A STUDY OF FLOW AND HEAT TRANSFER OF NANOFLUIDS: BETWEEN TWO PARALLEL PLATES, OVER A WEDGE AND PAST A STRETCHING SHEET

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

Faculty of Science Technology and Human Development
Universiti Tun Hussein Onn Malaysia

APRIL 2017

This thesis is consecrated to my beloved parents; Late Alhaji Salihu Usman (Madaki) and Hajiya Halimatu M. Salihu

ACKNOWLEDGEMENTS

First of all, I thank Allah (S.W.T.) the most gracious, the most merciful, for the infinite wisdom and blessings he bestowed upon me during the course of my Ph.D. programme until its completion. It is indeed a great pleasure to express my profound gratitude to all and sundry who have contributed towards seeing this work achieve success.

The role played by my supervisor Associate Professor Dr. Rozaini Bin Roslan, would never be overemphasized. So, I would like to acknowledge his outstanding andefficient work and contributions by introducing me to this charming area and regulardiscussions sessions to give guide in some gray and challenging areas until the successof this thesis is finally achieved. Furthermore, I would also like to acknowledge theremarkable contributions by my Co-supervisor Professor Dr. Ramasamy Kandasamyand for everything he did to me towards the success of this thesis. Their contributionsand participation, have been so helpful to this study.

I am grateful to the staff of the Department of Mathematics Universiti Tun Hussein Onn Malaysia, for being kind to me and provided me with all the necessary materials and bits of advice. Special thanks to all my colleagues in the research group, all my friends, and well-wishers for their incredible motivation toward the success of this study. It is an honor for me to express my sincere gratitude to my beloved mother, wife, brothers and sisters for their moral support, encouragement, and prayers throughout my studies.

Concerning the financial aid, I am equally grateful to the Universiti Tun Hussein Onn Malaysia for awarding me a research grant under the Postgraduate Research Assistant for Graduate Incentive Research Grant through the Vot number U191.

Finally, I am so much grateful to my employer, the Abubakar Tafawa Balewa University, Bauchi (ATBU), Nigeria, for allowing me a study leave and granted a full opportunity to pursue and complete my Ph.D. accordingly.

ABSTRACT

This thesis investigates analytically and numerically the flow and heat transfer of nanofluids: between two infinite parallel plates, over a wedge, and past a stretching sheet. Two problems have been considered for the parallel plates. A mathematical model of squeezing unsteady nanofluid flow is studied firstly in the presence of thermal radiation, and secondly, in the presence of both thermal radiation and heat generation/absorption. The solutions are obtained by using homotopy perturbation method (HPM) and fourth-order Runge-Kutta with shooting technique (RK4). The flow of nanofluids over a wedge leads to the derivation of the Falkner-Skan equation and this problem have been solved using the optimal homotopy asymptotic method (OHAM). Finally, three issues have been considered for nanofluids past the stretching sheet. Firstly, we considered a problem of flow and heat transfer of nanofluids over a dynamic stretching sheet with non-linear velocity and variable thickness in the presence of Brownian motion and thermal radiation. Secondly, the effect of a chemical reaction is taken into account. These two problems have been investigated using the OHAM and RK4. Lastly, a mathematical model for the effect of chemical reaction in a natural convective boundary-layer flow of nanofluids has been evolved. The HPM with Pade approximation (HPM-Pade) along with RK4 is used to solve the nonlinear governing equations. It is found that the thermal radiation had recorded a significant influence, in which it has been observed that the growing value of the thermal radiation parameter results to the decrease in the temperature profile in the case of squeezing flow problem. Thereby both the thermal boundary layer thickness and temperature profile have substantially risen in the flow and heat transfer over a stretching sheet cases. From the subsequent cases, we also found that the temperature is high due to the increase in both the Brownian motion and the thermophoresis parameters, while the scenario reverses as the nanoparticle concentration only increases with the strengthen thermophoresis parameter and slow down with an increase in the Brownian motion parameter.

ABSTRAK

Tesis ini mengkaji secara analitik dan berangka aliran dan pemindahan haba nanobendalir: yang berada di antara dua plat tak terhingga yang selari, terhadap baji dan melintasi helaian yang meregang. Dua masalah telah dipertimbangkan untuk aliran melalui plat selari. Pertamanya, model matematik terhadap aliran tak mantap nanobendalir yang dipicit dengan kehadiran sinaran terma dan keduanya, dengan kehadiran sinaran terma dan penjanaan/penyerapan haba. Penyelesaian diperoleh menggunakan kaedah usikan homotopi (HPM) dan skim Runge-Kutta peringkat empat dengan teknik tembakan (RK4). Aliran nanobendalir terhadap baji pula mendorong kepada pembentukan persamaan Falkner-Skan dan telah diselesaikan menggunakan kaedah homotopi asimptot optimum (OHAM). Akhirnya, tiga isu telah dipertimbangkan untuk nanobendalir yang melintasi helaian yang meregang. Pertamanya, masalah aliran dan pemindahan haba nanobendalir terhadap helaian yang meregang secara dinamik dengan halaju tak linear dan ketebalan yang berbeza diiringi dengan kehadiran pergerakan Brown dan sinaran terma. Keduanya, kesan tindak balas kimia telah diambil kira. Kedua-dua masalah ini telah dikaji menggunakan OHAM dan juga RK4. Akhirnya, model matematik bagi kesan tindak balas kimia pada perolakan tabii di dalam aliran lapisan sempadan nanobendalir telah dikaji. Kaedah HPM dengan anggaran Pade (HPM-Pade) bersama dengan RK4 digunakan untuk menyelesaikan persamaan menakluk tak-linear. Didapati bahawa sinaran terma memberi kesan yang penting, yang mana pada masalah aliran cubitan dengan meningkatkan parameter sinaran terma menghasilkan pengurangan pada profil suhu. Pada waktu yang sama pada masalah helaian merenggang, kedua-dua ketebalan lapisan sempadan terma dan profil suhu meningkat secara ketara. Pada masalah yang terakhir, didapati bahawa suhu meningkat akibat dari pada peningkatan parameter gerakan Brown dan termoforesis. Sementara itu, senario sebaliknya berlaku apabila kepekatan nanozarah hanya meningkat dengan kekuatan parameter termoforesis dan perlahan dengan peningkatan parameter gerakan Brown.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HPM	-	Homotopy perturbation method
OHAM	-	Optimal homotopy asymptotic method
MHD	-	Magnetohydrodynamic flow
HAM	-	Homotopy analysis method
BVP	-	Boundary value problem
IVP	-	Initial value problem
ADM	-	Adomian decomposition method
DTM	-	Differential transformation method
LSM	-	Least square method
CM	-	Collocation method
DRA	-	Duan-Rach approach
PHF	-	Prescribed heat flux

NOMENCLATURE

Roman Letters

a, b	-	Positive constants along the sheet
A	-	Ratio of the rates of free stream velocity to the parameter velocity of the stretching sheet
A_1, A_2, A_3	-	dimensionless constants
Bi	-	Biot number
B_0	-	Magnetic field
C	-	nanoparticle volume fraction
C_f	-	Skin friction coefficient of the fluid
$\mathbf{C}_i\,(i = 1, 2, ..., m)$	-	Concentration of each species i
$C_j\,(j = 1, 2, ..., m)\,, K$	-	positive Convergence-control parameters
C_w	-	nanoparticle volume fraction at the sheet surface (wall)
C_∞	-	Ambient nanoparticle volume fraction
D_B	-	Brownian diffusion coefficient, kg/ms
D_T	-	Thermophoretic diffusion coefficient, kg/msK
Ec	-	Local Eckert number
$f(\eta)$	-	Dimensionless stream function
$\overrightarrow{f}$	-	Body force per unit mass
h	-	Convective heat transfer coefficient
$\boldsymbol{h}$	-	Step size
$H\,(p)\,, H\,(p, \eta)$	-	Auxiliary functions
$\mathbf{J}$	-	Flux for the conserved quantity φ
$\mathbf{J}_i$	-	Flux
k_1	-	Rate of chemical reaction
k_f	-	Effective thermal conductivity of base fluid, W/mK

k_nf	-	nanofluid's thermal conductivity
k_s	-	thermal conductivity of the solid material
$\mathbf{K}$	-	Dissipation function
l	-	initial position of the plates
L	-	Linear operator
Le	-	Lewis number
M	-	Magnetic parameter
n	-	velocity power index parameter
N	-	Radiation parameter
$\mathcal{N}$	-	Nonlinear operator
Nb	-	Brownian motion parameter
Nt	-	Thermophoresis parameter
Nu	-	Nusselt number
Nur	-	Reduced Nusselt number
p	-	Pressure N/m^2
P	-	generalized pressure
$P_E(\eta)$	-	Polynomial of degree at most E
Pr	-	Prandtl number
q_m	-	Wall mass flux, kg/sm^2
q_r	-	Radiative heat flux
q_w	-	Wall heat flux, W/m^2
Q	-	heat generation/absorption coefficient
$Q_G(\eta)$	-	Polynomial of degree at most G
$\mathbf{R}$	-	Consumption term
Re_x	-	Local Reynolds number
S	-	squeezing integer
Sc	-	Schmidt number
Sh	-	Sherwood number
Shr	-	Reduced Sherwood number
T	-	Local fluid temperature, K
t	-	dimensionless time
T_w	-	Convective surface temperature, K

T_∞	-	Ambient temperature, K
u, v	-	Velocity components along x and y directions, m/s
U_w	-	Stretching sheet velocity at wall, m/s
U_∞	-	Free stream velocity, m/s
$\overrightarrow{V}$	-	Velocity vector
x	-	Coordinate along the sheet
y	-	Coordinate normal to the sheet
z	-	Independent variable
$'$	-	Differentiation with respect to η

Greek Letters

α	-	Thermal diffusivity of the base fluid, m^2/s
β	-	Wedge angle parameter
η	-	Similarity variable
γ	-	Chemical reaction parameter
Γ	-	boundary
λ	-	heat generation parameter
μ	-	Absolute viscosity of the base fluid, Ns/m^2
ν_f	-	Kinematic viscosity of the base fluid, m^2/s
∇	-	$\frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j}$ (vector operator)
ω	-	vorticity function
Ω	-	domain of the boundary
$\frac{\partial}{\partial n}$	-	Normal derivative pointing outward from Ω
$(\rho C)_f$	-	Effective heat capacity of the base fluid, kg/m^3K
$(\rho C)_p$	-	Effective heat capacity of the nanoparticle material, kg/m^3K
ρ_f	-	Density of the base fluid, kg/m^3

ρ_p	-	Nanoparticle mass density, kg/m^3
ψ	-	Stream function
σ_e	-	Electrical conductivity
τ	-	$(\rho C)_p/(\rho C)_f$
$\overline{\tau}$	-	Viscous stress tensor
θ	-	Dimensional temperature
θ_c	-	Ratio of the temperature of the hot fluid to the ambient temperature
φ	-	Dimensionless nanoparticle volume fraction

Superscripts

$'$	-	Differentiation with respect to η

Subscripts

f	-	fluid
nf	-	nanofluid
p	-	solid particle
w	-	surface (w)
∞	-	condition at the free stream

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