UNSTEADY MHD FREE CONVECTION FLOW OF JEFFREY FLUID AND JEFFREY NANOFLUID ALONG A VERTICAL PLATE WITH RADIATION EFFECT

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This thesis is dedicated to my late father, Mohd Zin Idris who pass away because of heart attack. No words can express how much I love and miss you, Ayah. You are the greatest gift I could ever receive from Allah SWT in my life. Dear Ayah, thank you very much for all your prayers for me during you alive. I really missed the way you treated me, called me "kakak", all your jokes, smile, smell and everythings about you. I pray that, Allah SWT grant you the highest level of jannah, Jannatul Firdous without "hisab", peace and save from torment of grave. Amin. And may our family will be reunited in Jannah, Insha Allah.

Al-Fatihah to my late father, Mohd Zin Idris
You will always be remember, 26.2.1957-11.4.2016
I love you forever, my dear Ayah

and

Al-Fatihah to my late son, Mohamad Miqdad Bin Mohamad Ashraf
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ABSTRACT

Fluid is a substance that continuously deform under the influence of shear stress. Basically, fluid can be classified into two categories which are Newtonian and non-Newtonian. In reality, most fluids belong to the class of non-Newtonian fluids and one of them is Jeffrey fluid. Jeffrey fluid is also known as viscoelastic fluid that exhibits both viscous and elastic characteristics. Recently, this type of fluid have received considerable attention due to their numerous applications in industries especially in polymer industries. Due to this reason, many investigations have been made to study the Jeffrey fluid in various aspects from both analytical and numerical methods. Therefore, in this thesis, the effect of thermal radiation on unsteady magnetohydrodynamics (MHD) free convection flow of Jeffrey fluid with and without nanoparticles past an infinite vertical plate are studied. The fluid is taken electrically conducting in the presence of uniform transverse magnetic field applied in a direction perpendicular to the flow. Specifically, focused of this study is to obtain an exact solution for velocity and temperature distributions under conditions of ramped wall temperature and isothermal plate. Using the constitutive relation of Jeffrey fluid and some assumptions of physical conditions, five specific problems are modelled as partial differential equations. For the first three problems, the fluid is considered as non-rotating fluid, while in the fourth and fifth problems the rotating fluid is analyzed. An appropriate dimensionless variables are employed to the dimensional governing equations and solved analytically with the help of Laplace transform technique. The effect of pertinent parameters such as Jeffrey fluid parameter, rotation parameter, phase angle, Hartmann number, permeability parameter, nanoparticles volume fraction, Grashof number, Prandtl number, radiation parameter and time on velocity and temperature are plotted graphically and discussed in details. Numerical results of Nusselt number and skin friction for various emerging parameters are calculated and presented in tabular forms. In order to authenticate the present results, the limiting cases are provided, where an excellent agreement are found. Results obtained show that, increasing of Hartmann number tends to retard the fluid flow due to the Lorentz force effect. Increasing the values of radiation parameter led to an increase in velocity and temperature fields. Further, in the case of rotating fluid, large values of rotation parameter reduces the primary velocity but enhance in the secondary velocity. On the other hand, increasing nanoparticles volume fraction causes the velocity of non-rotating fluid increases but decreases for rotating fluid. It also found that, the fluid motion for ramped wall temperature is always slower compared to an isothermal plate. Interestingly, Jeffrey fluid can be reduced to a Second grade fluid in the absence of material parameter.

ABSTRAK

Bendalir adalah bahan yang sentiasa berubah bentuk di bawah pengaruh tegasan ricih. Pada dasarnya, bendalir boleh diklasifikasikan kepada dua kategori iaitu Newtonan dan bukan Newtonan. Realitinya, kebanyakan bendalir adalah tergolong dalam bendalir bukan Newtonan dan salah satunya adalah bendalir Jeffrey. Bendalir Jeffrey juga dikenali sebagai bendalir viskoelastik yang mempamerkan dua ciri iaitu likat dan anjal. Akhir-akhir ini, bendalir Jeffrey telah mendapat perhatian kerana pelbagai aplikasinya dalam bidang industri terutamanya dalam industri polimer. Oleh sebab itu, banyak penyelidikan telah dilakukan untuk mengkaji bendalir Jeffrey dalam pelbagai aspek dari kedua-dua kaedah analitik dan berangka. Oleh itu, dalam tesis ini, kesan sinaran terma pada hidrodinamik magnet (MHD) aliran olakan bebas tak mantap bendalir Jeffrey melintasi plat menegak tak terhingga dengan dan tanpa nanozarah dikaji. Bendalir ini diambil dalam keadaan pengaliran elektrik dengan kehadiran arus medan magnet seragam yang melintang dan berserenjang dengan aliran bendalir. Secara khususnya, fokus kajian ini adalah untuk mendapatkan satu penyelesaian tepat untuk taburan halaju dan suhu di bawah syarat suhu tanjakan dinding dan plat isoterma. Menggunakan hubungan juzuk bendalir Jeffrey dan beberapa andaian keadaan fizikal, lima masalah dimodelkan sebagai persamaan pembezaan separa. Bagi tiga masalah pertama, bendalir dianggap sebagai aliran tak berputar, manakala dalam masalah keempat dan kelima aliran berputar dianalisis. Pembolehubah tak bermatra yang bersesuaian digunakan dalam persamaan menakluk dan diselesaikan secara analitik dengan bantuan kaedah penjelmaan Laplace. Kesan parameter yang bersangkut-paut seperti parameter Jeffrey, parameter putaran, sudut fasa, nombor Hartmann, parameter keliangan, isipadu pecahan nanozarah, nombor Grashof, nombor Prandtl, parameter radiasi dan masa terhadap halaju dan suhu diplot secara grafik dan dibincangkan secara terperinci. Keputusan berangka untuk nombor Nusselt dan geseran kulit bagi pelbagai parameter yang muncul dikira dan dipersembahkan dalam bentuk jadual. Untuk mengesahkan kesahihan penyelesaian yang telah diperolehi, kes penghad telah disediakan, dengan ketepatan yang sangat baik telah ditemui. Keputusan yang diperoleh menunjukkan bahawa peningkatan nombor Hartman cenderung untuk melambatkan aliran bendalir, disebabkan oleh kesan daya Lorentz. Peningkatan nilai parameter radiasi menyebabkan peningkatan dalam halaju dan suhu. Seterusnya, dalam kes bendalir yang berputar, untuk nilai parameter putaran yang besar, halaju pertama berkurangan tetapi meningkat pada halaju kedua. Sebaliknya, peningkatan isipadu pecahan nanozarah menyebabkan halaju bendalir tak berputar meningkat tetapi berkurangan bagi bendalir yang berputar. Didapati juga, aliran bendalir bagi kes suhu tanjakan dinding sentiasa lebih perlahan berbanding plat isoterma. Menariknya, bendalir Jeffrey boleh diturunkan kepada bendalir gred kedua dengan ketiadaan parameter bahan.

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LIST OF MATTERS

Ag	-	Silver
Cu	-	Copper

LIST OF SYMBOLS

Roman Letters

$\mathbf{A}_1$	-	First Rivlin-Ericksen tensor
$\mathbf{B}$	-	Total magnetic field
$\mathbf{B}_0$	-	Applied magnetic field
B_0	-	Magnitude of applied magnetic field
$\mathbf{b}$	-	Induced magnetic field
c_p	-	Specific heat at constant pressure
$\left(c_p\right)_s$	-	Heat capacity of solid nanoparticles
$\left(c_p\right)_f$	-	Heat capacity of base fluid
$\left(c_p\right)_{nf}$	-	Heat capacity of nanofluid
$\frac{d}{dt}$	-	Material time derivative
div	-	Divergence
$\mathbf{E}$	-	Electric field
e	-	Internal energy per unit volume
erfc	-	Complementary error function
$\mathbf{F}$	-	Force
F	-	Complex velocity
$\mathbf{g}$	-	Gravitational acceleration
Gr	-	Grashof number
$H(\bullet)$	-	Heaviside function
Ha	-	Hartmann number or magnetic parameter
$\mathbf{I}$	-	Identity vector
$\mathbf{i}$	-	Cartesian unit vector in the $x-$ direction

$\mathbf{J}$	-	Current density
$\mathbf{j}$	-	Cartesian unit vector in the $y-$ direction
$\mathbf{J}\times\mathbf{B}$	-	Lorentz force
K	-	Permeability parameter
k	-	Thermal conductivity
k_1	-	Absorption coefficient
k_s	-	Thermal conductivity of solid nanoparticles
k_f	-	Thermal conductivity of base fluid
k_{nf}	-	Thermal conductivity of nanofluid
$\mathbf{k}$	-	Cartesian unit vector in the $z-$ direction
Nu	-	Nusselt number
p	-	Pressure
p_h	-	Hydrostatic pressure
p_d	-	Dynamic pressure
$\hat{p}$	-	Modified pressure gradient
$\Pr$	-	Prandtl number
q	-	Laplace transform parameter
$\mathbf{q_r}$	-	Radiative heat flux vector
$\mathrm{q_r}$	-	Magnitude radiative heat flux
$\mathbf{q}''$	-	Heat conduction per unit area
q''	-	Magnitude of heat conduction per unit area
$\mathbf{r}$	-	Radial vector
r	-	Rotation parameter
$\mathbf{R}$	-	Darcy’s resistance
$\mathbf{S}$	-	Extra stress tensor
$\mathbf{T}$	-	Cauchy stress tensor
T	-	Temperature
t	-	Dimensionless time
t_0	-	Characteristic time
u	-	Velocity in $x-$ direction
U_0	-	Reference velocity

$\mathbf{V}$	-	Velocity vector field
V	-	Magnitude of the velocity
v	-	Velocity in $y-$ direction

Greek Letters

β_T	-	Volumetric coefficient of thermal expansion
β_s	-	Volumetric coefficient of thermal expansion of solid nanoparticles
β_f	-	Volumetric coefficient of thermal expansion of base fluid
β_{nf}	-	Volumetric coefficient of thermal expansion of nanofluid
$I_1(\bullet)$	-	Modified Bessel function of order one
κ	-	Permeability of porous medium
ρ	-	Density
ρ_s	-	Density of solid nanoparticles
ρ_f	-	Density of base fluid
ρ_{nf}	-	Density of nanofluid
μ	-	Dynamic viscosity
μ_f	-	Dynamic viscosity of base fluid
μ_{nf}	-	Dynamic viscosity of nanofluid
μ_m	-	Magnetic permeability
σ	-	Electric conductivity of the fluid
σ^*	-	Stefan-Boltzmann constant
φ	-	Nanoparticles volume fraction
ϕ_1	-	Porosity
θ	-	Dimensionless temperature
$\mathbf{\Omega}$	-	Constant angular velocity
λ	-	Jeffrey fluid parameter

$\lambda_i\left(i=1,2\right)$	-	Material parameter of Jeffrey fluid
τ	-	Dimensionless skin friction
υ	-	Kinematic viscosity
ω	-	Dimensionless frequency of plate oscillation
ωt	-	Phase angle

Subscripts

w	-	Conditions of the wall
∞	-	Free stream condition

Superscript

Tr	-	Transpose operation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter provides some basic terminologies of fluid mechanics, focusing on unsteady free convection flow of non-Newtonian Jeffrey fluid. A brief description of research background is addressed in Section 1.2. Problem statement and research objectives are given in Section 1.3 and Section 1.4, respectively. The scope of the study is discussed in Section 1.5, while Section 1.6 highlights the significance of findings. Section 1.7 presents the research methodology. Finally, the thesis organization is given in Section 1.8.

1.2 Research Background

Fluid mechanics is a subcategory of fluid dynamics, defined as science that deals with the behavior of fluids at rest (fluid statics) or in motion (fluid dynamics), and the interaction of fluids with solids or other fluids at the boundaries (Cengel and Cimbala, 2006). It is also referred to as fluid dynamics, by considering fluids at rest as a special case of motion with zero velocity (Cengel and Cimbala, 2006). Numerous applications of fluid mechanics can be found in biological and medical applications such as artificial heart, breathing machine and dialysis system. Other than that, it is applied widely in piping system, design building, transportation, and also broader scale such as design and analysis of aircraft, jet engines, submarines, rockets.

Fluid can be described as a substance that continuously deforms under the influence of shear stress. Primarily, fluid can be classified into two categories, which are Newtonian and non-Newtonian; differentiated based on their viscosity behavior. Fluids that obey Newton's Law viscosity are called as Newtonian fluid. In contrast, non-Newtonian fluids do not follow the Newton's Law viscosity. The relation that defined the Newtonian fluid behavior is

$$\tau = \mu \frac{\partial u}{\partial y}, \tag{1.1}$$

where τ is denoted as shear stress exerted by the fluid, μ is the dynamic viscosity of the fluid and $\partial u / \partial y$ is the shear rate, rate of strain or velocity gradient. This relation is known as Newton's Law of viscosity; named after Isaac Newton in his 1687 work, namely "Philosophie Principa Mathematica". The viscosity of this type of material will remain constant no matter how fast they are forced to flow through a pipe or channel. Water, mineral oil, gasoline, alcohol, glycerin and organic solvents are the examples of Newtonian fluid.

The Power Law, also called as Ostwald-de Waele relation, can be used to approximately describe non-Newtonian fluid based on the shear thinning and shear thickening behavior. The expression of Power Law can be written as

$$\tau = K \left(\frac{\partial u}{\partial y} \right)^n . \tag{1.2}$$

The power n is known as the power law index or flow behavior index, while K is the consistency coefficient and $\partial u / \partial y$ is the shear rate or the velocity gradient perpendicular to the plane of shear. For $n < 1,$ the fluids will show shear thinning behavior when the viscosity decreases with shear rate, and shear thickening when $n > 1$ when the viscosity increases with shear rate. The special case, $n = 1$ corresponds to the Newtonian behavior. It may be noted that, when $K = \mu,$ the Equation (1.2) will reduce to Newton's Law viscosity (1.1). The examples of non-Newtonian fluid can be found in many polymer solutions and molten polymers, such as ketchup, starch suspensions, paint and shampoo.

Due to the large difference in the chemical and physical structure of non-Newtonian fluids and the variation of flows, the usual Navier Stokes equations may fail and unable to represent all the rheological properties of non-Newtonian fluids. Thus, many mathematical models have been proposed to describe the physical behavior of these fluids, such as Maxwell fluid, Oldroyd fluid, Walter-B fluid, Second grade fluid, Jeffrey fluid and Burgers fluid. Unlike viscous fluid, the constitutive equations of non-Newtonian fluids are more complicated, thus highly nonlinear governing equations. This area of studies has attracted much attention from many researchers including Khan *et al*. (2013a), Shehzad *et al*. (2014a), Sivaraj and Kumar (2013), Khan *et al*. (2013b) and Samiulhaq *et al*. (2014a). Amongst these many models, the Jeffrey fluid is one of the relatively simplest types of viscoelastic fluid that exhibits both relaxation and retardation effects (Nadeem *et al*., 2014), which has been used in the present study. The reason of choosing Jeffrey fluid is because it is able to predict relaxation/retardation time effects, which are significant in studying the viscoelastics properties for the polymer industries (Ali and Asghar, 2014). Dilute polymer solution is one of Jeffrey fluids (Farooq *et al*., 2015).

Besides different types of fluids, another important transport aspect in fluid dynamics is heat transfer. Heat transfer can be described as the transport of the thermal energy driven by thermal nonequilibrium within a medium or among neighboring media (Kaviany, 2002). The fundamental modes of heat transfer can be grouped into three broad categories, namely conduction, convection and radiation. Ice melting, heating water in pot, and microwave oven operation are some examples of energy transfer. Conduction refers to the transfer of heat between two bodies or two parts of the same body through molecules which are more or less stationary, whereas convection heat transfer occurs because of the motion of fluid past a heated surface; in which the faster the motion, the greater the heat transfer (Nag, 2002). According to Jaluria (1980), radiation heat transfer is in the form of electromagnetic waves, where the energy is emitted from a material due to its temperature level, being larger for a larger temperature. It is then transmitted to another surface through the intervening space, which may be vacuum or a medium, which may absorb, reflect or transmit the radiation, depending on the nature and extent of the medium.

The mechanism of convection is further divided into three types, which are free, forced and mixed convections. Amongst three modes of convection, free convection is most highlighted in this research. Free, or also known as natural convection, happens when a fluid motion are caused by natural buoyancy forces alone and not generated by any other sources. The movement of a fluid induced by external sources like pump, fan and suction device are called as forced convection. Meanwhile, according to Joye (2003), mixed convection heat transfer occurs when forced convection currents take the same order of magnitude as natural flow velocities. In simple explanation, mixed convection exists when both natural and forced convections mechanism significantly and synchronously contribute to the heat transfer (Dawood *et al*., 2015).

In buoyancy driven flow (natural convection), Boussinesq approximation is needed. This is due to the fact that the exact governing equations are intractable in that particular flow. According to Gray and Giorgini (1976), this approximation is the simplest one which admits the buoyancy where some assumptions are considered: (i) viscous dissipation is neglected, (ii) constant density, except when it directly causes buoyant forces, and (iii) constant properties for all other fluids. Boussinesq equation is named after Joseph Boussinesq, a French mathematician. This equation can be expressed as difference density in the form of temperature difference, as

$$\rho_\infty - \rho = \rho\beta\left(T - T_\infty\right), \tag{1.3}$$

where ρ is density of the fluid, ρ_∞ is the density in the ambient medium, T is temperature, T_∞ is temperature in the ambient medium and β is the coefficient of thermal volumetric expansion,

$$\beta = -\frac{1}{\rho}\left(\frac{\rho_\infty - \rho}{T_\infty - T}\right). \tag{1.4}$$

Interesting investigations on heat transfer flow have been well documented in references by Foisal and Alam (2015), Seth *et al*. (2015a), Khan *et al*. (2014), Javaherdeh *et al*. (2015) and Animasaun (2015).

Together with heat transfer, effect of magnetohydrodynamics (MHD) is also a major interest to investigate in this study. MHD with heat transfer has crucial utilizations in solving engineering problems, and it can be found in many devices such as power generator, cooling reactor, design of heat exchangers, and MHD accelerators. Historically, the design of electromagnetic pump by Hartmann (1937) led to the study of MHD flows. The theory of MHD was initiated by Hannes Alfren in 1942. The term "MHD" represents magneto (magnetic field), hydro (water) and dynamics (movement). MHD flow is basically a bilateral interaction between a fluid flow and magnetic field. According to Ahmad (2016), MHD is defined as the capability of a moving conductive fluid to induce current, hence generating forces on the fluid and altering the magnetic field effect itself. Some development on this topic can be seen in studies by Christian *et al*. (2014), Yazdi *et al*.(2014), Farooq *et al*.(2015), Imtiaz *et al*. (2016) and Sukumar *et al*.(2016).

The study of fluid flow through a porous medium in the presence of MHD effect is also important, as reported by Jena *et al*. (2016), Hayat *et al*. (2016a), and Ellahi *et al*. (2014). According to Tripathi and Beg (2012), porous medium is a material containing a number of pores distributed throughout the matter. Meanwhile, fluid flow through porous medium can be described as the behavior of fluids moving through a porous medium, as in physical nature such as in seepage of water in river beds, limestone, the human lung, filtration of fluids, movement of underground water and oils, bile duct, rye bread, wood, gall bladder with stones and small vessels (Chauhan and Rastogi, 2012).

Usually, study of free convection flow and heat transfer problem depends on the thermal boundary conditions, in which, most of the practical problems are frequently engaged with non-uniform or arbitrary wall conditions. To understand such situations, it is worth to take into account the step discontinuities in the surface temperature into this present study. Generally, ramped wall temperature is known as the step change in wall temperature. Malhotra *et al*. (2006) employed ramped wall temperature in the fabrication of thin film photovoltaic devices to achieve a finish of the system. Besides that, periodic temperature step changes in building heat transfer applications such as air conditioning system has been explained in detail by

Antonopoulos and Democritou (1994), where conventional assumption of periodic outdoor conditions may lead to considerable errors, in case of a significant temporary deviation of the temperature from periodicity.

Liu (2008) has shown that the study of Stokes problem has a great significance and influences especially in geophysical flows and heat conduction. Basically, the traditional Stokes problem can be divided into two types, namely the first Stokes and second Stokes problems according to the motions of the rigid boundary below the fluid. Ai and Vafai (2005) defined that the shear flow of viscous fluid near a flat plate which is suddenly accelerated from rest and then moves in its own plane with a constant velocity leads to the first kind problem, or also known as Rayleigh type. Meanwhile, Stokes second problem occurs when the flow about the infinite flat plate executes harmonic oscillations parallel to itself (Schilichting, 1968). However, in this study, we only stressed on the Stokes second problem, or so called oscillating plate (Panton, 1968).

Besides the oscillation of the plates, rotation of the fluid is also important and interesting to study. Rotation is described as a circular movement of an object around a center or point of rotation. The influence of rotation can be observed in diverse phenomena such as ocean circulation, migration of sea winds, internal rotation rate of sun, calculating Coriolis drift of the trajectories of very long range artillery shells, galaxies formation, maintenance and secular variations of Earth’s magnetic field due to the motion of earth’s liquid core (Seth and Sarkar, 2015). This also helps to have a better understanding on the behavior of nanoparticle orientation in fluid systems through rotational diffusion (Dong and Cao, 2014; Dong *et al.*, 2015; Dong and Cao, 2015).

The Coriolis and centrifugal (inertial) forces are very significant when dealing with rotation; in which the Coriolis force is more dominant. Coriolis force, named after Gustave Coriolis, is an invisible force that appears to deflect a moving object in the frame rotating in the opposite direction. The Coriolis force depends on the rate of rotation, in which the deflection is greater near the poles and lesser near the equator. Earth rotation is an example of common rotating reference frame.

Assume that someone is standing in the equator and throwing an object to his friend in the Northern Hemisphere. The object's movement will bend to the right. In this case, the object may be the winds. Therefore, in the Northern Hemisphere, the winds will deflect to the right, whereas to the left in the Southern Hemisphere. Due to this fact, rotation analysis had been included in this study.

Nowadays, development of a new innovative class of heat transfer fluids, called nanofluids, is quite prominent. The term "Nanofluid" was coined by Choi and Eastman (1995), which describes a suspension of solid nanoparticles having diameter 1–100 nm in a conventional base fluid such as ethylene glycol, water, lubricant oil, kerosene oil and etc. Traditional heat transfer fluids are found to have limited heat transfer capabilities to achieve the cooling rate requirements in the industry, due to their low thermal conductivities compared to metals. Thus, the concept of insertion of nanoparticles in fluids leads to an increase in the thermal conductivity of the base liquids, which dramatically enhances the heat transfer performance. Due to these reasons, a number of investigations have been made to study nanofluids from both theoretical and experimental aspects, such as by Eastman *et al*. (1997), Lee et al. (1999), Eastman *et al*. (2001), Rashidi *et al*. (2014), Rajesh *et al*. (2015), Khan *et al*. (2015), Mohyud-Din *et al*. (2015), and Dinarvand *et al*. (2016).

Based on the discussions, the problems in this study have been split into two major interests, which are non-rotating and rotating fluid, with consideration of various aspects, such as ramped wall temperature, effect of nanoparticles and oscillating plate. All of these problems are tackled by applying Laplace transform technique, since the exact solutions are important for comparison with the numerical scheme. Further discussions are provided in Chapter 2, with reference from literature by previous researchers relevant to this study.

1.3 Problem Statement

Non-Newtonian fluids have gained much attention nowadays due to their potential in industrial and technological processes. Significantly, it is because viscous fluids are not capable to predict diverse characteristic of all non-Newtonian fluids using Navier Stokes equation. Theoretically, the analytical study of unsteady free convection flow non-Newtonian Jeffrey fluid with heat transfer along vertical plate is affected by some effects such as nanoparticles, ramped wall temperature, porous medium, rotation, and oscillation, which are rarely investigated but interesting to be explored. Particularly, most previous studies were conducted by using numerical analysis and semi-analytical technique, whereas very few were found applying the closed form solution. Therefore, this research has been conducted to answer the following questions:

(i) How are the mathematical models for rotating and non-rotating of non-Newtonian Jeffrey fluid past an infinite vertical plate formulated?

(ii) How does the presence of nanoparticles influence the velocity and temperature fields?

(iii) How are the Jeffrey fluid and Jeffrey nanofluid models compared with the existing second grade fluid model in the problem of unsteady MHD free convection flow with heat transfer?

(iv) How do Jeffrey fluid parameter, Hartmann number, permeability parameter, radiation parameter, rotation parameter and other pertinent parameters behave in the problem of unsteady free convection flow of Jeffrey fluid with ramped wall temperature and isothermal plate?

(v) How does the oscillating plate affect the fluid velocity in the case of ramped wall temperature and isothermal plate?

(vi) How can the exact solutions for unsteady non-Newtonian Jeffrey fluid past a vertical plate under different conditions be obtained?

Specifically, five problems are discussed in this thesis, which are: (a) unsteady free convection flow of Jeffrey fluid with ramped wall temperature, (b) porosity effect on unsteady MHD free convection flow of Jeffrey fluid past an oscillating vertical plate with ramped wall temperature, (c) unsteady MHD free convection flow of Jeffrey nanofluid saturated in porous medium, (d) unsteady MHD free convection flow of rotating Jeffrey fluid embedded in porous medium with ramped wall temperature, and (e) impact of nanoparticles on unsteady MHD free convection flow of rotating Jeffrey fluid filled in porous medium.

1.4 Research Objectives

The objectives of this study are:

(i) to extend and derive mathematical models of the problems:

(a) unsteady free convection flow of Jeffrey fluid (Khan, 2015) to unsteady MHD free convection flow of Jeffrey fluid with ramped wall temperature and radiation effect,

(b) unsteady MHD free convection flow of Jeffrey fluid with ramped wall temperature and radiation effect to unsteady MHD free convection flow of Jeffrey fluid past an oscillating vertical plate saturated in a porous medium,

(c) unsteady MHD free convection flow of Jeffrey fluid past an oscillating vertical plate saturated in a porous medium to unsteady MHD free convection flow of Jeffrey nanofluid with an isothermal plate,

(d) unsteady MHD free convection flow of Jeffrey fluid with ramped wall temperature and radiation effect to unsteady MHD free convection flow of rotating Jeffrey fluid embedded in a porous medium, and

(e) unsteady MHD free convection flow of rotating Jeffrey fluid embedded in a porous medium to unsteady MHD free convection flow of rotating Jeffrey nanofluid with an isothermal plate,

(ii) to provide the mathematical formulation of non-rotating and rotating Jeffrey fluid,

(iii) to obtain an exact solution for velocity and temperature distributions using Laplace transform technique,

(iv) to find the expressions of Nusselt number and skin friction for all problems and compute the numerical results in tabular forms for all emerging parameters, and

(v) to investigate the behavior of fluid velocity and heat transfer characteristic of Jeffrey fluid.

1.5 Scope of the Study

This thesis focuses on the unsteady MHD free convection flow of Jeffrey fluid and Jeffrey nanofluid past an infinite vertical plate in various situations. Two different driving forces, namely buoyancy force and oscillating boundary condition, have been considered, which are responsible to generate the movement of the fluid. The first problem stresses on unsteady MHD free convection flow of Jeffrey fluid over vertical plate with ramped wall temperature. The second problem emphasizes on the effect of porosity on unsteady MHD free convection flow of Jeffrey fluid with ramped wall temperature, by considering Stokes second problem. The third problem explores the impact of nanoparticles on unsteady MHD free convection flow of Jeffrey fluid past an oscillating vertical plate in porous medium with constant temperature. In this study, Tiwari and Das nanofluid model has been applied. The rotating Jeffrey fluid under ramped wall condition has been examined in the fourth problem. The last problem highlights the analysis of nanoparticles into problem four with constant temperature. The governing equations along the imposed initial and boundary conditions have been written into dimensionless system and solved analytically with the help of Laplace transform method. The expressions of Nusselt number and skin friction have been evaluated and presented in tabular forms, while the solutions for velocity and temperature profiles have been analyzed based on graphs which have been plotted using mathematical software called MATHCAD. In order to check the accuracy of present findings, the limiting cases have been obtained from general solutions and compared with the published works in the literature.

1.6 Significance of the Study

The significances of this study are as follows:

(i) to build a better understanding on the rheological behavior of non-Newtonian fluid, especially Jeffrey fluid,

(ii) enhance knowledge about the formulation of unsteady rotating and non-rotating Jeffrey fluid model using constitutive equation,

(iii) derive accurate analytical solutions for mathematical models involving ramped wall temperature and constant wall temperature,

(iv) to give insight the physical behavior of nanoparticles on the fluid velocity and temperature profile,

(v) to suggest the application of theoretical results of this research as a basis for fluid flow, which can contribute to the engineering applications and also in related fields, and

(vi) to provide exact solutions to assist scientists and engineers to check the accuracy of complex mathematical models solutions, which are obtained from numerical schemes.

1.7 Research Methodology

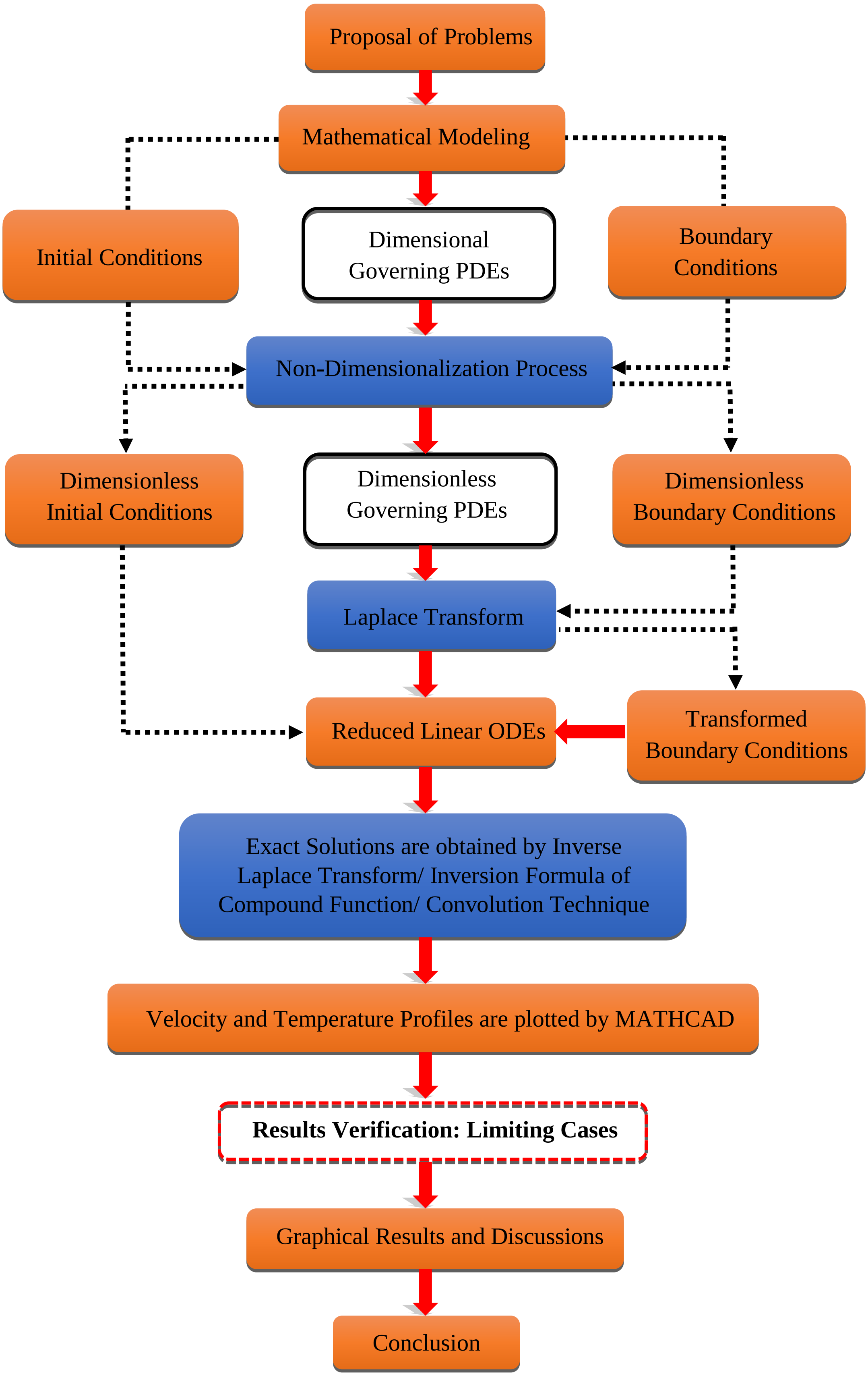

Figure 1.1 Operational framework.

1.8 Thesis Organization

This thesis is divided into eight chapters. Chapter 1 consists of research background, problem statement, research objectives, scopes, significance of the study and research methodology. Chapter 2 reviews related literature regarding the problems identified in the problem statement. Chapter 3 presents the problem of unsteady MHD free convection flow of Jeffrey fluid past a vertical plate with ramped wall temperature. Full derivation of continuity, momentum and energy equations are explained in this chapter. Using the constitutive relation of Jeffrey fluid together with some assumptions, the governing equations of non-rotating Jeffrey fluid is formulated in terms of partial differential equations. Dimensionless variables are introduced to reduce the dimensional governing equations, as well as appropriate initial and boundary conditions into non-dimensional system. Analytical solutions for velocity and temperature fields are obtained corresponding to two different thermal boundary conditions, namely ramped wall temperature and an isothermal plate using Laplace transform method. The expressions of Nusselt number and skin friction for both cases are determined. Special and limiting cases are provided and compared with some published works in the literature. The impact of all emerging parameters on velocity and temperature distributions are plotted graphically and discussed in details.

Chapter 4 investigates the effect of porosity on unsteady MHD free convection flow of Jeffrey fluid over an oscillating vertical plate with ramped wall temperature. The flow in the fluid is induced due to the cosines oscillation of the plate. Similar procedure as Chapter 3 is applied to solve the corresponding governing equations. The results obtained for both ramped wall and isothermal plate are plotted and discussed for all parameters interest. Chapter 5 is an extension of Chapter 4, where momentum equation takes into account the influence of nanoparticles. Kerosene oil is used as the conventional base fluid containing silver nanoparticles. In this chapter, only constant wall temperature is considered. Analogous procedure is utilized to find the solution of velocity and temperature distributions. The physical quantities effects on fluid flow and temperature are analyzed through graphs and discussed in details.

Chapter 6 conveys the unsteady MHD free convection flow of rotating Jeffrey fluid embedded in porous medium with ramped wall temperature. As continuation of previous chapters, the cases of ramped wall temperature and isothermal plate are studied. Formulation of rotating Jeffrey fluid incorporated with modified Darcy’s law is served. Appropriate dimensionless variables are employed to the governing equations and solved by Laplace transform technique. Nusselt number and skin friction are also calculated. Exact solutions for velocity and temperature profiles are sketched and the effect of pertinent parameters is explained. Chapter 7 is the extension of Chapter 6. This chapter discusses the impact of nanoparticles on rotating Jeffrey fluid and heat transfer with constant wall temperature. For the purpose of validation, current results have been compared with the findings by Khan (2015) and Samiulhaq *et al*. (2014b), where an excellent agreement is found. Finally, the summary of the whole chapters, conclusion and some recommendations for future research are presented in Chapter 8.

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