

VISCOUS OSCILLATORY HETEROGENEOUS FLUID FLOW THROUGH PARALLEL PLATES WITH HEAT TRANSFER

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

By

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(DEEMED TO BE UNIVERSITY)
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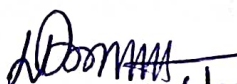
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of P.Ramani Priya (40630008) who carried out the project entitled "VISCOUS OSCILLATORY HETEROGENEOUS FLUID FLOW THROUGH PARALLEL PLATES WITH HEAT TRANSFER" under my supervision from December 2022 to May 2022.


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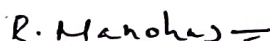
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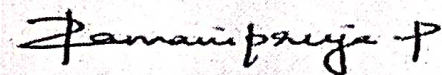
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DECLARATION

I **RAMANI PRIYA.P (40630008)** hereby declare that the Project Report entitled "**VISCOUS OSCILLATORY HETEROGENEOUS FLUID FLOW THROUGH PARALLEL PLATES WITH HEAT TRANSFER**" done by me under the guidance of **Dr.L. PRASANNA VENKATESH** (Internal) and (External) at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** submitted in partial fulfillment of the requirements for the award of Master of Science Degree in Mathematics.

DATE: 12.05.2022

PLACE: CHENNAI



SIGNATURE OF THE CANDIDATE

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ABSTRACT

The objective of this chapter is to analyze the heat transfer effects on viscous oscillatory stratified flow through a rectangular channel in presence of an angled magnetic field and radiative heat flux and heat source. The fluid is considered to have a very small electrical conductivity and the electromagnetic forces applied are in very small measurement. Analytical solutions for the problem are presented for the effect of several quantities involving the problem on velocity and heat outline, amplitude coefficient and Nusselt number.

KEYWORDS

- Fluid flow
- Parallel Plates
- Viscous
- Transverse Magnetic field

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CHAPTER-1

1. INTRODUCTION

1.1 FLUID DYNAMICS

1.1.1. FLUID DYNAMICS

Fluid dynamics is "the branch of applied science that is concerned with the movement of liquids and gases," according to the American Heritage Dictionary. Fluid dynamics is one of two branches of fluid mechanics, which is the study of fluids and how forces affect them. (The other branch is fluid statics, which deals with fluids at rest).

Scientists across several fields study fluid dynamics. Fluid dynamics provides methods for studying the evolution of stars, ocean currents, weather patterns, plate tectonics and even blood circulation. Some important technological applications of fluid dynamics include rocket engines, wind turbines, oil pipelines and air conditioning systems.

1.1.2 WHAT IS A FLOW?

The movement of liquids and gases is generally referred to as "flow," a concept that describes how fluids behave and how they interact with their surrounding environment for example, water moving through a channel or pipe, or over a surface. Flow can be either steady or unsteady.

Flow can also be either laminar or turbulent. Laminar flows are smoother, while turbulent flows are more chaotic. One important factor in determining the state of a fluid's flow is its viscosity, or thickness, where higher viscosity increases the tendency of the flow to be laminar.

1.1.3 IMPORTANT FACTOR OF FLUID FLOW

An important factor in fluid flow is the fluid's Reynolds number (Re), which is named after 19th century scientist Osborne Reynolds, although it was first described in 1851 by physicist George Gabriel Stokes. McDonough gives the

definition of Re as, "the ratio of inertial to viscous forces." The inertial force is the fluid's resistance to change of motion, and the viscous force is the amount of friction due to the viscosity or thickness of the fluid. Note that Re is not only a property of the fluid; it also includes the conditions of its flow such as its speed and the size and shape of the conduit or any obstructions.

1.1.4 IMPORTANCE OF FLUID FLOW

Air is all around us. We drink water every day. We clean ourselves and our environment using water. Almost 71% of the earth is covered with water. Our lives are highly interrelated with fluids. This highly necessitates the study of fluids. Fluids can be found in liquid or Gaseous state. Fluids, in its Engineering sense, can be defined as materials that shear constantly in the presence of a very small disturbance (Force and/or Gradient). Assume we pour water over a horizontal plate. The water will flow horizontally in all directions even if there is no gradient applied until it reaches stable position of a very minimal depth. The study of fluid dynamics is a very important area and is very useful in the area of modeling and simulation of fluid flow.

1.2 TYPES OF FLOW

1.2.1 LAMINAR AND TURBULENT FLOW

Flows can be broadly classified as Laminar and Turbulent flows. At a certain velocity and viscosity, flows are stable and have a defined property. The viscosity tend to dissipate the velocity and pressure terms and take the responsibility of calming the flow that it has a defined property, which is termed as Laminar flow.

But when the viscosity is small as compared to that of velocity of the flow, the flow shall have unpredictable and chaotic property, thereby called turbulent flow.

1.2.2 VISCOUS AND INVISCID FLOW

A fluid is formally termed viscous if the shear stress is directly proportional to the shear strain rate. In solids, materials with stress directly proportional to strain are called Elastic material or said to obey Hook's Law.

A fluid is in viscid if shear stress is not directly proportional to shear strain rate. By the same token, solids are termed as Inelastic if stress and strain are not directly related.

1.3 TERMS USED IN THE PROJECT

1.3.1 NUSSELT NUMBER

In fluid dynamics, the Nusselt number is the ratio of convective to conductive heat transfer at a boundary in a fluid. Convection includes both advection and diffusion. The conductive component is measured under the same conditions as the convective but for a hypothetically motionless fluid.

Nusselt number is denoted by the symbol Nu, and it is given by,

$$\therefore \text{Nu} = \frac{Q_{\text{Convection}}}{Q_{\text{Conduction}}} \quad (1.1)$$

1.3.2 BRUNT – VAISALA FREQUENCY

Brunt – Vaisala frequency is a measure of the stability of a fluid to vertical displacements such as those caused by convection.

$$N = \sqrt{\frac{-g}{\rho_0} \frac{\partial \rho}{\partial z}} \quad (1.2)$$

This is called the Brunt-Vaisala or buoyancy frequency, where g is the gravitational acceleration, ρ_0 is the density and it is the oscillation frequency of a parcel displaced vertically in an incompressible fluid and released.

But in our project, we assumed as $N^2 = \beta g$.

1.3.3 BOUSSINESQ APPROXIMATION

In fluid dynamics, the Boussinesq approximation is used in the field of buoyancy-driven flow (also known as natural convection). It ignores density differences except where they appear in terms multiplied by g, the acceleration due to gravity.

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\frac{1}{\rho_0} \nabla(p - \rho_0 \mathbf{g} \cdot \mathbf{z}) + \nu \nabla^2 \mathbf{u} - \mathbf{g} \alpha(T - T_0) \quad (1.3)$$

In the equation for heat flow in a temperature gradient, the heat capacity per unit volume, ρC_p , is assumed constant and the dissipation term is ignored. The resulting equation is

$$\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T = \frac{k}{\rho C_p} \nabla^2 T + \frac{J}{\rho C_p} \quad (1.4)$$

Where J is the rate per unit volume of internal heat production and K is the thermal conductivity

1.3.4 HARTMANN NUMBER

The Hartmann number is the ratio of electromagnetic force to the viscous force.

$$\mathbf{G} = \mathbf{r} \mathbf{H} \mathbf{c} \sigma \eta \quad (1.5)$$

Where r is the characteristic distance, σ is the electric conductivity of a medium, and H is the viscosity coefficient.

1.3.5 REYNOLDS NUMBER

The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities.

$$\text{Re} = \frac{\rho u L}{\mu} \quad (1.6)$$

Where ρ is the density of the fluid (SI units: kg/m^3), u is the flow speed (m/s)

L is a characteristic linear dimension (m), μ is the dynamic viscosity of the fluid ($\text{Pa}\cdot\text{s}$ or $\text{N}\cdot\text{s/m}^2$ or $\text{kg}/(\text{m}\cdot\text{s})$), ν is the kinematic viscosity of the fluid (m^2/s).

1.3.6 GRASH OF NUMBER

The Grash of number (Gr) is a dimensionless number in fluid dynamics and heat transfer which approximates the ratio of the buoyancy to viscous force acting on a fluid. It frequently arises in the study of situations involving natural convection and is analogous to the Reynolds number.

1.3.7 PERMEABILITY QUANTITY

Permeability is a measure of the ability of a porous material (often, a rock or an unconsolidated material) to allow fluids to pass through it. Permeability is part of the proportionality constant in Darcy's law which relates discharge (flow rate) and fluid physical properties (e.g. viscosity), to a pressure gradient applied to the porous media.

$$K = v \frac{\eta \Delta x}{\Delta P} \quad (1.7)$$

Where V is the fluid velocity through the porous medium (m/s), Δx is the permeability of a medium (m^2), η is the dynamic viscosity of the fluid ($Pa \cdot s$), ΔP is the applied pressure difference (Pa), K is the thickness of the bed of the porous medium (m)

1.3.8 PECLET NUMBER

The Peclet number is defined as

$$Pe = u a \frac{dL}{D} \quad (1.8)$$

Where $u a$ is the average velocity of the flow, dL the characteristic length of the system perpendicular to the direction of the flow, and D the diffusion coefficient of the particle or molecule of interest.

1.3.9 SKIN FRICTION

Skin friction drag is a component of parasitic drag, which is resistant force exerted on an object moving in a fluid. Skin friction drag is caused by the viscosity of fluids and is developed from laminar drag to turbulent drag as a fluid moves on the surface of an object.

$$C_f = \frac{dv}{dx} = \frac{dv_0}{dx} + \epsilon e^{-nt} \frac{dv_1}{dx} \text{ at } x = 0 \text{ and } x = 1 \quad (1.9)$$

CHAPTER-2

2. LITERATURE SURVEY:

The influences of heat transfer on an pulsating flow of fluid rectangular porous channels under the application of transverse magnetic field is dealt various engineering problems such as MHD generators of power, studies involving plasma cells, extraction of geothermal energy, environmental flows, petrol industries, and in many application of aerodynamics.

Mehta T. elaborated on “oscillatory fluid flow and heat transfer through porous medium between parallel plates in the presence of inclined magnetic field, radiative heat flux and heat source”.

Soundalgekar presented an “approximate solution to the problem of oscillatory MHD channel flow which is under the influence of transverse magnetic field” with the assumption that the plates are non-conducting and flow being unsteady and fully developed.

Mishra, J.C. studied the problem of “oscillatory MHD flow of blood in a porous arteriole in presence of chemical reaction and an external magnetic field has been investigated. Heat and mass transfer during arterial blood flow”.

Zhao, T.S and Cheng, P. numerically analyzed pulsating and reciprocating flows and their related problems on heat transfer.

Umavathi, J.C. et al considered the heat transfer problem of unsteady flow in a horizontal composite rectangular region filled with porous layer with some specific assumptions.

Makinde, O.D. solved the heat transfer on oscillatory flow through the channel which is filled with porous medium along with the combined effects of transverse magnetic field and radiative heat transfer by considering wall temperature to be varying in nature.

Choudury et al extended the problem for viscoelastic flow.

Prakash OM derived variable separable solution to heat transfer on MHD oscillatory dusty fluid flow through the channel filled with porous medium by using a suitable solution choice thereby converting the partial differential equations to an ordinary differential equation and solving the resultant equation by standard method for exact solution.

Anjali Devi, S.P. and Jothimani, S. obtained solutions to unsteady Magneto hydrodynamic flow of an incompressible electrically transmitting viscous fluid with heat transfer under the influence of the moving surface channel.

Adesanya and Makinde extended the heat transfer problem of conducting and pulsating slip flow in a channel which is full of porosity.

Prasanna Venkatesh presented effect of “Stratification in rectangular channel problem” with the assumption that the density when there is no disturbance in the fluid as a function of depth only and the flow being time dependent.

Prasanna Venkatesh and Surya prabha studied the “effect of narrow channel approximation on viscous oscillatory density stratified fluid flow through rectangular channels” by comparing the cases of flow without applying the lubrication approximation with that when it is applied.

In present problem the MHD flow of density stratified fluid which is oscillatory as well as viscous passing through a vertical rectangular channel with a pervious wall along which the withdrawal of fluid is taken place with a constant velocity with heat transfer is modeled.

CHAPTER-3

3. RESEARCH METHODOLOGY

3.1 AIM AND SCOPE

The main objectives of the work reported are:

- To study the effect of heat transfer effects on viscous oscillatory stratified flow through a rectangular channel in presence of an angled magnetic field and radiative heat flux and heat source.
- To study the effect of fluid with very small electrical conductivity and the electromagnetic forces which are applied are in very small measurement.
- Analytical solutions for the problem are presented for the influences of various quantities.

The scope of the work reported is:

- The influences of heat transfer on an pulsating flow of fluid rectangular porous channels under the application of transverse magnetic field is dealt various engineering problems such as MHD generators of power, studies involving plasma cells, extraction of geothermal energy, environmental flows, petrol industries, and in many application of aerodynamics.

3.2 DESCRIPTION OF RESEARCH WORK

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

Research Problem

The main objective of the research work is to analyze the heat transfer on an pulsating flow of fluid rectangular porous channels under the application of transverse magnetic field.

Research Methodologies

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

CHAPTER-4

4. MATHEMATICAL FORMULATION

We assume the fluid to be oscillatory and having the property of electrical conductivity. The problem starts by applying heat transfer between the parallel plates with the region of heat flow being filled with porous medium which is under the effect of an inclined magnetic field and heat source. The x^* - axis is considered perpendicular to the plate which y^* axis is considered along with one of the parallel plates. The velocity profiles and temperature profiles are functions of ' x ' and ' t ' only due to the plates are of infinite length. The fluid is density stratified with density in non-disturbed state is assumed to be linearly distributed while that in disturbed state is function of all space and time parameters.

The equation of incompressibility and density distributions are given by the following system of equations.

$$\frac{d\rho}{dt} \equiv \frac{\partial \rho}{\partial t} + u \frac{\partial \rho}{\partial x} + v \frac{\partial \rho}{\partial y} = 0 \quad (4.1)$$

$$\rho = \rho_0(y) + \rho^*(x, y, t) \quad (4.2)$$

$$\rho_0(y) = \rho_0'(1 - \beta y) \quad (4.3)$$

$$\Rightarrow \frac{\partial \rho^*}{\partial t} = \rho_0' \beta v \quad (4.4)$$

ρ_0' Denotes the mean density, $\rho^*(x, y, t)$ is perturbation density, β is the stratification parameter (a constant). Brunt – Vaisala frequency N assumes the expression $N^2 = \beta g$. Under the careful application of Boussinesq approximation, the equations concerning the flow after applying appropriate non dimensionalisation reduces to

$$Re \frac{\partial v}{\partial t} = \frac{\partial P}{\partial y} + \frac{\partial^2 v}{\partial x^2} + Gr \theta - (M^2 + K^2) v^* - Re \rho^* g \quad (4.5)$$

$$Pe \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial x^2} - R^2 \theta + S \theta \quad (4.6)$$

4.1 NOTATIONS

- v = dimensionless velocity in y direction
- t = time parameter
- y = height from x-axis
- P = pressure without dimension
- M = Hartman number with $\sin\phi$ multiplied
- Re = Reynolds number
- Gr = Grash of number
- K = permeability quantity
- Pe = Peclet number
- R = Radiation parameter
- S = Heat source parameter

4.2 BOUNDARY CONDITION:

The conditions for the problem on the boundary are correspondingly reduced in terms of dimensionless quantities in the following form

$$\left. \begin{array}{l} x=0: v = 0, \theta = 0 \\ x = h: v = e^{i\omega t}, \theta = e^{i\omega t} \end{array} \right\} \quad (4.7)$$

For the flow which is particularly oscillatory in nature we have

$$\left. \begin{array}{l} -\frac{\partial P}{\partial y} = \lambda e^{i\omega t} \\ v(x, t) = v_0(x)e^{i\omega t} \\ \theta(x, t) = \theta_0(x)e^{i\omega t} \end{array} \right\} \quad (4.8)$$

By using above substitutions in equations (4.1), (4.2) along with boundary conditions we get coupled differential equations with constant coefficient which is a complex number, and the corresponding solutions are given in the following set of

equations

$$[D^2 - (M^2 + K^2 + Re(\rho'_0 N^2 + i\omega))]v_0 = -Gr\theta_0 - \lambda$$

$$[D^2 - (R^2 - S + Pei\omega)]\theta_0 = 0 \quad (4.9)$$

The boundary conditions transformed into

$$x=0: v_0 = 0, \theta_0 = 0$$

$$x=1: v_0 = 1, \theta_0 = 1$$

} (4.10)

4.3 GENERAL SOLUTION OF EQUATION

The solutions are given by

$$\theta(x, t) = \frac{\sinh a_1 x}{\sinh a_1} e^{i\omega t} \quad (4.11)$$

$$v(x, t) = \left(\left(1 + \frac{\lambda}{a_2^2} (e^{-a_1} - 1) + \frac{Gr}{(a_1^2 - a_2^2)} \right) \frac{\sinh a_2 x}{\sinh a_2} - \frac{\lambda}{a_2^2} (e^{-a_1 x} - 1) - \frac{Gr}{(a_1^2 - a_2^2)} \frac{\sinh a_1 x}{\sinh a_1} \right) e^{i\omega t} \quad (4.12)$$

$$\text{In the above expression } a_1 = \sqrt{R^2 - S + Pei\omega}, a_2 = \sqrt{M^2 + K^2 + Re(\rho'_0 N^2 + i\omega)}.$$

The coefficient of skin friction in dimensionless stress tensor form at both the plates are given by

$$C_f = \frac{dv}{dx} = \frac{dv_0}{dx} + \varepsilon e^{-nt} \frac{dv_1}{dx} \text{ at } x = 0 \text{ and } x = 1 \quad (4.13)$$

4.4 EXPRESSION OF DIMENSIONLESS COEFFICIENT OF SKIN FRICTION

The dimensionless coefficient of skin – friction at the plate $x = 0$ is given by

$$(C_f)_0 = \left(\left(1 + \frac{Gr}{(a_1^2 - a_2^2)} \right) \frac{a_2}{\sinh a_2} - \frac{Gr}{(a_1^2 - a_2^2)} \frac{a_1}{\sinh a_1} \right) e^{i\omega t} \quad (4.14)$$

The dimensionless coefficient of skin – friction at the plate $x = 1$ is given by

$$(C_f)_1 = \left(\left(1 + \frac{Gr}{(a_1^2 - a_2^2)} \right) \frac{\cosh a_2}{\sinh a_2} - \frac{Gr}{(a_1^2 - a_2^2)} \frac{\cosh a_1}{\sinh a_1} \right) e^{i\omega t} \quad (4.15)$$

The heat transfer rate in the form of dimensionless Nusselt number at both the plates is presented in the following form.

$$Nu = - \left(\frac{\partial \theta}{\partial x} \right) = - \left(\frac{\partial \theta_0}{\partial x} \right) e^{i\omega t} \text{ at } x = 0 \text{ and } x = 1 \quad (4.16)$$

$$(Nu)_0 = \frac{a_1}{\sinh a_1} e^{i\omega t}, (Nu)_1 = \frac{\cosh a_1}{\sinh a_1} e^{i\omega t} \quad (4.17)$$

CHAPTER-5

5. RESULTS AND DISCUSSION

5.1 FIGURES AND DISCUSSION

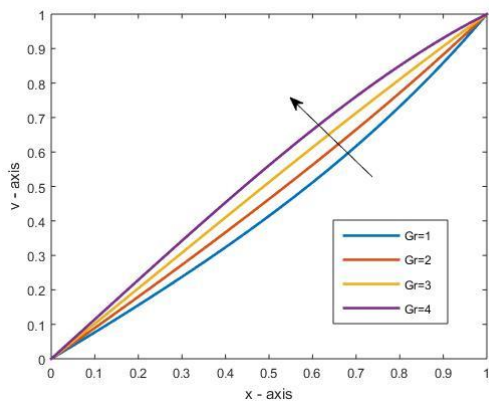


Figure 5.1: Velocity for varying Gr values

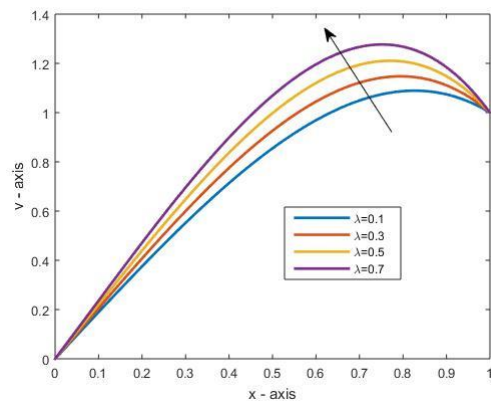


Figure 5.2: Velocity for varying λ values

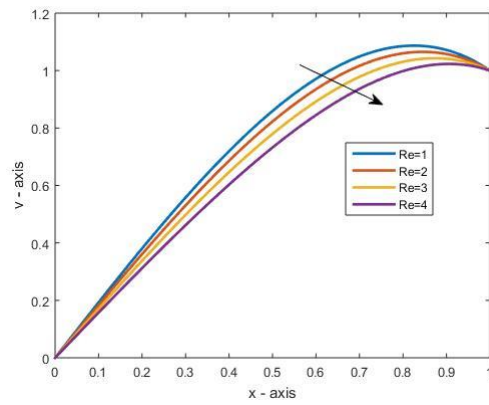


Figure 5.3: Velocity for varying Re values

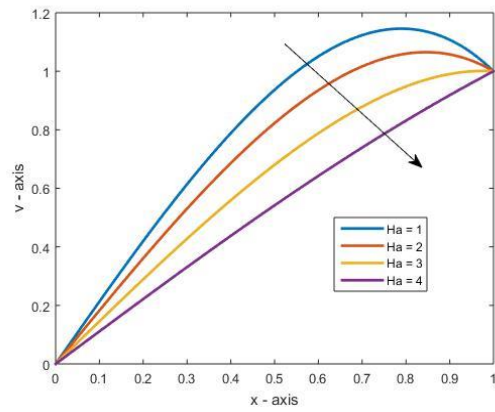


Figure 5.4: Velocity for varying Ha values

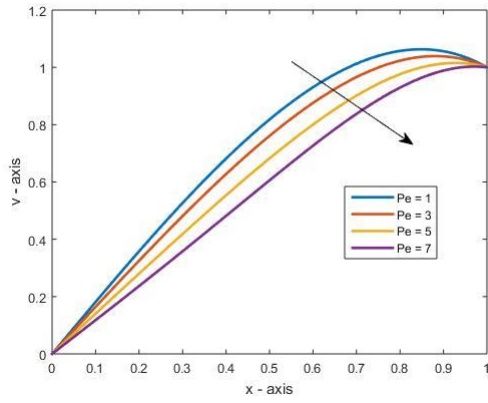


Figure 5.5: Velocity for varying Pe values

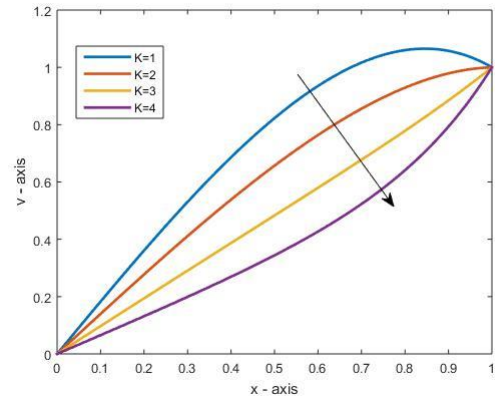


Figure 5.6: Velocity for varying K

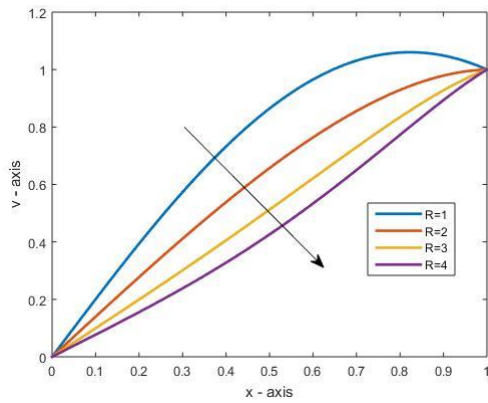


Figure 5.7: Velocity for varying R values

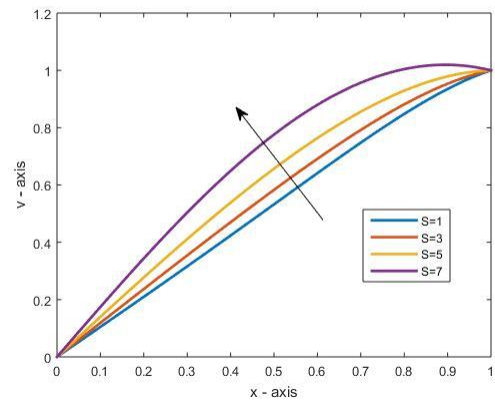


Figure 5.8: Velocity for varying S

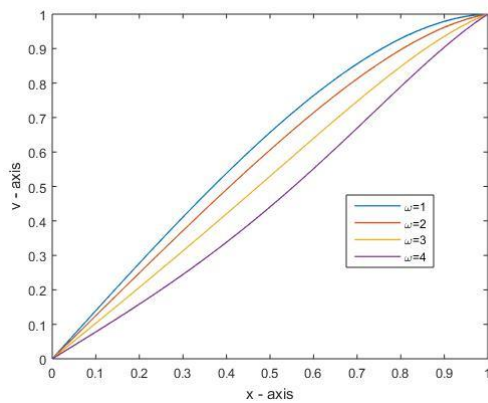


Figure 5.9: Velocity for varying w values

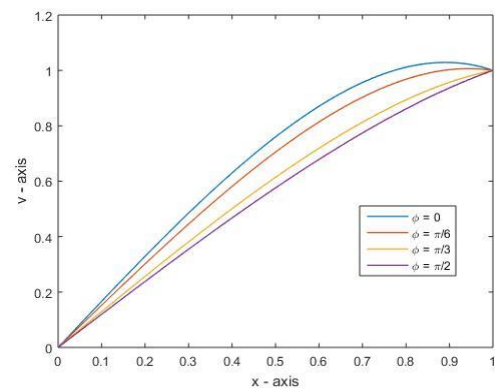


Figure 5.10: Velocity for varying Φ

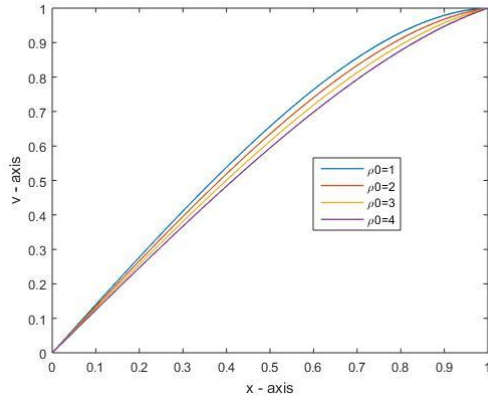


Figure 5.11: Velocity for varying p_0 values

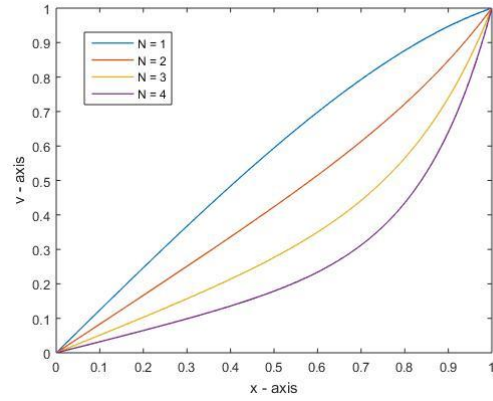


Figure 5.12: Velocity for varying N

It is observed that for figure 5.1 to figure 5.12, the velocity of the fluid increases with the increase of the grash of number, wavelength and heat source. It is noted that the velocity of fluid decreases for the Reynolds number, Hartmann number, Peclet number, permeability parameter, radiation parameter, Stratification parameter, frequency of the oscillation or angle between velocity and strength of the magnetic field.

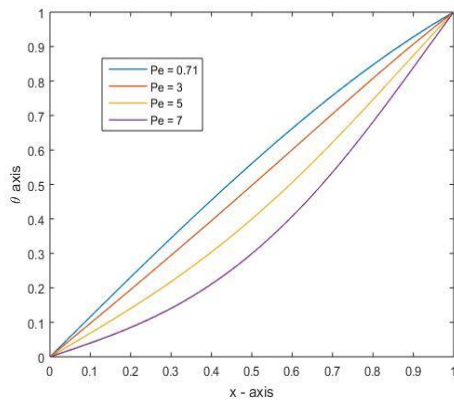


Figure 5.13: Temperature for varying Pe values

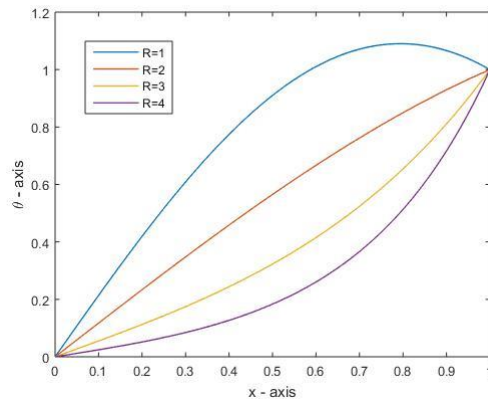


Figure 5.14: Temperature for varying R values

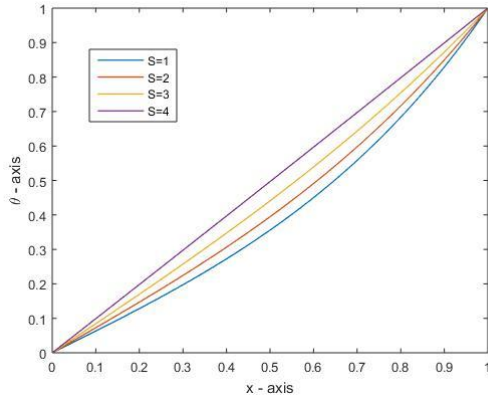


Figure 5.15: Temperature for varying S values

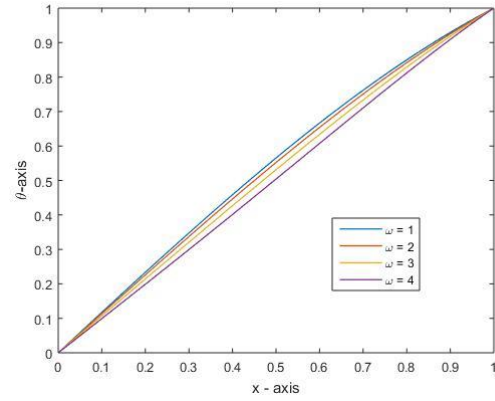


Figure 5.16: Temperature for varying w values

It is noted that from figure 5.13 to figure 5.16, the temperature of the fluid decreases due to decrease in the Peclet number, Radiation parameter, and Frequency of the oscillation. It increases for Heat source parameter.

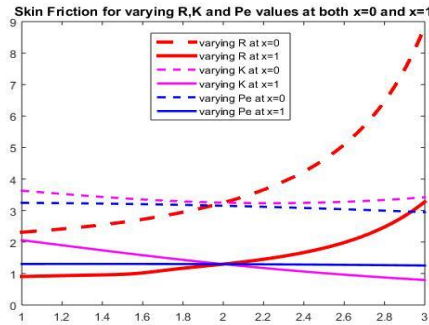


Figure 5.17: Skin friction for varying R, K, and Pe.

Figure 5.17 depicts skin friction for varying R, K and Pe from 1 to 3. At $x = 0$ it is observed that skin friction increases for an increase in value of R. It decreases up to $K = 2.5$ and increases from $K = 2.5$ onwards up to 3. For varying Pe values the skin friction does not have any visible significant changes on the plate $x = 0$. On the plate $x = 1$, up to $R = 1.5$, there is no effects on skin friction but for $R > 1.5$, it gradually increases. There is clear decrease in skin friction values for increased values of K. There is not much effect in skin friction for varying values of Pe.

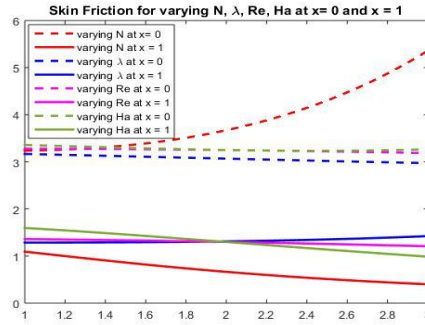


Figure 5.18: Skin friction for varying λ , N , Re and Ha .

Figure 5.18 depicts skin friction for varying λ , N , Re and Ha from 1 to 3. At $x=0$, up to $N=1.5$ there is no effect on skin friction, but $N > 1.5$, it gradually increases. For varying λ values the skin friction is showing mild decreasing at $x=0$. At $x=0$, for varying Re the skin friction does not have any visible significant changes on the plate. On the plate $x=0$, by varying Ha , the skin friction is significantly decreasing. At $x=1$ it is observed that skin friction decreases for an increase in value of N . For varying λ values the skin friction is showing mild increasing at $x=1$. At $x=1$, for varying Re the skin friction does not have any visible significant changes on the plate. As Ha increases skin friction is showing decrease in effect at $x=1$.

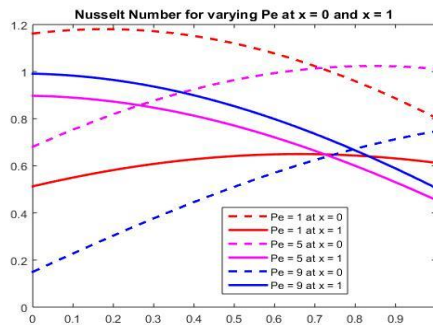


Figure 5.19: Nusselt number for varying Pe .

Figure 5.19 depicts Nusselt number for varying Pe from 1 to 3. For $Pe=1$ at $X=0$, $Pe > 0.3$ Nusselt number is increasing then $Pe < 0.3$ it is gradually decreasing. For $Pe=1$ at $X=1$, skin friction is gradually increasing. For $Pe=5$ at $X=0$, by varying Pe , the Nusselt number is rapidly increasing. For $Pe=5$ at $X=1$, from $Pe > 0.1$ Nusselt number is increasing but $Pe < 0.1$ it is gradually decreasing. For $Pe=9$ at $X=0$, by varying Pe , the Nusselt number is rapidly

increasing. For $Pe=9$ at $X=1$, $Pe > 0.1$ Nusselt number is increasing but $Pe < 0.1$ it is gradually decreasing.

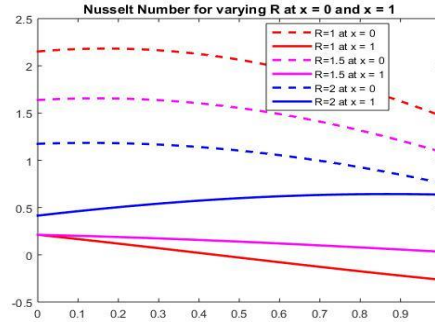


Figure 5.20: Nusselt number for varying R.

Figure 5.20 depicts Nusselt number for varying R from 1 to 3. For $R=1$ at $X=0$, $R > 0.5$ Nusselt number is increasing, but $R < 0.5$ it is decreasing. For $R=1$ at $X=1$, by varying R Nusselt number is rapidly decreasing. For $R=1.5$ at $X=0$, $R > 0.5$ Nusselt number is increasing, but $R < 0.5$ it is decreasing. For $R=1.5$ at $X=1$, Nusselt number is gradually decreasing. For $R=2$ at $X=0$, $R > 0.5$ Nusselt number is increasing, but $R < 0.5$ it is decreasing. For $R=2$ at $X=1$, Nusselt number is gradually increasing.

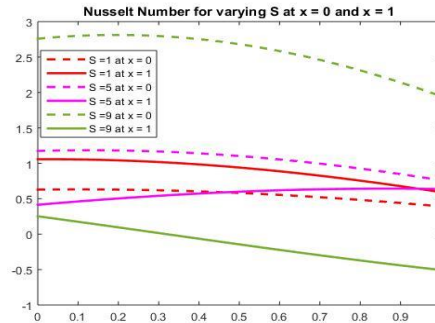


Figure 5.21: Nusselt number for varying S.

Figure 5.21 depicts Nusselt number for varying S from 1 to 3. For $S=1$ at $X=0$, $S > 0.4$ Nusselt number is increasing, but $S < 0.4$ it shows mild decrease. For $S=1$ at $X=1$, $S > 0.5$ Nusselt number is increasing, but $S < 0.5$ it shows mild decrease. For $S=5$ at $X=0$, $S > 0.4$ Nusselt number is increasing, but $s < 0.4$ it shows mild decrease. For $S=5$ at $X=1$, As S increases, Nusselt number is also increasing. For

$S=9$ at $X=0$, $S>0.3$ Nusselt number is increasing, $S<0.3$ it shows gradual decrease. For $S=9$ at $X=1$, As S increases, Nusselt number is rapidly decreasing.

CHAPTER-6

6. SUMMARY AND CONCLUSIONS

6.1 CONCLUSION

- In the above analysis the heat transfer effects on viscous oscillatory stratified flow through a rectangular channel in presence of an angled magnetic field and radiative heat flux and heat source are investigated.
- Equations of momentum and energy which govern the fluid flow and heat transfer are solved by using the analytic method.
- The effects of various physical parameters on the fluid velocity, temperature, and skin friction coefficient and Nusselt number at the places are observed, discussed numerically and shown through graphs.

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- Prasanna Venkatesh presented effect of “Stratification in rectangular channel problem” with the assumption that the density when there is no disturbance in the fluid as a function of depth only and also the flow being time dependent.
- Prasanna Venkatesh and Surya prabha studied the “effect of narrow channel approximation on viscous oscillatory density stratified fluid flow through rectangular channels” by comparing the cases of flow without applying the lubrication approximation with that when it is applied.