g-JITTER EFFECT ON HEAT AND MASS TRANSFER OF THREE-DIMENSIONAL STAGNATION POINT NANOFLUID FLOW

MOHAMAD HIDAYAD AHMAD KAMAL

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

Faculty of Science
Universiti Teknologi Malaysia

JUNE 2022

DEDICATION

We all have dreams. But in order to make dreams come into reality, it takes an awful lot of determination, dedication, self-discipline, and effort. This little book is the first-fruit from your love. Without whose loving support, all of this will not possible....

Thank you

My beloved mum,
Puan Asiah Ahamad

My sisters,
Nur Asmahidayu Ahmad Kamal
Nurul Hidayah Ahmad Kamal

My brother in law
Muhammad Firdaus Azman

My niece
Anggun Qashrina Muhammad Firdaus

ACKNOWLEDGEMENT

Bismillahirrahmanirrahim. In the name of Allah, The Most Greatest and Most Merciful. Praise Upon the Beloved Prophet, His Family and Companion. There is no power except by the power of Allah and I humbly return my acknowledgement that all knowledge belongs to Allah. Alhamdulillah, I thank Allah for granting me this opportunity to broaden my knowledge in this field.

First and foremost I would like to express my deepest appreciation to my supervisor, Dr. Anati Ali and co supervisor Associate Professor Dr. Sharidan Shafie and Dr. Noraihan Afiqah Rawi for their enthusiastic guidance, invaluable help, encouragement and patient for all aspect in helping me throughout this research. Also my biggest thanks to our beloved postdoctoral, Dr Lim that really helpful in completing my writing. Their numerous comment, criticism and suggestion during the preparation of this research are gratefully praised.

I acknowledge, appreciate, and return to the love and support of my family, without whom I would be lost. To my mother, Pn Asiah binti Ahamad and beloved sisters, Ku Yu and Ku Dik, my brother in law Abang Daus, my lovely and cutest niece Anggun, thank you very much for your continuous support.

Besides the above mentioned person, I would like to acknowledge with great gratitude to the financial support from Ministry of Higher Education (MOHE), Research Management Centre (RMC) UTM and School of Graduate Studies (SPS) UTM, for the financial support through MyBRAIN15 (MyPhD), research grant (5F166) and publication incentive claim.

My sincere appreciation also extends to all Fluid Mechanics Research Group members and my seniors Associate Professor Dr. Rahman and wife Dr Amalina, Dr Iskandar, Dr Wawi, Dr Sharena, Dr Tirah, Dr Rijal, Dr Rahimah and Alif who always provide an insightful ideas in completing my study. Not to forget also my senior from diffent field Dr Norzi and Dr Adnin that always provide me moral support.

My deepest appreciation to my very good friends, Zahran and Abg Jijul that always pray for me, Fendi, Azrin and Izzat that always ask about my PhD progress, Fakhru, Shahid, Shahril and Am who my degree brothers, Ida, Bella and Shihah that be with me at early of my postgraduate life. Your kindness and helps will be a great memory for me.

Not to forget, my huge support system during completing my PhD, Wan and Seha who are my labmate at my early stage of PhD, my very lovely brothers, Dr Awang Azrul, Dr Along Haqzim and Dr Ery who always with me when I need them, my *kakak* and *abang* during PhD, Dr Mus and Dr Haziq. Lastly, my dearly supportive friend, Chiep, Yuna, En Fathi, Azza and Qilah who always besides me during my deepest and worst, my happy and joy. *Sayang korang ketat ketat.*

ABSTRACT

The study of fluid motion in fluid mechanics is useful in many engineering applications. Fundamental studies based on physics law on fluid motion could be done by mathematical formulation. Effects based on thermal energy such as heat source and heat absorber with its transferring mode can also be formulated into a mathematical system. Due to this reason, a boundary layer nanofluid flow near a stagnation point region of a three-dimensional body is studied in this thesis. Here, nanofluid containing copper nanoparticles and hybrid nanofluid containing copper and alumina nanoparticles with water as a base fluid are considered. In addition, a microgravitational field environment known as g-jitter is also considered. The main purpose of this study is to investigate theoretically the effect of thermal radiation and heat generation on fluid characteristics, heat transfer behaviour, and concentration distribution of the fluid flow system. In this study, the mathematical models that govern the fluid flow consist of continuity, momentum, energy, and concentration equations. These nonlinear partial differential equations are initially reduced into a dimensionless system of equations using the similarity transformation technique. The resulting dimensionless governing systems are then solved numerically using the Keller-box method. The numerical values of the skin friction coefficients, Nusselt number, and Sherwood number as well as the velocity, temperature, and concentration profiles are obtained for various values of the curvature ratio, amplitude of modulation, frequency of oscillation, nanoparticle volume fraction, heat generation parameter and thermal radiation parameter. The results from the analysis in relation to the studied physical parameters are graphically displayed and validated by comparing them to those of previous studies. The current study shows that the curvature parameter had a significant effect on the skin friction coefficient where planar and axisymmetric stagnation point flow occurred in a specified range of this parameter. On the other hand, increasing the modulation's amplitude causes all the physical quantities to fluctuate. It is observed that, when a higher frequency of oscillation is induced, the physical quantities are seen to be reduced. The addition of a small amount of copper nanoparticle in the fluid results in enhancement of conductivity of the thermal, as demonstrated by the Nusselt number. However, a contradictory behaviour was noticed on Sherwood number as copper nanoparticle was considered in the fluid problem. The internal heat generation has caused the temperature profile to increase, while the heat flux to decrease. Also, thermal radiation is found to improve the rate of heat transfer. Moreover, the addition of other nanoparticles which are alumina, further increased the thermal characteristic of the fluid system.

ABSTRAK

Kajian gerakan bendalir dalam mekanik bendalir adalah berguna dalam banyak aplikasi kejuruteraan. Kajian asas berdasarkan prinsip fizik ke atas gerakan bendalir boleh dilakukan melalui perumusan matematik. Kesan berdasarkan tenaga terma seperti punca haba dan penyerap haba bersama dengan mod pemindahannya boleh juga dirumuskan dalam sistem matematik. Oleh sebab itu, aliran nanobendalir lapisan sempadan berhampiran kawasan titik genangan bagi badan tiga-dimensi telah dikaji dalam tesis ini. Di sini, nanobendalir yang mengandungi nanozarah tembaga dan hibrid nanobendalir yang mengandungi nanozarah tembaga dan alumina dengan air sebagai bendalir asas telah dipertimbangkan. Disamping itu, persekitaran medan mikrograviti yang dikenali sebagai ketar-g juga dipertimbangkan. Tujuan utama kajian ini adalah untuk mengkaji secara teori kesan sinaran terma dan penjanaan haba ke atas ciri bendalir, tingkah laku pemindahan haba dan taburan kepekatan bagi sistem aliran bendalir. Dalam kajian ini, model matematik yang mentadbir aliran bendalir adalah terdiri daripada persamaan keselanjaran, momentum, tenaga dan kepekatan. Persamaan pembezaan separa tak linear ini pada awalnya dikurangkan menjadi sistem persamaan tak bermatra menggunakan teknik jelmaan keserupaan. Sistem persamaan pembezaan separa tak bermatra yang diperoleh seterusnya diselesaikan secara berangka menggunakan kaedah kotak-Keller. Nilai berangka bagi pekali geseran kulit, nombor Nusselt dan nombor Sherwood serta profil halaju, suhu dan kepekatan diperoleh untuk pelbagai nilai nisbah kelengkungan, modulasi amplitud, ayunan frekuensi, pecahan isipadu nanozarah, parameter penjanaan haba dan parameter terma sinaran. Keputusan daripada analisis berkaitan dengan parameter fizikal yang dikaji telah dipaparkan secara grafik dan disahkan dengan membandingkannya dengan kajian terdahulu. Kajian semasa menunjukkan bahawa, parameter kelengkungan mempunyai kesan yang signifikan ke atas pekali geseran kulit di mana aliran titik genangan satah dan simetri sepaksi berlaku di dalam ruang yang tertentu bagi parameter ini. Sebaliknya, peningkatan modulasi amplitud menyebabkan semua kuantiti fizikal berubah-ubah. Adalah diperhatikan bahawa, apabila saiz ayunan frekuensi yang tinggi teraruh, kuantiti fizikal dilihat menurun. Penambahan sedikit nanozarah tembaga mengakibatkan kekonduksian dipertingkat di fluks haba, seperti yang ditunjukkan oleh nombor Nusselt. Walau bagaimanapun, tingkah laku yang bercanggah diperhatikan pada nombor Sherwood apabila nanozarah tembaga dipertimbangkan didalam masalah aliran bendalir. Penjanaan haba dalaman telah menyebabkan profil suhu meningkat, manakala fluks haba berkurangan. Juga, sinaran haba didapati dapat meningkatkan kadar pemindahan haba. Tambahan pula, penambahan nanozarah yang lain iaitu alumina telah meningkatkan lagi ciri termal sistem bendalir.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ag	-	Silver
ANN	-	Artificial Neural Network
Al_2O_3	-	Aluminum dioxide
$C_2H_6O_2$	-	Ethylene glycol
Cu	-	Copper
Cu_2O	-	Copper oxide
Fe_3O_4	-	Iron oxide
H_2O	-	Water
ISS	-	International Space Station
MgO	-	Magnesium oxide
MHD	-	Magnetohydrodynamics
MWCNT	-	Multiple wall carbon nanotube
NASA	-	National Aeronautics and Space Administration
SiO_2	-	Silicon dioxide
SWCNT	-	Single wall carbon nanotubes
TiO_2	-	Titanium dioxide

LIST OF SYMBOLS

Roman Letters

a	-	Principal curvature measured in $x-$direction
b	-	Principal curvature measured in $y-$direction
C	-	Dimensional concentration parameter
c	-	Curvature ratio
C_{fx}	-	Skin friction coefficient in $x-$direction
C_{fy}	-	Skin friction coefficient in $y-$direction
C_p	-	Specific heat capacity at constant pressure
C_w	-	Concentration at the boundary surface
C_∞	-	Concentration at the free stream
°C	-	Degree celsius
D	-	Mass diffusion
f	-	Dimensionless function
Gm	-	Mass Grashof number
Gr	-	Thermal Grashof number
$g(t)$	-	Gravitational field acceleration
g_0	-	Mean of the gravitational acceleration
h	-	Dimensionless function
k	-	Thermal conductivity
k^*	-	Mean of absorption coefficient
N	-	Nodal point
Nr	-	Thermal radiation parameter
Nu	-	Nusselt number
Pr	-	Prandtl number
Q	-	Dimensionless heat generation parameter
Q_0	-	Dimensional heat generation parameter
q_r	-	Radiative heat flux
S	-	Saddle point

Sc	-	Schmidt number
$Sh/Gr^{1/4}$	-	Sherwood number
T	-	Dimensional temperature
t	-	Dimensional time
T_w	-	Temperature of the body
T_∞	-	Temperature of the fluid in the free stream
u	-	Velocity component in $x-$direction
v	-	Velocity component in $y-$direction
w	-	Velocity component in $z-$direction
x	-	Coordinate system
y	-	Coordinate system
z	-	Coordinate system

Greek Letters

α	-	Thermal diffusion
β	-	Thermal expansion
Δ	-	Small change
ε	-	Amplitude of the gravity modulation
η	-	Boundary layer thickness
θ	-	Dimensionless temperature parameter
μ	-	Dynamic viscosity
ρ	-	Density
σ^*	-	Stefan-Boltzman constant
τ	-	Dimensionless time parameter
υ	-	Kinematic viscosity
Φ	-	Dimensionless concentration
ϕ	-	Nanoparticle volume fraction
ϕ_1	-	Copper nanoparticle volume fraction
ϕ_2	-	Alumina nanoparticle volume fraction
Ω	-	Dimensionless frequency of oscillation
ω	-	Dimensional frequency of oscillation

Superscripts

'	-	Differentiation with respect to η

Subscripts

f	-	Base fluid
hnf	-	Hybrid nanofluid
$n1$	-	Copper solid component
$n2$	-	Alumina solid component
nf	-	Nanofluid
s	-	Solid nanoparticles

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Research Background

Fluid mechanics is an important discipline in physics to understand the mechanical motion of the fluid itself. In most engineering applications such as automotive manufacturing, cooling system, food processing, biomedical application, plant design, and operation, the knowledge of fluid mechanics plays a very significant role in optimizing the machine durability and also enhancing the production numbers. Mathematics is closely related to all engineering sectors since most of the laws and principles of physics are expressed by using the language of mathematics. Navier-Stokes equation is the fundamental formula applied in describing the motion of inviscid viscous incompressible fluid. It was firstly developed by Claude-Louis Navier and then improved by Sir George Gabriel Stokes [1]. This balance differential equation was idealized from Newton's second law of motion together with the stress tensor assumption. Most of the phenomena in science and engineering such as water flow in pipe and air flow at airplane wings are well described by using this equation.

In fluid mechanics, there is a subdiscipline known as boundary layer flow where the fluid flow velocity is subjected to the sheering forces. It was first introduced by Prandtl [2] in 1904 at the Third International Mathematics Congress where he stated that the effect of friction is only experienced by the fluid near to the surface of the object. This small revolutionization later contributed massively to the advancement of the aerodynamic and fluid dynamics sector. The range of the boundary layer flow velocity varies from zero at the surface of the body to the maximum velocity at the free stream. The geometrical shape, body motion, body surface characteristic, and orientation of the body surface are the factors that influence the flow behaviour at the boundary layer. Besides that, the physical properties of the fluid such as density, viscosity, plasticity, thermal conductivity, and so on also contribute to the characteristic of the fluid flows. Fluids are commonly divided into two categories; the Newtonian fluid follows Newton's law of viscosity whereas the non-Newtonian fluid disobeys the law [3]. Theoretical study on Newtonian fluid has received a lot of attention from worldwide researchers as the adaptability and the importance of the analysis results in the industrial manufacturing process [4], [5]. However, analysis of the non-Newtonian fluid such as second-grade fluid, Casson fluid, and micropolar fluid is also being concerned due to the limitation hold by the Newtonian fluid in real application [6]–[8]. All the studies conducted will contribute to the advancement knowledge that needed in providing a better technology innovation platform in future.

The characteristic of the boundary layer fluid flow is significantly affected by either influence at the boundary or inside the fluid itself. The flow near the stagnation point was found highly effect the fluid characteristic due to the non-moving fluid that exists at the stagnation point. Based on Bernoulli's principle, the stagnation point holds the highest local pressure in the fluid flow [9]. The presence of a stagnation point in a boundary layer problem has produced a complicated field of fluid flow behaviour.

Studies on boundary layer flow are not limited to only investigating the behavior of the fluid flow, but also of the heat transfer properties. The heat transfer analysis in the fluid is also indispensable. Three modes in heat transferring are conduction, convection and radiation that transfer heat in a different way. The convection flow could be classified into two groups; natural convection flow is caused by gravitational force while forced convection flow occurs by an additional external force. It is known that mass transfer can only occur with the presence of heat transfer, but the heat transfer can occur alone without mass transfer. This knowledge is commonly applied in engineering application towards understanding the physical and chemical processes of a species involving diffusive and convective transport.

Enhancement of the heat transfer in a fluid is necessary for machine production to ensure the compatibility and durability of the machine in maximizing production. The durability of the machine could be increased by having a good cooling system. Fluids with higher thermal conductivity are found to have a better heat transportation property. The thermal conductivity of the conventional liquid such as water and ethanol can be enhanced by adding nanosized particles; this kind of fluid is called nanofluid. An experimental study by Choi [10] in 1995 found that the addition of a small number of copper (Cu) nanoparticles into water can increase the thermal conductivity of water. For the boundary layer flow problem, two well-known nanofluid models have been used theoretically for studying the characteristic of fluid flow and heat transfer. The Buongiorno nanofluid model takes into account the Brownian motion and thermophoresis effect [11]. On the other hand, the nanofluid model focuses on the effect of the types of nanoparticles utilized and the nanoparticle volume fraction [12].

Gravitational force is known as one of the forces that contribute to the body forces affecting the transportation matter. Since all objects on earth are restricted to a body mass, gravitational force thus plays a very important role and provides significant information when conducting an experimental study. In some experimental and manufacturing procedures such as the production of semiconductor, a defect final product due to doping process is caused by gravity. Interestingly, a fluctuating microgravity effect which is a non-existent effect on earth has been identified during space experiments. The fluctuating gravitational field is later known as the g-jitter effect and is found to significantly affect the experimental result obtained in outer space [13]. Thus, the assumed zero gravity environment then changes to microgravity environment due to the small gravity disturbance. Some experimental studies have concluded that crew motion and machine vibration are the sources of this effect where transient and oscillatory acceleration are arisen [14]. Therefore, the g-jitter effect has received a lot of attention in the fluid mechanic field since the analysis of this effect helps in producing a better mechanism in crystal growth [15].

Besides that, the presence of a heat source in the fluid will significantly affect the transport phenomenon that occurs at the boundary layer region. Exothermic condition happens when a heat source exists inside the fluid while the endothermic reaction occurs when a heat sink is inside of the fluid. In most cases, heat source and heat sink happen due to the chemical reaction generating or absorbing heat. In most cases, heat source and heat sink happen due to the chemical reaction that generating or absorbing heat. Studies on heat generation effect on boundary layer problem either for two-dimensional or three-dimensional cases have been conducted by various researchers [16], [17]. As for studies conducted on a three-dimensional stagnation point flow, presence of heat generation effect increases the fluid flow motion [18]. On the other hand, some researchers have extended the analysis of heat generation or absorption effect to the concentration distribution. By applying nanofluid boundary layer problem together with heat generation effect, the analysis shows an enhancement in Nusselt number that define the rate of change of heat transfer.

Many theoretical studies of the boundary layer field have been conducted in analyzing the fluid flow, heat, and mass transfer. There are some analytical and numerical analysis are performed in understanding the effect on different shape of geometrical body that locate the stagnation point itself. From the literature review on g-jitter, the effect of thermal radiation and internal heat generation significantly affecting the fluid characteristic. Thus, the aim of the present study is to investigate the effects of internal heat generation and thermal radiation near a stagnation point of nanofluid flow under the influence of g-jitter. All the important terminology discussed above related to this study are given in detail as follow

1.1.1 Fluid Mechanics

Fluid is defined as a substances that has no fixed shape and yields to external pressure. Fluids that are concerned with their own mechanics are known as fluid mechanics i.e. an important discipline in physics for understanding the mechanical motion of liquids, gases, or plasmas as illustrated in Figure 1.1.

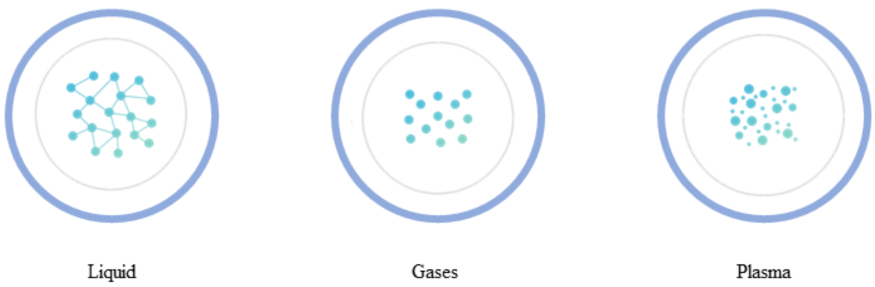

Figure 1.1 Fluid categories

1.1.1.1 Boundary Layer Theory

Boundary layer flow is a subdiscipline of fluid mechanics, defined as a thin layer of fluid flow near the body surface whereby the fluid flow velocity is subjected to the sheering forces. Figure 1.2 shows the most common illustration of boundary layer that flows, i.e. the thermal and concentration boundary layer.

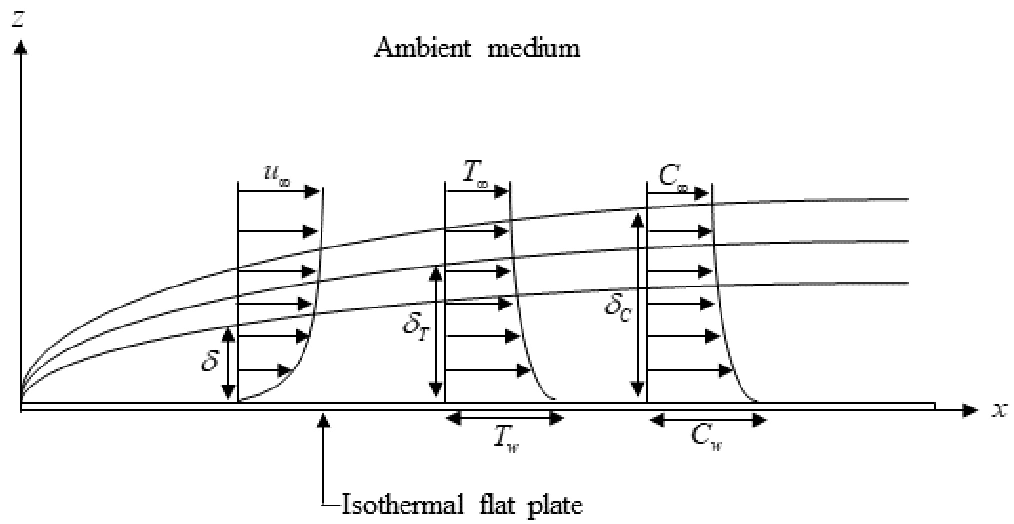

Figure 1.2 Velocity, thermal and concentration boundary layer

1.1.1.2 Stagnation Point

In fluid mechanics, a stagnation point is defined as a point on the surface of an object that has zero local velocity value. Thus, the study of fluid dynamics near the point is known as stagnation point flow. In most of the fluid flow cases, stagnation point flow occurs either in normal or oblique and forward or reverses conditions with some example shown in Figure 1.3 [19]. The pattern of stagnation point flows is highly affected by the geometry of the body surface.

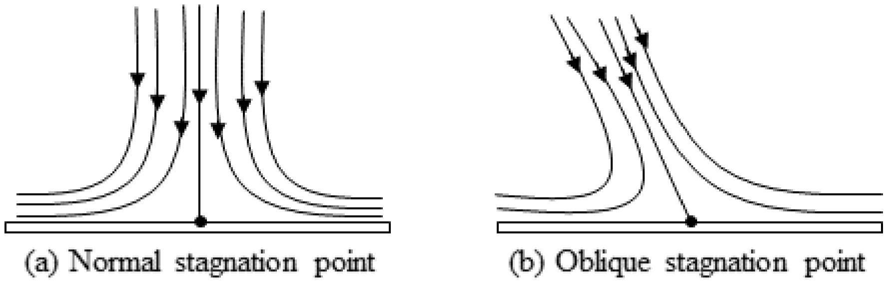

Figure 1.3 Types of stagnation point flow

1.1.1.3 Heat and Mass Transfer

Thermodynamics is a branch of physics that deals with heat, work, and temperature together with their relation to energy. The three modes in heat transference are conduction, convection and radiation as shown in Figure 1.4. Close contact between objects is applied to transfer heat via conduction where the heat energy is transferred as the collision between molecules occurs. On the other hand, thermal radiation is the transference of heat through an electromagnetic wave generated from the thermal motion. The changes of fluid density in a system due to a temperature gradient generate a fluid circulation in the system which allows for possible alterations in heat energy; this phenomenon is known as natural convection. Mass transfer is defined as the transportation of energy in the fluid system through a particle from one point to another based on the different concentrations.

1.1.1.4 Conventional and Hybrid Nanofluid

Nanofluid is a solid-liquid substances material. The nanofluid is found to enhance the thermal properties of the system and its production is cost-effective. Another innovative class of nanofluids is known as hybrid nanofluids. These types of fluidic systems are synthesized by two or more types of nanoparticles in one base fluid or a hybrid composite.

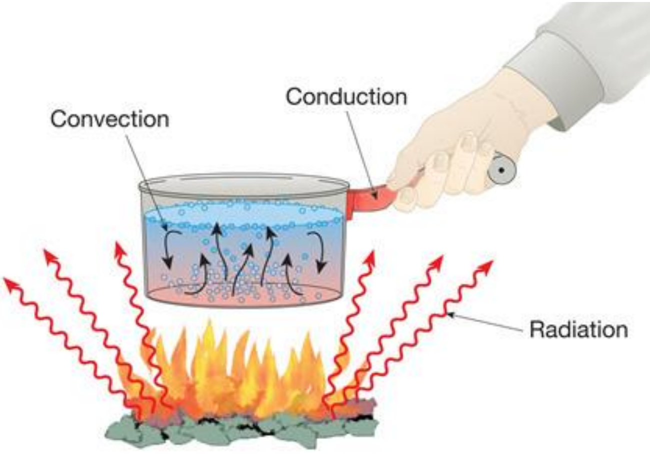

Figure 1.4 Modes of heat transfer

1.1.1.5 g-Jitter

When Yuri Gagarin became the first human to travel into space, the idea about experimenting without gravitational effect had inspired researchers. Since then, a fluctuating microgravity effect which is a non-existent effect on earth has been identified known as g-jitter. It is defined as the fluctuating gravitational field and found to significantly affect the experimental result obtained in outer space. Some examples of microgravity application are parabolic aircraft, space shuttle and International Space Station as shown in Figure 1.5 with varying periods of microgravity.

(a) (b) (c)

Figure 1.5 Microgravity environment applications (a) parabolic aircraft, (b) space shuttle and (c) Space Station

1.1.1.6 Internal Heat Generation

The presence of heat source inside the fluid known as internal heat generation will generate heat into the fluid system. The heat sink, on the other hand, is called heat absorbtion where both of this conditions can be classified as exothermic and endorthemic reactions. Exothermic reactions feel warm or hot or may even be explosive such as freezing water into ice cube, respiration, rain forming from water vapor in clouds and dissolving laundry detergent in water. On the other hand, endorthermic reaction occur when dissolving salt, converting frost to water vapor, baking bread and even cooking an egg.

1.1.1.7 Thermal Radiation

Thermal radiation is an electromagnetic radiation emitted from a material due to the heating of the material. An example of thermal radiation is the infrared radiation emitted by a common household radiator or electric heater. A person near a raging bonfire will feel the radiated heat of the fire, even if the surrounding air is very cold. Thermal radiation is generated when heat from the movement of charges in the material (electrons and protons in common forms of matter) is converted into electromagnetic radiation. Sunshine or solar radiation is thermal radiation from the extremely hot gasses of the sun which heats the earth. The earth also emits thermal radiation but at a much lower intensity because it is cooler. The balance between heating by incoming solar thermal radiation and cooling by the earth's outgoing thermal radiation is the primary process that determines the earth's overall temperature. As such, radiation is the only form of heat transfer that does not require a material to transmit the heat. This form of heat transfer is not only a function of the temperature difference between the two surfaces, but also of the frequency range of the emitted and received energy. As an example, sunlight is composed of the visible light spectrum as well as infrared energy and ultraviolet energy.

1.2 Problem Statement

In recent years, theoretical studies have significantly increased the rapid development in machine manufacturing, new technology, discovery of new materials and advancement in the engineering sector. The study of boundary layer flow in fluid mechanics has gained so much attention since it provides a promising result as a pioneer guideline in constructing experimental and production processes. The boundary layer flow is very important in understanding fluid behaviour theoretically. Many studies have been conducted for analyzing the boundary layer flow characteristics, heat transfer properties, and also concentration distribution in fluids. Stagnation point flow is defined as a region of a flow near to a point on the surface of a plane that has a zero-local velocity. In addition, gravitational force plays a significant role in fluid mechanics which correspond to fluid behaviour.

The cooling system is found to be necessary in most machinery applications for preventing the system from being overheated. The cooling system in a spacecraft is bounded to the g-jitter effect where the gravitational field is different compared to that on earth. Some researchers found that the internal heat source may also affect the fluid behaviour of the cooling system. In addition, the existence of thermal radiation in the cooling system significantly affects the rate of heat transfer. Recently, it was discovered that the nanofluid has better thermal propertices compared to the classical fluid. The design of the cooling system will then produce a stagnation point where the flow near the stagnation point region is affected.

Therefore, in this research, a fundamental study is conducted to investigate the unsteady three-dimensional viscous nanofluid boundary layer flow near the stagnation point region in a microgravity environment. Other effects such as internal heat generation and thermal radiation are also considered in this study. The problems are mathematically formulated based on physical laws and principal and then solved numerically using a finite difference approach. The problem is then analyzed graphically in terms of profiles and physical quantities. Hence, to achieve the objective of this study, several questions need to be answered:

1. How does the nature of unsteady free convection nanofluid flow near a three-dimensional stagnation point region with the effect of g-jitter can be modelled through a mathematical modelling perspective?
2. How do the different values of curvature ratio of stagnation point affect the flow characteristic based on velocity profiles and skin friction coefficients?
3. How does the fluctuation gravitational field caused by the g-jitter effect influence the physical quantities of the principle interest on fluid flow characteristic, heat transfer and concentration distribution?
4. How can the nanoparticle volume fraction parameter that presents the concentration of nanoparticles added into the conventional fluid enhanced the thermal characteristic of the fluid based on temperature profiles and Nusselt number?
5. How does the presence of physical parameter such as internal heat generation and thermal radiation provide a significant effect on the boundary layer nanofluid flow?

1.3 Research Objectives

The purpose of this study is to investigate the effect of g-jitter, nanoparticle volume fraction, heat generation and thermal radiation near an unsteady three-dimensional stagnation point viscous flow numerically. The detailed objectives of the study are as follows:

1. to derive and simplify the mathematical model consisting of a system of partial differential equation using boundary layer and Boussinesq approximation based on the problem considered,
2. to develop a computational algorithm to solve the system of equation numerically,
3. to obtain the numerical results of velocity profiles, temperature profile, concentration profile, skin frictions, Nusselt number and Sherwood number,
4. to analyze the behaviour of the flow, heat transfer characteristic and concentration distribution by the influence of curvature ratio, amplitude of

modulation, frequency of oscillation nanoparticle volume fraction, internal heat generation and thermal radiation.

1.4 Scope of the Research

This study focuses on an unsteady free convection boundary layer problem near a three-dimensional stagnation point region. The effect of g-jitter that occurs in a microgravity environment is taken into consideration. Furthermore, the effect of heat generation and thermal radiation are also examined in this study. Here, nanofluids are applied in the study where water (H_2O) as the Newtonian based fluid with copper (Cu) acts as dispersing nanoparticles. The nanoparticles are suspended inside the water where the based fluid and nanoparticles are assumed to be in thermal equilibrium. By following the recommendation of Tiwari and Das' [20], nanoparticles with thermophysical characteristics are utilized in this study. The mathematical model introduced is simplified using Boussinesq and boundary layer approximation. Besides that, constant wall temperature and no slip velocity are deliberated. These unsteady problems which are discussed in details in Chapters 4 to 8, are as follows:

1. The effect of g-jitter near a three-dimensional free convection stagnation point nanofluid flow.
2. The effect of g-jitter near a double diffusion three-dimensional free convection stagnation point nanofluid flow.
3. The effect of g-jitter near a double diffusion three-dimensional free convection stagnation point nanofluid flow with internal heat generation.
4. The effect of g-jitter near a double diffusion three-dimensional free convection stagnation point nanofluid flow with thermal radiation.
5. The effect of g-jitter near a three-dimensional free convection stagnation point hybrid nanofluid flow.

1.5 Significant of Research

The study of fluid mechanics provides a significant platform for understanding the factors that affect the durability of the product, selection of material in machine production, the invention of the cooling system, and reduction of production cost. Based on the fundamental study of the fluid characteristic in terms of fluid flow behaviour, heat transfer properties, and concentration distribution, the determined results and analysis can be used in the engineering and production sector as demanded in current industries and technologies. Hence, the significance of this study are as follow:

1. The analysis and discussion of the boundary layer fluid flow behaviour near a stagnation point is significant in designing a manufacturing cooling system, airplane wing, and also the lubricant flow in an automotive,
2. A better understanding of the g-jitter effect in a microgravity environment is necessary to optimize the growth of a crystal and also to ensure the effectiveness of the fluid movement of a machine in a spacecraft,
3. The physical explanation on the enhancement of the heat transfer characteristic in a conventional fluid due to the nanoparticles volume fraction,
4. The effect of the internal heat generation and thermal radiation on the boundary layer flow can be detected and provide the perception that the physical parameter is highly affecting the thermal characteristic of the fluid,
5. The computed results can serve as a guideline for a complex model in engineering and science application and further, the study can be extended later by considering other fluid types or different physical parameters.

1.6 Thesis Outline

This thesis consists of nine chapters including this chapter and focuses on unsteady free convection viscous boundary layer nanofluid flow near a three-dimensional stagnation point body with g-jitter, heat generation, and thermal radiation. Chapter 1 discusses the research background, problem statement, research objective, the scope of the research and the significance of the research. The literature reviews are presented and discussed in Chapter 2. The research methodology in conducting this study are discussed in Chapter 3 which include the derivation of the equations and solving method.

The first fluid problem is solved and discussed in Chapter 4 by proposing the three-dimensional stagnation point flow problem induced by g-jitter and nanoparticle. The problem is analyzed in terms of profiles and physical quantities by taking into account each parameter considered in this problem. Chapter 5 is a continuation of Chapter 4 whereby the heat and mass transfer are deliberated. The analysis focuses more on the concentration profiles and Sherwood number for physical quantity. All the results are presented through graphs and tables. Chapter 6 is an extension of Chapter 5 with the additional effect of heat generation. A comparison study is conducted for validation and verification purposes. Chapter 7 presents the analysis of the free convection nanofluid stagnation point flow under the effect of g-jitter and thermal radiation. The hybrid nanofluid problem is discussed in Chapter 8 with consideration of another type of nanoparticle namely alumina.

Finally, Chapter 9 summarizes this research along with some suggestions and recommendations for future research. The references and appendixes related to this study are listed at the end of this thesis.

REFERENCES

[1] William L. Hosch. *Navier-Stokes equation* [Internet]. Edinburgh, Scotland: Encyclopedia Britannica Inc; 2012 [updated 2020; cited 2021 June 23]. Available from: https://www.britannica.com/science/Navier-Stokes-equation

[2] Prandtl L. On the Motion of a Fluid with Very Small Viscosity. *Proceedings of 3rd International Mathematics Congress*. Heidelberg Germany. 1904. 484–491.

[3] Batchelor G. K. An Introduction to Fluid Dynamics. An Introduction to Fluid Dynamics. Cambridge: Cambridge University Press. 2000.

[4] Scott G, Richardson P. The application of computational fluid dynamics in the food industry. *Trends Food Sci Technol*. 1997. 8(4):119–24.

[5] Norton T, Sun DW. Computational fluid dynamics (CFD) - An effective and efficient design and analysis tool for the food industry: A review. *Trends Food Sci Technol*. 2006. 17(11):600–620.

[6] Nazar R, Amin N, Filip D, Pop I. Stagnation point flow of a micropolar fluid towards a stretching sheet. *Int J Non Linear Mech*. 2004. 39(7):1227–35.

[7] Nadeem S, Haq RU, Akbar NS, Khan ZH. MHD three-dimensional Casson fluid flow past a porous linearly stretching sheet. *Alexandria Eng J*. 2013. 52(4):577–582.

[8] Bariş S, Dokuz MS. Three-dimensional stagnation point flow of a second grade fluid towards a moving plate. *Int J Eng Sci*. 2006. 44(1–2):49–58.

[9] Guo J, Chen Z, Dai Y. Numerical study on self-propulsion of a waterjet propelled trimaran. *Ocean Eng*. 2020. 195:106655.

[10] Choi SU, Eastman JA. Enhancing thermal conductivity of fluids with nanoparticles. American Society of Mechanical Engineers,

International Mecahnical Engineering Congress & Exposition. November 12-17,1995. United States. 1995.

[11] Buongiorno J. Convective transport in nanofluids. *J Heat Transfer*. 2006. 128(3):240–250.

[12] Tiwari RK, Das MK. Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids. *Int J Heat Mass Transf*. 2007. 50(9–10):2002–2018.

[13] Hiraoka Y, Ikegami K, Maekawa T, Matsumoto S, Yoda S, Kinoshita K. Numerical analysis of crystal growth of an InAs-GaAs binary semiconductor under microgravity conditions. *J Phys D Appl Phys*. 2000. 33(19):2508–2518.

[14] Kamotani Y, Prasad A, Ostrach S. Thermal Convection in an Enclosure Due To Vibrations Aboard Spacecraft. *AIAA Pap*. 1980. 19(4):511–516.

[15] Yeckel A, Derby JJ. Dynamics of three-dimensional convection in microgravity crystal growth: g-jitter with steady magnetic fields. *J Cryst Growth*. 2004. 263(1–4):40–52.

[16] Al-Mudhaf A, Chamkha AJ. Similarity solutions for MHD thermosolutal Marangoni convection over a flat surface in the presence of heat generation or absorption effects. *Heat Mass Transf*. 2005. 42(2):112–121.

[17] Damseh RA, Al-Odat MQ, Chamkha AJ, Shannak BA. Combined effect of heat generation or absorption and first-order chemical reaction on micropolar fluid flows over a uniformly stretched permeable surface. *Int J Therm Sci*. 2009. 48(8):1658–1663.

[18] Hayat T, Saif RS, Ellahi R, Muhammad T, Alsaedi A. Simultaneous effects of melting heat and internal heat generation in stagnation point flow of Jeffrey fluid towards a nonlinear stretching surface with variable thickness. *Int J Therm Sci*. 2018. 132(5):344–354.

[19] Nadeem S, Khan AU, Saleem S. A comparative analysis on different nanofluid models for the oscillatory stagnation point flow. *Eur Phys J Plus*. 2016. 131(8):1-14.

[20] Oztop HF, Abu-Nada E. Numerical study of natural convection in partially heated rectangular enclosures filled with nanofluids. *Int J Heat Fluid Flow*. 2008. 29(5):1326–1336.

[21] Liu J, Ye Z, Zhang L, Fang X, Zhang Z. A combined numerical and experimental study on graphene/ionic liquid nano fl uid based direct absorption solar collector. *Sol Energy Mater Sol Cells*. 2015. 136:177–186.

[22] Nazari M, Ashouri M, Hasan M, Tamayol A. Experimental study of convective heat transfer of a nano fluid through a pipe filled with metal foam. *Int J Therm Sci*. 2015. 88:33–39.

[23] Kherbeet AS, Mohammed HA, Salman BH, Ahmed HE, Alawi OA, Rashidi MM. Experimental study of nanofluid flow and heat transfer over microscale backward- and forward-facing steps. *Exp Therm Fluid Sci*. 2015. 65:13–21.

[24] Sousa ACM. Experimental study of heat transfer and friction factor of Al2O3 nanofluid in U-tube heat exchanger with helical tape inserts. *Exp Therm Fluid Sci*. 2015. 62:141–150.

[25] Afrand M, Toghraie D, Ruhani B. Effects of temperature and nanoparticles concentration on rheological behavior of Fe3O4–Ag/EG hybrid nanofluid : An experimental study. *Exp Therm Fluid Sci*. 2016. 77:38–44.

[26] Afrand M, Toghraie D, Sina N. Experimental study on thermal conductivity of water-based Fe3O4 nanofluid : Development of a new correlation and modeled by artificial neural network. *Int Commun Heat Mass Transf*. 2016;75:262–269.

[27] Sarbolookzadeh S, Karimipour A, Afrand M, Akbari M, Orazio AD. An experimental study on thermal conductivity of F-MWCNTs–Fe3O4 EG/hybrid nanofluid: Effects of temperature and concentration. *Int Commun Heat Mass Transf*. 2016. 76:171–177.

[28] Zarringhalam M, Karimipour A, Toghraie D. Experimental study of the effect of solid volume fraction and Reynolds number on heat transfer coefficient and pressure drop of CuO–Water nanofluid. *Exp Therm Fluid Sci*. 2016. 76:342–351.

[29] Soltani O, Akbari M. Effects of temperature and particles concentration on the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid nanofluid : Experimental study. *Phys E Low-dimensional Syst Nanostructures*. 2016. 84:564–570.

[30] Hemmat M, Saedodin S, Biglari M, Rostamian H. An experimental study on thermophysical properties and heat transfer characteristics of low volume concentrations of Ag-water nanofluid. *Int Commun Heat Mass Transf*. 2016. 74:91–97.

[31] Zakaria I, Azmi WH, Mamat AMI, Mamat R, Saidur R, Talib SFA, et al. Thermal analysis of Al2O3-water ethylene glycol mixture nanofluid for single PEM fuel cell cooling plate: An experimental study. *Int J Hydrogen Energy*. 2016. 41(9):5096–5112.

[32] Nazari S, Safarzadeh H, Bahiraei M. Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: An experimental study. *J Clean Prod*. 2019. 208:1041–1052.

[33] Yan S, Kalbasi R, Nguyen Q, Karimipour A. Rheological behavior of hybrid MWCNTs-TiO2/EG nanofluid: A comprehensive modeling and experimental study. *J Mol Liq*. 2020. 308:113058.

[34] Pourrajab R, Noghrehabadi A, Behbahani M, Hajidavalloo E, Silver A. An efficient enhancement in thermal conductivity of water-based hybrid nanofluid containing MWCNTs-COOH and Ag nanoparticles: experimental study. *J Therm Anal Calorim*. 2020. 143(5):3331-3343.

[35] Ho CJ, Hsieh Y, Rashidi S, Orooji Y, Yan W. Thermal-hydraulic analysis for alumina/water nanofluid inside a mini- channel heat sink with latent heat cooling ceiling - An experimental study. *Int Commun Heat Mass Transf*. 2020. 112:104477.

[36] Asadi A, Alarifi IM, Foong LK. An experimental study on characterization, stability and dynamic viscosity of CuO-TiO2/water hybrid nanofluid. *J Mol Liq*. 2020. 307:112987.

[37] Li Y, Kalbasi R, Nguyen Q, Afrand M. Effects of sonication duration and nanoparticles concentration on thermal conductivity of silica-ethylene glycol nanofluid under different temperatures: An experimental study. *Powder Technol*. 2020. 367:464–473.

[38] Khanafer K, Vafai K, Lightstone M. Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids. *Int J Heat Mass Transf*. 2003. 46(19):3639–3653.

[39] Devi SSU, Devi SPA. Numerical investigation of three-dimensional hybrid Cu-Al2O3/water nanofluid flow over a stretching sheet with effecting Lorentz force subject to Newtonian heating. *Can J Phys*. 2016. 94(5):490–496.

[40] Abbas N, Malik MY, Alqarni MS, Nadeem S. Study of three dimensional stagnation point flow of hybrid nanofluid over an isotropic slip surface. *Phys A Stat Mech its Appl*. 2020. 554:124020.

[41] Jayachandra Babu M, Sandeep N. Three-dimensional MHD slip flow of nanofluids over a slendering stretching sheet with thermophoresis and Brownian motion effects. *Adv Powder Technol*. 2016. 27(5):2039–2050.

[42] Ramzan M, Bilal M. Three-dimensional flow of an elastico-viscous nanofluid with chemical reaction and magnetic field effects. *J Mol Liq*. 2016. 215:212–220.

[43] Hayat T, Muhammad T, Shehzad SA, Alsaedi A. On three-dimensional boundary layer flow of Sisko nanofluid with magnetic field effects. *Adv Powder Technol*. 2016. 27(2):504–512.

[44] Hayat T, Aziz A, Muhammad T, Alsaedi A. Three-dimensional flow of nanofluid with heat and mass flux boundary conditions. *Chinese J Phys*. 2017. 55(4):1495–1510.

[45] Nayak MK, Akbar NS, Tripathi D, Pandey VS. Three dimensional MHD flow of nanofluid over an exponential porous stretching sheet with convective boundary conditions. *Therm Sci Eng Prog*. 2017. 3:133–140.

[46] Hayat T, Muhammad T, Shehzad SA, Alsaedi A. Modeling and analysis for hydromagnetic three-dimensional flow of second grade nanofluid. *J Mol Liq*. 2016. 221:93–101.

[47] Hayat T, Khan M, Muhammad T, Alsaedi A. On model for three-dimensional flow of nanofluid with heat and mass flux boundary conditions. *J Therm Sci Eng Appl*. 2018. 10(3):1–6.

[48] Hayat T, Aziz A, Muhammad T, Alsaedi A. Numerical simulation for Darcy–Forchheimer three-dimensional rotating flow of nanofluid with prescribed heat and mass flux conditions. *J Therm Anal Calorim*. 2019. 136(5):2087–2095.

[49] Nield DA, Kuznetsov A V. The Cheng-Minkowycz problem for natural convective boundary-layer flow in a porous medium saturated by a nanofluid. *Int J Heat Mass Transf*. 2009. 52(25–26):5792–5795.

[50] Nield DA, Kuznetsov A V. Thermal instability in a porous medium layer saturated by a nanofluid. *Int J Heat Mass Transf*. 2009. 52(25–26):5796–5801.

[51] Kuznetsov A V., Nield DA. Natural convective boundary-layer flow of a nanofluid past a vertical plate. *Int J Therm Sci*. 2010. 49(2):243–247.

[52] Kuznetsov A V., Nield DA. The Cheng-Minkowycz problem for natural convective boundary layer flow in a porous medium saturated by a nanofluid: A revised model. *Int J Heat Mass Transf*. 2013. 65:682–685.

[53] Nield DA, Kuznetsov A V. Thermal instability in a porous medium layer saturated by a nanofluid: A revised model. *Int J Heat Mass Transf*. 2014. 68:211–214.

[54] Kuznetsov A V., Nield DA. Natural convective boundary-layer flow of a nanofluid past a vertical plate: A revised model. *Int J Therm Sci*. 2014. 77:126–129.

[55] Hussain Z, Hayat T, Alsaedi A, Ahmad B. Three-dimensional convective flow of CNTs nanofluids with heat generation/absorption effect : A numerical study. *Comput Methods Appl Mech Eng*. 2018. 329:40–54.

[56] Hayat T, Muhammad T, Shehzad SA, Alsaedi A. Three-dimensional boundary layer flow of Maxwell nanofluid : Mathematical model. *Appl Math Mech (English Ed)*. 2015. 36(6):747–762.

[57] Raju CSK, Sandeep N, Jayachandra Babu M, Sugunamma V. Dual solutions for three-dimensional MHD flow of a nanofluid over a nonlinearly permeable stretching sheet. *Alexandria Eng J*. 2016. 55(1):151–162.

[58] Hayat T, Muhammad T, Shehzad SA, Alsaedi A. An analytical solution for magnetohydrodynamic Oldroyd-B nanofluid flow induced by a stretching sheet with heat generation/absorption. *Int J Therm Sci*. 2017. 111:274–288.

[59] Durgaprasad P, Varma SV, Hoque MM, Raju CS. Combined effects of Brownian motion and thermophoresis parameters on three-dimensional (3D) Casson nanofluid flow across the porous layers slendering sheet in a suspension of graphene nanoparticles. *Neural Comput Appl*. 2019. 31(10):6275–6286.

[60] Ali A, Sulaiman M, Islam S, Shah Z, Bonyah E. Three-dimensional magnetohydrodynamic (MHD) flow of Maxwell nanofluid containing gyrotactic micro-organisms with heat source/sink. *AIP Adv*. 2018. 8(8).

[61] Hayat T, Qayyum S, Shehzad SA, Alsaedi A. Cattaneo-Christov double-diffusion theory for three-dimensional flow of viscoelastic nanofluid with the effect of heat generation/absorption. *Results Phys*. 2018. 8:489–495.

[62] Hayat T, Imtiaz M, Alsaedi A, Kutbi MA. MHD three-dimensional flow of nanofluid with velocity slip and nonlinear thermal radiation. *J Magn Magn Mater.* 2015. 396:31–37.

[63] Mustafa M, Mushtaq A, Hayat T, Alsaedi A. Rotating flow of magnetite-water nanofluid over a stretching surface inspired by non-linear thermal radiation. *PLoS One*. 2016. 11(2):1–16.

[64] Nayak MK, Akbar NS, Pandey VS, Khan ZH, Tripathi D. 3D free convective MHD flow of nanofluid over permeable linear stretching sheet with thermal radiation. *Powder Technol*. 2017. 315:205–215.

[65] Mahanthesh B, Gireesha BJ, Gorla RSR, Makinde OD. Magnetohydrodynamic three-dimensional flow of nanofluids with slip and thermal radiation over a nonlinear stretching sheet: A numerical study. *Neural Comput Appl*. 2018. 30(5):1557–1567.

[66] Koriko OK, Animasaun IL, Reddy MG, Sandeep N. Scrutinization of thermal stratification, nonlinear thermal radiation and quartic autocatalytic chemical reaction effects on the flow of three-dimensional Eyring-Powell alumina-water nanofluid. *Multidiscip Model Mater Struct*. 2018. 14(2):261–283.

[67] Ganesh Kumar K, Gireesha BJ, Manjunatha S, Rudraswamy NG. Effect of nonlinear thermal radiation on double-diffusive mixed convection boundary layer flow of viscoelastic nanofluid over a stretching sheet. *Int J Mech Mater Eng*. 2017. 12(1):1-18.

[68] Ganesh Kumar K, Ramesh GK, Gireesha BJ, Gorla RSR. Characteristics of Joule heating and viscous dissipation on three-dimensional flow of Oldroyd B nanofluid with thermal radiation. *Alexandria Eng J*. 2018. 57(3):2139–2149.

[69] Khan AS, Nie Y, Shah Z, Dawar A, Khan W, Islam S. Three-dimensional nanofluid flow with heat and mass transfer analysis over a linear stretching surface with convective boundary conditions. *Appl Sci*. 2018;8(11):2244.

[70] Bilal M, Sagheer M, Hussain S. Three dimensional MHD upper-convected Maxwell nanofluid flow with nonlinear radiative heat flux. *Alexandria Eng J*. 2018. 57(3):1917–1925.

[71] Saeed A, Shah Z, Islam S, Jawad M, Ullah A, Gul T, Kumam P. Three-dimensional Casson nanofluid thin film flow over an inclined rotating disk with the impact of heat generation/consumption and thermal radiation. *Coatings*. 2019. 9(4):248.

[72] Shafiq A, Rasool G, Khalique CM. Significance of thermal slip and convective boundary conditions in three dimensional rotating darcy-forchheimer nanofluid flow. *Symmetry (Basel)*. 2020. 12(5):1–21.

[73] Hayat T, Muhammad T, Shehzad SA, Alsaedi A. Similarity solution to three dimensional boundary layer flow of second grade nanofluid past a stretching surface with thermal radiation and heat source/sink. *AIP Adv*. 2015. 5(1): 017107.

[74] Shehzad SA, Abdullah Z, Alsaedi A, Abbasi FM, Hayat T. Thermally radiative three-dimensional flow of Jeffrey nanofluid with internal heat generation and magnetic field. *J Magn Magn Mater*. 2016. 397:108–114.

[75] Gorla RSR, Gireesha BJ. Convective heat transfer in three-dimensional boundary-layer flow of viscoelastic nanofluid. *J Thermophys Heat Transf*. 2016. 30(2):334–341.

[76] Khan M, Khan WA, Alshomrani AS. Non-linear radiative flow of three-dimensional Burgers nanofluid with new mass flux effect. *Int J Heat Mass Transf*. 2016. 101:570–576.

[77] Rauf A, Siddiq MK, Abbasi FM, Meraj MA, Ashraf M, Shehzad SA. Influence of convective conditions on three dimensional mixed convective hydromagnetic boundary layer flow of Casson nanofluid. *J Magn Magn Mater*. 2016. 416:200–207.

[78] Mahanthesh B, Mabood F, Gireesha BJ, Gorla RSR. Effects of chemical reaction and partial slip on the three-dimensional flow of a nanofluid impinging on an exponentially stretching surface. *Eur Phys J Plus*. 2017. 132(3):1-8.

[79] Rehman FU, Nadeem S, Haq RU. Heat transfer analysis for three-dimensional stagnation-point flow over an exponentially stretching surface. *Chinese J Phys*. 2017. 55(4):1552–1560.

[80] Borrelli A, Giantesio G, Patria MC, Roşca NC, Roşca A V., Pop I. Buoyancy effects on the 3D MHD stagnation-point flow of a Newtonian fluid. *Commun Nonlinear Sci Numer Simul*. 2017. 43:1–13.

[81] Hussain ST, Ul Haq R, Noor NFM, Nadeem S. Non-linear radiation effects in mixed convection stagnation point flow along a vertically stretching surface. *Int J Chem React Eng*. 2017. 15(1):11–20.

[82] Mabood F, Shafiq A, Hayat T, Abelman S. Radiation effects on stagnation point flow with melting heat transfer and second order slip. *Results Phys*. 2017. 7:31–42.

[83] Abbasi A, Riaz I, Farooq W, Ahmad M. Analysis of nonlinear thermal radiation and higher-order chemical reactions on the non-orthogonal stagnation point flow over a lubricated surface. *Heat Transf - Asian Res*. 2020. 49(2):673-692

[84] Shah F, Khan MI, Hayat T, Khan MI, Alsaedi A. Modeling and computational analysis of 3D radiative stagnation point flow of Darcy-Forchheimer subject to suction/injection. *Comput Methods Programs Biomed*. 2020;184:105104.

[85] Mahabaleshwar US, Nagaraju KR, Vinay kumar PN, Nadagoud MN, Bennacer R, Baleanu D. An MHD viscous liquid stagnation point flow and heat transfer with thermal radiation and transpiration. *Therm Sci Eng Prog*. 2020;16(7):100379.

[86] Prasannakumara BC, Gireesha BJ, Manjunatha PT. Melting phenomenon in MHD stagnation point flow of dusty fluid over a stretching sheet in the presence of thermal radiation and non-uniform heat source/sink. *Int J Comput Methods Eng Sci Mech*. 2015. 16(5):265–274.

[87] Sivasankaran S, Niranjan H, Bhuvaneswari M. Chemical reaction, radiation and slip effects on MHD mixed convection stagnation-point flow in a porous medium with convective boundary condition. *Int J Numer Methods Heat Fluid Flow*. 2017. 27(2):454–470.

[88] Mansur S, Ishak A, Pop I. The magnetohydrodynamic stagnation point flow of a nanofluid over a stretching/shrinking sheet with suction. *PLoS One*. 2015. 10(3):1–14.

[89] Malvandi A. The unsteady flow of a nanofluid in the stagnation point region of a time-dependent rotating sphere. *Therm Sci*. 2015. 19(5):1603–1612.

[90] Sulochana C, Sandeep N. Stagnation point flow and heat transfer behavior of Cu–water nanofluid towards horizontal and exponentially stretching/shrinking cylinders. *Appl Nanosci*. 2016. 6(3):451–459.

[91] Dinarvand S, Hosseini R, Pop I. Axisymmetric mixed convective stagnation-point flow of a nanofluid over a vertical permeable cylinder by Tiwari-Das nanofluid model. *Powder Technol*. 2017. 311:147–156.

[92] Ur Rehman F, Nadeem S, Ur Rehman H, Ul Haq R. Thermophysical analysis for three-dimensional MHD stagnation-point flow of nano-material influenced by an exponential stretching surface. *Results Phys*. 2018. 8:316–323.

[93] Nadeem S, Abbas N, Khan AU. Characteristics of three dimensional stagnation point flow of Hybrid nanofluid past a circular cylinder. *Results Phys*. 2018. 8:829–835.

[94] Ur Rehman F, Nadeem S. Heat transfer analysis for three-dimensional stagnation-point flow of water-based nanofluid over an exponentially stretching surface. *J Heat Transfer*. 2018. 140(5):1–7.

[95] Khashi'ie NS, Arifin NM, Pop I, Nazar R, Hafidzuddin EH, Wahi N. Non-axisymmetric Homann stagnation point flow and heat transfer past a stretching/shrinking sheet using hybrid nanofluid. *Int J Numer Methods Heat Fluid Flow*. 2020. 30(10):4583-4606.

[96] Gireesha BJ, Mahanthesh B, Shivakumara IS, Eshwarappa KM. Melting heat transfer in boundary layer stagnation-point flow of nanofluid toward a stretching sheet with induced magnetic field. *Eng Sci Technol an Int J*. 2016. 19(1):313–321.

[97] Bhatti MM, Rashidi MM. Numerical simulation of entropy generation on MHD nanofluid towards a stagnation point flow over a stretching surface. *Int J Appl Comput Math*. 2017. 3(3):2275–2289.

[98] Salahuddin T, Malik MY, Hussain A, Awais M, Khan I, Khan M. Analysis of tangent hyperbolic nanofluid impinging on a stretching cylinder near the stagnation point. *Results Phys*. 2017. 7:426–434.

[99] Ul R, Nadeem S, Hayat Z, Sher N. Thermal radiation and slip effects on MHD stagnation point flow of nanofluid over a stretching sheet. *Phys E Low-dimensional Syst Nanostructures*. 2015. 65:17–23.

[100] Ibrahim W. Nonlinear radiative heat transfer in magnetohydrodynamic (MHD) stagnation point fl ow of nanofluid past a stretching sheet with convective boundary condition. *Propuls Power Res*. 2015. 4(4):230–239.

[101] Das M, Mahatha BK, Nandkeolyar R. Mixed Convection and nonlinear radiation in the stagnation point nanofluid flow towards a stretching sheet with homogenous-heterogeneous reactions effects. *Procedia Eng*. 2015. 127:1018–1025.

[102] Hayat T, Khan MI, Waqas M, Alsaedi A, Farooq M. Numerical simulation for melting heat transfer and radiation effects in stagnation point flow of carbon – water nanofluid. *Comput Methods Appl Mech Eng*. 2017. 315:1011–1024.

[103] Babu MJ, Sandeep N. Effect of nonlinear thermal radiation on non-aligned bio-convective stagnation point flow of a magnetic-nanofluid over a stretching sheet. *Alexandria Eng J*. 2016. 55(3):1931–1939.

[104] Hayat T, Qayyum S, Waqas M, Alsaedi A. Thermally radiative stagnation point flow of Maxwell nanofluid due to unsteady convectively heated stretched surface. *J Mol Liq*. 2016. 224:801–810.

[105] Hayat T, Qayyum S, Alsaedi A, Ali S. Nonlinear thermal radiation aspects in stagnation point flow of tangent hyperbolic nanofluid with double diffusive convection. *J Mol Liq*. 2016. 223:969–798.

[106] Mabood F, Shateyi S, Rashidi MM, Momoniat E, Freidoonimehr N. MHD stagnation point flow heat and mass transfer of nanofluids in porous medium with radiation, viscous dissipation and chemical reaction. *Adv Powder Technol*. 2016. 27(2):742–749.

[107] Khan WA, Makinde OD, Khan ZH. Non-aligned MHD stagnation point flow of variable viscosity nanofluids past a stretching sheet with radiative heat. Int *J Heat Mass Transf*. 2016. 96:525–534.

[108] Gupta S, Kumar D, Singh J. MHD mixed convective stagnation point flow and heat transfer of an incompressible nanofluid over an inclined stretching sheet with chemical reaction and radiation. *Int J Heat Mass Transf*. 2018. 118:378–387.

[109] Pal D, Mandal G. Hydromagnetic convective-radiative boundary layer flow of nanofluids induced by a non-linear vertical stretching/shrinking sheet with viscous-Ohmic dissipation. *Powder Technol*. 2015. 279:61–74.

[110] Pal D, Mandal G, Vajravalu K. Soret and Dufour effects on MHD convective-radiative heat and mass transfer of nanofluids over a vertical non-linear stretching/shrinking sheet. *Appl Math Comput*. 2016. 287–288:184–200.

[111] Makinde OD, Khan WA, Khan ZH. Stagnation point flow of MHD chemically reacting nanofluid over a stretching convective surface with slip and radiative heat. *J Process Mech Eng*. 2016. 0(0):1–9.

[112] Karthikeyan S, Bhuvaneswari M, Sivasankaran S, Rajan S. Soret and Dufour Effects on MHD Mixed Convection Heat and Mass Transfer of a Stagnation Point Flow towards a Vertical Plate in a Porous Medium with Chemical Reaction , Radiation and Heat Generation. *J Appl Fluid Mech*. 2016. 9(3):1447–1455.

[113] Shevtsova V, Gaponenko YA, Sechenyh V, Melnikov DE. Dynamics of a binary mixture subjected to a temperature gradient and oscillatory forcing. *J Fluid Mech*. 2015. 767:290–322.

[114] Martínez I, Sanz-Andrés A, Meseguer J. Space experiments by Da Riva's team. *International Congress on Experiments in Space and Beyond*. Brussels; 2007. 1–21.

[115] Naden N, Prater TJ. *A Review of Welding in Space and Related Technologies*. Alabama; 2020.

[116] Sack A, Heckel M, Kollmer JE. Probing the validity of an effective-one-particle description of granular dampers in microgravity. *Granul Matter*. 2015. 17:73–82.

[117] Kiran P, Narasimhulu Y. Weakly nonlinear oscillatory convection in an electrically conduction fluid layer under gravity modulation. *Int J Appl Comput Math*. 2016. 3(3):1969–1983.

[118] Bhadauria BS, Singh A. Throughflow and g-jitter effects on chaotic convection in an anisotropic porous medium. *Ain Shams Eng J*. 2018. 9(4):1999–2013.

[119] Rawi NA, Ilias MR, Mahat R, Isa ZM. G-jitter induced mixed convection flow of a second grade fluid past an inclined stretching sheet. *2nd International Conference on Material Engineering and Advanced Manufacturing Technology*. France: EDP Sciences. 2018. 01006.

[120] Anjana K. An analytical study of linear gravity modulated Rayleigh-Benard convection in a rotating Boussinesq Stokes suspension with weak electric field. *Int J Eng Res Technol*. 2016. 5(2):18–23.

[121] Kiran P, Bhadauria BS, Narasimhulu Y. Oscillatory magneto-convection under magnetic field modulation. *Alexandria Eng J*. 2018. 57(1):445–453.

[122] Javadi K, Kazemi K, Javadi K, Kazemi K. Microgravity modulation effects on free convection problems LBM simulation Microgravity modulation effects on free convection problems LBM simulation. *Physic of Fluid*. 2018. 30:017104.

[123] Thomas NM, Maruthamanikandan S. Gravity modulation effect on ferromagnetic convection in a Darcy-Brinkman layer of porous medium. *International Conference on Applied and Computational Mathematics*. August 10,2018. United Kingdom: IOP Publishing. p. 012022.

[124] Amin WNZ, Shafie S, Qasim M. G-jitter induced mixed convection flow between two parallel plates with Newtonian heating. *Science Proceedings Series*. Connecting Asia Research Network. 2019. 107–110.

[125] Bhadauria BS, Singh A, Singh MK. Chaotic convection of viscoelastic fluid in porous medium under G-jitter. *Int J Appl Mech Eng*. 2019. 24(1):37–51.

[126] Kiran P. g-Jitter effects on chaotic convection in a rotating fluid. In: Jagannathan T, Sergey IP. Advances in Condensed-Matter and Materials Physics-Rudimentary Research to Topical Technology. London, United Kindom: IntechOpen. 151-174; 2020.

[127] Nor W, Amin Z, Qushairi A, Abdulhameed M. G-jitter fully developed heat transfer by mixed convection flow in a vertical channel with constant heat flux. *Malaysian J Fundam Appl Sci*. 2020. 16(1):105–108.

[128] Vanishree RK. Convection in Anisotropic porous medium with gravity modulation using Ginzburg-Landau model. *J Eng Res Appl*. 2020. 10(4):59–64.

[129] Naser N, Aurangzaib, Kasim ARM, Shafie S. g-Jitter mixed convection on double diffusion adjacent to a vertical stretching sheet. *Recent Adv Math*. 2013. 7:174–181.

[130] Rawi NA, Rahman A, Kasim M, Ali A, Isa M. The effect of g-jitter on double diffusion by mixed convection past an inclined stretching sheet. *Proceedings of the 21st National Symposium on Mathematical Sciences (SKSM21)*. November 6-8, 2013. Melville, USA: AIP Publishing. 2015. 392-397

[131] Saini BS, Rajvanshi SC. Three-dimensional MHD free-convection flow past an infinite vertical porous plate with gravity modulation. *Int J Appl Mech Eng*. 2011. 16(4):1093.

[132] Bhadauria BS, Kiran P. Chaotic and oscillatory magneto-convection in a binary viscoelastic fluid under g-jitter. *Int J Heat Mass Transf*. 2015. 84:610–624.

[133] Bhadauria BS, Kiran P. Weak nonlinear double diffusive magneto-convection in a Newtonian liquid under gravity modulation. *J Appl Fluid Mech*. 2015. 8(4):735–746.

[134] Salah F, Aziz ZA, Viswanathan KK. Effects of g-jitter combined with heat and mass transfer by mixed convection MHD flow of a second grade fluid in a porous medium. *Int J Appl Phys Math*. 2015. 5(4):234–242.

[135] Zhang K, Wang LB. Effect of unsteady natural convection mass transfer caused by g-jitter on protein crystal growth under microgravity. *Numer Heat Transf Part A Appl*. 2016. 70(8):902–916.

[136] Gupta VK, Kumar A, Singh AK. Analytical study of weakly nonlinear mass transfer in rotating fluid layer under time-periodic concentration/gravity modulation. *Int J Non Linear Mech*. 2017. 97:22–29.

[137] Anjana K, Vanishree RK. Study of effects of temperature modulation on double diffusive convection in Oldroyd-B liquids. *Int J Eng Res Technol*. 2016. 5(6):335–343.

[138] Kumar A, Gupta VK. Study of heat and mass transport in Couple-Stress liquid under g-jitter effect. *Ain Shams Eng J*. 2018. 9(4):973–984.

[139] Chamkha AJ. Effects of heat generation on g-Jitter induced natural convection flow in a channel with isothermal or isoflux walls. *Heat Mass Transf*. 2003. 39:553–560.

[140] Siddheshwar PG, Bhadauria BS, Hashim I. Study of heat transport in a porous medium under g-jitter and internal heating effects. *Transp Porous Media*. 2013;96:21–37.

[141] Srivastava A, Bhadauria BS, Hashim PG, I S. Heat transport in an anisotropic porous medium saturated with variable viscosity liquid under g-jitter and internal heating effects. *Transp Porous Media*. 2013. 99:359–376.

[142] Yekasi V, Pranesh S. Effects of gravity modulation and internal heat generation on the onset of Rayleigh-Bénard convection in a micropolar fluid. *J Adv Math*. 2016. 12(6):6270–6285.

[143] Bhadauria BS, Singh MK, Singh A, Singh BK, Kiran P. Stability analysis and internal heating effect on oscillatory convection in a viscoelastic fluid saturated porous medium under gravity modulation. *Int J Appl Mech Eng.* 2016. 21(4):785–803.

[144] Bhadauria BS, Singh BK. Stability analysis and internal heating effects on oscillatory convection in a viscoelastic fluid layer under gravity modulation. *Asia Pacific J Eng Sci Technol*. 2016. 2(2):1–22.

[145] Thomas M, Sangeetha GK. Effect of gravity modulation and internal heat generation on Rayleigh-Bénard convection in couple stress fluid with Maxwell-Cattaneo law. *Int J Appl Eng Res*. 2018. 13(5):2688–2693.

[146] Tlili I. Effects MHD and heat generation on mixed convection flow of Jeffrey fluid in microgravity environment over an inclined stretching sheet. *Symmetry (Basel)*. 2019. 438:1–11.

[147] Gorla MG, Chand K, Singh A. Effects of rotation and heat source on MHD free convective flow on vertically upwards heated plate with gravity modulation in slip flow region. *Proceedings of the National Academy of Sciences*. *India Section A: Physical Sciences*. 2015. 85(3):427-437.

[148] Srivastava A, Bhadauria BS, Singh AK. Study of heat and mass transport in Bénard-Darcy convection with g-jitter and variable viscosity liquids in a porous layer with internal heat source. *J Appl Fluid Mech*. 2018. 11(5):1217–1229.

[149] Das UJ. Free convection heat and mass transfer flow for magnetohydrodynamic chemically reacting and radiating elastico-viscous fluid past a vertical permeable plate with gravity modulation. *Int J Appl Comput Math*. 2016. 3(3):2021–2037.

[150] Kumar GS. Thermal radiation on oscillatory flow past a moving vertical plate in a time varying gravity field. *Glob J Eng Technol Adv*. 2020. 2(1):1–7.

[151] Rajvanshi SC, Saini BS, Jeet B. Effect of radiation and gravity modulation on unsteady MHD free convection flow through porous medium in slip-flow regime with entropy. *Walailak J Eng Phys Sci*. 2014. 11(3):225–242.

[152] Rees DAS, Pop I. The effect of g-jitter on free convection near a stagnation point in a porous medium. *Int J Heat Mass Transf*. 2001. 44:877–883.

[153] Rees DAS, Pop I. G-jitter induced free convection near a stagnation point. *Heat Mass Transf*. 2001. 37(4–5):403–408.

[154] Shafie S, Amin N, Pop I. g-Jitter free convection flow in the stagnation-point region of a three-dimensional body. *Mech Res Commun*. 2007. 34(2):115–122.

[155] Rawi NA, Lim YJ, Rahman A, Kasim M, Isa M, Shafie S. g-Jitter induced free convection of heat and mass transfer flow near a two-dimensional stagnation point in micropolar fluid. *Adv Math Stat Sci*. 2015. 254–262.

[156] Uddin MJ, Khan WA, Amin NS. G-Jitter mixed convective slip flow of nanofluid past a permeable stretching sheet embedded in a Darcian porous media with variable viscosity. *PLoS One*. 2014. 9(6):e99384.

[157] Rawi NA, Ilias MR, Isa ZM, Shafie S. g-Jitter induced mixed convection flow and heat transfer of micropolar nanofluids flow over an inclined stretching sheet. *International Conference on Mathematics, Engineering and Industrial Applications 2016 (ICoMEIA2016)*. August 10-12,2016. Melville, USA: AIP Publishing. 2016. 030020.

[158] Rawi NA, Athirah N, Zin M, Mohd AR. g-Jitter induced MHD mixed convection flow of nanofluids past a vertical stretching sheet. *Advances in Industrial and Applied Mathematics : Proceedings of 23rd Malaysian National Symposium of Mathematical Sciences (SKSM23)*. 24–26 November 2015. Melville, USA: AIP Publishing. 2016. 030017.

[159] Rawi NA, Kasim ARM, Isa ZM, Mangi A, Shafie S. g-Jitter effects on the mixed convection flow of nanofluid past an inclined stretching sheet. *Front Heat Mass Transf*. 2017. 8(12):1–7.

[160] Rawi NA, Ilias MR, Mat Isa Z, Shafie S. Effect of gravity modulation on mixed convection flow of second grade fluid with different shapes of nanoparticles. *Malaysian J Fundam Appl Sci*. 2017. 13(2):132–136.

[161] Siddheshwar PG, Kanchana C. Effect of trigonometric sine, square and triangular wave-type time-periodic gravity-aligned oscillations on Rayleigh–Benard convection in Newtonian liquids and Newtonian nanoliquids. *Meccanica*. 2019. 54(3):451–469.

[162] Uddin MJ, Khan WA, Ismail AI. g-Jitter induced magnetohydrodynamics flow of nanofluid with constant convective thermal and solutal boundary conditions. *PLoS One*. 2015. 10(5):1–15.

[163] Kiran P. Nonlinear thermal convection in a viscoelastic nanofluid saturated porous medium under gravity modulation. *Ain Shams Eng J*. 2016. 7(2):639–651.

[164] Kanchana C, Siddheshwar PG, Zhao Y. Regulation of heat transfer in Rayleigh–Bénard convection in Newtonian liquids and Newtonian nanoliquids using gravity, boundary temperature and rotational modulations. *J Therm Anal Calorim*. 2020. 142(4):1579–1600.

[165] Agarwal S, Rana P. Influence of g-jitter on the Rayleigh-Bénard convection in nanofluids with internal heat source. *Advancement in Mathematical Sciences*. Melville, USA: AIP Publising. 2017. 020013.

[166] Uddin MJ, Khan WA, Bég AO, Ismail AIM. Non-Similar solution of g-jitter induced unsteady magnetohydrodynamic radiative slip flow of nanofluid. *Appl Sci*. 2020. 10(4):1–17.

[167] Bejan A. 2013 *Convection Heat Transfer*. Forth Ed. John Wiley & Sons Inc. Hoboken, New Jersey.

[168] Lebon G, Jou D, Casas-Vázquez J. 2008. *Understanding Non-equilibrium Thermodynamics*. Springer. Verlag Berlin Heidelberg.

[169] Jaluria Y. 1980. *Natural Convection Heat and Mass Transfer*. Fifth Ed. Pergamon Press. England.

[170] William Kays MC. 2005. *Convective Heat and Mass Transfer*. Forth Ed. McGraw-Hill Companies. New York, United State.

[171] Cebeci, T. Bradshaw P. *Momentum transfer in boundary layers*. New York, Washington, D.C: Hemisphere Publishing Corp.1977.

[172] Sharidan bin Shafie. *Mathematical Modelling of g-Jitter Induced Free Convection*. Ph.D. Thesis. Universiti Teknologi Malaysia; 2005.

[173] Rawi NA, Kasim ARM, Isa M, Shafie S. G-jitter induced mixed convection flow of heat and mass transfer past an inclined stretching sheet. *J Teknol*. 2014. 71(1):27–31.

[174] Admon MA, Kasim ARM, Shafie S. Unsteady free convection flow over a three-dimensional stagnation point with internal heat generation or absorption. *World Acad Sci Eng Technol*. 2011. 51:530535.

[175] Kumar KG, Rudraswamy NG, Gireesha BJ. Effects of mass transfer on MHD three dimensional flow of a Prandtl liquid over a flat plate in the presence of chemical reaction. *Results Phys*. 2017. 7:3465–3471.

[176] Singh P, Kumar M. Mass transfer in MHD flow of alumina water nanofluid over a flat plate under slip conditions. *Alexandria Eng J*. 2015. 54(3):383–387.

[177] Kandasamy R, Mohamad R, Ismoen M. Impact of chemical reaction on Cu, Al2O3 and SWCNTs–nanofluid flow under slip conditions. *Eng Sci Technol an Int J*. 2016. 19(2):700–709.

[178] Ahmed N, Saba F, Khan U, Khan I, Alkanhal TA, Faisal I, Mohyud-Din ST. Spherical shaped (Ag−Fe3O4/H2O) Hybrid nanofluid flow squeezed between two Riga plates with nonlinear thermal radiation and chemical reaction effects. *Energies*. 2019. 12(1):76.

[179] Nath R, Krishnan M. Numerical study of double diffusive mixed convection in a backward facing step channel filled with Cu-water nanofluid. *Int J Mech Sci*. 2019. 153–154(11):48–63.

[180] Khalil-Ur-Rehman, Malik MY, Bilal S, Bibi M. Numerical analysis for MHD thermal and solutal stratified stagnation point flow of Powell-Eyring fluid induced by cylindrical surface with dual convection and heat generation effects. *Results Phys*. 2017. 7:482–492.

[181] Hayat T, Waqas M, Shehzad SA, Alsaedi A. Mixed convection stagnation-point flow of Powell-Eyring fluid with Newtonian heating, thermal radiation, and heat generation/absorption. *J Aerosp Eng*. 2017. 30(1):04016077.

[182] Pal D, Mandal G, Vajravalu K. Mixed convection stagnation-point flow of nanofluids over a stretching/shrinking sheet in a porous medium with internal heat generation/absorption. *Commun Numer Anal*. 2015. 2015(1):30–50.

[183] Takabi B, Salehi S. Augmentation of the heat transfer performance of a sinusoidal corrugated enclosure by employing hybrid nanofluid. *Adv. Mech. Eng.* 2014. 6(1):147059.

[184] Khan U, Zaib A, Ishak A, Sherif ESM, Waini I, Chu YM, Pop I. 2022. Radiative mixed convective flow induced by hybrid nanofluid over a porous vertical cylinder in a porous media with irregular heat sink/source. *Case Studies in Thermal Engineering*. 2022. 30:101711.

[185] Seshadri R, Sreeshylan N, Nath G. Unsteady three-dimensional stagnation point flow of a viscoelastic fluid. *Int J Eng Sci*. 1997. 35(5):445–454.

[186] Subba R, Gorla R, Dakappagari V, Pop I. Boundary layer flow at a three-dimensional stagnation point in power-law non-Newtonian fluids. *Int J Heat Fluid Flow*. 1993. 14(4):4008–4012.

[187] Mehmood A, Ali A. An explicit analytic solution of steady three-dimensional stagnation point flow of second grade fluid toward a heated plate. *J Appl Mech Trans ASME*. 2008. 75(6): 061003.

[188] Ellahi R, Hassan M, Zeeshan A. Shape effects of nanosize particles in Cu-H2O nanofluid on entropy generation. *Int J Heat Mass Transf*. 2015. 81:449–456.

[189] Sheikholeslami M, Bhatti MM. Forced convection of nanofluid in presence of constant magnetic field considering shape effects of nanoparticles. *Int J Heat Mass Transf*. 2017. 111:1039–1049.

[190] Ghadikolaei SS, Yassari M, Sadeghi H, Hosseinzadeh K, Ganji DD. Investigation on thermophysical properties of Tio2–Cu/H2O hybrid nanofluid transport dependent on shape factor in MHD stagnation point flow. *Powder Technol*. 2017. 322:428–438.

[191] Makinde OD, Khan WA, Khan ZH. Buoyancy effects on MHD stagnation point flow and heat transfer of a nanofluid past a convectively heated stretching/shrinking sheet. *Int J Heat Mass Transf*. 2013. 62:526–533.

[192] Bhattacharyya K, Vajravelu K. Stagnation-point flow and heat transfer over an exponentially shrinking sheet. *Commun Nonlinear Sci Numer Simul*. 2012. 17(7):2728–2734.

[193] Hayat T, Farooq M, Alsaedi A. Homogeneous-heterogeneous reactions in the stagnation point flow of carbon nanotubes with Newtonian heating. *AIP Adv*. 2015. 5(2):027130.

[194] Rashidi MM, Erfani E. A new analytical study of MHD stagnation-point flow in porous media with heat transfer. *Comput Fluids*. 2011. 40(1):172–178.

LIST OF PUBLICATIONS

1. Shafie, S., **Kamal, M. H. A.**, Jiann, L. Y., Rawi, N. A. and Ali, A. (2022). Quadratic Convective Nanofluid Flow at a Three-Dimensional Stagnation Point with the g-Jitter Effect. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *93*(2). pp.111-124.

2. **Kamal, M. H. A.**, Ali, A., Jiann, L. Y., Rawi, N. A. and Shafie, S. (2022). Stagnation Point Flow of a Hybrid Nanofluid Under the Gravity Modulation Effect. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *92*(2). pp.157-170.

3. **Kamal, M. H. A.**, Lim, Y. J., Ali, A. and Rawi, N. A. (2021). 'Stagnation Point Flow Solution using Keller-Box Method' in Zulkifly, M. I. E. and Embong, A. F. (ed.) *Geometric Modelling and Simulation on Heat Transfer Problems*. Malaysia: PENERBIT UTM PRESS, pp.103-126.

4. **Kamal, M. H. A.**, Ali, A., Lim, Y. J., Rawi, N. A. and Shafie, S. (2021). Shape Effect of Cu, Al2O3 and Tio2 Nanoparticles on Stagnation Point Nanofluid Flow in a Microgravity Environment. *Data Analytics and Applied Mathematics (DAAM)*, *2*(2). pp.01-13.

5. **Kamal, M. H. A.**, Ali, A., Rawi, N. A., Jiann, L. Y. and Shafie, S. (2021). 'g-Jitter Induced on Free Convection Nanofluid Flow Near a Stagnation Point with Newtonian Heating' In *The 2nd International Professional Doctorate and Postgraduate Symposium*, pp.486-489. 26th September 2021.

6. Ismail, M. A., **Kamal, M.H.A.**, Jiann, L. Y., Ali, A. and Shafie, S. (2021). Transient Free Convection Mass Transfer of Second-grade Fluid Flow with Wall Transpiration. *CFD Letters*, *13*(11). pp.35-52.

7. **Kamal, M. H. A.**, Rawi, N. A., Ali, A. and Shafie, S. (2020). Effects of g-Jitter and Radiation on Three-Dimensional Double Diffusion Stagnation Point Nanofluid Flow. *Applied Mathematics and Mechanics, 41*(11). pp.1707-1722.

8. **Kamal, M. H. A.**, Rawi, N. A., Ali, A., and Shafie, S. (2020). 'g-Jitter and Radiation Effect on Double Diffusion Stagnation Point Nanofluid Flow' *In Conference Proceedings: 8th International Graduate Conference on Engineering, Science and Humanities*, pp.219-223. 18th – 19th August 2020.

9. **Kamal, M. H. A.**, Ali, A., Shafie, S., Rawi, N. A. and Ilias, M. R. (2020). g-Jitter Effect on Heat and Mass Transfer of 3D Stagnation Point Nanofluid Flow with Heat Generation. *Ain Shams Engineering Journal*, *11*(4). pp.1275-1294.

10. Hamdan, F. R., **Kamal, M. H. A.**, Rawi, N. A., Mohamad, A. Q., Ali, A., Ilias, M. R. and Shafie, S. (2020). g-Jitter Free Convection Flow Near a Three-Dimensional Stagnation-Point Region with Internal Heat Generation. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 67*(1). pp.119-135.

11. **Kamal, M. H. A.**, Ali, A., Shafie, S., Rawi, N. A. and Ilias, M. R. (2020). 'Copper Nanoparticles Effects on Electrical Conducted Nanofluid Flow at Stagnation Point Region with Fluctuating Gravitational Field' *In CASEAN-6 PROCEEDINGS: 6th Academic Conference on Natural Science for Young Scientists, Master & Phd Students from Asean Countries*, pp.274-280. 23rd – 26th October 2019.

12. **Kamal, M. H. A.**, Rawi, N. A., Ali, A. and Shafie, S. (2019). 'g-Jitter Induced Natural Convection Nanofluid Flow with Mass Transfer in The Stagnation Point Region of a Three-Dimensional Body' *In Journal of Physics: Conference Series*, *1366*(1). p. 012036. 23rd – 25th July 2019.

13. **Kamal, M. H. A.**, Rawi, N. A., Ilias, M. R., Ali, A. and Shafie, S. (2019). Effect of Thermal Radiation on a Three-Dimensional Stagnation Point Region in Nanofluid Under Microgravity Environment. *Universal Journal of Mechanical Engineering, 7*(5). pp.272-284.

14. **Kamal, M. H. A.**, Rawi, N. A., Ali, A. A. and Shafie, S. (2019). 'The Flow and Heat Transfer with Thermal Radiation at a General Stagnation Point in Nanofluid Under Microgravity Environment' in *Science Proceedings Series*, 1(2). pp.58-61. 1st -2nd May 2019.

15. **Kamal, M. H. A**., Rawi, N. A., Ali, A. and Shafie, S. (2019). g-Jitter Induced Free Convection Flow Near a Three-Dimensional Stagnation Point Region in Nanofluid with Heat Generation. *ASM Sc. J: Akademi Sains Malaysia Sains Jurnal*, *12*(Special Issue 6), pp.125-136.

16. **Kamal, M. H. A.**, Ali, A. and Shafie, S., (2019). g-Jitter Free Convection Flow of Nanofluid in The Three-Dimensional Stagnation Point Region. *MATEMATIKA: Malaysian Journal of Industrial and Applied Mathematics, 35*(2). pp.260-270.