UNSTEADY FREE CONVECTION NANOFLUID FLOW NEAR STAGNATION POINT OF A THREE-DIMENSIONAL BODY

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Special dedication to my beloved parents and to my husband

Saidin Bin Hassan

Zaroni Binti Senapi

and

Ahmad Ghadaffi Bin Muhamad,

also to all of my brothers and sisters.

To my great supervisor and co-supervisor

Dr. Mohd Ariff Bin Admon

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ABSTRACT

Industrial systems gain a lot of benefit from unsteady free convection flow near the stagnation point of three-dimensional body such as the cooling of an infinite metallic plate in cooling baths and the boundary layer along material handling conveyers. In this study, a mathematical model of an unsteady free convection flow near the stagnation point of a three-dimensional body is developed. The problem considered involves the flow in nanofluid. The governing equations consist of continuity, momentum, energy and nanoparticle volume fraction are solved numerically through the Keller-box method. The effect of the physical parameters such as Brownian motion, thermophoresis and buoyancy parameters on the velocity, temperature and concentration profiles are investigated and discussed. Furthermore, various values of the physical parameter are examined by the skin friction coefficient in *x*- and *y*- directions, the local Nusselt number and Sherwood number. The results of the skin friction, velocity, temperature and concentration profile are presented and computed using FORTRAN and MATLAB software. The results have shown that Brownian motion, buoyancy, thermophoresis parameters and Lewis number give rises to the concentration profile. In addition, the skin friction is increased when the curvature parameter is increased.

ABSTRAK

Sistem perindustrian mendapat banyak faedah daripada aliran titik genangan tiga matra simetri sepaksi seperti penyejukan plat logam tak terhingga di dalam penyejuk mandian dan lapisan sempadan di sepanjang pengelolaan bahan-bahan penghantaran. Dalam kajian ini, model matematik dibina untuk mengkaji aliran cecair nano bagi jasad tiga matra tidak mantap berhampiran dengan titik genangan. Masalah aliran yang dipertimbangkan adalah aliran dalam nano. Persamaan menakluk yang terdiri daripada persamaan keselanjaran, persamaan tenaga, persamaan momentum dan pecahan jumlah partikel nano diselesaikan secara berangka menggunakan kaedah kotak-keller. Kesan parameter fizikal seperti parameter gerakan Brownian, parameter thermophoresis, parameter keapungan pada halaju, suhu dan kepekatan dikaji dan dibincangkan. Tambahan pula, pelbagai nilai parameter fizikal diperiksa oleh pekali geseran kulit di arah x dan arah y, nombor Nusselt dan nombor Sherwood. Hasil yang ditunjukkan termasuk geseran kulit, halaju, suhu dan kepekatan dikira menggunakan perisian FORTRAN dan MATLAB. Keputusan menunjukkan bahawa parameter gerakan Brownian, parameter keapungan, parameter thermophoresis dan nombor lewis memberikan peningkatan kepada profil kepekatan. Di samping itu, geseran kulit meningkat apabila parameter kelengkungan meningkat.

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LIST OF SYMBOLS

a	-	acceleration
a1, **a**2	-	unit vectors
a, b	-	principles curvature in the *x*-and *y*-planes
c	-	curvature parameter
c_p	-	heat at constant pressure
D_B	-	Brownian diffusion coefficient
D_T	-	thermophoretic diffusion coefficient
F	-	force
g	-	gravity acceleration
J_σ	-	surface curvature
k	-	fluid conductivity
	-	thermal conductivity
m	-	mass
n	-	unit normal
n	-	index point on ξ plane
O	-	nodal stagnation point
P	-	pressure
P_D	-	dynamic pressure
R	-	vector position
r	-	surface of the body S
S	-	body surface
t	-	time
T	-	fluid temperature
T_w	-	wall temperature
T_∞	-	ambient temperature

u, v, w	-	velocity component along x-, y-, z-axes
V	-	velocity vector
x, y, z	-	Cartesian coordinates

Greek Symbols

α	-	thermal diffusivity
β	-	thermal expansion
∇	-	gradient operator
∇_s	-	surface gradient operator
η	-	plane along y-axis
h	-	volumetric heat addition
μ	-	dynamic viscosity
v	-	kinematic viscosity
ϕ	-	viscous dissipation
ρ	-	density
τ	-	dimensionless parameter
	-	viscous stress
θ	-	dimensionless parameter
ξ	-	plane along x-axis

Superscripts

'	-	differentiation with respect on η

Subscripts

s	-	steady-state flow
w	-	wall condition
∞	-	far field condition

Nondimensional number

C_{fx}	-	skin friction coefficient in x-direction
C_{fy}	-	skin friction coefficient in y-direction
Gr	-	Grashof number

Le	-	Lewis number
Nu	-	Nusselt number
N_b	-	Brownian motion parameter
N_r	-	buoyancy parameter
N_t	-	thermophoresis parameter
Pr	-	Prandtl number
Ra	-	Rayleigh number
Re	-	Reynold number
Sh	-	Sherwood number
	-	mass transfer Nusselt number

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The study of convective heat transfer in nanofluids is gaining a lot of attention. As we know, a nanofluid is a fluid that contains nanometer-sized particles called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid, which is the term proposed by Choi (1995) to describe the new class of nanotechnology-based heat transfer fluids that exhibit thermal properties superior to those of their base fluids or conventional particle fluid suspensions. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. The nanofluids have novel properties that make them potentially useful in many engineering applications in the industry including microelectronics, fuel cells, pharmaceutical processes and hybrid-powered engines.

These fluids can be assumed to be single phase or two-phase models. Classical theory of single phase models can be applied when nanoparticles and base fluids are considered as a single homogeneous fluid while two-phase models can be useful when equations of motion for handling nanoparticles and base fluids separately. Since the inception of the nanofluid concept about two decades ago, the potentials of nanofluid in heat transfer applications have attracted more attention from researchers. Accordingly, some of the applications of nanofluid are electronic applications, transportations and industrial cooling applications. Therefore, the present work has been undertaken in order to study the unsteady free convection nanofluid flow near stagnation point of a three-dimensional body.

1.2 Research Background

Free convection on boundary layer flow near a stagnation point has gained a great deal of attention from several researchers in this field. Free convection or natural convection may occur in many applications, such as cooling molten metals, fluid flows around shrouded heat dissipation fins, and solar ponds. This convection occurs naturally without any forces and is considered as an important finding in solving many applications in real life. Due to this reason, many researchers have studied theoretically and performed experiments that are related to this problem. For example, the steady three-dimensional boundary layer equations were derived by Poots (1964). The investigation was focused on the isothermal curved surface. The researcher maintained the temperature above the ambient temperature of the fluid. Thus, the stagnation point is defined at the lowest point of the surface and it shows that the stagnation point was solved numerically depending on Prandtl number and Grashof number.

Next, this paper was continued by Xu *et al*. (2008) that studied the series solution of unsteady free convection flow in the stagnation-point region of three-dimensional body in ambient fluid. Xu *et al*. (2008) focused to continue the Poots (1964) work but in an unsteady case. The original momentum and energy equation have been reformulated and applied to the homotopy analysis method to obtain the accurate series solutions of resulting equations.

Most importantly, this research focused to expand the following works by Admon *et al.* (2011) who studied the unsteady free convection flow near the stagnation point of three-dimensional body and to investigate the behavior of heat and mass transfer on viscous and incompressible fluid. This problem has similar problems with Poots (1964) but was solved numerically using different methods.

The governing boundary layer equation was transformed first into non-similar boundary layer and solved numerically using finite-difference scheme known as Keller-box method. This research investigated the effect of curvature parameter, c and Prandtl number, Pr to the flow and heat transfer characteristics.

Nanoparticles are defined to be an object with at least one dimension smaller than 100 nanometer-sized. When a particle is that small and the area of the particle which got the surface is much higher than its weight, this causes the particle to develop new and exciting properties. The addition of nanoparticles in a base fluid like water and a solution where the suspension of nanoparticles can be stabilized will result in the creation of something extraordinary. This set-up is defined as nanofluids.

Choi (1995) is the first among many to use the term nanofluids. The purpose of the nanofluids is to intensify the heat transfer properties and the development of the nanofluids is potentially useful for several applications such as cooling of electronics and cooling of data center where a computer ejects a lot of heat, coolants, and so forth. The in-depth study on nanofluids can be found in the book, Nanofluids: Science and Technology, by Das *et al*. (2007), in the review paper by Wang and Mujumdar (2008), Yang *et al*. (2013), and Jahani *et al*. (2013). Kuzetsov and Nield (2010) used Buogiorno (2006) model to investigate a natural convection flow of a nanofluid over a vertical plate.

Since the heat and mass transfer are very extensive in the industry, the unsteady three-dimensional body near stagnation point can give a significant impact on the heat transfer process. Thus, it can improve the previously developed result. Therefore, on the present study, this research will be focusing on the numerical study of the unsteady free convection near the stagnation point of the three-dimensional body in nanofluid.

1.3 Problem Statement and Research Questions

This present study will concentrate on these problems and explore the following questions:

(1) What is the mathematical model for the unsteady free convection nanofluid flow near stagnation point problem?

(2) How to apply Keller-box method for this problem?

(3) What happens to the skin friction, velocity, temperature and concentration profile of unsteady free convection near stagnation point flow in the present nanofluid particle?

1.4 Objective of the Study

The main objective of this study is to investigate the unsteady boundary layer flow near the three-dimensional stagnation point in nanofluid theoretically. It is required to construct the correct mathematical model and solve the equation numerically. Following are the objectives for this study:

(1) To develop a mathematical model for unsteady free convection nanofluid flow near stagnation point of a three-dimensional body.

(2) To simulate the governing equation using the Keller-box method.

(3) To investigate the effects of nanofluid on skin friction, velocity, temperature and concentration profile of unsteady free convection near the stagnation point.

1.5 Scope of the Study

This study focused on the unsteady free convection flow near the stagnation point of a three-dimensional body in nanofluid. Three-dimensional mathematical modeling will be formulated. Numerical solution is obtained using implicit finite-difference scheme of Keller-box method. Mathematical software of FORTRAN and MATLAB were used to compute and plot all interested profiles of the skin friction, velocity, temperature and concentration profile. In this research, no experimentation is needed.

1.6 Significance of the Study

Boundary layer and stagnation point flow have important impacts on the industry and technology application. Many applications such as in the food processing industry can be demonstrated using boundary layer flow near stagnation point theory. Boundary layer theory calculates the skin friction drag which acts on the body movement through all types of fluid. Furthermore, this theory is suitable to identify the shape that is right for the body to avoid bad results. Besides that, it is also suitable to be used in turbine blade, aeroplane wing and drag of the ship.

For decades, the research on heat and mass transfer has been carried out by many researchers and there are many methods that have been used and put forward. For this recent year, there are many researchers studying the flow of heat transfer in nanofluid. This fluid can extremely enhance the heat transfer characteristics of the base fluid. Thus, there are many applications of nanofluid in the industry such as heat exchangers, coolants, micro-channel heat sinks and lubricants. Finally, this study is a medium to give better understanding on the behaviors of fluid motion, the effects of nanofluid on the boundary layer flow near the stagnation point and phenomena of fluid mechanics and heat transfer.

1.7 Research Organization

This study consists of six chapters. Chapter 1 includes introduction, research background, problem statement, objectives of study, scope of the study, significance of study. The literature review is a summary of research on previous works related to unsteady free convection boundary layer near stagnation points and will be discussed in Chapter 2. Chapter 3 discusses the derivation of the equation of motion. The governing equations of the unsteady free convection nanofluid flow near stagnation point of a three-dimensional body are discussed in Chapter 4. Chapter 5 will explain the result and discussion. Lastly, Chapter 6 describes the conclusion and followed by some suggestions for future research.

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