor", $\bar{J}$ "induced current", $\bar{B} = (0, B_0, 0)$ the field of magnetic, μ_c "constant viscosity", ρ "fluid density", k "permeability", Q_H "heat generation" c_T "specific heat at constant pressure", K_T "thermal conductivity", Q "radioactive heat flux", D "coefficient of mass diffusivity", K_r^* "chemical reaction coefficient", K_H "thermal diffusion ratio" and T_m "the mean fluid temperature".

4.4 Constitutive Equation:

The fundamental equation for the tangent hyperbolic fluid given by: [20], [1]

$$\bar{\mathcal{S}} = [\mu_\infty + (\mu_c + \mu_\infty) \tanh(\Gamma \bar{\dot{\gamma}})^n] \bar{\dot{\gamma}} \quad (4.5)$$

where μ_c is the constant viscosity, $\bar{\dot{\gamma}}$ is the shear rate, μ_∞ infinity shear rate viscosity, Γ time constant, n the dimensionless power law index

In this study the constitutive equation considered when $\mu_\infty=0$. It has been considered the tangent hyperbolic fluid which represent shear thinning characteristics when $\Gamma \bar{\dot{\gamma}} < 1$. Therefore Eq (4.5) becomes:

$$\begin{aligned} \bar{\mathcal{S}} &= \mu_c [(\Gamma \bar{\dot{\gamma}})^n] \bar{\dot{\gamma}} \\ \bar{\mathcal{S}} &= \mu_c [1 + n(\Gamma \bar{\dot{\gamma}} - 1)] \bar{\dot{\gamma}} \end{aligned} \quad (4.6)$$

and $\bar{\dot{\gamma}}$ the Rivlin-Ericksen [9] tensors which is defined by:

$$\bar{\dot{\gamma}} = \nabla \bar{V} + (\nabla \bar{V})^T \quad (4.7)$$

where $\bar{V} = (\bar{u}, \bar{v}, \bar{w})$ is the velocity field in Cartesian coordinates system (x, y, z) , $\nabla \bar{V}$ is the gradient of velocity, and $(\nabla \bar{V})^T$ is the transpose of the velocity gradient, which is given by:

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and $\dot{\gamma}$ is defined by;

$$\dot{\gamma} = \sqrt{\frac{1}{2} \sum_i \sum_j \dot{\gamma}_{ij} \dot{\gamma}_{ji}}$$

Since $(u(y, t), 0, 0)$ is the velocity field, then

$$\bar{\dot{\gamma}} = \left(\frac{\partial \bar{u}}{\partial \bar{y}} \right). \quad (4.8)$$

Substituting equations (4.8) into equation (4.6), we have

$$\bar{\mathcal{S}} = \mu_c \left[1 + n \left(\Gamma \frac{\partial \bar{u}}{\partial \bar{y}} - 1 \right) \right] \frac{\partial \bar{u}}{\partial \bar{y}}. \quad (4.9)$$

The stress components are given by:

$$\begin{aligned} \bar{\mathcal{S}}_{\bar{x}\bar{x}} &= \bar{\mathcal{S}}_{\bar{y}\bar{y}} = 0, \\ \bar{\mathcal{S}}_{\bar{x}\bar{y}} &= \bar{\mathcal{S}}_{\bar{y}\bar{x}} = \mu_c \left[(1 - n) \frac{\partial \bar{u}}{\partial \bar{y}} + n \Gamma \left(\frac{\partial \bar{u}}{\partial \bar{y}} \right)^2 \right], \end{aligned} \quad (4.10)$$

The radioactive heat flux [50] is given by:

$$\nabla Q = 4\eta^2 (T_0 - T), \quad (4.11)$$

where Q is a radioactive heat flux, η is a radiation absorption.

Substituting equations (4.10) and (4.11) into equations (4.1) - (4.4), we have the following equations;

The continuity equation:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0. \quad (4.12)$$

The momentum equation in the x - direction:

$$\begin{aligned} \rho \left(\frac{\partial \bar{u}}{\partial \bar{t}} + \bar{u} \frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v} \frac{\partial \bar{u}}{\partial \bar{y}} \right) &= -\frac{\partial \bar{p}}{\partial \bar{x}} + \frac{\partial \bar{\mathcal{S}}_{\bar{x}\bar{y}}}{\partial \bar{y}} + \rho g \beta_T (T - T_0) + \rho g \beta_C (C - \\ &C_1) - \sigma B_0^2 \bar{u} - \frac{\mu_c}{k} \bar{u}. \end{aligned} \quad (4.13)$$

The momentum equation in the y - direction:

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$$\rho \left(\frac{\partial \bar{v}}{\partial \bar{t}} + \bar{u} \frac{\partial \bar{v}}{\partial \bar{x}} + \bar{v} \frac{\partial \bar{v}}{\partial \bar{y}} \right) = - \frac{\partial \bar{p}}{\partial \bar{y}} + \frac{\partial \bar{\mathcal{S}}_{y\bar{x}}}{\partial \bar{x}} - \sigma B_0^2 \bar{v} - \frac{\mu_c}{k} \bar{v}. \quad (4.14)$$

The temperature equation:

$$c_T \rho \left(\frac{\partial T}{\partial \bar{t}} + \bar{u} \frac{\partial T}{\partial \bar{x}} + \bar{v} \frac{\partial T}{\partial \bar{y}} \right) = K_T \left(\frac{\partial^2 T}{\partial \bar{x}^2} + \frac{\partial^2 T}{\partial \bar{y}^2} \right) + Q_H (T - T_0) - 4\eta^2 (T - T_0). \quad (4.15)$$

The concentration equation:

$$\frac{\partial C}{\partial \bar{t}} = D \frac{\partial^2 C}{\partial \bar{y}^2} - K_r^* (C - C_0) + \frac{DK_H}{T_m} \frac{\partial^2 T}{\partial \bar{y}^2}. \quad (4.16)$$

The temperatures and concentration at the walls of the channel are given as:

$$T = T_1, C = C_1 \text{ at } \bar{y} = h, \text{ and } T = T_0, C = C_0 \text{ at } \bar{y} = -h. \quad (4.17)$$

4.5 Method of Solution:

In order to simplify the governing equations of the problem, we may introduce the following dimensionless transformations as follows:

Substituting equations (3.21) into equations (4.12) - (4.17), we have the following of non-dimensional equations:

$$\begin{aligned} \frac{\partial(Uu)}{\partial(xh)} + \frac{\partial(Uv)}{\partial(yh)} &= 0, \\ \rho \left(\frac{U \partial u}{\frac{h}{U} \partial t} + Uu \frac{U \partial u}{h \partial x} + Uv \frac{U \partial u}{h \partial y} \right) &= - \frac{\frac{\mu_c U}{h} \partial p}{h \partial x} + \frac{\frac{\mu_c U}{h} \partial \mathcal{S}_{xy}}{h \partial y} + \rho g \beta_T (\Delta T) \theta + \\ &\quad \rho g \beta_C (\Delta C) \Phi - \sigma B_0^2 Uu - \frac{\mu_c U}{k} u, \end{aligned}$$

$$\rho \left(\frac{U \partial v}{\frac{h}{U} \partial t} + Uu \frac{U \partial v}{h \partial x} + Uv \frac{U \partial v}{h \partial y} \right) = - \frac{\frac{\mu_c U}{h} dp}{h dy} + \frac{\frac{\mu_c U}{h} \partial \mathcal{S}_{xy}}{h \partial x} - \sigma B_0^2 Uv - \frac{\mu_c U}{k} v,$$

$$c_T \rho \frac{\partial(\theta(T_1 - T_0) + T_0)}{\frac{h}{U} \partial t} = K_T \left(\frac{\partial^2(\theta(T_1 - T_0) + T_0)}{h^2 \partial y^2} \right) + Q_H \theta \Delta T + 4\eta^2 \theta \Delta T,$$

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$$\frac{\partial(\Phi(C_1 - C_0) + C_0)}{\frac{h}{U} \partial t} = D \frac{\partial^2(\Phi(C_1 - C_0) + C_0)}{h^2 \partial y^2} - K_r^*(\Phi(C_1 - C_0)) +$$

$$\frac{DK_H}{T_m} \frac{\partial^2(\theta(T_1 - T_0) + T_0)}{h^2 \partial y^2}.$$

implies that

$$\frac{U}{h} \left(\frac{\partial(u)}{\partial(x)} + \frac{\partial(v)}{\partial(y)} \right) = 0, \quad (4.18)$$

$$\rho \frac{U^2}{h} \frac{\partial u}{\partial t} = - \frac{\mu_c U}{h^2} \frac{\partial p}{\partial x} + \frac{\mu_c U}{h^2} \frac{\partial \mathcal{S}_{xy}}{\partial y} + \rho g \beta_T (\Delta T) \theta + \rho g \beta_C (\Delta C) \Phi -$$

$$\sigma B_0^2 U u - \frac{\mu_c U}{k} u, \quad (4.19)$$

$$\rho(0) = - \frac{\mu_c U}{h^2} \frac{\partial p}{\partial y} + 0 + 0 - 0, \quad (4.20)$$

$$\frac{c_T \rho U}{h} \frac{\partial(\theta(T_1 - T_0) + T_0)}{\partial t} = \frac{K_T}{h^2} \left(\frac{\partial^2(\theta(T_1 - T_0) + T_0)}{\partial y^2} \right) + Q_H \theta(T_1 - T_0) +$$

$$4\eta^2 \theta(T_1 - T_0), \quad (4.21)$$

$$\frac{U}{h} (C_0 - C_1) \frac{\partial \Phi}{\partial t} = \frac{D}{h^2} (C_0 - C_1) \frac{\partial^2 \Phi}{\partial y^2} - K_r^* C_0 - C_1 \Phi + \frac{DK_H}{T_m} \frac{(T_1 - T_0)}{h^2} \frac{\partial^2 \theta}{\partial y^2}, \quad (4.22)$$

$$\text{and } \frac{\mu_c U}{h} \mathcal{S}_{yx} = \mu_c \left[(1 - n) \frac{U \partial u}{h \partial y} + n \Gamma \left(\frac{U \partial u}{h \partial y} \right)^2 \right]$$

$$\Rightarrow \mathcal{S}_{xy} = (1 - n) \frac{\partial u}{\partial y} + n \Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2. \quad (4.23)$$

with the boundary conditions of the temperature equation and concentration equation.

$$\left. \begin{aligned} \theta \Delta T + T_0 &= T_0, \quad \Phi(C_1 - C_0) + C_0 = C_0 \quad \text{at } hy = -h, \\ \theta \Delta T + T_0 &= T_1, \quad \Phi(C_1 - C_0) + C_0 = C_1 \quad \text{at } hy = h \end{aligned} \right\} \quad (4.24)$$

Substituting the equation (4.23) into the equations (4.18) - (4.24), after that simplify the equations, we obtain;

$$\rho \frac{U h}{\mu_c} \frac{\partial u}{\partial t} = - \frac{\partial p}{\partial x} + \frac{\partial}{\partial y} \left((1 - n) \frac{\partial u}{\partial y} + n \Gamma \frac{U}{h} \left(\frac{\partial u}{\partial y} \right)^2 \right) + \frac{\rho g \beta_T h^2}{\mu_c U} (\Delta T) \theta +$$

$$\frac{\rho g \beta_C h^2}{\mu_c U} (\Delta C) \Phi - \frac{\sigma B_0^2 h^2}{\mu_c} u - \frac{h^2}{k} u, \quad (4.25)$$

$$\frac{\partial p}{\partial y} = 0, \quad (4.26)$$

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$$\frac{c_T \rho U h}{K_T} \frac{\partial(\theta(T_1 - T_0) + T_0)}{\partial t} = \left(\frac{\partial^2(\theta(T_1 - T_0) + T_0)}{\partial y^2} \right) + \frac{h^2}{K_T} (Q_H \theta(T_1 - T_0)) + \frac{h^2}{K_T} (4\eta^2 \theta(T_1 - T_0)), \quad (4.27)$$

$$\frac{\partial \Phi}{\partial t} = \frac{D}{Uh} \frac{\partial^2 \Phi}{\partial y^2} - \frac{h K_r^*}{U} \Phi + \frac{D K_H}{T_m U h (C_0 - C_1)} \frac{\partial^2 \theta}{\partial y^2}. \quad (4.28)$$

with the non-dimensional boundary conditions of the temperature equation and the concentration equation.

$$\theta = 1, \Phi = 1 \text{ at } y = 1 \text{ and } \theta = 0, \Phi = 0 \text{ at } y = -1. \quad (4.29)$$

Now the last form of the system of equations governing the flow of the tangent hyperbolic fluid is as follows;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \quad (4.30)$$

$$\frac{\partial p}{\partial x} = -Re \frac{\partial u}{\partial t} + (1 - n) \frac{\partial^2 u}{\partial y^2} + 2nWe \frac{\partial u}{\partial y} \frac{\partial^2 u}{\partial y^2} + G_r \theta + G_c \Phi - \left(M^2 + \frac{1}{Da} \right) u, \quad (4.31)$$

$$S_{xy} = (1 - n) \frac{\partial u}{\partial y} + nWe \left(\frac{\partial u}{\partial y} \right)^2, \quad (4.32)$$

$$Pe \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + (N^2 + E) \theta, \quad (4.33)$$

$$\frac{\partial \Phi}{\partial t} = \frac{1}{S_c} \frac{\partial^2 \Phi}{\partial y^2} - K_r \Phi + S_r \frac{\partial^2 \theta}{\partial y^2}. \quad (4.34)$$

where $Re = \frac{\rho h U}{\mu_c}$ " Reynolds number", $Da = \frac{k}{h^2}$ "Darcy number", $M =$

$\sqrt{\frac{\sigma B_0^2 h^2}{\mu_c}}$ "magnetic parameter", $Pe = \frac{c_T \rho h U}{K_T}$ "Peclet number", $N = \sqrt{\frac{4\eta^2 h^2}{K_T}}$

"radiation parameter", $We = \Gamma \frac{U}{h}$ "Weissenberg number", $E = \frac{h^2 Q_H}{K_T}$ "the het

generation parameter, $G_c = \frac{\rho g \beta_c h^2 (\Delta C)}{\mu_c U}$ is solutal Grashof number, $G_r =$

$\frac{\rho g \beta_T h^2 (\Delta T)}{\mu_c U}$ "thermal Grashof number, $K_r = \frac{h K_r^*}{U}$ is the Chemical reaction

parameter, $S_c = \frac{Uh}{D}$ is the Schmidt number, and $S_r = \frac{D K_H (T_1 - T_0)}{T_m U h (C_1 - C_2)}$ "Soret

number.

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The temperature equation and the concentration equation both include boundary conditions

$$\begin{aligned} u = 0, \theta = \Phi = 1 & \quad \text{at} \quad y = 1 \\ u = \theta = \Phi = 0 & \quad \text{at} \quad y = -1 \end{aligned}$$

4.6 Solution of the Problem:

In this part, the temperature equation and concentration equation are solved, and then the momentum equation.

4.6.1 Solution of the temperature equation

To solve the heat equation (4.33) with associative boundary conditions $\theta(1) = 1, \theta(-1) = 0$.

Let $\theta(y, t) = \theta_0 e^{i\omega t}$ and by substituting into equation (4.33), after simplifying the result, we obtain

$$Pe \frac{\partial}{\partial t} (\theta_0(y) e^{i\omega t}) = \frac{\partial^2}{\partial y^2} (\theta_0(y) e^{i\omega t}) + (N^2 + E)(\theta_0(y) e^{i\omega t}),$$

By dividing by $e^{i\omega t}$, and after simplification, we have

$$\frac{\partial^2 \theta_0}{\partial y^2} + (N^2 + E - i\omega Pe) \theta_0 = 0 \quad (4.35)$$

Therefore, the temperature function is:

$$\begin{aligned} \theta(y, t) = & \left(\left(\frac{1}{2} e^{-it\omega} \text{Sec}[\sqrt{A}] \right) \text{Cos}[\sqrt{A}y] + \right. \\ & \left. \left(\frac{1}{2} e^{-it\omega} \text{Csc}[\sqrt{A}] \right) \text{Sin}[\sqrt{A}y] \right) e^{i\omega t} \end{aligned} \quad (4.36)$$

4.6.2 Solution of the concentration equation

To solve the heat equation (4.34) with associative boundary conditions $\Phi(1) = 1, \Phi(-1) = 0$.

Let $\Phi(y, t) = \Phi_0 e^{i\omega t}$ and by substituting into equation (4.34), after simplifying the result, we obtain

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$$\frac{\partial^2 \Phi_0}{\partial y^2} - S_c(K_r + i\omega)\Phi_0 = -S_c S_r \frac{\partial^2 \theta_0}{\partial y^2} \quad (4.37)$$

Therefore, the concentration function is:

$$\begin{aligned} \Phi(y, t) = e^{i\omega t} \left(e^{\sqrt{B}y} \left(\frac{e^{3\sqrt{B}-it\omega}(A+B+AS_c S_r)}{(A+B)(-1+e^{4\sqrt{B}})} \right) + e^{-\sqrt{B}y} \left(-\frac{e^{\sqrt{B}-it\omega}(A+B+AS_c S_r)}{(A+B)(-1+e^{4\sqrt{B}})} \right) - \right. \\ \left. \frac{Ae^{-it\omega} \text{Csc}[2\sqrt{A}]\text{Sin}[\sqrt{A}(1+y)]S_c S_r}{A+B} \right) \end{aligned} \quad (4.38)$$

4.6.3 Solution of the momentum equation

Suppose that the nonslip condition the boundary conditions are, $\bar{u} = 0$ at $\bar{y} = h$, and $\bar{u} = 0$ at $\bar{y} = -h$. from equation (4.31) the non-dimensional boundary conditions are $u(1) = u(-1) = 0$

To solve the momentum equation (4.31), hence let

$$-\frac{\partial p}{\partial x} = \lambda e^{i\omega t}, \quad (4.39)$$

$$u(y, t) = u_0(y)e^{i\omega t}, \quad (4.40)$$

where ω be an oscillation of frequency and λ is a real constant.

The non-dimensional boundary conditions are as follows:

$$u(1, t) = 0, \quad u(-1, t) = 0$$

$$0 = u(1, t) = u_0(1)e^{i\omega t} \Rightarrow u_0(1) = 0$$

$$0 = u(-1, t) = u_0(-1)e^{i\omega t} \Rightarrow u_0(-1) = 0.$$

By substituting equations (4.39) and (4.40) into equation (4.31), we have;

$$\begin{aligned} -\lambda e^{i\omega t} = -Re \frac{\partial}{\partial t} (u_0(y)e^{i\omega t}) + (1-n) \frac{\partial^2}{\partial y^2} (u_0(y)e^{i\omega t}) + \\ 2nWe \frac{\partial}{\partial y} (u_0(y)e^{i\omega t}) \frac{\partial^2}{\partial y^2} (u_0(y)e^{i\omega t}) + G_r \theta_0 e^{i\omega t} + \\ G_c \Phi_0 e^{i\omega t} - \left(M^2 + \frac{1}{Da} \right) u_0(y)e^{i\omega t} \end{aligned}$$

By dividing by $e^{i\omega t}$, and after simplification, we have

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$$-\lambda = -(i\omega Re + M^2 + \frac{1}{Da})u_0 + (1 - n) \frac{\partial^2 u_0}{\partial y^2} + G_r \theta_0 + G_c \Phi_0 + 2nWe e^{i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2}$$

By dividing by $(n - 1)$, and after simplification, we have

$$\frac{\partial^2 u_0}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_0 - \frac{2n}{n-1} We e^{i\omega t} \frac{\partial u_0}{\partial y} \frac{\partial^2 u_0}{\partial y^2} = \frac{\lambda + G_r \theta_0 + G_c \Phi_0}{n-1} \quad (4.41)$$

So will use the perturbation technique to find the solution of problem as follows:

$$u_0 = u_{00} + We u_{01} + O(We^2) \quad (4.42)$$

Now, by substituting equation (3.42) in equation (3.41), we obtain:

$$\begin{aligned} & \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial^2 u_{01}}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{00} + We \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{01} - \\ & \frac{2n}{1-n} We e^{i\omega t} \left(\frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial u_{01}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} + We \frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{01}}{\partial y^2} + \right. \\ & \left. (We)^2 \frac{\partial u_{01}}{\partial y} \frac{\partial^2 u_{01}}{\partial y^2} \right) = \frac{\lambda + G_r \theta_0 + G_c \Phi_0}{n-1} . \end{aligned} \quad (4.43)$$

We can find the equation as following by boundary conditions are:

$$0 = u_0(1) = u_{00}(1) + We u_{01}(1) \Rightarrow u_{00}(1) = 0, u_{01}(1) = 0$$

$$0 = u_0(-1) = u_{00}(-1) + We u_{01}(-1) \Rightarrow u_{00}(-1) = 0, u_{01}(-1) = 0$$

then equating the like powers of we obtain the following results presented in the forthcoming subsections:

I - Zeros-order system (we⁰)

$$\frac{\partial^2 u_{00}}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{00} = \frac{\lambda + G_r \theta_0 + G_c \Phi_0}{n-1} \quad (4.44)$$

The associated boundary conditions are:

$$u_{00}(1) = u_{00}(-1) = 0 \quad (4.45)$$

II – First- order system (we¹)

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$$\frac{\partial^2 u_{01}}{\partial y^2} + \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right) u_{01} = \frac{2n}{n-1} e^{i\omega t} \frac{\partial u_{00}}{\partial y} \frac{\partial^2 u_{00}}{\partial y^2} \quad (4.46)$$

The associated boundary condition is:

$$u_{01}(1) = u_{01}(-1) = 0 \quad (4.47)$$

III - Zeros-order solution

Solution of Eq. (4.44) subset to the associate boundary conditions (4.45)

$$u_{00} = \frac{F}{D} - \frac{F \text{Sec}[\sqrt{D}]}{D} \text{Cos}[\sqrt{D}y] \quad (4.48)$$

IV - First-order solution

Solution of Eq. (4.46) subset to the associate boundary conditions (4.47)

$$u_{01} = \frac{S}{D} - \frac{S \text{Sec}[\sqrt{D}]}{D} \text{Cos}[\sqrt{D}y] \quad (4.49)$$

From the solution of equations (4.48) and (4.49), and substitution in equation (4.40), we obtain the solution of the equation of motion.

$$u(y, t) = e^{it\omega} \left(\frac{F}{D} - \frac{F \text{Sec}[\sqrt{D}]}{D} \text{Cos}[\sqrt{D}y] + \right. \\ \left. We \left(\left(\frac{e^{it\omega} F^2 n \text{Csc}[\sqrt{D}] \text{Sec}[\sqrt{D}]^2 \text{Sin}[2\sqrt{D}]}{3D^{3/2}(-1+n)} \right) \text{Sin}[\sqrt{D}y] - \right. \right. \\ \left. \left. \frac{e^{it\omega} F^2 n \text{Sec}[\sqrt{D}]^2 \text{Sin}[2\sqrt{D}y]}{3D^{3/2}(-1+n)} \right) \right) \quad (4.50)$$

where $B = S_c(K_r + i\omega)$, $A = (N^2 + E - i\omega Pe)$, $D = \left(\frac{i\omega Re + M^2 + \frac{1}{Da}}{n-1} \right)$,

and $F = \left(\frac{\lambda + G_r \theta_0 + G_c \Phi_0}{n-1} \right)$.

4.7 Results and Discussion

This section discusses the use of MATHEMATICA-13 to collect statistical solutions and graphs. The momentum equation is solved using a perturbation technique, and all results are graphed in the region $-1 \leq y \leq 1$, which is the diameter of the flow channel.

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1. Figures (4.2) - (4.17) show the velocity profile. The velocity profile u increases as G_r increases, as see in Figure 4.2. Figure 4.3 demonstrates how the impact of K_r on velocity profile u diminishes. Figure 4.4 demonstrates how the impact of t on velocity profile u diminishes. As see in Figure 4.5, the velocity profile u increases as the parameters G_c from the middle of the canal to its upper wall. The velocity profile u increases as the parameters λ rise, as see in Figure 4.6. The velocity profile u increases as the parameters Da rises, as see in Figure 4.7. Figure 4.8 illustrates that as the parameters Pe are increased, the velocity profile u decrease. The velocity profile u increases E as increases, as see in Figure 4.9. Figure 4.10 illustrates that as the parameters S_r are increased, the velocity profile u decrease. Figure 4.11 illustrates that as the parameters S_c are increased, the velocity profile u decrease. As for the We parameter, it increases the fluid velocity near the upper channel wall and vice versa at the lower wall of the flow channel, where the fluid velocity decreases with the increase of the We parameter. which is clear in Figure 4.12. Figure 4.13 illustrates that as the parameters M are increased, the velocity profile u decrease. The velocity profile u decreases ω as increases, as see in Figure 4.14. The velocity profile increases in the center of the flow path when the parameter N increases as seen in Figure 4.15. The velocity profile increases in the center of the flow path when the parameter n increases as see in Figure 4.16. In Figure 4.17, we can observe that as Re increases, the velocity profile lowers.
2. Figures (4.18)-(4.21) illustrate the temperature profile. Figure 4.18 indicates that as ω increases, the temperature lowers. As seen in Figure 4.19, the temperature rises as E increases. The temperature rises as N increases, as seen in Figure 4.20. In Figure 4.21, we can observe that as Pe increases, the temperature profile lowers.

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3. Figures (4.22) -(4.28) illustrate the concentration profile. the concentration lowers with increases E as seen in Figure 4.22. Figure 4.23 we can observe that as ω increases, the concentration rises. Figure 4.24 we can observe that as Pe increases, the concentration rises. The concentration profile diminishes as N increases, as seen in Figure 4.25. Figure 4.26 demonstrates how the impact of S_r on concentration profile diminishes. Figure 4.27 demonstrates how the impact of S_c on concentration profile diminishes. The concentration profile diminishes as K_r increases, as seen in Figure 4.28.

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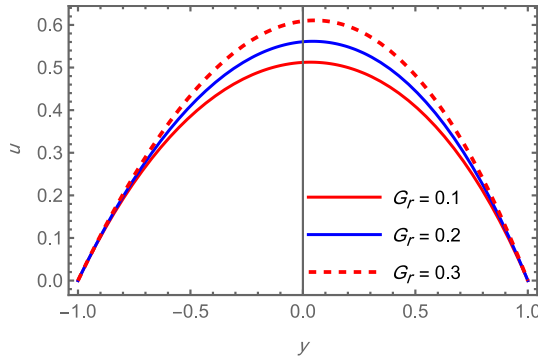


Figure 4.2 Velocity profile with different values G_r , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

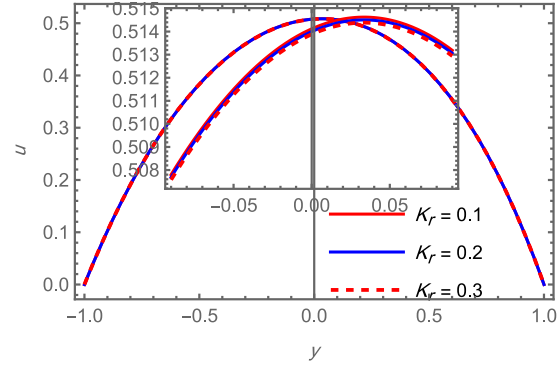


Figure 4.3 Velocity profile with different values K_r , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

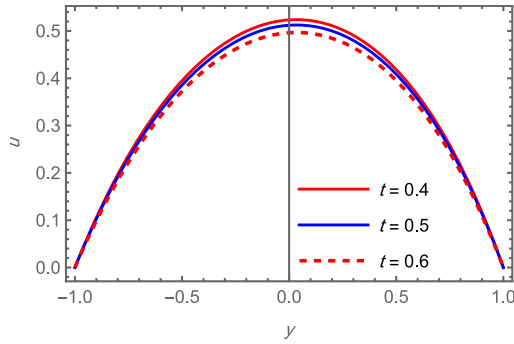


Figure 4.4 Velocity profile with different values t , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}$.

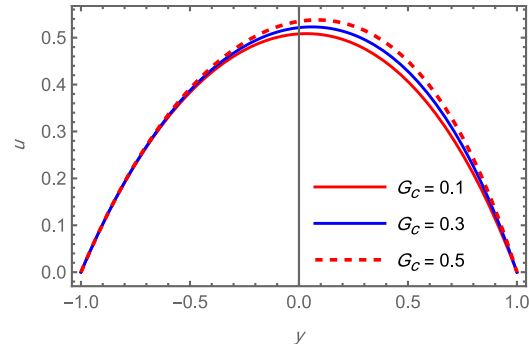


Figure 4.5 Velocity profile with different values G_c , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

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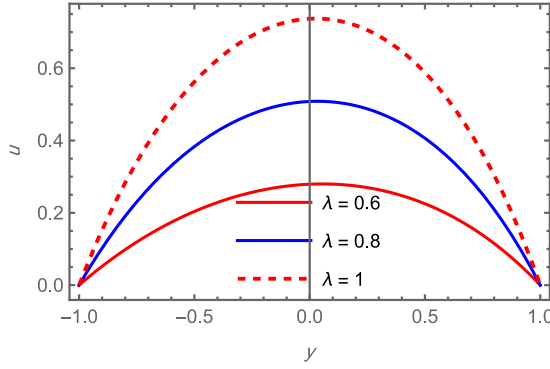


Figure 4.6 Velocity profile with different values λ , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

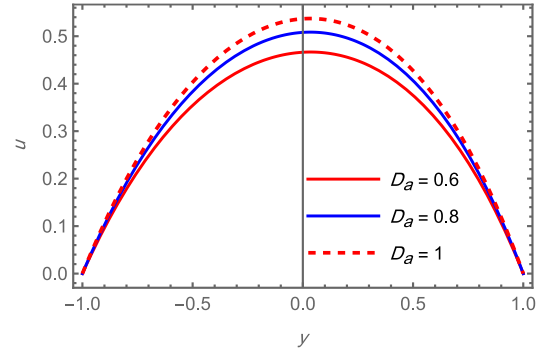


Figure 4.7 Velocity profile with different values D_a , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

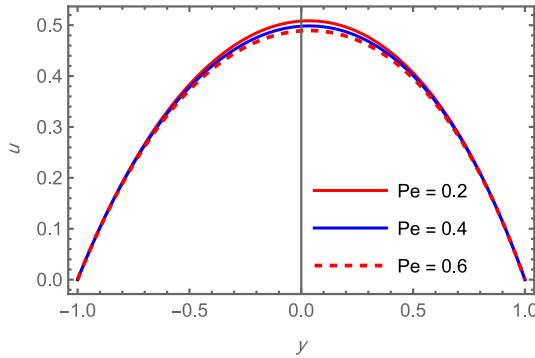


Figure 4.8 Velocity profile with different values Pe , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

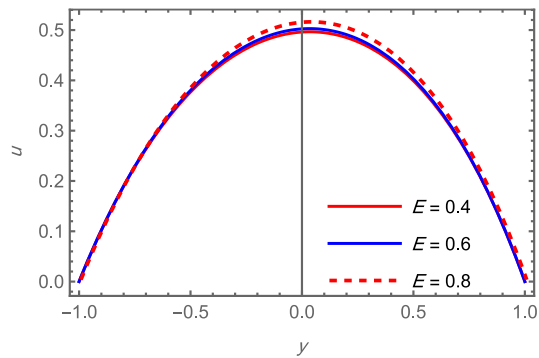


Figure 4.9 Velocity profile with different values E , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

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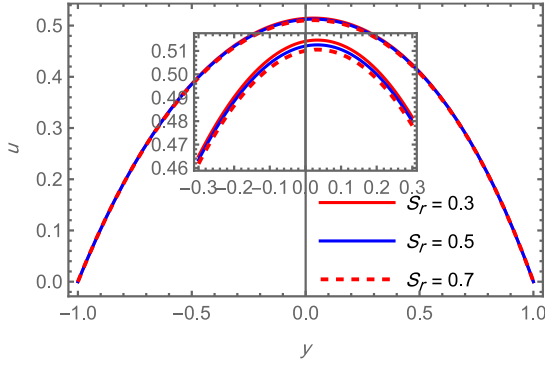


Figure 4.10 Velocity profile with different values S_r , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

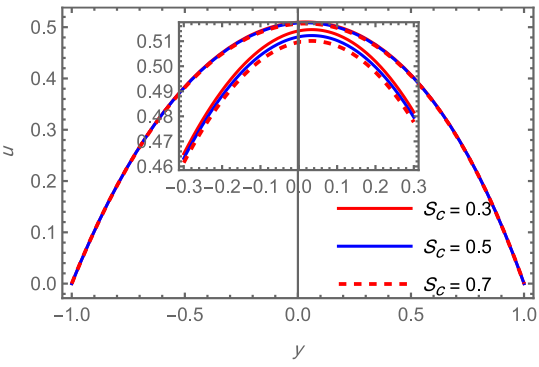


Figure 4.11 Velocity profile with different values S_c , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, i = \sqrt{-1}, t = 0.5$.

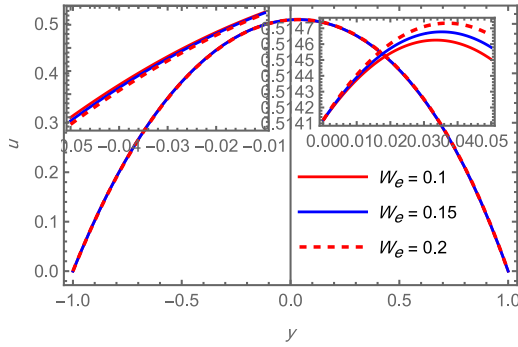


Figure 4.12 Velocity profile with different values W_e , with $\omega = 1, N = 1, n = 0.1, R_e = 1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

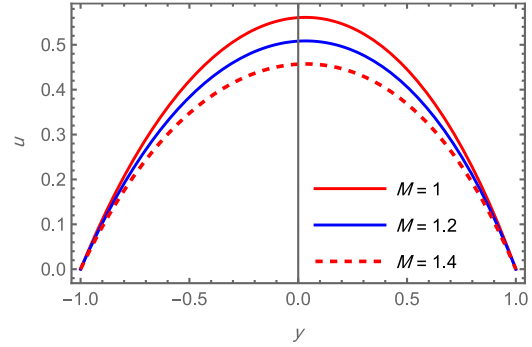


Figure 4.13 Velocity profile with different values M , with $\omega = 1, N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

Influence of temperature on the concentration and thus on the MHD oscillatory flow of a tangent hyperbolic fluid through a regular permeable channel

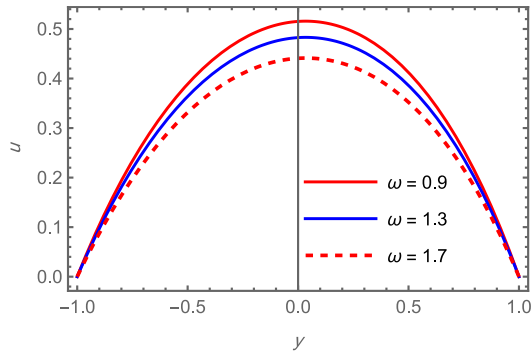


Figure 4.14 Velocity profile with different values ω , with $N = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

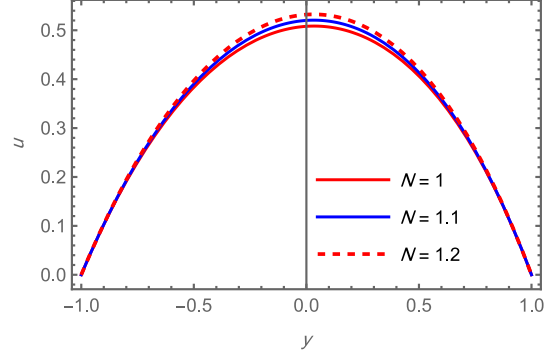


Figure 4.15 Velocity profile with different values N , with $\omega = 1, n = 0.1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

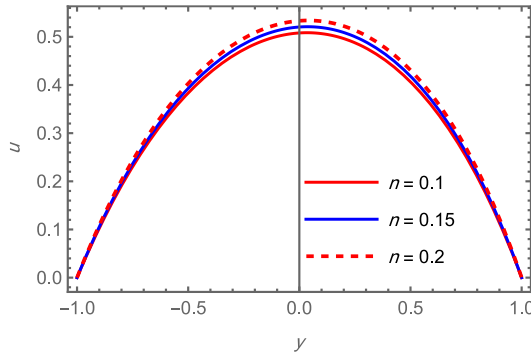


Figure 4.16 Velocity profile with different values n , with $\omega = 1, N = 1, R_e = 1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

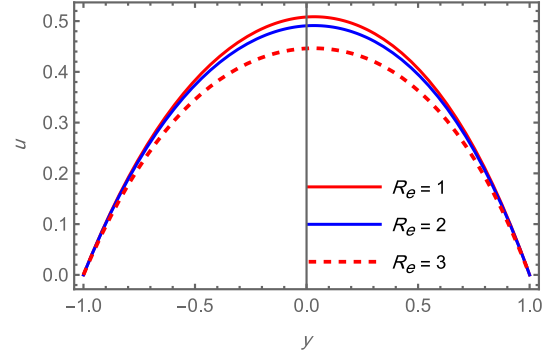


Figure 4.17 Velocity profile with different values R_e , with $\omega = 1, N = 1, n = 0.1, W_e = 0.1, D_a = 0.8, M = 1.2, G_r = 0.1, G_c = 0.1, \lambda = 2, E = 0.8, Pe = 0.1, K_r = 0.1, S_r = 0.3, S_c = 0.3, i = \sqrt{-1}, t = 0.5$.

Influence of temperature on the concentration and thus on the MHD oscillatory flow of a tangent hyperbolic fluid through a regular permeable channel

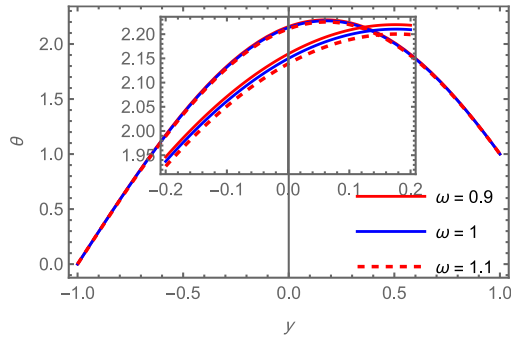


Figure 4.18 Temperature profile with different values ω , with $N = 1, n = 0.1, E = 0.8, Pe = 0.1, i = \sqrt{-1}, t = 0.5$

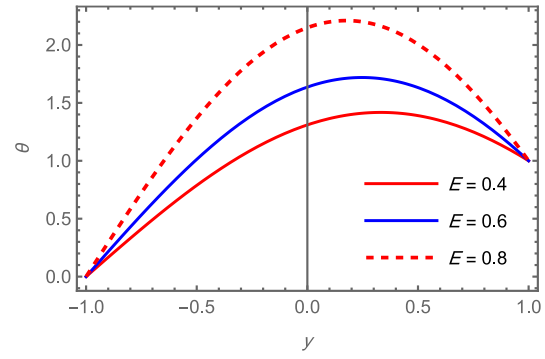


Figure 4.19 Temperature profile with different values E , with $\omega = 1, N = 1, n = 0.1, Pe = 0.1, i = \sqrt{-1}, t = 0.5$

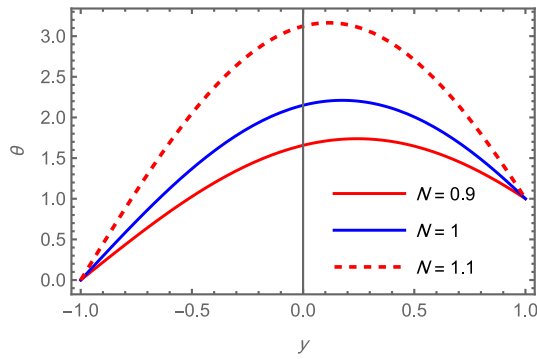


Figure 4.20 Temperature profile with different values N , with $\omega = 1, N = 1, n = 0.1, E = 0.8, Pe = 0.1, i = \sqrt{-1}, t = 0.5$

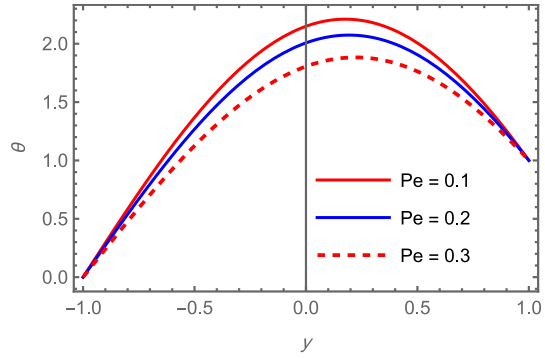


Figure 4.21 Temperature profile with different values Pe , with $\omega = 1, N = 1, n = 0.1, E = 0.8, i = \sqrt{-1}, t = 0.5$

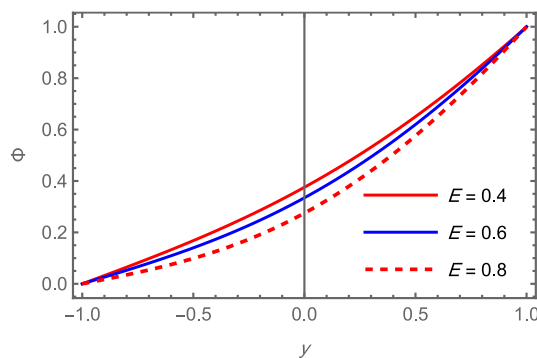


Figure 4.22 concentration profile with different values E , with $\omega = 1, N =$

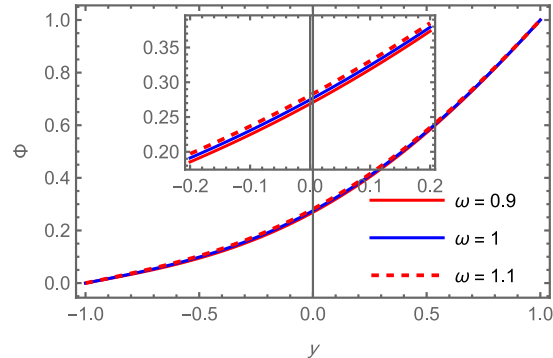


Figure 4.23 concentration profile with different values ω , with $N = 1, n =$

Influence of temperature on the concentration and thus on the MHD oscillatory flow of a tangent hyperbolic fluid through a regular permeable channel

$1, n = 0.1, Pe = 0.2, K_r = 0.1, S_r = 0.5, S_c = 0.3, i = \sqrt{-1}, t = 0.5$

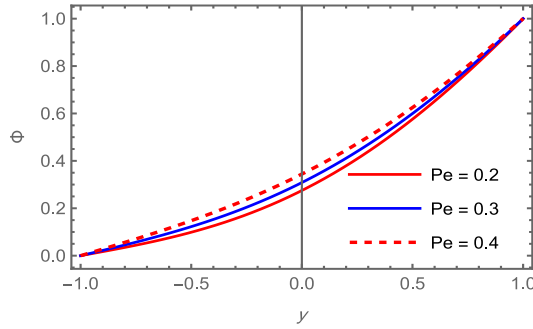


Figure 4.24 concentration profile with different values Pe , with $\omega = 1, N = 1, n = 0.1, E = 0.8, Pe = 0.2, K_r = 0.1, S_r = 0.5, S_c = 0.3, i = \sqrt{-1}, t = 0.5$

$0.1, E = 0.8, Pe = 0.2, K_r = 0.1, S_r = 0.5, S_c = 0.3, i = \sqrt{-1}, t = 0.5$

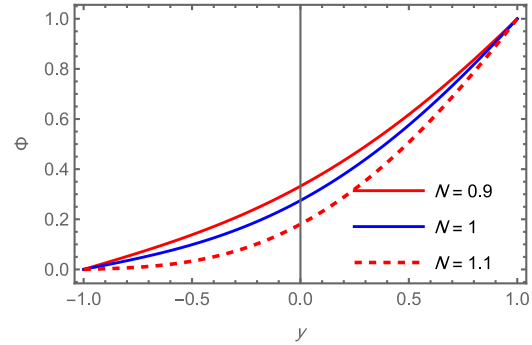


Figure 4.25 concentration profile with different values N , with $\omega = 1, n = 0.1, Q = 0.8, Pe = 0.2, K_r = 0.1, S_r = 0.5, S_c = 0.3, i = \sqrt{-1}, t = 0.5$

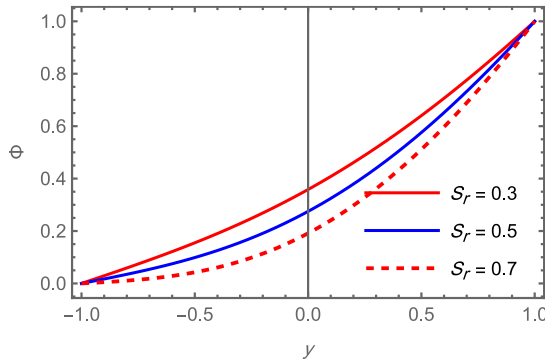


Figure 4.26 concentration profile with different values S_r , with $\omega = 1, N = 1, n = 0.1, E = 0.8, Pe = 0.2, K_r = 0.1, S_c = 0.3, i = \sqrt{-1}, t = 0.5$

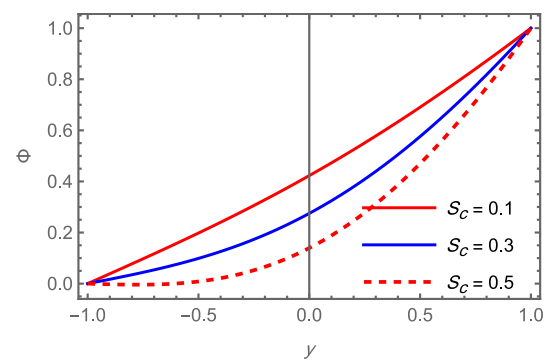


Figure 4.27 concentration profile with different values S_c , with $\omega = 1, N = 1, n = 0.1, Q = 0.8, Pe = 0.2, K_r = 0.1, S_r = 0.5, i = \sqrt{-1}, t = 0.5$

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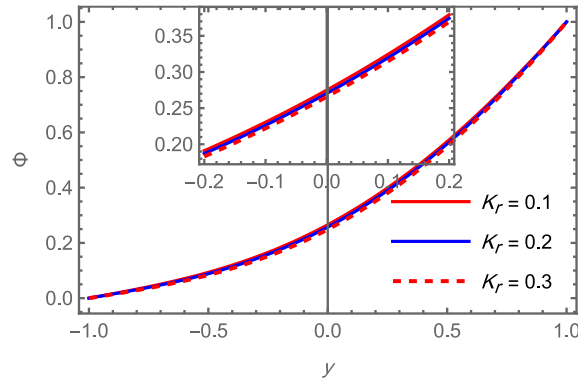


Figure 4.28 concentration profile with different values K_r , with $\omega = 1, N = 1, n = 0.1, Q = 0.8, Pe = 0.2, S_r = 0.5, S_c = 0.3, i = \sqrt{-1}, t = 0.5$

4.8- Conclusion Remarks

This thesis aims to analyze a mathematical model that studies the effect of temperature on concentration and then study them together on oscillatory flow MHD through a regular horizontal porous channel of a tangential hyperbolic fluid. Using the method of separation of variables, the system of equations was solved and using the Mathematica13 program we discussed the effect of the parameters on the results obtained through graphs, we reviewed some of the important results of this study:

- The fluid's velocity increases when the parameters G_r, n, λ, D_a , and G_c increase, while it decreases when the following parameters increase M, R_e and t .
- The velocity of the fluid increases in the upper wall of the channel when the parameter We increases, while the effect of the parameter is reflected in the lower wall of the channel and the velocity decreases.
- The parameters E and N have a positive effect on the fluid velocity and temperature, while its effect is negative on the concentration.
- The parameters S_r, S_c and K_r have a negative effect on the fluid velocity and concentration.
- The concentration of the liquid increases and its velocity and temperature decrease when the values of the parameters Pe and ω .

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الخلاصة

تهدف هذه الرسالة إلى دراسة وتحليل نوع واحد من الموائع غير القابلة للضغط، وهو مائع زائدي المماس غير النيو توني. تم فحص ثلاث مسائل للتدفق المتذبذب غير المستقر لمائع زائدي المماس لنوعين من التدفق هما Poiseuille و Couette. استخدمنا طرق مختلفة لحل نظام المعادلات التفاضلية الجزئية غير الخطية التي تحكم هذه المسائل، وحللنا النتائج التي حصلنا عليها من خلال برنامج "Mathematica 13".

في المسألة الأولى، تضمنت دراسة النقل الجماعي على التدفق التذبذبي لمائع زائدي المماس خلال قناة أفقية. وحللنا تأثير تغيير سرعة السائل على درجة حرارته.

في المسألة الثانية، درسنا تأثير التدفق التذبذبي للهايدروديناميك الممغنطة (MHD) وعلى درجة حرارة وتركيز المائع الزائدي المماس خلال قناة نفاذية منتظمة.

في المسألة الأخيرة وجدنا تأثير درجة الحرارة على التركيز وبالتالي على التدفق التذبذبي ال MHD لسائل زائدي مماس عبر قناة نفاذية منتظمة.



جمهورية العراق
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جامعة القادسية / كلية العلوم
قسم الرياضيات

تحليل التدفق المتذبذب لمائع زائدي المماس

رسالة

مقدمة إلى مجلس كلية العلوم جامعة القادسية كجزء من متطلبات نيل
درجة الماجستير في علوم الرياضيات

من قبل

أيمان سعد صالح فليح

بإشراف

أ.د. ضياء غازي صالح الخفاجي

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