OPTIMIZATION OF MAGNETOHYDRODYNAMIC PARAMETERS IN A TWO DIMENSIONAL INCOMPRESSIBLE FLUID FLOW ON A POROUS CHANNEL

CAROLYNE KWAMBOKA ONYANCHA

BACHELORS OF EDUCATION (MT. KENYA UNIVERSITY)

A THESIS SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN APPLIED MATHEMATICS IN SCHOOL OF PURE AND APPLIED SCIENCES, DEPARTMENT OF MATHEMATICS AND ACTURIAL SCIENCES.

KISII UNIVERSITY

2023

DECLARATION

I the undersigned declare that this thesis is my unique work and has not been presented elsewhere for academic purpose in this University or any other University whatsoever. No part of this thesis report may be produced without prior written permission of the author and/or Kisii University.

Signature ……………………… Date………………………….

REG NO: MPS12/70001/18

Carolyne Kwamboka Onyancha

Declaration by supervisors:

This thesis has been submitted for examination with our approval as the University supervisors.

Signature: ………….……... Date: ………….……

Dr. Joash Kerongo, PhD.

Department of Mathematics and actuarial sciences

Kisii University

Signature: ………….……… Date: ………….……

Dr. Vincent Bulinda, PhD.

Department of Mathematics and actuarial sciences

Kisii University

PLAGIARISM DECLARATION

Declaration by Student

I certify that I have read and comprehended the academic dishonesty policies of Kisii University and other related papers, and I am aware that disregarding such policies is not an acceptable defense for breaking them. I am aware that it is my duty to constantly look for clarification if I have any concerns or uncertainties so that I can fully comprehend. My own task must be done. I am aware that my thesis might receive a "F" mark if I engage in academic dishonesty like plagiarism. I am also aware that academic dishonesty may result in my suspension or expulsion from the university.

Sign…..…………………… Date……………

Carolyne Onyancha

MPS12/70001/18

Declaration by Supervisors

We declare that this thesis/project has been submitted to plagiarism detection service and that it contains less than 20% of plagiarized work. Therefore we hereby give consent for marking.

1. Sign…………………… Date…………
   Dr. Joash Kerongo, PhD

2. Sign................................. Date……………
   Dr. Vincent Bulinda, PhD

DECLARATION OF NUMBER OF WORDS

Name: Carolyne Onyancha **Adm. No:** MPS12/70001/18

School: School of Pure and Applied Sciences

Department: Mathematics

Thesis Title: Optimization of Magnetohydrodynamic parameters in a two dimensional incompressible fluid flow on a porous channel

I hereby confirm that the word length of:

1. The thesis, including footnotes is 20, 116

2. The bibliography is ………..

3. The appendices are ………..

I further certify that the electronic version of the thesis coincides with those upon which the examiners made their recommendation for the granting of the Master of Science in Applied Mathematics and is similar to the final, hardbound copy of the thesis.

Carolyne Onyancha Sign: …………………… Date ………………..

We certify that the candidate whose name appears above has submitted a thesis that meets with the pertinent word count requirements set out in the rules for master's and doctoral degrees established by the School of Postgraduate and Commission of University Education.

Dr. Joash Kerongo, PhD Sign......................... Date…………….

Dr. Vincent Bulinda, PhD Sign............................ Date……………

COPYRIGHT

DEDICATION

I dedicate this thesis to my dad Mr. Francis Onyancha, my mother Mrs. Linet Onyancha and to my children: Kimberly, Blessed, Happiness and Hadassah, my friend Elijah Oanya and to my dear sister Roseline Onyancha. May God bless you.

ACKNOWLEDGEMENTS

My gratitude goes to my supervisors Dr. Joash Kerongo and Dr. Vincent Bulinda for the academics guidance and for the knowledge I acquired from them during my study. My supervisors ensured that I did my best as well as better my understanding in matters academics. To my colleagues who accorded me a lot of moral support and especially to my Chief Principal Dr. Teresa Atieno who always challenged me to do my best, she always gave me the noble time to do my research work. To Mr. Muga who gave me the technical guidance on ICT, I am humbled for the assistance. My appreciation also goes to all my family members for their support and positive criticism that enabled me to push the research work to completion. May God bless you.

TABLE OF CONTENTS

CHAPTER THREE

CHAPTER FOUR

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The speed of a liquid at any given position in space varies with time in constant flow. However, practically all flows are unstable in some way, resulting in velocity variations over time. Magnetohydrodynamics parameters optimization of incompressible fluid flow on a porous channel was evaluated in this case. The fluid flow was considered as viscous, unsteady, incompressible and flowing in a two dimensional porous channel. The study identified the impact of optimizing the magnetic parameter and Darcy number on velocity profiles, the impact of Eckert value on temperature profile in the flow and the effects of optimizing pressure was also analyzed. The governing equations were solved numerically using the Finite Difference Method (FDM) and the Partial Differential Equations obtained were solved using the Central Scheme (SC). The velocity profile was inversely affected by the magnetic parameters along the porous channel and it indicated that an increased in Darcy number relatively led to an increase in the velocity profile along the porous channel. The temperature profile increased with an increase in the Eckert number whereas the temperature in the flow decreased with decrease in the Eckert number. The fluid pressure was also analyzed to have an inverse effect on the velocity profile. To increase velocity profile in the flow along the channel, a decrease in the pressure was required. The optimum velocity was realized at the lowest pressure in the fluid flow. These results were tabulated and analyzed by tables and graphs with the help of MATLAB software. The study results are applicable in the nuclear heat transfer control in industries and will contribute towards giving alternative methodology and equations that are applicable in engineering where optimization of Magnetohydrodynamic parameters is essential.

LIST OF SYMBOLS

Greek symbols	Meaning	SI unit
κ	Permeability of porous medium	$\frac{N}{A^2}$
ρ	Density	kgm^{-3}
υ	Kinetic coefficient of viscosity	m^2s^{-1}
σ	Electrical conductivity	$\Omega^{-1}m^{-1}$
k	Thermal conductivity	$Wm^{-1}k^{-1}$
C_p	Specific heat at constant pressure	$JKg^{-1}K^{-1}$
T	Temperature	K
μ	Coefficient of viscosity	$kgm^{-1}s^{-1}$
ϕ	Viscous dissipation function	s^{-2}
D_H	Hydraulic diameter	m
Q	Volumetric flow rate	m^3/s
A	The pipe's cross-sectional area	m^2
u	Mean velocity of the fluid	m/s
U	Characteristic velocity scale	m/s
B	Magnetic field	W
W	The mass flow rate of the fluid	kg/s
L	Characteristic length	m
p_c	Pressure coefficient	Jm^{-3}
D	Diffusion coefficient	m^2/s
α	Thermal diffusivity	m^2/s
Ha	Hall current	
N	Stuart number	
M	Magnetic parameter	
V_f	Darcy velocity	
ΔP	Pressure difference	

LIST OF ABBREVIATIONS

MHD	Magnetohydrodynamics
MATLAB	Matrix Laboratory
FDM	Finite Difference Method
FDA	Finite Difference Approximation
CFD	Computational Fluid Mechanics
CS	Central Scheme
ODE	Ordinary Differential Equation
PDE	Partial Differential Equation

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The study of Magnetohyodynamic flow through a porous channel is of great interest to the scientific researchers. In industries most application on it occurs as well as a wide range of astronomical and geophysical phenomena. The knowledge gained from this research has practical applications in various fields of engineering and science, such as electromagnetic lubrication, boundary setting in cooling equipment, bio-physical systems, and many more. In reality, because of their useful applications in numerous fields of science and technology, fluid flows via porous channels have caught the interest of many academics. It is possible to analyze a porous material that is not homogeneous by treating it as such by assuming that its dynamical properties are equal to the average of the initial non-homogeneous continuum. In this instance, a flow issue in a porous media is reduced to a homogenous fluid flow issue with some added resistance (Ahmad *et al*., 2020).

Magnetohydrodynamics (MHD) the terms Magneto, Hydro, and Dynamics are derived from magnetic fields, often known as magneto Hydro meaning the fluid and Dynamics also means movement on a channel or in surfaces. The properties and applications of MHD fluid were first established by Hanns Alfven in 1970, a scholar who received a Nobel Prize for the great initiative. This has helped build a package of knowledge which is influencing alternative solutions to various MHD flow problems. MHD in fluid dynamics is a discipline of research that blends electromagnetism with fluid mechanics in order to describe the motion of electrically conducted fluids focusing on its magnetic properties and behavior for example liquid metals and electrolytes (Kumari and Nath, 2012).

Davidson, (2001) also agrees in his study that MHD include magneto-magnetic field, hydro-fluid and dynamics-movement as was initiated earlier by other scholars. The essential idea underlying MHD is the notion that magnetic flux may generate currents in a flowing conductive fluid, which alters the flux and reciprocally modifies the magnetic flux. It is the study of how fields of magnets and electrically conductive fluids move in relation to one another. The momentum, mass, and energy equations are all affected by MHD parameters in a flow is associated with engineering difficulties in areas like plasma confinement, liquid metallic substances, nuclear reactor cooling, and electronic equipment Davidson, (2017).

In this study to Optimize MHD Parameters is key, where action is taken to make the best or most effective use of a parameter to ensure the various variables have the desired output. Optimization is an act, process, or methodology of making velocity profile, temperature or pressure as fully perfect, functional, or effective as possible specifically, depending on the variable or variables related by a given function. In other words, it is to maximize, fine tune or enhance a component. This study will contribute towards having alternative models and methodology to be used in various aspects of engineering as indicated by (Fatunmbi, Ogunseye & Sibanda, 2020).

This study considers incompressible fluid which is a fluid whose density does not change in a flow. The liquids that are considered in most cases as gas can be incompressible when just a small pressure difference is applied. This fluid flow is also referred to as isochoric flow, where the fluid has unaltered density. In this study, the fluid considered is incompressible where the particles have no air particles and changes in the density of the fluid flowing along the channel that is porous.

The Lagrangian observer, like the particle frame of reference, sees no density change where, $\frac{\partial \rho}{\partial t} = 0$. In this scenario, the conservation of mass has the simple form v = 0, often referred to as the continuity equation. The assertion can be as simple as ρ = constant for a fluid that is incompressible at normal pressures and temperatures. Fluid density in the ocean, on the other hand, is a complex relationship of temperature, pressure, and salinity, as depicted by Gill, (1982).

Optimization of MHD Parameters on flow through a porous channel was the study's main subject. The problem of the study was solved using Finite Difference Method. The energy equation, momentum equation, and continuity equations were used as the governing equations.

The method is quite effective and has both commercial and non-commercial applications. Aerodynamics of airplanes and vehicles, lift and drag, ship hydrodynamics, and power plants are some of these applications. The approach is also used in engine and gas turbine combustion, in addition to flows inside spinning passageways and diffusers. In electrical and electronic engineering, it will be useful in cooling of equipment including microcircuits as well as in chemical process in engineering where mixing and separation of fluids take place.

Additionally, the method is used in polymer molding, and it can be used to improve wind loading, heating, and ventilation in both the interior and exterior environments of buildings. Other fields in which it can be used include marine engineering, which deals with loads on offshore structures, environmental engineering, which deals with the distribution of pollutants and effluents, hydrology, and oceanography, which deals with flows in rivers, estuaries, and oceans, and meteorology, which deals with weather prediction and where the technique will be very important.

Sharma, Jain & Kumar, (2002) emphasized on the speed of a liquid at any given position in space varies with time in constant flow in their study. However, practically all flows are unstable in some way, resulting in velocity variations over time. Switching off a faucet to halt the flow of fluid is an illustration of a non-periodic, unstable flow. In some flows, the unsteady impacts may be periodic, repeating every time in the same manner. As an example, imagine periodically injecting a gasoline-air combination into the cylinder of an automobile engine. The unstable character of a flow is rather random in many cases, that is, there is no recurring regular variation to the unsteadiness. This phenomenon is observed in turbulent flow but not in laminar flow.

A deterministic laminar flow is shown by the smooth flow of excessively viscous syrup onto a pancake. It's not like the turbulent flow seen in the uneven spraying of water from a faucet onto the sink below it. The wind's unpredictable gustiness symbolizes yet another random chaotic flow. In an unstable flow, flow characteristics such as velocity and thermodynamic parameters fluctuate with time at each location in space by (Gurivi *et al*., 2017).

The study of MHD fluid dynamics on a porous channel is a field that has been of high interest by many scholars. According to Hady *et al*. (2006), the creation of internal heat or absorption to the flow while evaluating the presence of their study on a free convection movement on a vertical wavy surface immersed in an electrically conducting fluid with saturation of porous medium. They looked at how thermal radiation and a heat source affected an incompressible viscous fluid's irregular periodic motion. When a magnetic field that is transverse is present, the fluid was assumed to flow via a porous planer channel they explored the irregular periodic viscous fluid flow that is incompressible inside a porous medium while taking a transverse magnetic field's existence into account (Kumar *et al*., 2010).

Other scholars like; (Omboga *et al*., 2013) who did study MHD free convective flow past an infinitely vertical porous plate found the fluid in the study to be an incompressible electrically conducting fluid. The transverse magnetic fields were taken into account in Pawan *et al*. (2013) investigation of the finite difference technique for unstable MHD periodic flow of a viscous fluid via a planer channel, and Kumar *et al*. (2013) investigation of the finite element using the galerkin's method in the case of viscous incompressible fluid movement through a medium that is porous in coaxial cylinders.

In view on the foregoing background it has been shown that a lot of research has been done on MHD optimization with consideration on steady and Unsteady MHD periodic flow either considering a porous planer channel or steady and unsteady flow with an account of the external heat source. In some studies oscillatory MHD flow where it is an electrically conducting fluid. In other study focus has been on effects of chemical reactions in the flow and slip conditions on flows in a porous channel. In this study, there is focus on the optimization of MHD parameters on unsteady two dimensional incompressible flows. The flow is considered to be unsteady and flowing through a porous channel. The study problem is solved through the Finite Difference Equation precisely the central scheme method.

1.2 Statement of the Problem

Effect of optimizing MHD parameters on the flow variables such as viscosity, velocity profile and temperature in a free convective, two-dimensional flow through a permeable media channel represents a complex dynamical scheme for confined flow in physical and industrial processes. The focus was on the Magnetic number, the Darcy number and Eckert number that were the MHD parameters optimized and analysis done on their effects on the flow variables like the velocity and the temperature in the flow along the channel. This study took into account the flow of an incompressible, viscous, and unsteady fluid via a porous channel. The system of governing equations was discretized to obtain the initial and boundary conditions of the flow, and solved them analytically using the central scheme one of the Finite Difference Methods.

In previous studies focus was on steady and unsteady convective fluid flow taking on account the effects of external heat source to the flow. The flows considered either oscillatory effects with introduction of the external magnetic effect or external heat source. A one dimensional flow through a porous channel initially was also considered. In this study, there is no external heat source considered and the externally induced magnetic field was neglected. No oscillatory effect was considered either. The flow was considered unsteady, viscous and two dimension flowing along the length of a porous channel.

1.3 Objectives

1.3.1 General Objectives

Optimization of Magnetohydrodynamic parameters in a two dimensional incompressible fluid flow on a porous channel.

1.3.2 Specific Objectives

i. To determine the effects of magnetic parameter and Darcy number on velocity profiles for incompressible fluid flow within a porous channel.

ii. To determine the effect of variable viscosity and Eckert number on temperature distribution for incompressible fluid flow within a porous channel.

iii. To optimize the pressure of the incompressible fluid flow in a porous channel and determine its effect on the velocity profile.

1.4 Justification

There are several applications from studying MHD flows on the convection of air in a porous channel which include the field of engineering as well as the geophysical areas; Chemical engineering applications include filtration and purification processes, agricultural engineering for channel irrigation, and the analysis of subsurface water resources. The knowledge acquired is also significant when employed in petroleum engineering to look into the flow of petroleum, natural gas, and other types of water channels, concentrating on how different fluid absorption and element transfer on a flow.

1.5 Expected output of the Study

Optimization of the Magnetic parameter, Eckert number and Pressure component is expected to lead to an increase or decrease on the velocity profile. By increasing the Magnetic parameter and the pressure, the velocity is likely to reduce due to the resisting effect of the parameters to the flow. This leads to a slow flow rate on a porous channel. The Darcy number in a flow on a porous channel leads to an increase the permeability effect on a porous channel. In this study, the velocity is expected to skew positively with increase in the Darcy number. The temperature profile in the flow through the porous channel is expected to increase with increase in the Eckert number due the increase on the rate of converted from the inertia to kinetic energy.

1.6 Significance of the Study

In irrigation, the drip method ensures food supply security from the agricultural sector by a continuous supply of water. This study will highly contribute to alternative solutions of ensuring that the amount of fertilizer being supplied to farm is at a regulated rate by either decreasing or increasing the parameters that affect the velocity profiles in the porous channel. The supply of the water may be decreased during the rainy season hence the velocity will be decreased by increasing the magnetic parameter and the pressure coefficient in the flow, whereas the Darcy number will be decreased. In the dry season, the velocity will be increase by increasing the Darcy number and reducing the magnetic parameter and the pressure coefficient on the flow.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is a discussion on relevant literature related to the two-dimensional indestructible fluid flow in a porous channel and optimization of MHD parameters analyzing their effects on the flow variables. The discussion has been done according to the specific objectives of this study. Related studies on effects of Magnetic parameter and Darcy number analyzing its effects on velocity are discussed. A related literature on Eckert number and Pressure coefficient was as well discussed. The various gaps on the related literature were also elaborated after each author and at the end of every objective discussed.

2.2 Effect of Magnetic parameter and the Darcy number on the velocity profile.

The unstable free convection fluid was investigated how an incompressible fluid behaved on a semi-infinite vertical porous plate by (Kinyanjui *et al*., 1998). In their study the effect of angle of inclination in the flow on a porous channel was analyzed. They also examined how the changes on Grashof number affected the velocity profile of the flow and the Eckert number affected the temperature profile of the flow. There was a laminar boundary layer-restricted chilled plate and the heated plate that was considered in their study.

Kinyanjui, *et al*. (1998) analysis indicated that when the Eckert number was increased there was an increase in the fluid temperature. The increase in angle of inclination in the flow channel led to the acceleration on the primary velocity profiles at the initial boundary, however a deceleration was noted on the secondary profiles.

Focus on their study was majorly on the impact of the inclination in the porous channel had on the flow, taking onto the account the chilled or heated plate. They used the Eckert number in the analysis of their study. In this study focus is on analyzing the effects on various variables by optimizing the MHD parameters on a porous channel. One of the parameters used is the Eckert number though a variation was on the channel in the study that was not inclined nor heated at any point of the channel. The flow was considered porous and a two dimensional without altering the size of the channel or inclining it.

A 2009 investigation on the impact of heat transport and Hall current on MHD flow was conducted by Dileep and Priyanka. Their study flow was on a channel half filled with a porous substance and had a rotating mechanism. The fluid was electrically conductive, viscous, and unstable. In a parallel plate channel, where they were partially filled with a porous substance, heat transmission occurred primarily. In a spinning system where the Hall current effect was taken into consideration, some of it was partially filled with a transparent fluid that was thought to have an angled magnetic field.

The findings in (Dileep and Priyanka, 2009) demonstrated that, in contrast to the initial flow before an inclination effect, the Hall current impact increased the fluid velocity on the succeeding flow. In their study, they focused on the Hall current parameters in evaluating its effect on the velocity along the inclined channel using a half filled porous medium with a rotating effect on the channel while in this study the focus is on the Darcy number and its effect on the velocity in a porous channel. The channel has no inclined effect and no rotation effect subjected to the flow. MHD Parameters are optimized to evaluate their effects on the flow.

Whereas their focus was on the porous channel with a rotating effect, this study did not interfere with the porous channel at any point; they used the hall current parameter and the

Darcy umber analyzing their effect and impact on the velocity while in this study the focus was on the impact on the velocity be the Magnetic parameter and the Darcy number. The channel was only porous and considering the axial and the transverse velocity of the fluid along the channel.

Nazue, *et al*. (2013) focused on the effects of the Hall Current on Magnetohydrodynamics Fluid over an Infinite Rotating Vertical Porous Plate which is embedded in Unsteady Laminar Flow. The study's main objective was to numerically analyze the parameters of MHD fluid flow for unsteady conditions. They considered heat transmission and the flows were assumed to be passing a vertical, infinitely rotating porous plate. The Hall current parameter was used to evaluate its impact on the velocity profile.

The results observed were solved by the numerical transformation methods. Their study had flow framework considered to be a one-dimensional unsteady one. The equations were discretized by going from a dimensional to a non-dimensional form. By using the implicit finite difference approach, the dimensionless momentum problem and the energy equation were numerically solved. They were debated for various intervals of time as well as for many factors of importance to engineering and physics. Additionally, the matching wall shear stresses and the rate of heat coefficient transmission, or Nusselt number, were calculated.

In their study, Nazue *et al*. (2013), they focused on Heat transmission and fluid flow via an infinitely revolving vertical porous plate while taking into account Hall current in a one-dimensional unsteady flow, in this study the focus is on the optimization of the various parameter like the Eckert number, Darcy number on the flow in a two dimensional unsteady flow through a porous channel.

Rotation Effects on Coupled Heat and Mass Transfer on Unsteady MHD Free Convection Flow of a Porous Medium past an Infinite Inclined Plate by Zulkhibri *et al*. (2014). They did investigate the effects of rotation on coupled heat as well as the mass transfer by erratic MHD free convection flow. They considered the channel to be porous and had an infinite inclined plate. The flow was viscous and unsteady. It was a spontaneous convection flow, buried in an endless inclined plate through a saturated porous medium. They used Laplace transforms technique based on the rate, temperature, and content in getting the exact solutions of the study. They computed the analytic equations for Nusselt number and Sherwood number during the discretization process.

In their results, (Zulkhibri *et al*., 2014), showed that the rotational effect and the inclined angle were evaluated to show their effects on the velocity profile and the temperature change. The rotational parameters and inclination angle influenced the velocity profiles on the flow fields. In their study the porous channel was considered with an inclined angle together with the rotational effect whereas in this study the porous channel had neither inclination nor rotational effect taken into an account. The flow in this study was presumed to be on a uniformly porous channel with no further alteration of the channel. The effects of velocity were analyzed by optimization of the Darcy number and the fluid pressure in the flow.

Chamkha & Krishna, (2018) Hall current effects on second-grade fluid passing through a porous media with ramping temperature of the wall and ramping surface concentration during an unstable MHD flow was studied. Thermo-diffusion and heat absorption on an unstable open convection MHD flow of a second-grade fluid an endless vertical plate via a porous media while accounting for the Hall current. In their study assumptions were that the boundary plate had an isothermal temperature and a ramped surfaces concentration which was in addition to a ramped temperature.

Using the Laplace transformation method, (Chamkha & Krishna, 2018) analytically solved the problem of their study. The governing equations were derived and simplified. They discovered that ramped temperatures with ramped top concentrations had lower temperature layer on the flow, concentration, and velocity profiles than isothermal temperatures with ramped top concentrations. They considered the rampered wall temperature whereas we are only considering the effects on temperature by the Eckert number in the flow through the porous channel.

Ramzan *et al*. (2020) did study the Significance of a bio convective in three dimensions Hyperbolic tangential nanofluid flow susceptible to Arrhenius activation energy. Hall current effect and Ion slip were seen. The dynamics of a partially ionized fluid flow subjected to a magnetic field were entirely different from the flow of normal fluids. The goal of the current study was to look at the three-dimensional electrically conductive Tangent hyperbolic bio convective Nano fluid flow with Hall and ion slip under the effect of magnetic field and heat transfer phenomena beyond a stretched sheet.

The results in Ramzan *et al.* (2020), showed that the fluid's velocity increased as the Ion slip and Hall parameter values rose. Additionally, concentration of the fluid increased as the activation energy parameter values increased. Increasing the relaxation time and eventually decreased velocity in both directions was witnessed. They focused on an electrically conductive bio convective Nano fluid on a three dimensional fluid while in this study the focus is on a two dimensional flow of an MHD fluid.

Hassan, Samad & Hossain, (2020) Effects of Hall Current and Ohmic Heating on Non-Newtonian Fluid Flow Caused by a Peristaltic Wave in a Channel in an asymmetrical porous channel where the peristaltic wave was removed. They studied non-Newtonian flow of fluids and heat transmission. Temperature, stream function, and the heat transfer coefficient analytical solutions were attained. For the linked nonlinear equations, the numerical solutions were found.

The results showed that velocity decreased with an increase in magnetic parameter. There was a growth in the velocity of fluid near the central part of the channel when they increased the temperature. The magnitude of the velocity along the x axis increased with increase in Hall parameter. It was a proven fact that when the magnetic parameter and velocity rose, the effective conductivity, which was present in the momentum equation, decreased. Additional findings demonstrated that the velocity rose as the flow rate rose as shown in (Hassan, Samad, & Hossain, 2020).

A study on the effects of Magnetohydrodynamics Flow on Multilayer Coatings of Newtonian and Non-Newtonian Fluids through a rotating, porous channel was done by Nasir *et al*. (2022). They did investigate a multilayer coating which was fully developed and had a steady Newtonian and non-Newtonian fluid. The flow was on a long a parallel inclined plate. In their study a rotating channel with an angular velocity was analyzed. Their study focused on three regions filled with different fluids, Newtonian fluid and Jeffrey fluid by use of a porous media. They solved equations that control the flows thus the Navier stokes equations and energy equations. They used the Darcy number into solving the study gap.

Nasir *et al*. (2022) solved their study problem analytically for both regions one and three where the Newtonian fluid was used whereas the regular perturbation method was used to solve for region two where the Jeffrey fluid was used. They analyzed the impacts on velocity in the examination of variables like magnetic field, the Grashof number, proportion of a height, angle of preference, and proportion of viscosity. It should be observed that the three layers' axial along with transverse velocities and temperatures were improved by the rise in buoyancy force brought about by the Grashof number and angle of inclination.

They discovered that when the pair stress parameter increased, the Nusselt number increased as well. At the lower plate, when the pair stress parameter increased both the skin friction and the magnetic field characteristics reduced. They realized that with a rise in the Jeffrey parameter, region two's temperature increased as well as the velocity profiles. In their study they focused on Newtonian fluid and the Jeffrey fluid whereas in this study the focus is on the MHD fluid. Optimization of the MHD parameters like the Eckert number and the Darcy number through a porous channel is focused on but in their study the Grashof number and the Nusselt number is used to analyze the flow in their study.

Shilpa *et al.* (2022) did a Numerical investigation of the viscoelastic dissipation and generated magnetic field effects on MHD combined convection over a vertical microporous channel. They used a Darcy model in the study. The dissipation model they used was three different flows as well as a three wall ambient layer were considered. Difference on the temperature on the different layered flow was considered in their study. They did show in their study that the viscous dissipation model impacted to the velocity distribution in the flows. Their study analysis showed that the magnetic field that was produced, Nusselt number, skin friction as well as the current density was affected by the viscous dissipation model.

Increase in the Darcy number led to an increase in the velocity profile of the flow in the channel for various wall ambient values with different ratios of the temperature. They discovered that the increase in the skin friction was directly affected with increase in the Darcy number. Using the Pranditl number, the evaluation showed that increasing the induced density led to an increase in the magnetic effect on the flow as a result of an increase in the Lorentz force (Shilpa *et al.,* 2022).

Whereas the scholars did a study using the Darcy number to evaluate its effect on the skin friction of the flow, they also did consider the vertical micro-porous channel. In this study the effect of optimizing the Darcy number was considered using the central scheme and analyzing its impact on the velocity profile on the flow on a two dimensional porous channel (Nasir *et al*., 2022).

Prince & Pandey, (2022) analyzed hybrid Nano fluid moving via partly porous wavy channels. The impact of porous slab depth and Darcy number on thermo hydraulic transport properties was studied. The Darcy number was analyzed on how it affects the thermo hydraulic performance that was of three different shapes of corrugated porous channels. They were triangular shape, trapezoidal shape and sinusoidal shapes, filled with material that is partially permeable.

The analysis showed that the parameters varied like the Nusselt number and enhancement ratio parameters performance increased with increase of the thickness of the partly porous slab whereas it led to a decrease on the Darcy number. Hydraulic performance reduced because of the reduction on the fluid pressure as there was an increase on the trapezoidal partly porous slab. It also showed that the Darcy number led to an optimal increase on the temperature where a fluid coolant was used especially water (Prince & Pandey, 2022).

The considered porosity was majorly partial on slabs of different shapes with different thickness, having their focus on its effect on temperature and cooling effect on the flow, in this study the thickness and shape of the channel was maintained and analysis on how the velocity profile is affected by optimizing the Darcy number was done. They focused on a partial the medium's porosity as opposed to the porosity that is evenly distributed in this study was general (Prince & Pandey, 2022).

Ahmemad *et al.* (2022) analyzed Hall current effects on a second-grade fluid passing through a vertical porous plate with chemically reacting MHD. The impacts of second-grade fluid immersed beyond a half-unlimited porous surface within a gyratory structure's radiation-absorption, chemical reactions, and heat generation was studied. They also focused on the absorption of fluctuating MHD, heat, and mass transit laminar flow taking into account the effects of the Hall current. They assumed that the plate was in motion due to the constant velocity confined by the fluid's flow direction.

The fluid was being drawn into an even magnetic field that was operating perpendicular towards the porous plate, with its suction velocity varying with specific instants of time. With the help of harmonic and non-harmonic idioms, the relevant dimensionless equations that govern the configuration were solved. The study results showed that increasing permeability in the flow resulted with an increase in the velocity components (Ahmemad *et al.*, 2022).

Whereas (Ahmemad *et al.*, 2022) focused on a porous plate with radiation absorption, chemical reaction with a suction effect, in this study the channel had neither radiation nor chemical reaction. The plate was considered static throughout the study period.

Panel *et al*. (2023) used a semi numerical approach to analyze heat transmission in a Williamson fluid flow inside a ciliated porous channel. In the porous channel the Williamson fluid helped understand the rate of heat transmission on a non-Newtonian fluids characteristic. The channel in the study was ciliated, porous and with the account of the effects of the magnetic field. A semi numerical method was used to solve the study problem. The problem of partial differential equations was made more difficult in viscous dissipation by the mathematical description of the issue.

Their results showed that the conduction process increased the heat transfer through the molecules of the liquid. It was further suggested that increasing the Darcy's number let to an increase in the velocity profile which was due to an increase in the porosity of the study channel. In their study, the porous channel was as well ciliated and they used a semi numerical method to analyze their study while in this study the partial differential analysis was used to solve the problem in a porous channel that was not ciliated.

Kimanthi, (2023), did a study on the effects of varying transverse magnetic fields and changing pressure gradient on MHD flow among parallel plates. Analysis was done on the effects on MHD flow by applying a passing through two parallel plates while experiencing a changing pressure gradient. Transverse magnetic fields in the flow were influenced by temperature and velocity. It was assumed that the flow was constant, incompressible, and passing across parallel plates. While the smaller plate stayed stationary, the upper plate, which was porous, was moving in the opposite direction of the fluid flow.

The governing equations in his study involved the equation of conservation of mass, electromagnetic equations and the equation of energy. The study's challenge was resolved using the finite difference method. He examined the completed equations for the velocity profile and the profiles of temperatures for various thermo-physical parameters in the Matrix laboratory. The findings demonstrated that when the Reynolds number increased, the flow's velocity profile and temperature profile decreased. A rise in the magnetic parameter resulted to an increase in the fluid temperature, which also led to a decrease in the velocity profile (Kimanthi, 2023).

It was also demonstrated that increasing the suction parameter in the flow led to an increase in the temperature profile while it led to a decrease in velocity. As the velocity dropped and temperature profile rose, this led to widening of the pressure gradient. An increase in the temperature was realized with an increase in the Eckert number. The results also showed that a decrease was realized on the velocity with a raise in the Prandtl parameter leading to an increase on the temperature. The focus in his study was on a varied channel where the boundary was of two plates having one rotating and the other being static while in this study, focus is on a channel without movement with a uniform porosity along it (Kimanthi, 2023).

Most previous studies focused on a convective Heat transmission and fluid movement through a porous channel where either the fluid is chemically reactive, viscous, electrically conductive fluid. The channels are one dimensional vertically porous, partially porous, porous with inclined angles on it considered or ramped wall temperature and ramped surface concentration are put into account. The Darcy number, Prandtl number and Hall current are among the parameters that were used to solve study problems in the previous studies. Analysis was done numerically by Implicit Difference Method, analytically by Laplace Transform System to come up with results.

In this study focus is on a two dimensional, viscous, unsteady incompressible fluid. The effect of various variables such as viscosity, induced magnetic field, heat energy flow and temperature profiles in a free convective flow within a porous channel is considered. The MHD fluid in the study is considered not compressed and passes through a porous channel. The system of governing equations was introduced to optimize MHD parameters in incompressible fluid flow in a porous channel through two dimensions. These equations will then be discretized and then solved numerically through central scheme method where the Darcy number, Eckert number are used to analyze the flows variables.

2.3 Effects of Eckert number on temperature distribution for incompressible fluid flow within a porous channel.

Seddeek, (2000) did study Hydromagnetic flow and heat transfer through a constantly porous border as a result of fluctuating viscosity. The effect of magnetic field and varying viscosity on heat flow transfer on a continuously revolving porous plate inside a stationary fluid was examined, taking the radiation effect into account. It was presumed that the fluid viscosity varied as a negative linear relationship with the fluid temperature. The shooting technique was used to quantitatively calculate the initial speed and temperature fields. Along the calculations was the skin friction as well as heat transfer outcomes from their constant values, utilizing similarity solutions.

In their study, the fluid viscosity was varied through constant porous channel with a revolving porous plate inside a stationary fluid considered. The porosity was on the channel as well as having the porous effect in the fluid by the porous plate inserted in the still fluid. The magnetic field in their study was accounted for. In this study the porosity is on the channel only and the fluid is considered a two dimensional viscous flow. The viscosity of the fluid is considered constant and the induced magnetic field was neglected on the study.

Borthakur & Hazarika, (2006) studied variations in the viscosity as well as thermal conductivity and their impact on the fluid movement, on heat profile and fluid of a stretched surface in a spinning micropolar fluid. The flow in their study involved suction and blowing in the channel. Taking place at the border was a heat transfer region on a spinning micropolar fluid caused by suction and blowing on a two-dimensional stretched surface. The study problem was solved numerically while taking into account the sheet with a specified wall temperature. It was presumable that thermal conductivity and fluid viscosity change with temperature.

The working fluid was described using Eigen's micropolar model. Using similarity the partial differential equations, transformations regulating motion, angular transformed to ordinary differential formulas for momentum and energy which were then numerically solved using the Runge-Kutta shooting method. For different choices of non-dimensional parameters, the results were visually displayed for velocity distribution, temperature distribution, and micropolar distributions. It is discovered that the variables denoting viscosity and heat conductivity have considerable influence.

Patowary & Sut, (2011) examined the impact of a micropolar fluid's fluctuating viscosity on thermal conductivity in a tube with holes. They did evaluate how thermal radiation affected an unstable boundary layer flow caused by a stretched sheet in a porous channel with different heat conductivity and fluid viscosity. In their study, a numerical model was created and the presence of a magnetic field was taken into account. The energy equation which includes the radioactive heat flux was utilized with the Rosseland diffusion approximation was described.

Using the appropriate transformations, the governing equations were simplified and the boundary layer to the equations were then resolved using the shooting technique. The findings demonstrated that when radiation and thermal conductivity parameters increased, so did the values of the Nusselt number increased. On the other hand, when the inertia coefficient of porous medium rose, the Nusselt number increased however it led to the shear stress decreasing.

Patowary, and Sut, (2011) study focused on the micropolar fluid flow on a porous channel evaluating the effects of its varied temperature as well as the fluid viscosity. They equally focused on the radioactive heat flux. They solved their study question using the shooting technique using the Nusselt number and the thermal conductivity parameter for their specific solutions was used. Whereas in this study focus was on MHD fluid on a porous channel where Darcy number and Eckert number were optimized and their effects evaluated. Central scheme was used to numerically solve the study problem. Neither varied viscosity nor varied temperature on the flow was considered since the conditions were never altered.

Alim, and Parveen, (2011) looked at Magnetohydrodynamic Naturally Convection Flow over a Vertical Wavy Surface and Temperature-Dependent Variable Viscosity. Along a vertical, wave-like surface that was evenly heated, the fluid was deemed viscous and incompressible. Using an appropriate collection of dimensionless variables, such as the viscosity parameter, magnetic parameter, as well as Prandtl number, Initial non-dimensionalization of the governing layer boundary equations was performed. After being translated into the area of a horizontal, vertical plate, the resultant nonlinear system of the partial differential equations was numerically solved using the Keller-box technique, an implicit finite difference approach.

They were interested in the impacts of temperature-dependent viscosity, magnetohydrodynamic field strength, and Prandtl number changes evaluating their impacts to the flow variables. The findings demonstrated that while the rate of heat transmission was significantly accelerated, the skin's coefficient of friction reduced as the Prandtl number rose along the whole boundary layer. Raising the viscosity parameter had the opposite effect, increasing the local skin friction coefficient led to a reduction of the regional heat transfer velocity. Additionally, they discovered that when the values of the magnetic parameter increased, the local friction coefficient of the skin and the regional velocity of heat transfer altogether decreased (Alim, and Parveen, 2011).

Ndiritu, (2015) performed research on how magnetohydrodynamic flow across a continuously moving surface is affected by temperature-dependent viscosity. Researchers have looked at how temperature affects viscosity during the magneto hydrodynamic movement of a viscous, incompressible fluid over a moving surface. The passage of a constantly moving surface with a uniform surface temperature and velocity in two dimensions has been contemplated. The continuous surface is parallel to the y-axis, which runs perpendicular to the x-axis and through the motion. Along the y-axis, the magnetic field is applied.

Using a collection of dimensionless variables, the governing boundary layer equations have been translated into a non-dimensional form using the finite difference approach, a non-linear set of partial differential equations regulating the flow has been numerically solved. Matlab software has been used to solve the equations. The effects of altering various factors on the velocity and temperature profiles have been found.

The results were then graphically shown after that. There has been discussion on the observations. Changes in a number of factors have been seen to positively or unfavorably impact the skin friction coefficient, the speed of heat transfer, the velocity, and the pattern of temperatures on a continuously moving surface. It was found that velocity decreased as the magnetic parameter was raised. Along with the rise in magnetic parameter, temperature also fell (Ndiritu, 2015).

Achola, (2018) in his research on the mathematical modeling of both heat rays and Newtonian warming in the stream of variable viscosity hydromagnetic boundary layers found constructing electronic devices' cooling systems gadgets, nuclear reactors are cooled, capturing geothermal reservoirs, solar energy, thermally insulated structures, and heat exchangers are all applications for magnetohydrodynamic boundary layer flow in business and engineering.

This flow involves a fluid with variable viscosity that has been heated by Newtonian heating and thermal radiation. The design of nuclear reactors, gas turbines, and machinery for the propulsion of airplanes, missiles, satellites, and rockets must take thermal radiation heat transfer into consideration. Thermal radiation heat transfer is crucial for engineering operations that take place at high temperatures. In this study, a numerical answer to the fluid motion equations governing the movement of particles across the outermost layer of a fluid with electrical conductivity with varying the viscosity which is subject to an unchanged field of magnets, as well as being warmed by thermal radiation and Newtonian heating, is found using the fourth order Runge-Kutta approach and the shooting technique (Achola, 2018).

The graphical findings showing how different thermophysical factors affect the fluid's velocity and temperature profiles are shown, followed by a quantitative discussion. According to the study, the fluid's velocity rises as the magnetic parameter as well as variable viscosity parameter's values rise. Additionally, the temperature of the fluid will drop when the values from the thermal energy parameter as well as the value of the viscosity parameter rise as the magnetic field's parameter, Brinkmann number, and local Biot number values rise (Achola, 2018).

Ajibade, and Tafida, (2020) examined how natural convection couette flow is affected by varying viscosity and variable thermal conductivity. They examined how fluid flow and thermodynamics in a vertical channel were affected by the combined impacts of changing viscosity and thermal conductivity. Utilizing the homotopy perturbation approach, energy and momentum equations that characterize the flow scenario were resolved.

The results of the investigation showed that fluid velocity and temperature increased as heat generation dropped as heat absorption increased, and declined as viscosity increased. The outcomes demonstrated that as thermal conductivity increased, fluid temperature and velocity dropped. While the temperature effect of viscosity depends on the imposed thermal boundary condition, increased viscosity causes a reduction in fluid velocity. The integration of variable viscosity and heat conductivity into fluid flow equations has a significant impact on stream formation and thermodynamics inside the channel (Ajibade & Tafida, 2020).

In this literature we realize that most studies focused on either a stationary fluid or the fluid is flowing through boundaries with radiation, stretching surfaces or vertically wavy surfaces. Some focus on the velocity moving axially. They considered Heat transfer within a porous channel flowing in one direction in some cases. In this study, the effect of velocity on viscosity is considered in a two dimensional fluid flow where the flow is considered viscous, incompressible, and unsteady flowing through a porous channel.

Eko *et al*. (2023) studied the Effects of Effective Thermal Conductivity of Porous Materials. On the channel was Vapor Flow in a Rapid expansion-contraction coupled with local transfer of heat. They aimed at assessing the absorption of the local heat and the characteristic convection of the local heat in a system. Here the flow is of heated vapor where it transfers the thermal energy through a heat sink plate that is horizontal. Inside a sudden-enlargement-contraction-channel, the heat permeated a layer of porous materials with varying thermal conductivity.

The local Nusselt as well as Metais-Eckert numbers were the focus of the two non-dimensional parameters. Additionally, solid particles were employed in the permeable bed. The governing equation of the conservation of mass, the momentum equation, and the energy equation were solved numerically using the Ansys-Fluent software program. They were used to obtain their effects on the profiles to the local temperature and velocity profiles. The results of this investigation show that the local Nusselt number is mostly influenced by the general Porous materials' efficient thermal conductivity substances filled with vapor (Eko *et al*., 2023).

They demonstrated that a rise in the local Nusselt number increased the flow velocity of the porous materials' leading to an overall increase on the thermal conductivity. They realized that the Metais-Eckert number was increased by the sudden enlargement-contraction of the porous channel. They also realized an increase on the Reynolds number leading to an increase in the flow velocity (Eko *et al*., 2023).

They considered how the Eckert number affected the thermal conductivity along the porous channel due to sudden enlargement of the porous channel whereas in this study the size of the porous channel remained unchanged but the Eckert number was optimize and its effect on the flow affected the temperature profile along the porous channel. The Nusselt number was used to evaluate the fluid velocity and the temperature change while in this study a Darcy number optimization and the pressure coefficient optimization was used to analyze their effect on the fluid velocity through a porous channel without altering the size of the lumen of the pipe (Eko *et al*., 2023).

A study on Tangent Hyperbolic Fluid Flow on a Divergent Channel in the Presence of Porous Medium was done by Sushila, Prasun, and Balachandra, (2023). In their study flow the Suction effect and Heat Source was accounted for. In their study a boundary layer appearance in a permeable channel was considered for a non-Newtonian hyperbolic tangent fluid. An injection effect was also investigated. They did control the backflow of the fluid to ensure that the fluid only had a forward flow. This brought about the nonlinearly association ordinary differential equations that were derived from a partially differential equations. Formation of the boundary layer for tangent fluid brought about the restrictions of their study. A mass suction as an expression of Hartmann number as well as porosity parameter, the power index parameter having passed a specific quantity within a given boundary was taken into consideration.

They established the results using the Renge-Kutta fourth order which showed that the boundary layer decreased as the weissenberg number was increased in the flow of the study. The heat source as well as the radiation which was considered had an influence on the overall temperature system. With the increase of the suction effect at a higher level in the flow, the temperature profile of the flow decreased. They also analyzed that the low temperature was drawn by suction in the regions around the wall which led to a lower temperature effect along the walls of the other part of the channel. In their conclusion they were able to outline that the Hartmann number increase led to an increase on the velocity profile while it led to a decrease in the temperature profile (Sushila, Prasun, & Balachandra, 2023).

In their study they analyzed numerically the effects of Hartmann number and the Weissenberg number on the fluid flow through a porous channel with a suction effect on the velocity profile and the temperature profile. The used the Renge-Kutta fourth order methodology into solving their study problem. The channel had alteration of the external temperature that was also accounted for. In this study the study flow never considered a suction effect. Focus was mainly on internally generated heat and how the optimization of the MHD parameters on a flow will affect the velocity and temperature was evaluated. Numerically the solutions were solved through the PDE where the CS was used.

2.4 Effect of pressure in the velocity on an incompressible fluid flow in a porous channel.

Kaviany, (1985) did focus on Laminar flow in a canal with openings where it was bounded by two parallel plates. He used the Darcy model where he modified it to solve problems on Momentum that was solved using the velocity square term from the momentum equation. He neglected the energy equation while solving the problem in the axial flow of the study. In his analysis the results showed that a fully developed fluid flow increased with an increase of the Nusselt number of the flow in the porous media shaped parameter. The results also indicated that pressure profile dropped as the entrance region decreases.

In his study Kaviany, focused using the Darcy number and the Nusselt number in solving his study problem. His study channel was an open canal with two parallel plates while in this study, optimization of the pressure, the Darcy number and the Eckert number are used in solving the study problem. The channel was considered porous and not bounded with the parallel plates.

Kuznetsov, (1998) Movement of fluid and transfer of heat in the flow through a stiff saturated porous media was analyzed analytically. In his study the fluid flow occurred in a moving wall. The flow was modeled using a Darcy equation. Analytically, the boundary layer of the flow was along an extending porous wall in a porous medium and an assessment done. The wall in the study was considered as a two wall boundary conditions that had a lower-law distribution of a wall temperature or of a heat flux. In Kuznetsov study, his equations considered both isothermal and isoflux cases.

The continuity, energy equations together with the momentum equation was used to analyze the problem being investigated. These governing equations were reduced to specific equations of Ordinary Differential Equations to enable get results. The transformed ordinary equations were used to analytically evaluate and solve the problem using the homotopy analysis method. The findings showed that an increase in the Reynolds number led to an increased heat transmission.

The rise in Prandtl number led to increase in the heat transmission as well as increasing the surface suction of the flow. Increase on the Nusselt number with Reynolds Number on the wall shear stress had a reverse effect to the mass transfer from the wall as well as the injection parameter in the flow. They also did demonstrate that by raising the Prandtl number on the equation led to a reduction of thickness of the thermal boundary layer.

In (Kuznetsov, 1998) study, the governing equations were developed into specific equations using the Pranditl number, the Nusselt number and the Reynolds umber. The suction effect was considered in the study. This study's guiding principles equation was lowered to specific methods using the Darcy number, Eckert number as well as the Magnetic parameter to solve the problem. No suction effect was considered or subjected to the flow in the study however the flow was also in two dimensional and through a porous channel.

Hady *et al.* (2006) they analyzed a free convection flow down a vertical surface that had waves and was submerged in a fluid that conducts electricity. There considered a free convection flow down a vertical surface that had waves and was submerged in a fluid that conducts electricity. The flow had an internally generation heat that had the absorption effect on the flow. Their study focused on the effect of thermal radiation as well as the heat source on the unsteady periodic flow. A viscous fluid was considered to be incompressible through a porous planer channel which had an influence of transverse magnetic field. They methodology used to solve the study is the perturbation technique. The results showed that increase in temperature directly led to an increase on the absorption effect to the fluid by the Darcy number.

Whereas (Hady *et al.*, 2006) used the Perturbation technique as a method to solve their study considering an internally generated heat in the flow, in this study any generated heat within the flow was also accounted for. The fluid in their study was considered through a channel with effects of waves on it which is not the case on the porous channel in this study. The analysis of the study problem is analytical through the central scheme of the ordinary differential equation.

Singh *et al*. (2009) did a study on the interaction of a free convection flow with MHD in a porous channel with the rotational and Hall current effects. They considered two insulating porous plate that were subjected to a constant injection and suction effect on the stationary plate. The assumption in their study was transversal magnetic field subjected in the flow to be normal to the plate. The applied magnetic field was constant and uniform throughout the flow. The study had small and large rotations which depended on the steady and unsteady resultant velocity that is also normal to the plate. The results showed that both the steady and the unsteady resultant velocity led to an increase from the stationary point towards a rotating or oscillating point.

The analysis showed a phase lag on the large values of rotation and the effect of injection on the plate. There was also an increase in the rotational of the channel and the Hartmann number which led to an increase near the stationary plate. The Hall current parameter and the Pranditl number increased with a decrease on the rotational effect on the plate. They also showed that the amplitude of the unsteady shear stress led to an increase in the Grashoff number.

In their study they focused on the rotational effect of the plate through the injection and suction on the stationary plate considering the porosity on the plate, this study no injection or suction effect is subjected to the flow, the channel has no external force to ensure that the temperature rise and velocity profile is only affected internally as an effect of the MHD parameter optimization on the flow through the porous channel.

Anil *et al.* (2010) did a study on an unsteady periodic flow of a viscous incompressible fluid. The flow was through a porous channel where the transverse magnetic field was also considered. In their study, the fluid was considered to be incompressible having a constant density. They analyzed the study problem using the perturbation approach. They did study how the viscosity of the fluid affected the fluids velocity as well as the temperature on the flow. They also put into the account the flow's experiences with the magnetic field. The heat generated internally as well as absorbed from external sources was considered.

The results showed that skin friction and heat transport rates are related had a direct effect in the flow. They also showed that there was a rise in the speed as well as the Grashof number. The radiation parameter increase led to an increase on the velocity and the heat source parameter also directly led to an increase in the velocity. However they also did show that a drop in the velocity was realized with a rise in the flow's magnetic parameter as shown in (Anil *et al.*, 2010) study.

In their study they considered heat absorbed in the flow and specifically used the Perturbation technique in solving the problem in their study and focused on how the fluid viscosity affected the velocity profiles. In this study central scheme of the differential equation technique was used to analyze the fluid dynamics focusing on how the Darcy number and pressure coefficient affected the fluid velocity profiles. No external heat was subjected to the porous channel and no heat absorption was accounted for in this study.

Omboga *et al.* (2013) did study magnetohydrodynamic free convective flow past an infinitely vertical porous plate. The fluid was considered viscous, unsteady, incompressible and electrically conductive. The heat absorbed was accounted for and its effect on the velocity profile was analyzed. The PDE was utilized to resolve the flow's governing equations. Specifically they used the explicit finite difference scheme to solve the problem. Numerically they analyzed impacts of the Grashof number on the velocity profile on the flow. It revealed that the velocity profiles increased as the Grashof number increased along the length of the porous channel. An expansion of Prandtl number was shown in the analysis that it led to an inverse effect on the dispersion of temperature. The velocity profile decreased as the Hartman number rose.

While they numerically analyzed their study using the explicit finite scheme, in this study a central scheme was used to do the analysis. They also used the Grashof number and the Pranditl number to develop their specific equations from the governing equation while in this study Darcy number and the Eckert number was used to get the exact results to the problem of the study.

Pawan *et al* (2013) investigated finite difference Technique for unsteady MHD periodic flow of viscous fluid. The flow was considered to be through a porous planer channel and when a transverse magnetic field was present. The flow was also considered to be unsteady with a periodic flow. The effect of transverse magnetic field was considered in the flow. Analytically the velocity profile was expressed.

Using the numerical computation, results were obtained on how the various parameters in the study affected the velocity profile as well as the temperature changes. To determine their impact on the flow, variables including the Hartmann number, Grashoff number, and Peclet number, permeability of porous media, wall slip parameter, and radiation parameter were examined. The results demonstrated that the fluid velocity decreased as the Peclet number increased, but the velocity increased when the wall slip parameter increased. The shear stress distribution was inversely proportional to the effect of the wall slip parameter effect on the flow. The analysis also showed that the magnetic imposition on the flow led to a velocity decrease in the flow.

They did focus on a porous planer channel while in this study the focus was majorly on a two dimensional porous channel. Parameters used to analyze their study included the Grashoff number, Peclet number, wall slip parameter and radiation parameter whereas in this study focus was also on optimize of the MHD parameters like the Darcy number, Eckert number, Pressure coefficient and their effect on the flow analyzed.

Kumar *et al.* (2013) studied viscous incompressible flow of fluids using the Finite Element Galerkin's Approach. Coaxial cylinders were used to analyze the flow variables of a flow through a porous media. They noticed that the type of gap duct that connects two coaxial cylinders affects the velocity profile. For a particular Grashoff number, a small gap duct had a lower axial velocity than a wider gap duct that led to an increase the axial velocity. Since the velocity profile increases with increasing values of Darcy's parameter in both narrow and wide gap ducts, the enhancement in the larger gap duct was greater than the enhancement in the small gap duct to the oil channel/reservoirs.

In their study (Kumar *et al.,* 2013) the porous channel was considered to be of a coaxial cylinder with a different size of a gap duct connecting them. They also used the Galerkin's Approach in getting their results with help of the Grashoff number. In this study the flow channel was not considered to have different canal size, it was considered having same size of the canal with uniform porous all through the length of the study channel. The Partial Differentia Equations were solved using the central scheme method with the help of the Darcy number and the Eckert number.

Another theoretical investigation of an oscillatory MHD flow over a porous medium confined by horizontal parallel porous plates was carried out by Sahin & Hamida, (2013). On a porous plate, their study's stationary plates were both continuously exposed to the identical injection and suction velocities. The stationary plate also received a consistent magnetic field that was applied perpendicular to the plate planes. These effects had an effect on the plate's oscillation to enable the model to change in both velocity profile as well as the temperature through the flow.

They analyzed an oscillatory MHD flow across a porous material enclosed by horizontal, parallel porous plates theoretically. Same constant injection and suction velocities were applied to both stationary plates. On top of the plate planes, a regular magnetic field was placed in a normal direction. They discovered that the fluid velocity profiles dropped as the Darcy number or suction/injection parameter was raised. Increases in the suction/injection parameter were demonstrated to accelerate the flow whereas increases in the magnetic MHD constant fluid flow between two infinitely parallel vertical porous plates with heat transfer was concluded in the study (Kimeu *et al.*, 2014).

The findings demonstrate that the fluid velocity increased as the Grashof number increased, fluid temperature was decreased as the Prandtl number increased. The field's magnetic parameter increase also caused an increase in the velocity flow. The amplitude in the magnetic field lines increases with increases in the parameter for the magnetic field and the suction parameter. They also did show that Increasing Hartmann number led to a decreased in the shear stresses.

Ahmad *et al.* (2015) investigated MHD suction is used to transport heat and flow via a porous media across a surface that is contracting or stretching. The MHD flow across a stretching/shrinking surface with suction and heat transfer was numerically solved. The primary conclusions of their investigation were that, while the magnetic parameter as well as suction parameter had opposite impacts on fluid flow over decreasing surfaces, the velocity component for flow over stretching surfaces dropped with rising values.

Additionally, when the Prandtl number as well as suction parameter values increased, the temperature function dropped. The outcome is the same for fluid flow through stretching or contracting surfaces, although the temperature spread was greater for fluid flow across contracting surfaces.

Whereas in their study, (Ahmad *et al.*, 2015) focused on a porous media with a contraction or stretching effect on the flow channel where a suction effect was considered, this study considered the channel static with no stretch effect or contraction effect on it. No suction effect was considered in the flow. The Prandtl number was used to analyze the suction effect of the flow to the temperature profile in their study while in this study the optimization of the Eckert number was used to analyze its effect on temperature profiles of the flow.

Gurivi *et al.* (2017) investigated the impacts of radiation, chemical reaction, and slip state and irregular MHD periodic circulation of an incompressible, viscous electrically conductive fluid through two instances. The first case, they considered a Uniform plate Temperature and Uniform Concentration and in the second case, they considered Constant heat and mass flux. The governing equations were solved by perturbation technique.
They noticed that the Shear stress rose as the magnetic parameter or permeability parameter increased, and that the opposite impact was found in both cases for the slip parameter or Schmidt number. The velocity increased with an increase in the slip parameter, Grashof number, modified Grashof number, Schmidt number, and Radiation Parameter, but it demonstrated a decrease on the velocity with a rise in the magnetic parameter, time, the Permeability parameter, or Reynolds number.
According to Gurivi *et al.* (2017), a chemical reaction with a periodic circulation of the fluid is considered. The porous channel plates they considered had a uniform temperature with uniform concentration and another one with a constant heat with a constant mass flux. Either the channels were having a bounded condition to temperature or the fluid having a specific concentration. They used perturbation technique as the method for solving their

study problem. In this study the temperature was not subjected to the channel and the fluid concentration of the fluid remains constant all through. The mass flux was not accounted for in this study. Central Scheme was the method used in getting the exact solutions to the study.

Third-grade fluid with porous medium and steady flow and heat transfer analysis were the subjects of a 2017 research by Akimbowale. In his investigation, the third-grade non-Newtonian fluid flow and heat transfer in a porous material with an internal heat source was analyzed. The flow channel had parallel plates that were held horizontally against one another where the fluid was carried. The analysis of the nonlinear regular equations brought on by visco-elastic effects originating from the fluid's mechanics which was done using the adomian decomposition technique.

It was determined using Vogel's temperature-dependent viscosity model. On heat and flow transmission. The impacts of pressure gradient, heat generating parameter, and porosity term were examined. While increasing heat production term revealed a large rise on the distribution of temperature towards the top plate, rising porosity term demonstrated a modest reducing influence on velocity distribution. Whereas he used ADM to solve the study question of nonlinear regular equations, in this study the CS was used to solve the study question of partial differential equation.

Danial *et al.* (2018) given that the fluid was flowing over a porous surface and via a porous material in an accelerating sheet. It was assumed that the laminar viscous fluid flow is electrically conductive. A radiative heat source, an applied magnetic field and slip circumstances were hypothesized to have an impact on the flow. The governing partial differential equations were converted into ordinary differential forms using the similarity transformation in the mathematical technique. By calculating findings for temperature and velocity field for a variety of relevant factors were solved such as slip parameter, porosity parameter, magnetic field parameter, Prandtl number, parameter of Radiative heat, and mixed convection parameter, where the physical foundation of the problem was explored.

According to the findings, porosity increased fluid flow rate while increase in the radiative heat led to an increase in the temperature. The increases in magnetic field strength caused an increase in Lorentz force that opposes the flow and thus higher values of, Magnetic field parameter shows reduction in flow speed and an increase in Prandtl number causes reduction in the temperature field.

Through the use of a porous planer channel, Kumar, (2018), investigated transverse magnetic field-induced heat generation in the irregular periodic flow of a viscous incompressible fluid. The governing equations were resolved using the perturbation method. There were closed-form solutions for both temperature and fluid velocity. The outcomes showed that when there is an increase in the magnetic field to the flow, the flow slows down. Additionally, they discovered that when Reynolds number values rise, fluid velocity falls. The velocity increased as the radiation parameter rose.

In their study the porous planer channel was used with an irregular flow of the fluid considered. The induced magnetic field was accounted for in their study where they used the perturbation method to solve the study problem. In this study the porous channel was studied with an unsteady viscous fluid flow was considered of two dimensional. The induced magnetic field was not considered and the Central Scheme method was used to solve the study problem.

In a transverse magnetic field that is fluctuating, Mayaka *et al.* (2019), looked at the Analysis of the implied method for the MHD Stokes convection-free circulation model equation's stability and consistency. They studied the analysis of the consistency and stability of the implicit scheme for solving nonlinear partial differential equations in order to investigate MHD free convective flow of an incompressible fluid past an infinitely long, porous plate along with joule heating in the presence of variable transverse magnetic field. The implicit scheme's derivation was created. The Eigen values for the amplification of the matrices were evaluated and proved to be less than one, and the stability of the scheme is then examined using the von Neumann technique.

The scheme was shown to be unconditionally stable and convergent, according to the results.

While their focus mainly was on consistency and stability of the implicit scheme that helped solve the nonlinear partial differential equation, in this study focus is on optimizing the MHD parameters and the central scheme is used to solve the PDE for the question in the study.

Mohammed *et al*. (2021) researched on pressure drop optimization and improved heat transmission in a horizontal porous pipe that receives localized downward heating. In this study, transient mixed conduction heat and fluid flow transfer inside a horizontal porous layer flanked by two impermeable plate that receive specific heating from below is investigated using numerical analysis. The study makes use of the one-equation energy model and the Brinkman-Forchheimer-extended Darcy model, both of which are founded on the idea of local thermal balance. The effects of porosity and porosity, as indicated by the Darcy number, were examined.

In their findings Mohammed *et al*. in 2021 demonstrate that the presence of porous material raises Nusselt number, although does not alter Reynolds number's tendency for all Richardson number. Additionally, it was demonstrated that at higher Reynolds and Richardson numbers, unstable, oscillating flow and temperature fields were created in both porous and empty channels. It was discovered that when porosity grew, both the heat transfer as well as the pressure drop decreased; nevertheless, the impact of Darcy number was highly influenced by the range of Reynolds number.

Gruyler, (2021) the channel flow with baffle's pressure drop and heat transfer were optimized. In his research, a numerical study was conducted to optimize pressure drop, heat transfer, and channel geometry in the context of a rectangular baffle and two-dimensionally constant temperature. Software for computational fluid dynamics was applied to address the differential equations used in modeling. The operating fluid was water, and the Reynolds numbers were varied. At the inlet, outlet, and channel wall, the periodic boundary condition was utilized. The channel axis was subjected to the axisymmetric boundary condition. K-SST model and genetic algorithm were used, respectively, to model and optimize the turbulence.

In the 2021 paper, Gruyler showed that increasing heat transmission and pressure decrease by including a rectangular baffle in the channel. As a result, the effective geometrical variables were introduced and the effectiveness of the heat transfer factor together with the greatest heat transfer and minimal pressure loss was explored. The findings demonstrated an inverse link among baffle step and pressure drop as well as heat transmission. The heat transmission efficiency and coefficient of friction in the baffle increased with height, according to the modeling results. According to the findings, adding a baffle to the channel sped up pressure loss and increased the rate of heat transmission. The baffles with fewer pitches for the same heights showed the biggest rise in Nusselt number as well as pressure decrease. Due to the decrease in pressure, the baffle with a higher pitch got better heat transmission performance.

Most previous studies focused on a laminar viscous fluid, third grade fluid and convective fluid flow, incompressible fluid as well as the conductive fluid. In some cases a shrinking surface or electrically conducting surface was considered, having some with a convective, angular or rotational effect on them. In other cases suction effect to the channel or contraction pressure was considered on the flow channels.

Different techniques were also used to solve the problems like homotopy analysis method, perturbation technique, explicit infinite difference scheme as well as finite element Galekin's approach. In this study, the fluid is considered viscous, incompressible and unsteady flowing through a porous channel. The channel in the study is considered having no variation in the shape, no shrinking or angular variation of it and no suction effect considered. The governing equations were solved numerically through Central Scheme method and numerically analysis done on optimization of the MHD parameters on the porous channel.

In other studies focus was on flow on vertically porous plate, porous media in a coaxial cylinder and in the presence of heat transfer along the flow channel. They also considered inclined angle on the flow, this study mainly focused on optimization of MHD parameters on viscous incompressible and two dimensional on a porous channel flow. Heat is not taken into account in this study and the magnetic field is negligible.

Then Kimeu *et al*. (2014) studied MHD steady fluid flow between two infinite parallel vertical porous plates having a focus on heat changes within the flow. The scholars did their studies focusing on oscillatory MHD flow where the porous channel was bounded by horizontal parallel plates as well as Over endless parallel vertically porous plates, there is a constant flow, but in the study the channel is porous and in a two dimensional unsteady flow.

The impacts of the slip state, chemical reaction, radiation, and irregular MHD periodic flow were the subject of studies conducted by (Gurivi *et al*., 2017). The flow in their study was through a porous medium and in two different conditions was evaluated. The first case, they did consider a Uniform plate with even distribution on temperature and a uniform concentration. In the second case, they did consider a constant heat and mass flux. They did take into account the heat transmission, radiation, and chemical responses in the flow. This study considers optimization of the MHD parameters on the flow where the magnetic effect will be one of the parameters.

Gurivi *et al.* (2017) considered the heat generated internally in the flow was not considered and no external heat is subjected into the flow. There was no applied magnetic field externally into the flow. However they considered internally generated magnetic field due to the MHD parameter. The flow of fluid through a porous media was taken into account by Daniel *et al*. (2018) together with a laminar viscous fluid flow that was electrically conducting because of an accelerated sheet. The flow was thought to be influenced by a magnetic field outside. In their investigation, the impact of radiated source of heat and the slide situation were also taken into account.

Kumar, (2018) investigated the transverse magnetic field-assisted heat production is taken into consideration as a thick, compressible liquid flows periodically through a canal with porousness. Using the perturbation method, the governing equations were resolved, and closed-form answers for the fluid velocity and temperature were discovered. They discovered that the flow decelerates when a magnetic field is applied. Velocity accelerates as the radiation parameter increases was also analyzed.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The general equations that govern the fluid flow are presented in the first section of this chapter. These equations include: First, Applying the tenet that mass cannot be generated or destroyed, the preserving of mass for a system leads to the continuity equation. The second equation is the momentum formula, by using Newton's second law of motion, is obtained. Third, utilizing the idea that the amount of heat provided to the structure is equal to the change in its own energy as well as the amount of energy lost as an outcome of work done on the system, the calculation of energy is derived using the first law of thermodynamics. The steps followed in the process of discretization is also elaborated and discussed in this chapter. In the methodology, boundaries are set to enable discrete approximation that will enable the study problems to be solved and analyzed. The assumptions of the flow and the channel were also discussed.

3.2 Assumptions and Approximations

The assumptions below were considered in this study:

i. The channel is long enough in x-direction considering the positive unit o to 4
ii. Externally induced magnetic field is neglected
iii. The fluid flow is laminar, two-dimensional, and unstable due to the flow.
iv. The fluid is viscous and incompressible

3.3 Geometry of the Problem

The geometry of the problem was set up as shown in figure 3.1 and mathematical conservation equations were applied on MHD fluid flows through a channel along the x-axis (labeled, a) which is from o units to 4 units and along the y-axis (labeled, b) through the porous part of the channel.

The magnetic field is at the part labeled (a) in definite length where it is expected to have a difference of the pressure and the viscosity of the fluid as the flow gets through the porous part of the channel.

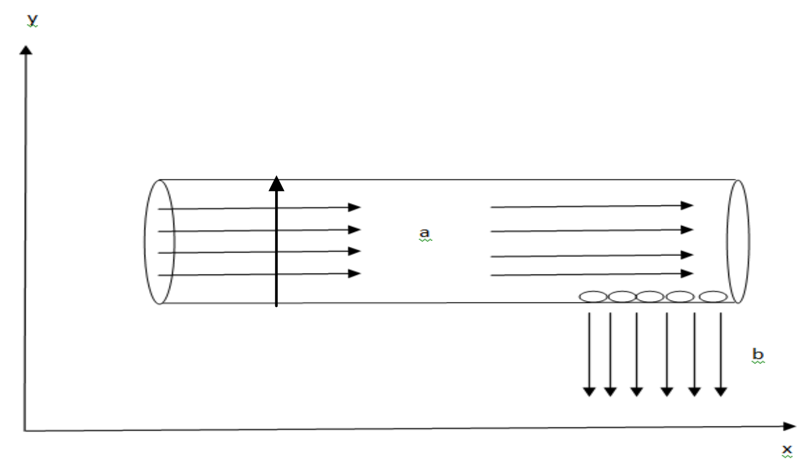

Figure 3.1**:** Geometry of the flow through the porous channel.

The equations derived from the physical relationship are more specific to the dimensional analysis on the study. The number of independent variables that characterize the problem is decreased through the process of discretization. The governing equations for this study's non-dimensional quantities were introduced into the general equation to make the specific dimensionless equation which finally was used in solving the study problem. The following are some of the dimensionless equations and parameters that were used in the study.

$$x = \frac{\bar{x}}{a} \tag{3.1a}$$

$$y = \frac{\bar{y}}{a} \tag{3.1b}$$

$$u = \frac{\bar{u}}{a} \tag{3.1c}$$

$$t = \frac{\bar{t}v}{a} \tag{3.1d}$$

$$p = \frac{\bar{p}}{\rho v^2} \tag{3.1e}$$

$$\theta = \frac{T - T_o}{T_1 - T_0} \tag{3.1f}$$

$$\lambda = \frac{Va}{v} \tag{3.1g}$$

$$Da = \frac{\bar{k}v}{va} \tag{3.1h}$$

$$M = aB_0\sqrt{\frac{\sigma}{\mu}} \tag{3.1i}$$

Where, t is time, u is the axial speed, v the transverse speed, p is the pressure, λ is the parameter for the injection/suction, Da is the Darcy number and M is the magnetic parameter, θ the temperature change, T_0, T_1 represents the initial temperature as well and the final temperature respectively. T represents the general fluid temperature. $\bar{x}, \bar{y}, \bar{u}, \bar{v}, \bar{p}$ these are symbols showing the specific value of x value, y value, specific axial velocity, specific transverse velocity and specific value of pressure reduced by a constant a to help in reducing the partial differential equations to a specific partial differential approximations.

3.4 Main Concepts and Principles

The MHD fluid is considered to be an electrically conducting fluid with different parameters affecting the flow variables. Governing equations on the study focused on different dynamics and Maxwell's equations. Where the equations considered were the continuity equation, energy equation on the flow as well as the momentum equation.

MHD fluid formulas were developed to relate to the fluids fundamental density, velocity, thermodynamic pressure, and magnetic flux. In the derivation of the specific questions to be used in optimization of the MHD parameters, one should not put into account the internal or externally generated heat as well as the induced magnetic field into the flow. The motion of electrons in the fluid was considered.

The first equation is the mass continuity,

$$\frac{\partial \rho}{\partial t} + \nabla(\rho V) = 0 \qquad (3.2)$$

This states that matter only changes in form but cannot be created or destroyed.

The second equation is the equation of motion of an element of the fluid,

$$\rho[\frac{\partial V}{\partial t} + (VV)V] = -\nabla \rho + jB \qquad (3.3)$$

The Euler equation is another name for this. The vector j represents the density of electric current as indicated by the magnetic field.

The third equation is the energy equation, which has the following form in the simplest adiabatic case;

$$\frac{d}{dt}\left(\frac{\rho}{\rho V}\right) = o \qquad (3.4)$$

The temperature t, of the fluid can be determined from the density ρ and the thermodynamic pressure, using the state equation such as the ideal gas law. For example, in a pure hydrogen fluid, this equation is

$$P = \frac{K_B}{m_p} \rho T \tag{3.5}$$

Where m_p the mass of the proton is pressure, T temperature and k_B is Boltzmann's constant.

3.5 Dimensionless Numbers

Dimensionless numbers are used in fluid mechanics to analyze the behavior of the fluid in a flow, they are a collection of dimensionless quantities that play a significant role in the process of discretization into specific equations that analyze a problem in a study. The relative strengths of the various phenomena of inertia, viscosity, conductive heat transfer and diffusive mass movement are expressed by various dimensionless numbers. The momentum equation, the energy equation and the continuity equation are non-dimensionalized to reduce the complexity of the equations to simple specific equation that is useful in the process of solving the study problem in this study.

3.5.1 Reynolds Number (Re)

In the analysis of a flow dynamics, the Reynolds number (Re) is used to evaluate and forecast the flow patterns for various fluid flows. The Reynolds number is applied in different areas to achieve specific results depending on the uniqueness of the flow. This includes liquid flow via pipes, planners, and porous channels. In addition to being used to scale comparable flows or even different-sized flow scenarios, it is also utilized to anticipate the transition from turbulent to laminar flow. Reynolds number is used such that it can evaluate a flow between wind tunnel-based airplanes Model. It is highly helpful to project fluid flow behavior on a bigger scale given distinct specified conditions with predefined boundaries and the capacity to forecast the early stage of turbulence and following their impacts. This aids in areas like local or global air/water flow and its consequent influence on meteorological and climatological phenomena. George Stokes made a point of demonstrating this in 1851. Arnold, (1908) gave the Reynolds number its name. The Reynolds number is defined as shown in the equations below,

$$\mathrm{Re} = \frac{\mu L}{v} = \frac{\upsilon L}{v} \qquad (3.6a)$$

But $$v = \frac{\mu}{\rho} \qquad (3.6b)$$

Hence $$\mathrm{Re} = \frac{\rho u L}{\mu} \qquad (3.6c)$$

The Reynolds number of flow inside a pipe or tube is often defined as shown in the steps below

$$v = \frac{\mu}{\rho} \qquad (3.7a)$$

$$u = \frac{Q}{A} \qquad (3.7b)$$

$$W = massflux = \rho Q \qquad (3.7c)$$

$$\mathrm{Re} = \frac{uD_H}{v} = \frac{\rho u D_H}{\mu} = \frac{\rho Q D_H}{\mu A} = \frac{W D_H}{\mu A} \tag{3.7d}$$

Re is the ratio of the inertia forces to viscous forces:

$$\mathrm{Re} = \frac{\rho U_0 L_0}{\mu} = \frac{U_0 L_0}{\upsilon} \tag{3.8}$$

3.5.2 Pranditl Number (Pr)

Prandtl's Number, a measurement of the fluid's relative ability to permit momentum and heat diffusion, is used to describe the mixing of warm and cool particles in convection-based heat transfer, which also involves momentum transfers. Because of the temperature difference between the warm and cool particles, local heat conduction results from their interaction.

$$\mathrm{Pr} = \frac{\mu c_p}{\kappa} \tag{3.9}$$

3.5.3 Pressure Coefficient (P_c)

This is also known as the Euler's number. It's described as

$$P_c = \frac{p_0}{\rho U_0^{\,2}} \tag{3.10}$$

The pressure coefficient gives the importance of pressure term relative to inertia term.

3.5.4 Magnetic Parameter (M)

The Stuart number (N), commonly referred to as the magnetic interaction parameter, is a dimensionless quantity of gases or liquids. It is called the electromagnetic to inertial force ratio, which provides an estimation of the relative significance of a magnetic flux on a flow.

$$M = \frac{B^2 L_c \sigma}{\rho U} = \frac{Ha^2}{\mathrm{Re}} \tag{3.11}$$

3.5.5 Darcy Number (Da)

Fluid dynamics through a porous media has its dynamics analyzed and predicted using the Darcy number. Relatively the Da represents the relative effect of it to the velocity profile of the flow. Darcy's Law describes the linear relationship between the pressure difference on the fluid flow and the flow rate. It is a dimensionless number used to solve models of flows on a porous channel.

The volume flow rate is denoted as Q which is determined by the syringe pump, and the following relationship yields the Darcy velocity V_f.

$$V_f = Q_f/A \tag{3.12}$$

A denotes the cross-section's area. The drop in pressure ΔP is measured subsequently separated by the sample length l to get the pressure gradient P.

$$Da = \frac{\bar{k}v}{va} \tag{3.13}$$

3.5.6 Eckert Number (E_c)

This is a dimensionless number applicable in the study of fluid dynamics on a porous channel. It affects the temperature directly by converting the internal friction energy into a kinetic energy. In this case it causes the fluid's temperature profiles to increase. The Eckert number was first named by Ernest Eckert early 1950's. It is a quantity used in determining the relative effective in viscous heating of a fluid flow. It is also how much mechanical energy there is which is internal friction transformed leading to an increase in the thermal heat dissipation. It is known as the proportion of temperature to dynamic temperature as well as the force that propels the transfer of heat in fluid movements.

$$E_c = \frac{u_o^2}{C_p \Delta T.L} \quad (3.14a)$$

$$E_c = \frac{u_o^2}{C_p \left(T_1 - T_o\right) L} \quad (3.14b)$$

Where u denotes the fluid velocity, C_p is the particular thermal capacity at persistent pressure, and ΔT denotes the temperature change, resulting in the distinction between the wall temperature and the free stream temperature.

The energy equation simplifies to equilibrium between conduction and convection when the Eckert number is lower than one, allowing the components that explain the effects on pressure changes, viscous dissipation, along with body forces on the energy balance to be omitted.

3.6 Method of solution

In this research the numerical schemes have been developed using Finite Difference Method (FDM). The FDM was used to solve the Partial differential equation (PDE) of the continuity equation, momentum equation and the energy equation. The dependent variables in the equations are the fluid velocity and the fluid temperature whereas the independent variables are the parameters like the magnetic parameter, the Darcy number, Eckert number and pressure coefficient among others.

These were the conditions that were satisfied for the solution of the FDE leading to reasonably accurate approximation to the solution of the corresponding PDA. These conditions were associated with the concepts of stability and consistency therefore coming up with values that are examined to get specific solutions. The PDA was then solved with the use of Central scheme (CS) with the boundary and beginning value restrictions met. The results were presented for different parameters under investigation and compared. MATLAB software was used to solve and generate values in this study. The analysis are done with the help of tables and the graphs

3.7 Finite Difference Method

The partial in the derivatives partial differential equation, as well as the boundary and initial conditions, are replaced by the associated finite difference approximations using the finite difference technique. The resulting linear algebraic set of equations is then solved using a conventional iterative process or by using a direct method. At the mesh locations, the dependent variable's numerical values are acquired.

Thus, finite difference approximations are obtained in algebraic form, and the solutions are presented on grid points.

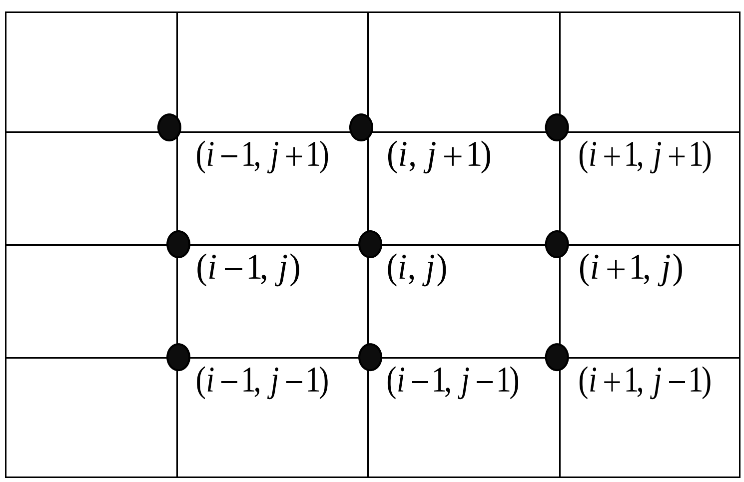

Figure 3.2**:** Finite Difference Mesh

3.8 Discretization of Governing Equations

Discretization of equations involves transformation of functions, continuous variables, or models into discrete forms. To look at PDE models' predictions, it is found necessary to numerically approximate their solutions. The approximate solutions are then represented by functional values at certain discrete points. The discretization of partial derivative for first derivative with respect to time denote as u_t while the first and second derivative with respect to the flow on the axial and the transverse flow denoted as u_x, u_{xx} and u_y, u_{yy} respectively. The following derivatives are described in the following equation showing the steps used in the process of solving the study problem.

$$u_t = \frac{u_{i,j}^{n+1} - u_{i,j}^{n}}{\Delta t} \tag{3.15}$$

$$u_x = \frac{u_{i+1,j}^{n} - u_{i+1,j}^{n}}{2\Delta x} \tag{3.16}$$

$$u_y = \frac{u_{i,j+1}^{n} - u_{i,j-1}^{n}}{2\Delta y} \tag{3.17}$$

$$u_{xx} = \frac{u_{i+1,j}^{n} - 2u_{i,j}^{n} + u_{i-1,j}^{n}}{(\Delta x)^2} \tag{3.18}$$

$$u_{yy} = \frac{u_{i,j+1}^{n} - 2u_{i,j}^{n} + u_{i,j-1}^{n}}{(\Delta y)^2} \tag{3.19}$$

3.9 Continuity Equation

The equation of continuity (equation of conservation of mass) is always provided based on two fundamental principles: conservation of mass of fluid, and continuity in fluid flow.

Taking into account an incompressible fluid (whose density is considered to remain constant), the general continuity equation in a two dimensional fluid flow where w=0 then the equation is expressed as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3.20}$$

3.10 Momentum Conservation Equations

In the momentum equation, the body and surface forces are offset by the momentum change rate. Surface forces, which originate from stresses like static pressure as well as viscous stresses operating on the outermost layer of the volume element, are proportional to area. Body forces, such as centrifugal and gravitational forces, are forces that operate on the fluid element from an external force field and are equal to the volume element. When considering a certain flow arrangement, the forces acting on the fluid must be defined. Classically, Newton's second law of motion is used to generate the equation for momentum conservation. For forced convection the following momentum equation holds,

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - F \tag{3.21}$$

The above is the general equation for motion.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{\sigma B_o^2}{\rho}-\frac{\nu}{\kappa} \tag{3.22}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{\sigma B_o^2}{\rho}-\frac{\nu}{\kappa} \tag{3.23}$$

Where u and v are velocity apparatuses, ρ the liquid's density, B_0 is the magnetic field's strength, K is the permeability, δ electrical conductivity and μ coefficient of viscosity.

In applications, equation (3.23) is dimensionalized to research the impacts of magnetohydrodynamic parameters on incompressible fluid flow systems.

3.10.1 Dimensinalizing Momentum Equation

To make the situation a less complicated physical problem, first the momentum equation (3.20) was dimensionalized by introducing equations (3.1i) and (3.1j) into equation (3.23), yielding

$$U\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}=-\frac{\partial P}{\partial x}+\frac{1}{\lambda}\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}\right)-\left(\frac{M^2}{\lambda}+\frac{1}{Da}\right)U$$

(3.24)

Where the emerging quantities are: t is time, U is the axial velocity, V is the transverse velocity, P is the pressure, λ is the injection/suction parameter, *Da* is the Darcy number and M is the magnetic

3.10.2 Discretization of Momentum Equation

Equation (3.22) was then discretized to study the effects of pressure change ΔP, Darcy number *Da*, and magnetic parameter *M* on velocity profiles and temperature distribution of an incompressible fluid over a varied length of porous channel. Discretization was achieved using a central difference numerical scheme in which partial derivatives U_x, U_y, U_{xx}, and U_{yy} were replaced by three-point central difference approximation by substituting these approximations into equation (3.24), yielding

$$\frac{U^{n+1}{}_{i,j} - U^{n-1}{}_{i,j}}{2\Delta t} + U\frac{U^{n}{}_{i+1,j} - U^{n}{}_{i-1,j}}{2\Delta x} + V\frac{U^{n}{}_{i,j+1} - U^{n}{}_{i,j-1}}{2\Delta y} =$$

$$-\left(\frac{P^{n}{}_{i+1,j} - P^{n}{}_{i-1,j}}{2\Delta x}\right) + \frac{1}{\lambda}\left(\frac{U^{n}{}_{i+1,j} - 2U^{n}{}_{i,j} + U^{n}{}_{i-1,j}}{(\Delta x)^2} + \frac{U^{n}{}_{i,j+1} - 2U^{n}{}_{i,j} + U^{n}{}_{i,j-1}}{(\Delta y)^2}\right) - \left(\frac{1}{\lambda}M^2 + \frac{1}{Da}\right)U^{n}_{i,j}$$

(3.25)

The effects of *Da* and *M* on the fluid velocity profiles were investigated. Taking $\Delta t = 0.01$ and $\Delta x = \Delta y = 0.2$, in a square mesh and letting $V = U = \lambda = 1$, and multiplying by $2\Delta t$ gives the central difference scheme,

$$-2U^{n}{}_{i+1,j} + \left(10 + 0.2M^2 + \frac{0.2}{Da}\right)U^{n}{}_{i,j} - 3U^{n}{}_{i-1,j}$$

$$= 2U^{n}{}_{i,j+1} + 3U^{n}_{i,j-1} + U^{n-1}_{i,j} - U^{n+1}_{i,j} - 0.5P^{n}_{i+1,j} - 0.5P^{n}_{i-1,j}$$

(3.26)

Taking *i=1, 2,…, 5* and *j= 1* and *n=0* in equation (3.24)the following systems of linear algebraic equations were formed.

$$i = 1, \quad -2U^{0}{}_{2,1} + \left(10 + 0.2M^2 + \frac{0.2}{Da}\right) U^{0}{}_{1,1} - 3U^{0}{}_{0,1}$$
$$= 2U^{0}{}_{1,2} + 3U^{0}{}_{1,0} + U^{-1}{}_{1,1} - U^{1}{}_{0,1} - 0.5P^{0}{}_{2,1} - 0.5P^{0}{}_{0,0}$$

$$i = 2, \quad -2U^{0}{}_{3,1} + \left(10 + 0.2M^2 + \frac{0.2}{Da}\right) U^{0}{}_{2,1} - 3U^{0}{}_{1,1}$$
$$= 2U^{0}{}_{2,2} + 3U^{0}{}_{2,0} + U^{-1}{}_{2,1} - U^{1}{}_{1,1} - 0.5P^{0}{}_{3,1} - 0.5P^{0}{}_{1,0}$$

$$i = 3, \quad -2U^{0}{}_{4,1} + \left(10 + 0.2M^2 + \frac{0.2}{Da}\right) U^{0}{}_{3,1} - 3U^{0}{}_{2,1}$$
$$= 2U^{0}{}_{3,2} + 3U^{0}{}_{3,0} + U^{-1}{}_{3,1} - U^{1}{}_{2,1} - 0.5P^{0}{}_{4,1} - 0.5P^{0}{}_{2,0}$$

$$i = 4, \quad -2U^{0}{}_{5,1} + \left(10 + 0.2M^2 + \frac{0.2}{Da}\right) U^{0}{}_{4,1} - 3U^{0}{}_{3,1}$$
$$= 2U^{0}{}_{4,2} + 3U^{0}{}_{4,0} + U^{-1}{}_{4,1} - U^{1}{}_{3,1} - 0.5P^{0}{}_{5,1} - 0.5P^{0}{}_{3,0}$$

$$i = 5, \quad -2U^{0}{}_{6,1} + \left(10 + 0.2M^2 + \frac{0.2}{Da}\right) U^{0}{}_{5,1} - 3U^{0}{}_{4,1}$$

$$= 2U^{0}{}_{5,2} + 3U^{0}{}_{5,0} + U^{-1}{}_{5,1} - U^{1}{}_{4,1} - 0.5P^{0}{}_{6,1} - 0.5P^{0}{}_{4,0}$$

(3.27)

The initial conditions were set from discretization of energy equation as $U(x, y, 0) = 10, P(x, 0,0) = 0$ and boundary conditions as $U(0, y, 1) = 0,$ and $U(x, 0, -1) = 0.$ Letting *P(x,1,0)* = Δ*P* and applying the set initial conditions and boundary conditions, the above algebraic equations (3.25) were expressed in matrix form as

$$\begin{bmatrix} \left(10+0.2M^2+\frac{0.2}{Da}\right) & -2 & 0 & 0 & 0 & 0 \\ -3 & \left(10+0.2M^2+\frac{0.2}{Da}\right) & -2 & 0 & 0 & 0 \\ 0 & -3 & \left(10+0.2M^2+\frac{0.2}{Da}\right) & -2 & 0 & 0 \\ 0 & 0 & -3 & \left(10+0.2M^2+\frac{0.2}{Da}\right) & -2 & 0 \\ 0 & 0 & 0 & -3 & \left(10+0.2M^2+\frac{0.2}{Da}\right) & -2 \\ 0 & 0 & 0 & 0 & -3 & \left(10+0.2M^2+\frac{0.2}{Da}\right) \end{bmatrix} \begin{bmatrix} U_{1,1}^0 \\ U_{2,1}^0 \\ U_{3,1}^0 \\ U_{4,1}^0 \\ U_{5,1}^0 \\ U_{6,1}^0 \end{bmatrix} = \begin{bmatrix} 0.5\Delta P+10 \\ 0.5\Delta P+10 \\ 0.5\Delta P+10 \\ 0.5\Delta P+10 \\ 0.5\Delta P+10 \\ 0.5\Delta P+10 \end{bmatrix}$$

(3.28)

The solutions for varying values of M, Da and ΔP were obtained by solving the above matrix equation (3.28) numerically with the help of the MATLAB. The magnetic parameter (M) was varied between 2.0 to 4.0, while Darcy's number (Da) was varied between 0.1 to 0.3, and fluid pressure (ΔP) was varied from $1.0\ KPa$ to $4.0\ KPa$. The numerical results obtained for M, Da and ΔP were recorded in tables 4.1, 4.2 and 4.4 respectively.

3.11 Energy Conservation Equation

According the rule of preservation that energy is a primary source of power, overall energy content of any static isolated system and that energy and matter cannot be transferred over a system's boundary, energy can only be changed from a single state to another; it cannot be generated or destroyed. According to the first rule of thermodynamics, the rate of energy acquisition in a system is equivalent to the heat contributed to the system and the work done on the system, is where the energy equation is obtained. You may write the energy equation as, assuming there is no external heat source:

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u \frac{\partial T}{\partial x} + \rho c_p v \frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \Phi \qquad (3.30)$$

Where $\Phi = \mu\left\{2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right]\right\}$ denotes the dissipation function and α is the thermal diffusivity.

3.11.1 Dimensinalizing Energy Equation

To dimensionalize the Energy equation, equation (3.30) below was considered,

$$\frac{\rho c_p u_o (T_1 - T_o)}{L}\frac{\partial\theta}{\partial t} + \frac{\rho c_p u_o (T_1 - T_o)}{L}\left(U\frac{\partial\theta}{\partial x} + V\frac{\partial\theta}{\partial y}\right) = \alpha\frac{(T_1 - T_o)}{L^2}\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right) + \frac{\mu u_o^2}{L^2}\Phi \tag{3.31}$$

Simplifying equation (3.31) gives

$$\frac{\partial\theta}{\partial t} + U\frac{\partial\theta}{\partial x} + V\frac{\partial\theta}{\partial y} = \frac{\alpha}{\rho c_p u_o L}\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right)$$

$$+\frac{\mu u_o^2}{\rho c_p L (T_1 - T_o)}\left\{\left(\frac{\partial U}{\partial x}\right)^2 + \left(\frac{\partial U}{\partial y}\right)^2 + \left(\frac{\partial\theta}{\partial y} + \frac{\partial\theta}{\partial x}\right)^2\right\} \tag{3.32}$$

Since the flow is along the x-axis, and for low velocities viscous dissipation is negligible, equation (3.32) becomes

$$\frac{\partial\theta}{\partial t} + U\frac{\partial\theta}{\partial x} + V\frac{\partial\theta}{\partial y} = \frac{\alpha}{\rho c_p u_o L}\left(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right) + \frac{\mu u_o^2}{\rho c_p L (T_1 - T_o)}\left\{\left(\frac{\partial U}{\partial x}\right)^2\right\} \tag{3.33}$$

The viscosity (δ) of the fluid in this study taken was stated as an inverse linear function of temperature in the following form (Abdou and Zahar, 2012).

$$\delta = \frac{1}{\alpha(T - T_\infty)} \tag{3.34}$$

$$\left(\frac{\mu u_0^2}{\rho c_p L(T - T_0)}\right) = \left(\frac{u_0^2}{\rho c_p L(T - T_0)\alpha(T - T_\infty)}\right) = \left(\frac{u_0^2}{\rho c_p (T - T_\infty)}\right)\mu$$
$$= \left(\frac{u_0^2}{\rho c_p (T - T_\infty)}\right)\left(\frac{1}{\alpha(T - T_\infty)}\right) \tag{3.35}$$

Rewriting expressions in equations (3.35)

$\frac{\alpha}{\rho c_p u_0 L} = \frac{\alpha}{\rho c_p u_0 L}\left(\frac{\mu}{\mu}\right) = \left(\frac{\alpha}{\mu c_p}\right)\left(\frac{\mu}{\rho u_0 L}\right)$, $Pr = \frac{\mu c_p}{\alpha}$, $Re = \frac{\rho u_0 L}{\mu}$, $E_c = \frac{u_0^2}{C_p(T_1 - T_0)L}$, and

$\delta = \frac{1}{\alpha(T - T_\infty)}$. Equation (3.35), therefore, becomes

$$\frac{\partial \theta}{\partial t} + U\frac{\partial \theta}{\partial x} + V\frac{\partial \theta}{\partial y} = \frac{1}{\mathrm{Re}\,\mathrm{Pr}}\left(\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2}\right) + E_c\delta\left(\frac{\partial u}{\partial x}\right)^2 \tag{3.36}$$

3.11.2 Discretization of Energy Equation

Equation (3.14) was discretized to study the effects of Eckert number *(E_c)* and viscosity (δ) on temperature distribution. Using a three-central-difference numerical scheme, the partial derivatives θ_x, θ_x, θ_{xx} and θ_{yy} were replaced by three-point-central difference approximation by inserting the approximations into equation (3.14), yielding

$$\frac{\theta_{ij}^{n+1}-\theta_{ij}^{u}}{\Delta t}+\frac{\theta_{i+1,j}^{n}-\theta_{i-1,j}^{u}}{2\Delta x}+\frac{\theta_{i,j+1}^{u}-\theta_{i,j-1}^{n}}{2\Delta y}$$
$$=\left(\frac{1}{PrRe}()\left(\frac{\theta_{i+1,j}^{u}-2\theta_{ij}^{n}+\theta_{i-1,j}^{n}}{(\Delta x)^{2}}+\frac{\theta_{i,j+1}^{n}-2\theta_{ij}^{n}+\theta_{i,j-1}^{n}}{(\Delta y)^{2}}\right)_{c}\left(\frac{\left(u_{i,j+1}^{n}\right)^{2}+2u_{i,j+1}^{n}-u_{i,j-1}^{n}+\left(u_{i,j+1}^{n}\right)^{2}}{4(\Delta y)^{2}}\right)\right)$$

(3.37)

Simplifying (3.1), and letting *Pr = Re = 1*, the central difference scheme gives,

$$2\theta_{i+1,j}^{n}-44\theta_{i,j}^{n}-2\theta_{i-1,j}^{n}=18\theta_{i,j}^{n}+22\theta_{i,j+1}^{n}+10E_{c}\delta \quad (3.38)$$

Taking and *i = 1,2,3,..,5* and *j = 1* the following systems of linear algebraic equations were formed.

$i=1,\quad 2\theta_{2,1}^{0}-44\theta_{1,1}^{0}-2\theta_{0,1}^{0}=18\theta_{1,1}^{0}+22\theta_{1,2}^{0}+10E_{c}\delta$

$i=2,\quad 2\theta_{3,1}^{0}-44\theta_{2,1}^{0}-2\theta_{1,1}^{0}=18\theta_{2,1}^{0}+22\theta_{2,2}^{0}+10E_{c}\delta$

$i=3,\quad 2\theta_{4,1}^{0}-44\theta_{3,1}^{0}-2\theta_{2,1}^{0}=18\theta_{3,1}^{0}+22\theta_{3,2}^{0}+10E_{c}\delta$

$i=4,\quad 2\theta_{5,1}^{0}-44\theta_{4,1}^{0}-2\theta_{3,1}^{0}=18\theta_{4,1}^{0}+22\theta_{4,2}^{0}+10E_{c}\delta$

$i=5,\quad 2\theta_{6,1}^{0}-44\theta_{5,1}^{0}-2\theta_{4,1}^{0}=18\theta_{5,1}^{0}+22\theta_{5,2}^{0}+10E_{c}\delta$

(3.39)

The initial and boundary conditions obtained from discretization of energy equation were $\theta_{i,0}^{0}=\theta_{0,j}^{0}=10$ and boundary conditions $\theta_{i,2}^{0}=\theta_{i,1}^{0}=0$, respectively. Applying these conditions in the above algebraic equations (3.17) and expressing the equations in matrix gives,

$$\begin{bmatrix} -44 & 2 & 0 & 0 & 0 \\ -2 & -44 & 2 & 0 & 0 \\ 0 & -2 & -44 & 2 & 0 \\ 0 & 0 & -2 & -44 & 2 \\ 0 & 0 & 0 & -2 & -44 \end{bmatrix} \begin{bmatrix} U_{1,1}^{0} \\ U_{2,1}^{0} \\ U_{3,1}^{0} \\ U_{4,1}^{0} \\ U_{5,1}^{0} \end{bmatrix} = \begin{bmatrix} 10E_c\delta + 20 \\ 10E_c\delta \\ 10E_c\delta \\ 10E_c\delta \\ 10E_c\delta \end{bmatrix}$$

(3.40)

The solutions for varying values of Eckert number (E_c) and fluid viscosity (δ) were obtained by solving the above matrix equation (3.39) in MATLAB. The numerical results obtained for varying Eckert number and fluid viscosity (δ) were recorded in tables 4.3.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The simulation results obtained in this study focus on the effects of the Magnetic parameter *M*, Darcy number *Da*, and fluid pressure *P*, Eckert number E_C and viscosity δ , on velocity profile and temperature distribution, respectively.

4.2 Effects of Magnetic parameters on velocity profile

Equation (3.27) was solved numerically using MATLAB to obtain the results of the effects of *M* on velocity profile as shown in table 4.1.

Table 4.1: Value of velocity profile for varying Magnetic parameters

Magnetic parameters	**Length of Porous channel**				
	0	**1**	**2**	**3**	**4**
M = 2	68.83728	85.55858	89.31898	88.30366	76.16492
M = 3	62.54598	76.56727	79.49516	78.66569	68.55051
M = 4	55.48979	66.722339	68.21814	68.21814	60.17463

The results in table 4.1were presented in figure 4.1.

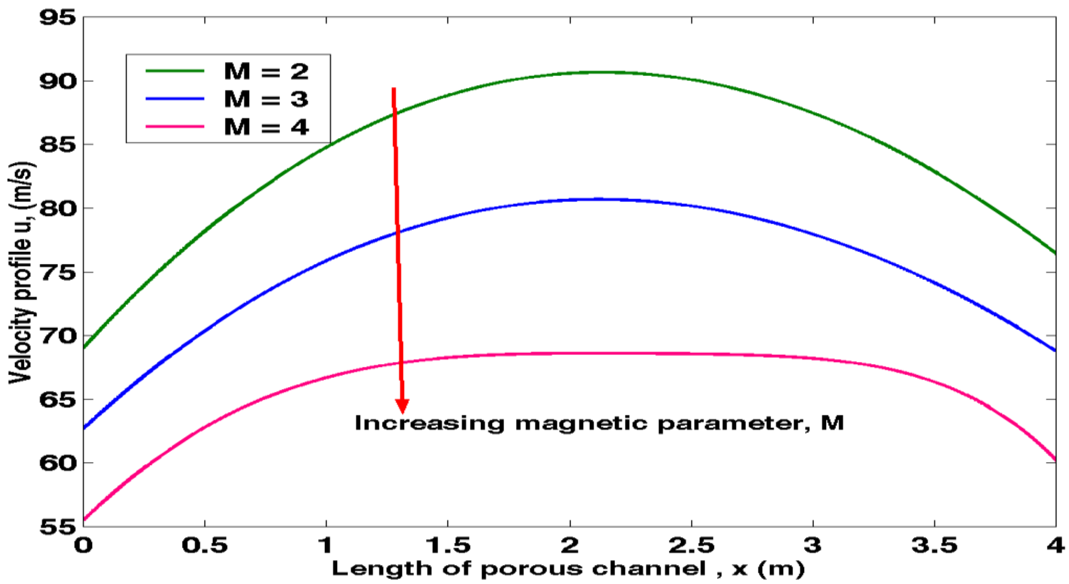

Figure 4.1: Velocity profile against Length of Porous channel at varying Magnetic

The magnetic parameter's impact on velocity profile can be observed from figure 4.1. The magnetic parameter is increasing leading in the velocity profile declining. This is as a result of the Lorentz force, which is produced when an applied magnetic field with a constant inclination and provides resistance to fluid motion, hence reducing flow. The Lorentz force increases in the flow as the magnetic parameter increases. This causes the flow of the fluid to experience more resistance, which reduces the fluid's velocity. As we optimize the magnetic parameter in the flow in a porous channel, the velocity is minimized hence leading to the best diffusivity effect on the flow.

Adeyemi *et al.* (2015) observed a significant decrease on the velocity profile of the fluid domain with increase in the value of the magnetic parameter in their study. They further agreed with the findings in this study that the magnetic parameter led to a drag effect on the flow that leads to a reduction effect on the velocity of a fluid flowing through a porous channel. In his analysis Wubshet, (2016) showed that the magnetic parameter rise led to a decrease to the fluid velocity since the magnetic parameter had a retarding force on the flow which resulted to a decrease on the velocity. The resistance of the flow velocity is experience as the Magnetic parameter is increased, therefore the higher the magnetic parameter the higher the resistance leading to a lower velocity profile in the flow.

4.3 Effects of Darcy numbers on velocity profile

Equation (3.27) was solved numerically in MATLAB to obtain the results of impacts of *Da* amount of velocity profile as shown in table 4.2.

Table 4.2: Value of velocity profile for varying Darcy numbers

Darcy numbers					
	Length of Porous channel				
	0	**1**	**2**	**3**	**4**
Da = 0.1	68.83728	85.55858	89.31898	88.30366	76.16492
Da = 0.2	75.23219	97.3234	102.8954	101.5184	85.31186
Da = 0.3	84.24966	108.3732	114.6778	113.1684	95.40957

The results in table 4.2were presented in figure 4.2.

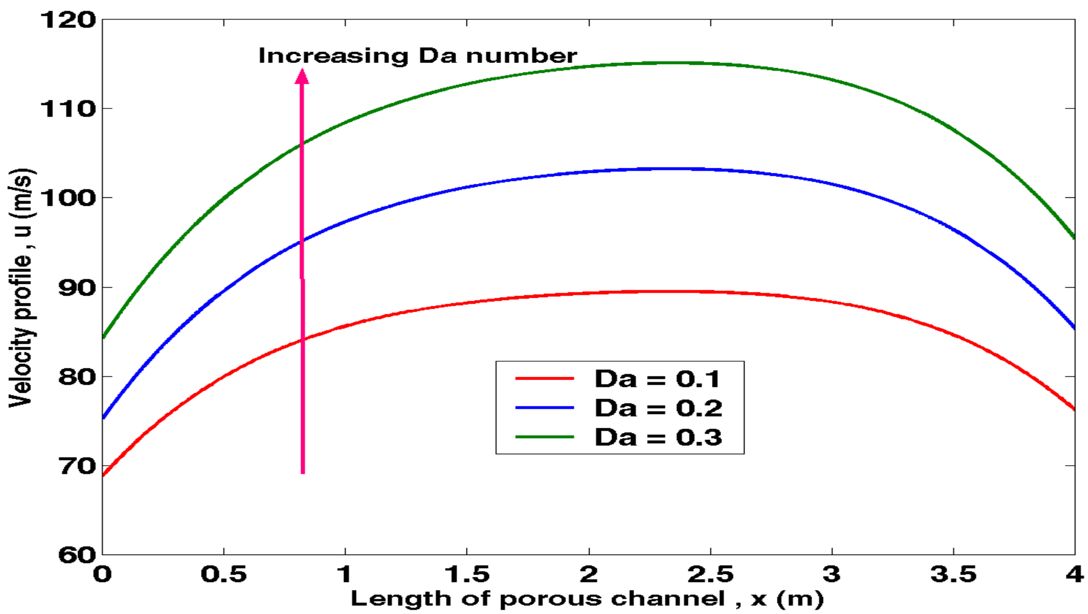

***Figure 4.2*:** Graph of velocity against Length of Porous channel at varying Darcy numbers

The effect of Darcy numbers can be observed from figure 4.2. Also, at initial stages the fluid velocities increase from *x=0* to *x=2* but it starts to decrease thereafter upto *x=4.*It indicates that a positive increase in Darcy numbers strongly accelerates the flow. An increase in Darcy number results in the improvement in the permeability leading to it increasing the strong convective mode. Finally, this causes the velocity profile to grow.

In the findings done with Kumar *et al.* (2013) showed that the velocity profile was affected directly in the presence of the Darcy number. A rise in the Darcy parameter led to an increase in the velocity on both the narrow and wide porous channels in their study. This was in agreement with the 2021 paper by Mohammed *et al.* whose results showed that both the Darcy number and the Reynolds number led to a positive skew to the velocity of the flow.

In Hady *et al.* (2006), the study results showed that an increase in the Darcy number led to an increase in the absorption effect leading to an increase in the velocity. They went ahead and showed how directly it led to an increase in the temperature of the flow.

In all the related studies the results agree on the findings that the Darcy number increase leads to a rise on the velocity. The work has significant applications in magnetohydrodynamic energy generation, material processing, and nuclear heat transfer control.

4.4 Effects of Eckert number on temperature distribution

Equation (3.36) was solved numerically in MATLAB to obtain the results of the effects of Eckert number on temperature distributions recorded in table 4.3.

Table 4.3: Value of temperature distribution for varying Eckert number

Eckert number	**Length of Porous channel**				
	0	**1**	**2**	**3**	**4**
E_C = 15	1.607319	1.013841	0.8660641	0.8231372	0.7450029
E_C = 20	1.812403	1.269772	1.134412	1.092474	0.9921149
E_C = 25	2.017488	1.525702	1.402759	1.361811	1.239227

The results in table 4.4 were presented in figure 4.3.

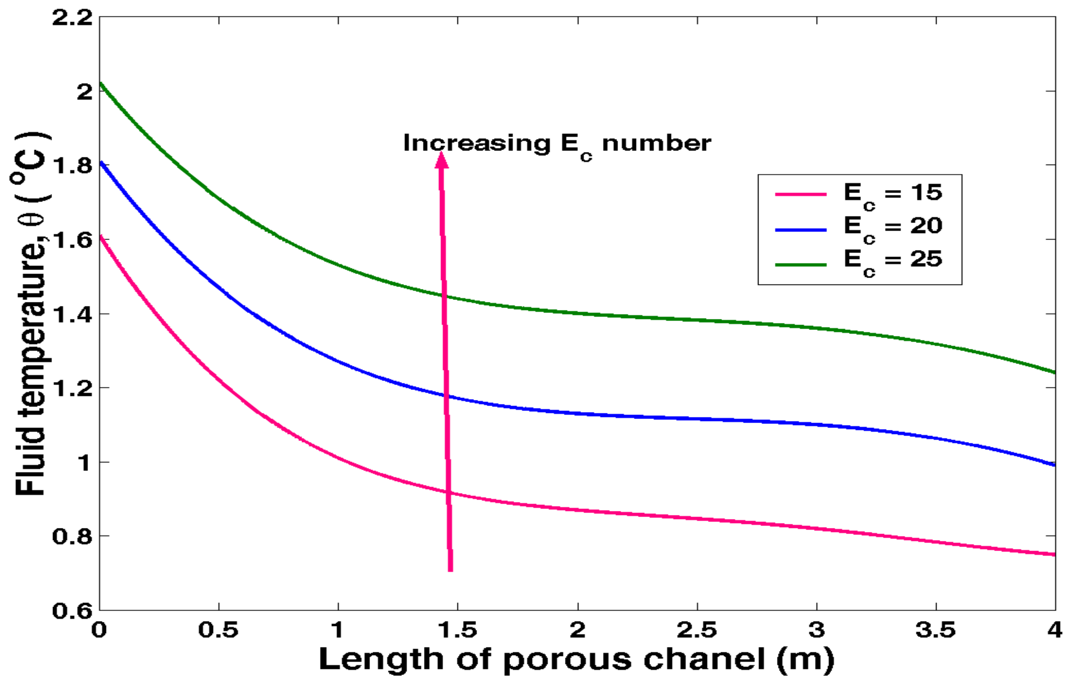

***Figure 4.3*:** Temperature distribution against Length of Porous channel at varying Eckert number.

The effect of Eckert (Ec) number on fluid temperature can be observed from figure 4.3. that an increase in Ec number leads to an increase in the temperature distribution. The Eckert number causes a higher rate of internal energy which is created by working against the tensions of a viscous fluid to convert kinetic energy. It expresses the relationship between the kinetic energy in the flow and the enthalpy difference which is used to characterize heat transfer dissipation. In this flow it is realized that as the Ec is increased then the internal energy is equally increased because of its effect leading to an increase in the general temperature of the flow.

In the 1998 investigation done by Kinyanjui *et al.*, the results indicated that a rise in the Ec number caused an increase in the Temperature profile which is in agreement with other scholars like Solomon *et al.* (2021) whose findings showed that the temperature profile of the fluid rose with increase in the Eckert number, however, in their study they realized no effect on the velocity with difference on the Ec number.

Erick, Eustace, & Stephen, (2016) in their study they also analyzed and concluded that the Eckert number thus the viscous dissipation parameter increase did lead to a rise in the flows temperature profile. This is in agreement with the findings in this study. Optimizing the Ec number as analyzed in the study along the porous channel leads to optimizing the temperature profiles in a two dimensional incompressible flow. Applications of optimizing the Ec number in a flow include MHD energy generation, material processing that high temperature is key and heat transfer in industry.

4.5 Effects of Pressure on velocity profile

Equation (3.28) was solved in MATLAB to obtain the results of the effects of pressure on velocity profile as shown in table 4.4.

Table 4.4: Value of velocity profile for varying fluid pressure

Fluid Pressure	**Length of Porous channel**				
	0	**1**	**2**	**3**	**4**
P = 1000	49.4465	61.45757	64.15871	63.42939	54.71001
P = 1200	59.14189	73.50807	76.73885	75.86652	65.43747
P = 1400	68.83728	85.55858	89.31898	88.30366	76.16492

The above results in table 4.3 were presented in figure 4.4.

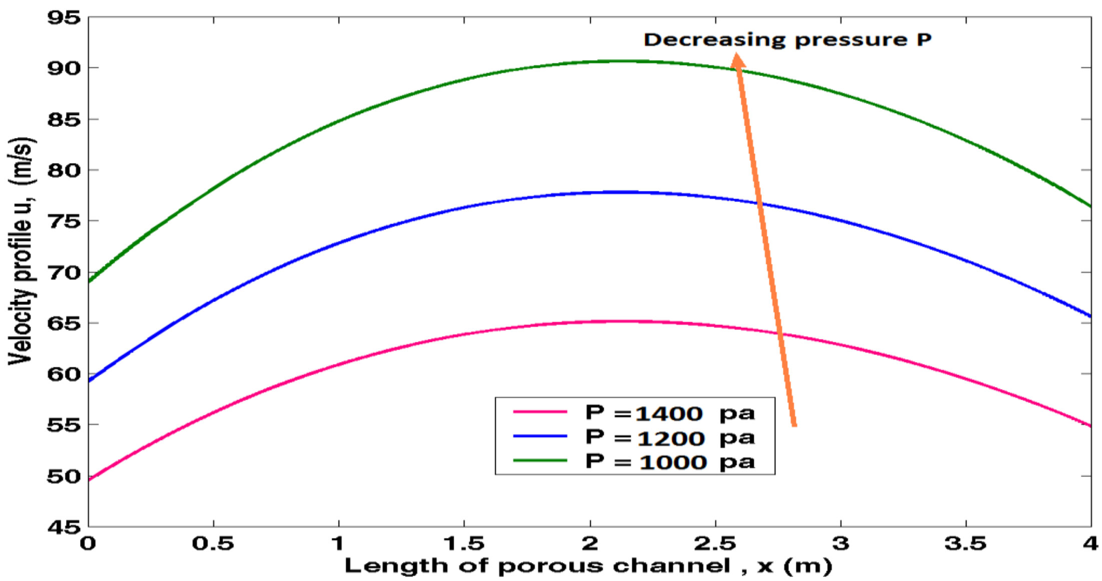

Figure 4.4: Graph of velocity profile against Length of Porous channel at varying fluid pressure.

Fluid pressure's impact on the fluid velocity profile can be observed from figure 4.4. Increase in fluid pressure decrease in the velocity profile. The velocity and pressure is inversely proportional. In order to keep the pressure, kinetic energy, and potential energy's algebraic sum constant, the velocity drops as pressure rises. As velocity rises, the sum of potential energy, kinetic energy, and pressure stays constant whereas decreasing pressure does the opposite.

When a fluid flow is restricted, the fluid's velocity falls, resulting in a decrease in kinetic energy. However, the corresponding amount of energy is raised as pressure energy, which raises the fluid's point pressure. In the study is also observed that indeed the when pressure was at p=1000 the velocity was higher that when pressure was at p=1400. This indicated that the increase in pressure lead to a decrease in the fluid velocity.

Inverse link among the baffle step and pressure drop on heat transfer was the conclusion done by Gruyler, (2021). In a low pressure effect there is a high baffle to the channel this led a higher pitch that got better heat transmission performance. A reversed effect by increase in pressure was shown in their results. Together with Kavianyi's results in his 1985 study, he did find out that the pressure profile dropped and as a results there was an increase on the velocity profile. These findings as well agree to the findings in this study. This is highly applicable in solute transport in porous media.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter a summary of the study findings are discussed. Some of the conclusions that were realized from this study were also elaborated in this chapter. In the conclusion done, a discussion was done together with their relevant application in various fields in engineering and agricultural sector among others. Recommendations were also given to areas where further studies could be explored.

5.2 Summary and Conclusion

Through the research, observations were done on impacts of optimizing various parameters had on the flow. Further, analysis was done to find out on the reasons of having the results as so, together with the applications of the results in various disciplines. The following observations and conclusions were made from the results of this study.

i. A rise in the magnetic parameters causes a drop on the velocity profile since it has a resistance effect or a drag effect on the fluid causing an inverse effect on the velocity. By the increase of the magnetic parameter, a decrease is realized on the velocity according to the findings.

ii. The flow profile increases with the greater Darcy number. A positive increase in Darcy numbers leads to increasing the permeability on the flow through a porous channel. This strongly accelerates the fluid flow hence the profile of velocity directly increases with increase on the Darcy number along a porous length.

iii. The velocity profile is decreased by an increase in the fluid pressure coefficient. The fluid pressure has an inverse relation to the velocity due to the constant algebraic some that has to be maintained between the kinetic energy, fluid potential energy and the pressure. With increase in any of the components, then, the other components must reduce to maintain the equilibrium. This leads to an inversely proportional relationship on the fluid pressure to the flow velocity on a porous channel. This helps control flows in the cooling chambers in the factories.

iv. Increase in Eckert number causes the temperature distribution to rise due to an increase in the conversion of the fluid internal energy into the kinetic energy. The Eckert number leads to an increase in the temperature on the fluid. Optimization of the Eckert Number is applicable in energy generating machines like the generator, in factories that depend on higher temperature.

The study was able to give results that are useful in various areas where fluid flows in porosity and porous media is key. To achieve maximum velocity and maximum temperature in a flow analysis realized that an increase in the Magnetic parameter, reduction on Pressure coefficient, increase in the Ec and Da would be appropriate. In the nuclear heat transfer control there is more interest in reducing the fluid velocity. Therefore the velocity will be reduced by increasing the Pressure coefficient and reducing the Darcy number to enable longer time of heat absorption and increasing the Eckert number to increase the heat profile. In the same flow pressure will be reduced by increasing the magnetic effect onto the flow.

The findings will be applicable in varied areas like in material processing and magnetohydrodynamic energy generators, in agriculture where drip irrigation depends on flow through the porous channel, in generators, coolants, engineering and factories among others.

5.3 Recommendation

From this study, the following are some of the areas recommended for further study:

i. An extension of this study of optimization of MHD parameters on 3-D on a porous channel with heat generation along the fluid flow.

ii. An extension of this study to incorporate friction coefficient between flow channel and fluid surface. This will obviously affect the rate of fluid flow.

REFERENCES

Achola Okello John. (2013) Mathematical Modelling of Variable Viscosity Hydromagnetic Boundary Layer Flow with Thermal Radiation and Newtonian Heating. Kenyatta University.

Adeyemi, I. F., *et al.,* (2015) Dufour and soret effects on steady MHD convective flow of a fluid in a porous medium with temperature dependent viscosity: Homotopy analysis approach. Journal of the Nigerian Mathematical Society 34(3)

Ajibade, and Tafida, (2020) Natural convection coquette flow examinating their effecton fluid flow and thermodynamics in vertical challen.

Ahmad, M., Muhammad, T., Ahmad, I., and Aly, S., (2020). Time-dependent 3D flow of viscoelastic nanofluid over an unsteady stretching surface. Phys. A Stat. Mech. Appl., 551, 124004.

Aldoss, T. K., Al-Nimr, M. A., Jarrah, M. A., & Al-Sha'er, B. J. (1995). Magnetohydrodynamic mixed convection from a vertical plate embedded in a porous medium. *Numerical Heat Transfer, Part A: Applications*, *28*(5), 635-645.

Alim and Parveen, (2011) Effect of Temperature-Dependent Variable Viscosity on Magnetohydrodynamic Natural Convection Flow along a Vertical Wavy Surface

Anil Kumar , SP Agrawal and Pawan Preet Kaur (2013) Finite Element Galerkin’s Approach for Viscous Incompressible Fluid Flow through a Porous Medium in Coaxial Cylinders, Journal of Mathematical Sciences and Applications, 2013, Vol. 1, No. 3, 39-42.

Anil Kumar, CL Varshney and Sajjan Lal (2013): Perturbation Technique of MHD Free Convection Flow through Infinite Vertical Porous Plate with Constant Heat Flux, International Journal of Mathematical Modeling and Physical Sciences Vol. 01, (02) pp 1-5, 2013.

Ndiritu Flore, (2015) The Effect of Temperature Dependent Viscosity on Magnetohydrodynamic Flow Past a Continuous Moving Surface. Jomo Kenyatta University of Agriculture And Technology

Eko, S., Denny, W., Mochammad, A. C., and Yasuo Katoh. (2023). Effects of Effective Thermal Conductivity of Porous Material under Vapor flow in Suden Enlargement Contraction Channel on Local Heat Transfer. 212-265

Erick, M., Eustace, M., and Stephen, K., (2016) Effects of Temperature Dependent Viscosity and Viscous Dissipation on Fluid Flow past a Moving Isothermal Flat Plate.

Fatunmbi, E.O., Ogunseye, H.A., Sibanda, P., (2020). Magnetohydrodynamic micropolar fluid flow in a porous medium with multiple slip conditions. Int. Common. Heat Mass Transf. 115, 104577

Hassan, O. M., Sultan, G. I., Sabry, M. N., and Hagazi, A. A. (2022). Investigation of Heat Transfer and Pressure Drop in a porous Media with Internal Heat Generation.

Helmy, K. A., (1998). MHD unsteady free convection flow past a vertical porous plate. ZAMM-Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik: Applied Mathematics and Mechanics, 78(4), 255-270.

Helmy, K.A. (1998): MHD unsteady free convective flow past a vertical porous plate, Z AMP, Z.Angew Math. Mech., 78(4), 255-270.

Helmy, K. A. (1998). MHD unsteady free convection flow past a vertical porous plate. *ZAMM‐Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik: Applied Mathematics and Mechanics*, *78*(4), 255-270.

Islam, S., Khan, A.; Kumam, P., Alrabaiah, H., Shah, Z.; Khan, W., Zubair, M., Jawad, M., (2020). Radiative mixed convection flow of maxwell nanofluid over a stretching cylinder with joule heating and heat source/sink effects.Sci. Rep., 10, 1–18.

Kaur, P. P., Agrawal, S. P., & Kumar, A. (2013). Finite Difference Technique for Unsteady MHD Periodic Flow of Viscous Fluid through a Planer Channel. American Journal of Modeling and Optimization, 1(3), 47-55.

Kim, Y.J., (2000): Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction, International Journal of Engineering Science, 38,833-842.

Kumari, M., and Nath, G., (2012) Unsteady Rotating Flow Over an Impulsivel Rotating Infinite Disk with Axial Magnetic Field and Suction.

Kumar, K.A., Sugunamma, V., Sandeep, N., (2019). Effect of thermal radiation on MHD Casson fluid flow over an exponentially stretching curved sheet. Journal of Thermodynamic Analysis. Carolim, 140, 2377-2385.

Kumam, *et al.*, (2021). Chemically reactive nanofluid flow past a thin moving needle with viscous dissipation, magnetic effects and hall current, 16, e0249264.

K. M. Pandy and Prince Kumar (2022). Effects of Porous Lab Thickness and Darcy number on Thermohydraulic Transport Characteristic of Ag-Tio2/Water Hybrid Nanofluid flow through a Partially Porous Wavy Channel.

Kumar, A., Agrawal, S. P., & Kaur, P. P. (2013). Finite Element Galerkin's Approach for Viscous Incompressible Fluid Flow through a Porous Medium in Coaxial Cylinders. *Journal of Mathematical Sciences and Applications*, *1*(3), 39-42.

Kumar, A., Varshney, C. L., & Lal, S. (2010). Perturbation technique to unsteady MHD periodic flow of viscous fluid through a planer channel. *Journal of engineering and technology research*, *2*(4), 73-81.

Kimanthi, P. T., (2023). Effects of Variables Pressure Gradient on MHD Flow between Parallel Plate considering Variables Transverse Magnetic Field

Sushila, C., Prasun, C., and Balachandra, P. (2023) Tangent Hyperbolic Fluid Flow under Condition of Divergent Channel in the Presence of Porous Medium with Suction/Blowing and Heat Source: Emergence of the Boundary Layer *International Journal of Mathematics and Mathematical Sciences*, pp 1-14

Li, Y.X., Alshbool, M.H.; Lv, Y.-P.; Khan, I., Khan, M.R.; Issakhov, A., (2021). Heat and mass transfer in MHD Williamson nanofluid flow over an exponentially porous stretching surface. Case Study. Therm. Eng., 26, 100975.

Luo, C., *et al.*, (2021). Seasonal variations in the water residence time in the Bohai Sea using 3D hydrodynamic model study and the adjoint method. Ocean Dynamics, 71(2), 157-173.

Makinde, O. D., & Osalusi, E. (2006). MHD steady flow in a channel with slip at the permeable boundaries. *Romanian Journal of Physics*, *51*(3/4), 319.

Makinde, O.D., and Mhone, P.Y., (2005): Heat transfer to MHD Oscillatory flow in a channel filled with porous medium, Romanian Journal of physics, 50(9-10), 931-938.

Manjunatha, S., Kuttan, B.A., Ramesh, G.K., Gireesha, B.J., Aly, E.H. (2020). 3D flow and heat transfer of micropolar fluid suspended with mixture of nanoparticles (Ag-CuO/H2O) driven by an exponentially stretching surface. Multidiscip. Modeling Mater. Struct., 16, 1691–1707.

Mehmood, A., & Ali, A. (2007). The effect of slip condition on unsteady MHD oscillatory flow of a viscous fluid in a planer channel. *Romanian journal of physics*,*52*(1/2), 85.

Muhammad, T., Rafique, K., Asma, M., Alghamdi, M., (2020). Darcy–Forchheimer flow over an exponentially stretching curved surface with Cattaneo–Christov double diffusion. Phys. A Stat. Mech. Appl., 556, 123968.

Patowary and Sut, (2011) study the Micropolar Fluid Flow near the Stagnation on a Vertical Plate with Prescribed Wall Heat flux.

Pawan, P. K., SP Agrawal, Anil K., (2013) Finite Difference Technique for Unsteady MHD Periodic Flow of Viscous Fluid through a Planer Channel. *American Journal of Modeling and Optimization, 2013, Vol. 1, No. 3, 47-55*

Raptis A., Massias C., and Tzivanidis G., Hydro magnetic free convection flow through porous medium between two parallel plates, Physics Letter, 90(A), 288-289, 1982.

Seddeek, M. A. (2000) "Effects of variable viscosity on hydromagnetic flow and heat transfer past a continuously moving porous boundary with radiation" Int. Comm. Heat Mass Trans. 27, 1037-1064

Sharma, G. C., Jain, M., & Kumar, A., (2002). The flow between annular spaces surrounded by coaxial cylindrical porous medium. In Published in National Conference (Vol. 67, pp. 27-30).

Singh, K.D., and Kumar, Suresh (1993): Free convective fluctuating flow through a porous medium with variable permeability, Journal of Mathematical and Physical Sciences, 27(2), 141-148.

Solomon, B. K., Mitiku, D., and Abebe G., (2021) Investigation of Effects of Thermal Radiation, Magnetic Field, Eckert Number, and Thermal Slip on MHD Hiemenz Flow by Optimal Homotopy Asymptotic Method

Vereshchagin, A. S., and Dolgushev, S. V. (2011). Low-velocity Viscous Incompressible Fluid Flow around a Hollow Porous Sphere. J Apple Mech Tech Phy 52(3): 406- 414. Do1:10.113

Wubshet Ibrahim, (2016)The effect of induced magnetic field and convective boundary condition on MHD stagnation point flow and heat transfer of upper-convected Maxwell fluid in the presence of nanoparticle past a stretching sheet

APPENDICES

Appendix 1: Plagiarism Report

OPTIMIZATION OF MAGNETOHYDRODYNAMIC PARAMETERS IN A TWO DIMENSIONAL INCOMPRESSIBLE FLUID FLOW ON A POROUS CHANNEL

ORIGINALITY REPORT

17%	13%	9%	6%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Kisii University Student Paper	1%
2	Submitted to Royal Melbourne Institute of Technology Student Paper	1%
3	www.preprints.org Internet Source	1%
4	www.ijesit.com Internet Source	1%
5	www.researchgate.net Internet Source	1%
6	pubs.sciepub.com Internet Source	<1%
7	www.ijsr.net Internet Source	<1%
8	Donald A. Nield, Adrian Bejan. "Convection in Porous Media", Springer Nature, 2017 Publication	<1%

Appendix 2: Publication

SvedbergOpen
DISSEMINATION OF KNOWLEDGE
International Journal of Pure and Applied Mathematics Research
16th, Union Avenue, Pinelands, Cape Town, South Africa 7405.

Date: 16/06/2023

Dear Dr. Carolyne Kwamboka,
Greetings from International Journal of Pure and Applied Mathematics Research!
Manuscript Ref. No: IJPAMR20052023Q8X7.

We are pleased to inform you that your article titled **" Optimization of Magnetohydrodynamic Parameters in Two- Dimensional Incompressible Fluid Flow on a Porous Channel''**
IJPAMR20052023Q8X7 is accepted for publication in the International Journal of Pure and Applied Mathematics Research.

Further process, we are herewith attaching the copyright declaration form and also APC details for your perusal. You are requested to pay US$ 221.6 towards Article Processing Charges (APCs) and send the signed copyright at the earliest, so that the paper will be forwarded to the production department for the next stage of processing.

You can pay the publication fee through PayPal. We are herewith sending the details for your reference.

PayPal Link: https://www.svendbergopen.com/pay

With regards,
Ms. Sophia,
Editorial Team Member,
International Journal of Pure and Applied Mathematics Research,
SvendbergOpen
16th, Union Avenue,
Pinelands, CapeTown,
South Africa 7405.
Web: https://www.svendbergopen.com/

On Thur, May 18, 2023 at 12:26 PM < carolyneonyancha11@gmail.com> :
Name: Carolyne Kwamboka
Email: carolyneonyancha11@gmail.com
Country: Kenya
Address: Kisii university
Paper Type: Research Paper
Journal Short Name: IJPAMR
Titel: **Optimization of Magnetohydrodynamic Parameters in Two- Dimensional Incompressible Fluid Flow on a Porous Channel.**

Appendix 3: Computer Codes

VARYING PRESSURE COEFFICINT

```
x=[0 1 2 3 4 ];

y=[49.4 61.5 64.2 63.4 54.7];

p = polyfit(x,y,3)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)

hold on

y=[59.1 73.5 76.7 75.7 65.4];

p = polyfit(x,y,3)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
hold on
y=[68.8 85.6 89.3 88.3 76.2];
p = polyfit(x,y,3)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);
```

```
plot(x,y,x2,y2)
```

VARYING MAGNETIC PARAMETER

```
x=[0 1 2 3 4 ];

y=[68.8 85.6 89.3 88.3 76.2];

p = polyfit(x,y,3)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
```

hold on

```
y=[62.5 76.6 79.5 78.7 68.6];

p = polyfit(x,y,3)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
```

hold on

```
y=[55.5 66.7 68.6 68.2 60.2];

p = polyfit(x,y,5)
```

```
 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
```

VARYING Da

```
x=[0 1 2 3 4 ];

y=[68.8 85.6 89.3 88.3 76.2];

p = polyfit(x,y,4)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)

hold on

y=[80.2 102.3 107.9 106.5 90.3];

p = polyfit(x,y,4)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)

hold on
```

```
y=[84.2 108.4 114.7 113.2 95.4];

p = polyfit(x,y,4)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
```

VARYING E_C

```
x=[0 1 2 3 4 ];
y=[1.61 1.01 0.87 0.82 0.75];
p = polyfit(x,y,4)
 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)

hold on

y=[1.81 1.27 1.13 1.1 0.99 ];

p = polyfit(x,y,4)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
```

```
hold on
y=[2.02 1.53 1.40 1.36 1.24];
p = polyfit(x,y,4)
 x2 = 0:.001:4;
 y2 = polyval(p,x2);
 plot(x,y,x2,y2)
```

VARYING VISCOSITY

```
x=[0 1 2 3 4 ];
y=[2.21 1.27 1.13 1.1 0.99 ];
p = polyfit(x,y,3)
 x2 = 0:.001:4;
 y2 = polyval(p,x2);
 plot(x,y,x2,y2)
hold on
y=[2.47 1.84 1.69 1.63 1.49 ];
p = polyfit(x,y,3)
 x2 = 0:.001:4;
```

```
 y2 = polyval(p,x2);

 plot(x,y,x2,y2)

hold on

y=[2.73 2.29 2.21 2.17 1.98];

p = polyfit(x,y,3)

 x2 = 0:.001:4;

 y2 = polyval(p,x2);

 plot(x,y,x2,y2)
```

Appendix 4: Introduction Letter

KISII UNIVERSITY

Telephone: +25420 2352059 · Facsimile: +254020 2491131 · Email: research@kisiiuniversity.ac.ke
P.O. BOX 408 – 40200, KISII · www.kisiiuniversity.ac.ke

OFFICE OF THE REGISTRAR RESEARCH AND EXTENSION

REF: KSU/R&E/ 03/5/ 594 **DATES:** 27th July, 2022

The Head, Research Coordination
National Council for Science, Technology and Innovation
(NACOSTI) Utalii House, 8th Floor, Uhuru Highway
P. O. Box 30623- 00100
NAIROBI - KENYA.

Dear Sir/Madam,

RE: CAROLYNE KWAMBOKA ONYANCHA MPS12/700001/15

The above mentioned is a student of Kisii University currently pursuing a Degree of Master of Science in Applied Mathematics. The topic of her research is, "***Optimization of Magnetohydrodynamic Parameters in A Two Dimensional Incompressible Fluid Flow on a Porous Channel***".

We are kindly requesting for assistance in acquiring a research permit to enable her carry out the research.

Thank you.

Prof. Anakalo Shitandi, PhD
Registrar, Research and Extension

Cc: DVC (ARA)
Registrar (ARA)
Director SPGS

KISII UNIVERSITY 27 JUL 2022 REGISTRAR RESEARCH & EXTENSION

Appendix 4: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **647907**

Date of Issue: **25/March/2023**

RESEARCH LICENSE

This is to Certify that Ms.. Carolyne KWAMBOKA Onyancha of Kisii University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Kisii on the topic: OPTIMIZATION OF MAGNETOHYDRODYNAMIC PARAMETERS IN A TWO DIMENSIONAL INCOMPRESSIBLE FLUID FLOW ON A POROUS CHANNEL for the period ending : 25/March/2024.

License No: **NACOSTI/P/23/24725**

647907

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions