

**MHD FLOW PAST AN IMPULSIVELY STARTED VERTICAL PLATE IN A  
ROTATING FLUID**

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ROTATING FLUID

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A dissertation submitted in partial fulfillment of the  
requirements for the award of the degree of  
Master of Science (Mathematics)

Faculty of Science  
University Teknologi Malaysia

JANUARY 2013

To my beloved father and mother

## ACKNOWLEDGEMENT

First of all, a special thanks and a deep appreciation to my supervisor, Dr. Sharidan Shafie. He had taught me a great deal throughout the course of this study. Under his guidance enabled me to see things more clearly and think critically. He will consult and encourage me at any time I needed. Again thank a lot to Dr. Sharidan Shafie. Besides that, I sincerely have to thank to all those who have supported and helped me in writing this report especially Dr Ilyas Khan.

Apart from that, I also would like to extend my sincere appreciation to my entire friends, who had kindly provided valuable and helpful comments in the preparation of the thesis, and to those who have involve directly or indirectly in the preparation of this thesis, whom I have not mentioned above.

Last but not least, we would like to express our grateful to our family for their advice and moral support.

## ABSTRACT

In this research we study the heat and mass transfer for the magnetohydrodynamic (MHD) free convection flow over an impulsively started infinite vertical flat plate in the presence of thermal radiation and thermal diffusion (Soret effect) in a rotating viscous fluid. The governing equations, which are the momentum equation, energy equation and mass equation, are derived by using the conservation law. The governing equations are transformed into non-dimensional forms by using the non-dimensional variables. The exact solutions of the non-dimensional governing equations are obtained with the help of Laplace transform technique. These solutions satisfy all imposed initial and boundary. The numerical results of velocity, temperature, concentration, skin friction, the rate of heat transfer and mass transfer are displayed and analysed through graphs and tables. The results show that with increasing rotation parameter  $E$ , the secondary velocity increases whereas primary velocity decreases. The primary velocity and secondary velocity are increased by increasing of Soret number,  $So$  but decreased by increasing radiation parameter,  $R$ .

## ABSTRAK

Dalam kajian ini, pemindahan haba dan jisim bagi aliran olakan bebas hidrodinamik magnet (MHD) melintasi suatu plat rata menegak tak terhingga dimulakan secara dedenyut dikaji dengan kehadiran sinaran haba dan resapan terma di dalam bendalir likat berputar. Persamaan menakluk yang terdiri daripada persamaan momentum, persamaan tenaga dan persamaan jisim diterbitkan dengan menggunakan hukum pengabadian. Persamaan ini diubah ke bentuk tak bermatra menggunakan pembolehubah tak bermatra. Penyelesaian tepat bagi persamaan menakluk tak bermatra ini diperolehi dengan bantuan teknik penjelmaan Laplace. Penyelesaian ini memenuhi semua syarat awal dan syarat sempadan yang dikenakan. Penyelesaian berangka bagi halaju, suhu, kepekatan, geseran permukaan, kadar pemindahan haba dan pemindahan jisim dipaparkan dan dianalisis melalui graf dan jadual. Keputusan menunjukkan apabila parameter putaran,  $E$  meningkat halaju sekunder meningkat, manakala halaju utama menurun. Halaju utama dan halaju sekunder meningkat dengan peningkatan Nombor Soret,  $So$  tetapi menurun dengan peningkatan parameter radiasi,  $R$ .

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## SYMBOLS

### Nomenclature

$a^*$  = absorption coefficient

$B_0$  = strength of the applied magnetic field

$C_p$  = specific heat at constant pressure

$\dot{C}$  = species concentration

$\dot{C}_\infty$  = species concentration of the fluid far away from the plate

$\dot{C}_w$  = species concentration at the plate

$D$  = molecular mass diffusivity

$D_1$  = thermal diffusivity

$E$  = rotation parameter

$G$  = Grashof number for heat transfer

$Gr$  = Grashof number for mass transfer

$g$  = acceleration due to gravity

$k$  = thermal conductivity

$m$  = magnetic parameter

$Pr$  = Prandtl number

$p$  = pressure

$q_r$  = radiative flux

$q$  = velocity vector

$R$  = radiation parameter

$Sc$  = Schmidt number

$So$  = Soret number

$\dot{T}_w$  = temperature at the plate

$\dot{T}_\infty$  = temperature of the fluid far away from the plate

$t$  = time

$\dot{T}$  = temperature

$U_0$  = plate velocity

$(\dot{u}, \dot{v}, 0)$  = components of  $q$

$(u, v, 0)$  = non-dimensional velocity components

$(\dot{x}, \dot{y}, \dot{z})$  = Cartesian coordinates

$(x, y, z)$  = non-dimensional Cartesian coordinates

## **Greek Symbols**

$\theta$  = non-dimensional temperature

$C$  = non-dimensional species concentration

$\rho$  = fluid density

$\sigma$  = electrical conductivity

$\gamma$  = the kinematic viscosity

$\beta$  = coefficient of volume expansion for heat transfer

$\beta^*$  = coefficient of volume expansion for mass transfer

$\Omega$  = angular velocity

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.0 Introduction**

In this chapter, the background of the problem that will be investigated in this research will be explained in detail. Then, the statement of the problem and the objective of this research will be shown. Since, we cannot do everything in one time so the limitation or the scope of the research will be discussed here. Besides that, the most significant in this study will be mentioned. Finally, several expected results that intend to achieve in this research are presented.

## 1.1 Background of Research

A transformation of a rigid body around a fixed point in a plane or space is called rotation. The rotating reference frame is a non-inertial reference frame that is rotating relative to an inertial reference frame. For example, the surface of the Earth is a rotating reference frame. Generally, in this study a vertical plate, which in a state of rigid rotation with uniform angular velocity about axis fixed in the space perpendicular to the surface of the plate, is considered. The surface of the plate is a rotating reference frame. Hence, there are two coordinate systems being considered, one fixed on the surface of the plate and the other fixed in a space with the origin at the centre of the rotation, they are in translational and rotational motion with respect to each other. As a result, the motion of the fluid will be affected by rotation and translation when observed from the surface of the plate.

Normally, convection process can be separated into three cases; free/natural convection, force convection or mixed convection. Forced convection occurs when there are an external force acts on the flow such as pressure gradient. Convection flow happens in heated or cooled pipes is the model of forced convection. While, natural convection happens due to temperature and concentration gradients. The flow generated by the fires, or cooling system of rooms is an example of the free convection. When a rotating system is being considered, what changes it will lead in flows patterns and the transport properties of the convection flow. Convection of heat and mass transfer happens in a rotating system has attracted attention of many researchers due to its application in many industrial, geothermal, geophysical technological, and engineering application. The study of the convection flow in a rotating fluid is extremely important and useful in designing the turbines and turbo mechanics. Besides that, an understanding of the transport properties of the convection flow in a rotating system will helps the petroleum engineers to observe the movement of oil and gas through the reservoir. In

this research, the natural convection in a rotating fluid past an impulsively started vertical plate will be focused.

An electrically conducting fluid is considered, and if the fluid moves in a magnetic field then the study of the dynamics of this kind of fluid is called magnetohydrodynamics (MHD). Examples of such fluid are plasmas, liquid metals and salt water or electrolytes. The study of the electrical conducting fluid in a rotating medium is sufficiently weighty in the field of geophysics and astrophysics. This is because it is able used to describe the motion of space and astrophysical plasmas. In addition, the study of the MHD is also motivated by its applications in the engineering field and magnetic drug targeting.

Subsequently, the effect of the thermal radiation on the convection flow will be investigated in this study. Thermal radiation is one of the fundamental methods of heat transfer others than conduction and convection. The vibration or thermal motion of charged particles in the matter will generate electromagnetic radiation. The generated electromagnetic radiation will cause the thermal radiation to happen. For example, we can feel the heat of the sun's light is because of the thermal radiation generated by the hot plasma from the sun. Thermal radiation is essential in many engineering applications. Energy transfer in furnaces, combustion chambers, fires, rocket plumes and explosion of the chemical are examples of fields that applied the thermal radiation. Realize the behaviour or characteristics of the thermal radiation make the design and operation of such devices more easy and safe. Hence, it is valuable to scrutinize the influence of the thermal radiation on the properties and the motion pattern of the flow in this research.

Furthermore, the influence of the thermal diffusion on the flow also been considered in this study. The diffusion process happens when the particles in the flow spread through random motion. Normally, the particles move from the high

concentration area to a region of lower concentration. However, the diffusion process also happens due to the reason of temperature gradient. The force of a temperature gradient will cause the particle in the flow to spread, and different types of the particle will react to it differently. This kind of diffusion process is named as thermal diffusion or Soret effect. Thermal diffusion is used wisely in commercial precipitators, manufacturing of optical fibre, drug discovery and applied to separate different polymer particles in field flow fractionation. The reaction or behaviour of properties of the fluid toward the thermal diffusion will be investigated in this research.

The governing equations that describe the motion and the transport process of heat and mass of the magnetohydrodynamic (MHD) free convection flow over an impulsively started vertical plate in a rotating system with the presence of thermal radiation and thermal diffusion are complex. Hence the exact solutions of the governing equations are difficult to obtain due to the fact that the equations are nonlinear. However, there are several simplification methods that can be applied to the governing equations such as Boussinesq's approximation and the boundary layer approximation to obtain the approximate dimensionless governing equations. Consequently, the simplified governing equations can be solved analytically by the method shown in the literature. In this research, the Laplace transform technique will be used to solve the equations exactly. Generally, the Laplace transform method is a well-known integral transform method that uses to solve boundary and initial value problems. The easy approach of the Laplace transform method will accelerate the process of obtaining the analytical solution of the governing equations.

Singh (1983) was one of the active researchers who intended to explain analytically on the hydromagnetic free convection flow past an impulsively started vertical plate in a rotating fluid by using the Laplace transform technique. Based on his research the increase of rotation parameter will decrease the primary velocity. However, he does not consider the effect of the thermal radiation in his study. Later, Bestman and

Adjepong (1988) studied the unsteady MHD free convection flow near a moving infinite flat plate in a rotating medium in the presence of radiation heat transfer without considering the mass transfer process in the flow. In this research, they used perturbation methods to analyse and discuss the problem. Soon, Singh et al. (1991) studied the MHD free convection flow past an impulsively started vertical plate with the magnetic field fixed on the plate. Later, Lahurikar (2010) investigated the flow past an impulsively started vertical isothermal plate in a rotating fluid. The exact solutions of the problem were obtained by using the Laplace transform technique. Subsequently, Vijayalakshmi (2010) extended the study by considering the radiation effect. Since, the mass transfer had many industrial applications so there is a need to study the properties of mass transfer. This was being done by Nanousis (1992), the MHD free convection and mass transfer flow past a moving infinite vertical plate in a rotating fluid was analysed analytically with the help of Laplace transform methods. In his research, the thermal diffusion effect was being considered, but the effect of thermal radiation is ignored. Recently, Mbeledogu and Ogulu (2007) investigated the same problem but this time the flow was past a vertical porous flat plate in the presence of radiation heat transfer. The effect of thermal diffusion was ignored. However, the investigation of the heat and mass transfer of MHD free convection flow past an impulsively started vertical plate in a rotating fluid in the presences of thermal radiation and thermal diffusion was not being considered so far. The aims of this research are to show an analytical study of the flow problem with the help of Laplace transform methods and discuss the effect of the rotation parameter, Soret number and radiation parameter on the properties of the flow.

## 1.2 Statement of the Problem

The aim of this study is to investigate the heat and mass transfer in the MHD free convection flow past an impulsively started vertical plate in a rotating fluid with the presence of thermal radiation and thermal diffusion. As a result, few questions are explored in this study there are; How to derive the governing equations that describe the behaviour of the fluid? How to obtain the dimensionless governing equations? How the rotating systems affect the transport process? What happens to the fluid when the effect of thermal radiation and thermal diffusion considered?

## 1.3 Objectives of the Study

The objectives of this research are:

1. To obtain the continuity equations, momentum equations, energy equations and diffusion equations with the application of conservation principle.
2. To approximate the governing equations using Boussinesq's approximation and transform the governing equations into non-dimensional equations using dimensionless variables.
3. To obtain the analytical expression of velocity, temperature and concentration profiles using the Laplace transform technique.

4. To investigate and discuss the effect of various dimensionless parameters such as Rotation parameter, Soret number and Radiation parameter on the fluid characteristics.

#### **1.4 Scope of the Study**

The present study will focus on the MHD free convective flow past over an impulsively started vertical plate in a rotating frame reference. Besides that, the fluid is considered as an unsteady incompressible Newtonian flow. In additions, the flow is imposed by thermal radioactive and thermal diffusion effects. The governing equations will be solved entirely by using the Laplace transform technique. Then, the influences of the various parameters will be analysed analytically and will represent in the form of a graph.

#### **1.5 Significant of the Study**

The study of the MHD free convection flow in a rotating system is similar at understanding and predicting fluid flow phenomena on the earth's surfaces, since the earth is rotating, especially for the understanding of the circulation of the large scale atmospheric and oceanic flow. Nowadays, the problem of global change, acid precipitations, sea level rise and so forth are being concerned by many researchers.

Besides that, we are living within the atmosphere and are helplessly affected by weather and its rather chaotic behaviour. Hence, there is a necessity to study or to understand the convection process in a rotating system. Moreover, the earth is affected by the thermal radiation from the sun, so perhaps study the pattern of the effect of the thermal radiation in a rotating system helps to predict the climate change on the earth. In addition, the climate change is also affected by the pollutant gas emitted from the factory like carbon dioxide, CFC, and others. Understanding the effect of the diffusion process of this kind of particles in the atmosphere will help to estimate the atmospheric flows and weather.

Apart from that, due to the application in the navigation, fisheries and pollution disposal make the study of the dynamic of ocean essential. Besides that, there are many industrial applications also, for example, the design and operation in furnaces, combustion chambers, fires, rocket plumes and explosion of chemical need a lot of information of the characteristic or behaviour of the heat and mass transfer process in the fluid especially in a rotating medium. Moreover, petroleum engineers need to understand the convection process in the rotating system for them to detect the movement of oil and gas through the reservoir.



## 1.6 Expected Result

According to the objectives of this research, the expected results are as follows:

1. The governing equations of the thermal radiation and thermal diffusion effect on the MHD free convection flow over an impulsively started vertical plate in a rotating coordinate system will be derived.
2. The approximate dimensionless governing equations will be obtained.
3. The exact solutions of the approximate non-dimensional governing equations will be determined.
4. The determined solutions will be represented in the form of graph for different values of Soret number, rotation parameter and radiation parameter.
5. The influences of the essential parameters to the velocity of the fluid will be observed.

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