CONVECTIVE BOUNDARY LAYER FLOW IN GENERALIZED NEWTONIAN NANOFLUID UNDER VARIOUS BOUNDARY CONDITIONS

MOHAMMED MAHDI FAYYADH ALSHAMMARI

A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy in Science

Faculty of Applied Sciences and Technology
Universiti Tun Hussein Onn Malaysia

JUNE 2021

DEDICATED TO
My beloved father and mother
All this become possible just because of their prayers.
My wonderful wife, NS
With special gratitude to ARWA the best daughter, I can imagine. you have been a gift from the beginning.

ACKNOWLEDGEMENT

I earnestly put on record my immense gratitude to my research supervisor, Professor **DR. ROZAINI BIN ROSLAN** of Mathematics and Statistics Department, Faculty of Applied Sciences and Technology, University Tun Hussein Onn Malaysia, and my research co-supervisor **PROF. DR. ISHAK HASHIM**, School of Mathematical Sciences, University Kebangsaan Malaysia, for extraordinary generosity in guiding me through my research endeavors at all stages. Their tireless and enthusiastic guidance had no boundaries during the preparation of this thesis.

My sincere thanks also go to **DR. KOHILAVANI NAGANTHRAN**, Department of Mathematical Sciences, Universiti Kebangsaan Malaysia, and **DR. MD FAISAL MD BASIR,** Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, who provided me with an opportunity to join their team and allowed me to conduct the essential thesis research. Without their precious support, it would not be possible to conduct this research. I express my special thanks to Professor **DR. RAMASAMY KANDASAMY,** for his genuine support at the beginning of this research work.

I would like to acknowledge **PROF. DR ROSLINDA BT. MOHD NAZAR** and **ASSOC. PROF. DR. KAVIKUMAR S/O JACOB** for their insightful comments, helpful suggestion, and corrections.

I record my sincere gratitude to my mother, wife and siblings to be pillars of my strength and give me their unconditional love. Appreciation also goes to everyone who is directly or indirectly involved in compiling this thesis.

ABSTRACT

Convection heat transfer with the nanofluid plays a vital role in many applications. The four mathematical models of boundary layer flow solved under different boundary conditions. The first problem considered the unsteady squeezing flow of the Carreau nanofluid over the sensor surface, where three different nanoparticles were suspended in the base fluid. A comparison of the results of suspended materials in liquids proved that increased surface permeability leads to increased heat transfer. The second problem described the magnetohydrodynamics (MHD) Darcy-Forchheimer model, which considers Maxwell nanofluids' flow. It was observed that an increase in the Biot number coefficient increased heat transfer. The third problem evaluated activation energy and binary reaction effect on the MHD Carreau nanofluid model. Buongiorno nanofluid model was applied to shear-thinning or pseudoplastic fluid over the pereamble surface. The relationship between the activation energy and chemical reaction is influential and controls heat transfer processes. The fourth problem analyzed the radiative Sutterby model over a stretching/shrinking sheet towards stagnation point flow. Dual solutions were found using the scaling group transformation, which was examined by a stability approach. Such a problem found an increment in the suction parameter, the Deborah number, and the nanoparticle volume fraction delayed the flow separation. The influence of various pertinent parameters on the velocity and temperature distributions has been presented. The most relevant results by the forceful impacts of thermo-physical properties on fluids were analyzed through this work. Modeled equations are based on the conservation laws under the boundary layer approximation. The similarity transformation method is used to convert the governing partial differential equations into ordinary differential equations. They are then solved using a numerical technique, known as the Runge-Kutta-Fehlberg method with shooting technique in the MAPLE 17 or *bvp4c* method in the MATLAB 2019a.

ABSTRAK

Empat model matematik bagi aliran lapisan sempadan pada bendalir Newtonan teritlak telah diselesaikan menggunakan pendekatan separa-analisis tertakluk kepada syarat sempadan yang berlainan. Masalah pertama mempertimbangkan aliran lapisan sempadan nanobendalir Carreau di atas permukaan sensor; tiga nanozarah berlainan telah diletakkan di dalam bendalir asas. Perbandingan keputusan bahan yang direndam di dalam cecair membuktikan bahawa ketelapan permukaan menyebabkan pemindahan haba bertambah. Masalah kedua menggambarkan model Darcy-Forchheimer megnetohidrodinamik (MHD), yang mengambil kira aliran nanobendalir Maxwell dan didapati dengan peningkatan pekali nombor Biot juga meningkatkan pemindahan haba. Masalah ketiga menilai tenaga pengaktifan dan kesan reaksi dedua terhadap model nanobendalir Carreau MHD. Model nanobendalir Buongiorno telah digunakan untuk bendlir penipisan ricih atau bendalir pseudoplastik atas permukaan sedutan/semburan. Begitu juga hubungan di antara tenaga pengaktifan dengan reaksi kimia yang mempengaruhi dan mengawal proses pemindahan haba. Masalah keempat menganalisis model radiasi Sutterby atas helaian telap yang meregang/mengecut terhadap aliran titik genangan dalam nanobendalir. Penyelesaian dual telah diperoleh menggunakan penjelmaan kumpulan penskalaan dan dikaji dengan pendekatan kestabilan. Didapati dengan penambahan parameter sedutan, nombor Deborah, dan pecahan isipadu nanozarah telah melambatkan pemisahan aliran. Pengaruh pelbagai parameter penting ke atas halaju dan taburan suhu digambarkan secara bergraf dan jadual serta dibincangkan. Persamaan-persamaan yang dimodelkan adalah berasaskan kepada hukum-hukum keabadian tertakluk kepada penghampiran lapisan sempadan. Kaedah penjelmaan keserupaan telah digunakan untuk menukar persamaan menakluk kepada persamaan terbitan biasa. Ia kemudian diselesaikan secara penyelesaian berangka, iaitu kaedah Runge-Kutta Fehlberg dengan teknik tembakan menggunakan MAPLE 17 atau kaedah bvp4c di MATLAB 2019a.

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A_1 - First order Rivlin-Erickson (deformation rate tensor)
Al_2O_3 - Aluminium oxide
b - Squeezed flow parameter
B_o - Magnetic field strength
Bi - Biot number
c - Constant
c_p - Specific heat capacity at constant pressure
C - Nanoparticle concentration
C_w - Nanoparticle concentration at the wall
C_∞ - Ambient nanoparticle concentration
C_A - Nanoparticle concentration of A case reaction
C_b - Drag coefficient
C_{fx} - Skin friction coefficient
C_B - Diffusion parameter $C_{B=} D_B /T$
C_T - Diffusion parameter $C_{T=} D_T / \phi$
Cu - Copper
D_B - Brownian diffusion coefficient
D_b - Diffusion coefficient
D_T - Thermophoretic diffusion
De - Deborah number
$\phi(s')$ - Error for guess s' for initial condition
$\phi(s^*)$ - Error for guess s^* for initial condition
E - Activation energy parameter
E_a - Activation energy
Ec - Eckert number

f - Dimensionless stream function

F - Non-uniform inertia coefficient of the porous medium

Fe_3O_4 - Magnetite nanoparticles

Fr - Inertia coefficient (Forchheimer number)

G - Generalized parameter of the scaling group

$h(t)$ - Highest squeezed channel

h_o - Constant

h_w - Heat transfer coefficient at the wall

h_m - Convection mass transfer coefficient

H - Fitted rate constant

I - Identity tensor

j - Mass flux of nanoparticle

k - Thermal conductivity

k_B - Boltzmann constant

k_1 - Rosseland mean absorption

K - Permeability of porous medium

K_r^2 - Binary chemical reaction rate

l - Characteristic shape of nanoparticle

L - Characteristic length scale

M - Magnetic field parameter

n - Power law index parameter

$\check{n}$ - Normal unit vector at a point

N_b - Brownian motion parameter

N_t - Thermophoresis parameter

Nu - Nusselt number

Nu_x - Local Nusselt number

N_A'' - Mass flux of reaction A

P - Pressure

Pr - Prandtl number

$q(x)$ - Heat flux of the wall

q''_w - Surface heat flux

Rd - Radiation parameter

Re - Reynolds number
Re_x - Local Reynold number
s - Permeable velocity parameter
s', s^* - guesses for unknown initial conditions
$\boldsymbol{S}$ - Extra stress tensor
Sc - Schmidt number parameter
Sh_x - Sharwood number parameter
t - Time
t^* - guess value
T - Temperature of the fluid
$\boldsymbol{T}$ - Cauchy stress tensor
T_o - Reference temperature
T_w - Temperature at the wall
T_∞ - Temperature at the stream flow
$T(y)$ - Temperature gradient in y-directions
$tr(A_1^2)$ - Trace of matrix A_1^2
u, v - Velocity components in x, y directions, respectively
u_1, v_1 - reference velocity components in x, y directions, respectively
$\bar{u}, \bar{v}$ - Velocity vector components in $\bar{x}, \bar{y}$ -directions
u_o - Characteristic velocity vector component
$\bar{u}_w, \bar{v}_w$ - Velocity vector component at the wall
$\bar{u}_e$ - Free stream velocity vector component
U_∞ - Uniform velocity of the free stream flow
U_w - Uniform velocity of the free stream flow
$u(y)$ - Velocity gradient in y-directions
$U(x)$ - Uniform velocity of the free stream flow
$\boldsymbol{V}$ - Characteristic velocity of the flow
We - Weissenberg number
ω_i - Constant to be determined in which $i=1\ldots,8$

Greek symbols

α	-	Thermal diffusivity
α', β'	-	Two-point boundary conditions values
$\dot{\gamma}$	-	The rate of shear stress
γ	-	Eigenvalue parameter
δ	-	Boundary layer thickness
δ_t	-	Thermal boundary layer thickness
δ_c	-	Concentration boundary layer thickness
δ_1	-	Temperature difference parameter
ε	-	Stretching/shrinking
ϵ	-	Small quantity constant
η	-	Similarity variable
θ	-	Dimensionless temperature
$-\theta'(0)$	-	The rate of heat transfer
κ	-	Binary reaction parameter
λ	-	Porosity parameter of porous medium
μ	-	Dynamic viscosity
μ_∞	-	Viscosity of infinite shear rate
μ_o	-	Low shear rate viscosity
υ	-	Kinematic viscosity
ρ	-	Density of fluid
ρc_p	-	Heat capacity
σ^{**}	-	Stefan-Boltzmann constant
σ	-	Electrical conductivity
$\tau_{xy}, \tau_{yx}, \tau_{xx}, \tau_{yy}$	-	momentum components shear stresses
τ	-	Similarity transformation for time
τ_w	-	Shear stress at the wall
φ	-	Dimensionless concentration
ϕ	-	Nanoparticle volume fraction
ψ	-	Stream function
Γ	-	Material time constant
Υ	-	Nanoparticle volume fraction parameter

Subscript

bf - Fluid
nf - Nanofluid
s - Nanoparticle
p - Particle
w - Surface
∞ - Infinity (free stream flow)

Superscripts

T - Transpose of matrix

Abbreviations

BVP - Boundary value problem
bvp4c - Boundary value problem with fourth-order accuracy
IVP - Initial value problem
MHD - Magnetohydrodynamic
MWCNTs - Multi-walled carbon nanotubes
ODEs - Ordinary differential equations
PDEs - Partial differential equations
SWCNTs - Single-walled carbon nanotubes
2D - Two-dimensional

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LIST OF PUBLICATIONS

Fayyadh, M. M., Naganthran, K., Md Basir, M. F., Hashim, I., & Roslan, R. (2020). Radiative MHD Sutterby nanofluid flow past a moving sheet: Scaling group analysis. *Mathematics*, 8(9) doi:10.3390/MATH8091430

Fayyadh, M. M., Roslan, R., Kandasamy, R., & Ali, I. R. (2019). Thermal energy on water and oil placed squeezed Carreau nanofluids flow. *International Journal of Mechanical and Mechatronics Engineering, 19*(3), 79-87. Retrieved from www.scopus.com

Fayyadh, M. M., Roslan, R., Kandasamy, R., Ali, I. R., & Hussein, N. A. (2019). Effect of biot number on convective heat transfer of Darcy-Forchheimer nanofluid flow overstretched zero mass flux surface in the presence of a magnetic field. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 59*(1), 93-106. Retrieved from www.scopus.com

Fayyadh, M. M., Roslan, R., Kandasamy, R., & Ali, I. R. (2019). MHD squeezing flow of nano liquid on a porous stretched surface: Numerical study. *ARPN Journal of Engineering and Applied Sciences, 14*(20), 3572-3584. Retrieved from www.scopus.com

Kandasamy, R, **Fayyadh, M. M.** and Mohammad, Radiah, (2018), Solar Radiation Energy Issues on Nanoparticle Shapes in the Potentiality of Water-Based Cu, Al2O3 and SWCNTs, *Archives Of Nanomedicine: Open Access Journal*, **1**, issue 2, p. 41-50.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The theoretical investigation of the flow of generalized Newtonian fluid or non-Newtonian fluids continues to receive special status in the literature due to the growing importance of such fluid in modern technology and industries. The flows of generalized Newtonian fluids occur in many applications, with important examples in industrial processes that involve synthetic fibbers, extrusion of molten plastic, flows of polymer solutions, bioengineering and heat exchange efficiency (Rieutord, 2014). Simple examples of generalized Newtonian fluids are slurries, pastes, polymer solutions, multigrade engine oils, toothpaste, liquid soaps and peanut. The main distinguishing feature of many generalized Newtonian fluids is that they exhibit both viscous and elastic properties. Note that shear stress depends only on the shear rate, while the relation between shear stress and the shear rate depends on time (Schowalter, 1978).

These fluids exhibit numerous strange features, for example, shear-thinning or thickening and display of elastic effects. Hence, the classical Navier-Stokes equations are not appropriate in describing their rheological behavior. Due to the large difference in the chemical and physical structure of generalized Newtonian fluids and the variation of flows, the usual Navier Stokes equations may fail. They cannot represent all the rheological properties of generalized Newtonian fluids. Thus, many mathematical models have been proposed to describe these fluids' physical behavior, such as Carreau fluid, Maxwell fluid, and Sutterby fluid. Unlike viscous

REFERENCS

Abbasi, F., Hayat, T., & Alsaedi, A. (2015). Effects of inclined magnetic field and Joule heating in mixed convective peristaltic transport of non-Newtonian fluids. *Bulletin of the Polish Academy of Sciences Technical Sciences, 63*(2), 501-514.

Abel, M. S., & Mahesha, N. J. A. M. M. (2008). Heat transfer in MHD viscoelastic fluid flow over a stretching sheet with variable thermal conductivity, non-uniform heat source and radiation. *Applied Mathematical Modelling 32*(10), 1965-1983.

Agarwal, R., Verma, K., Agrawal, N. K., Duchaniya, R. K., & Singh, R. J. (2016). Synthesis, characterization, thermal conductivity and sensitivity of CuO nanofluids. *Applied Thermal Engineering, 102*, 1024-1036.

Agarwal, R., Verma, K., Agrawal, N. K., & Singh, R. (2017). Sensitivity of thermal conductivity for Al2O3 nanofluids. *Experimental Thermal and Fluid Science, 80*, 19-26

Aghbari, A., Agha, H. A., & Sadaoui, D. (2019). Soret-Dufour Effect on Mixed Convection Past a Vertical Plate in Non-Darcy Porous Medium Saturated With Buongiorno Nanofluid in the Presence of Thermal Dispersion. *Journal of Mechanics 35*(6), 851-862.

Aman, S., Al-Mdallal, Q., & Khan, I. (2020). Heat transfer and second order slip effect on MHD flow of fractional Maxwell fluid in a porous medium. *Journal of King Saud University-Science, 32*(1), 450-458.

Ahmed, N., Khan, U., Mohyud-Din, S. T., Bin-Mohsin, B. (2016). A finite element investigation of the flow of a Newtonian fluid in dilating and squeezing porous channel under the influence of nonlinear thermal radiation. *Neural Computing and Applications 29*(2), 501-508.

Ahmed, N., Khan, U., Mohyud-Din, S. T., & Waheed, A. (2017a). Shape effects of nanoparticles on the squeezed flow between two Riga plates in the presence of thermal radiation. *The European Physical Journal Plus, 132*(7), 321.

Ahmed, N., Erturk, V. S., Khan, U., Mohyud-Din, S., Bin-Mohsin, B. (2017b). MHD flow of a viscous Fluid between Dilating and Squeezing Porous Walls. *Iranian Journal of Science and Technology, Transactions A: Science, 41*(4), 951-956.

Ahmed, N., Abbasi, A., Khan, U., Mohyud-Din, S. T. (2018a). Thermal radiation effects on flow of Jeffery fluid in converging and diverging stretchable channels. *Neural Computing and Applications, 30*(8), 2371-2379.

Ahmad, S., Khan, M. I., Hayat, T., Khan, M. I., Alsaedi, A. (2018b). Entropy generation optimization and unsteady squeezing flow of viscous fluid with five different shapes of nanoparticles. *J Colloids Surfaces A: Physicochemical Engineering Aspects 554*, 197-210.

Ahmad, S., Farooq, M., Javed, M., & Anjum, A. (2018c). Double stratification effects in chemically reactive squeezed Sutterby fluid flow with thermal radiation and mixed convection. *Results in Physics, 8*, 1250-1259.

Ahmed, N., Khan, U., Mohyud-Din, S. T., Bin-Mohsin, B. (2018d). A finite element investigation of the flow of a Newtonian fluid in dilating and squeezing porous channel under the influence of nonlinear thermal radiation. *Neural Computing and Applications*, *29*(2), 501-508.

Akbar, N., Nadeem, S., Haq, R. U., & Ye, S. (2014). MHD stagnation point flow of Carreau fluid toward a permeable shrinking sheet: Dual solutions. *Ain Shams Engineering Journal*, *5*(4), 1233-1239.

Akbar, N. S. (2015). Peristaltic flow of a Sutterby nanofluid with double-diffusive natural convection. *Journal of Computational and Theoretical Nanoscience, 12*(8), 1546-1552.

Akmal, N., Sagheer, M., & Hussain, S. (2018). Numerical study focusing on the entropy analysis of MHD squeezing flow of a nanofluid model using Cattaneo–Christov theory. *AIP Advances*, *8*(5), 055201.

Alawi, O. A., Sidik, N. A. C. (2014). Influence of particle concentration and temperature on the thermophysical properties of CuO/R134a nanorefrigerant. *International Communications in Heat and Mass Transfer, 58*, 79-84.

Ali, F., Khan, I., Sheikh, N. A., Gohar, M., & Tlili, I. (2018). Effects of Different Shaped Nanoparticles on the Performance of Engine-Oil and Kerosene-Oil: A generalized Brinkman-Type Fluid model with Non-Singular Kernel. *Scientific reports, 8*(1), 15285.

Alshomrani, A., Ullah, M. Z., Capizzano, S., Khan, W., & Khan, M. (2019). Interpretation of chemical reactions and activation energy for unsteady 3D flow of Eyring–Powell magneto-nanofluid. *Arabian Journal for Science and Engineering, 44*(1), 579-589.

Aly, E. H. (2019). Dual exact solutions of graphene–water nanofluid flow over stretching/shrinking sheet with suction/injection and heat source/sink: Critical values and regions with stability. *Powder technology, 342*, 528-544.

Alzahrani, A. K. (2018). Importance of Darcy–Forchheimer porous medium in 3D convective flow of carbon nanotubes. *Physics Letters A, 382*(40), 2938-2943.

Atif, S., Hussain, S., & Sagheer, M. (2019). Effect of thermal radiation and variable thermal conductivity on magnetohydrodynamics squeezed flow of Carreau fluid over a sensor surface. *Journal of Nanofluids*, *8*(4), 806-816.

Ayub, S., Hayat, T., Asghar, S., & Ahmad, B. (2017). Thermal radiation impact in mixed convective peristaltic flow of third grade nanofluid. *Results in Physics, 7*, 3687-3695.

Azhar, E., Iqbal, Z., & Maraj, E. N. (2016). Impact of Entropy Generation on Stagnation-Point Flow of Sutterby Nanofluid: A Numerical Analysis. *Zeitschrift für Naturforschung A, 71*(9), 837-848.

Balazadeh, N., Sheikholeslami, M., Ganji, D. D., & Li, Z. (2018). Semi analytical analysis for transient Eyring-Powell squeezing flow in a stretching channel due to magnetic field using DTM. *J Journal of Molecular Liquids 260*, 30-36.

Barbés, B., Páramo, R., Blanco, E., Casanova, C. (2014). Thermal conductivity and specific heat capacity measurements of CuO nanofluids. *Journal of Thermal Analysis and Calorimetry*, *115*(2), 1883-1891.

Behi, M., Mirmohammadi, S. A., (2012). *Investigation on thermal conductivity, viscosity and stability of nanofluids*. Royal Institute of Technology (KTH), School of Industrial Engineering and Management, Department of Energy Technology, Division of Applied Thermodynamics and Refrigeration. Stockholm,Sweden: Master's Thesis

Bhattacharyya, K., & Layek, G. C. (2011). Effects of suction/blowing on steady boundary layer stagnation-point flow and heat transfer towards a shrinking sheet with thermal radiation. *International Journal of Heat and Mass Transfer*, 54(1-3), 302-307.

Bilal, S., Sohail, M., Naz, R., Malik, M. Y., & Alghamdi, M. (2019). Upshot of ohmically dissipated Darcy-Forchheimer slip flow of magnetohydrodynamic Sutterby fluid over radiating linearly stretched surface in view of Cash and Carp method. *Applied Mathematics and Mechanics*, *40*(6), 861-876.

Bird, R. B., Stewart, W. E., & Lightfoot, E. N. (2006). *Transport phenomena* (Vol. 1). John Wiley & Sons.

Bourantas, G., Skouras, E., Loukopoulos, V., & Burganos, V. (2014). Heat transfer and natural convection of nanofluids in porous media. *European Journal of Mechanics-B/Fluids, 43*, 45-56.

Brinkman, H. (1952). The viscosity of concentrated suspensions and solutions. *The Journal of Chemical Physics*, *20*(4), 571-571.

Buongiorno, J. (2006). Convective transport in nanofluids. *Journal of Heat Transfer, 128*(3), 240-250.

Buongiorno, J., & Hu, L.-w. (2009). Nanofluid heat transfer enhancement for nuclear reactor applications. *Proceedings of the ASME 2009 Second International Conference on Micro/Nanoscale Heat and Mass Transfer*. Shanghai, China. December 18–21, pp 517-522.

Carreau, P. J. (1972). Rheological equations from molecular network theories. *Transactions of the Society of Rheology*, *16*(1), 99-127.

Çelik, İ. (2019). Squeezing flow of nanofluids of Cu–water and kerosene between two parallel plates by Gegenbauer Wavelet Collocation method. *Engineering with Computers*, 1-14.

Choi, S. U., & Eastman, J. A. (1995). Enhancing thermal conductivity of fluids with nanoparticles. *Conference*. *International mechanical engineering congress and exhibition*. San Francisco, CA (United States).12-17

Chopkar, M., Sudarshan, S., Das, P., Manna, I. (2008). Effect of particle size on thermal conductivity of nanofluid. *Metallurgical and Materials Transactions A*. *39*(7), 1535-1542.

Cousteix, T. C. J. (2005). *Modeling and computation of boundary-layer flows*. California: Springer.

Das, K. (2013). Lie group analysis for nanofluid flow past a convectively heated stretching surface. *Applied Mathematics and computation, 221*, 547-557.

Das, P. K., Mallik, A. K., Ganguly, R., Santra, A. K. (2016). Synthesis and characterization of TiO2–water nanofluids with different surfactants. *International Communications in Heat and Mass Transfer*, *75*, 341-348.

Das, P. K., Islam, N., Santra, A. K., & Ganguly, R. (2017). Experimental investigation of thermophysical properties of Al2O3–water nanofluid: Role of surfactants. *Journal of Molecular Liquids. 237*, 304-312.

Das, S. K., Putra, N., Thiesen, P., & Roetzel, W. (2003). Temperature dependence of thermal conductivity enhancement for nanofluids. *J. Heat Transfer*, *125*(4), 567-574.

Das, S. K., Choi, S. U., & Patel, H. E. (2006). Heat transfer in nanofluids—a review. *Heat transfer engineering*, *27*(10), 3-19.

Das, S. K., Choi, S. U., Yu, W., & Pradeep, T. (2007). *Nanofluids: science and technology*: John Wiley & Sons.

Dhlamini, M., Kameswaran, P. K., Sibanda, P., Motsa, S., & Mondal, H. (2019). Activation energy and binary chemical reaction effects in mixed convective nanofluid flow with convective boundary conditions. *Journal of Computational Design and Engineering*, *6*(2), 149-158.

Dogonchi, A., Waqas, M., Afshar, S., Seyyedi, S. M., Hashemi-Tilehnoee, M., Chamkha, A. J. & Ganji, D. D (2019). Investigation of magneto-hydrodynamic fluid squeezed between two parallel disks by considering Joule heating, thermal radiation, and adding different nanoparticles. *International Journal of Numerical Methods for Heat & Fluid Flow*, 30(2), 659-680.

Dullien, F. A. (2012). *Porous media: fluid transport and pore structure*: Ontario, Academic press.

Duwairi, H., Tashtoush, B., Damseh, R. A. J. H., & transfer, m. (2004). On heat transfer effects of a viscous fluid squeezed and extruded between two parallel plates. *Heat and mass transfer*, *41*(2), 112-117.

Ellahi, R., Zeeshan, A., Hussain, F., & Asadollahi, A. (2019). Peristaltic blood flow of couple stress fluid suspended with nanoparticles under the influence of chemical reaction and activation energy. *Symmetry, 11*(2), 276.

Esfahani, J. A., & Bordbar, V. (2011). Double diffusive natural convection heat transfer enhancement in a square enclosure using nanofluids. *Journal of Nanotechnology in Engineering and Medicine*, *2*(2), 021002.

Esfe, M. H., Saedodin, S., Wongwises, S., Toghraie, D. (2015). An experimental study on the effect of diameter on thermal conductivity and dynamic viscosity of Fe/water nanofluids. *Journal of Thermal Analysis and Calorimetry*, *119*(3), 1817-1824.

Faragó, I. (2014*). Numerical methods for ordinary differential equations*. Typo. Tech, Budapest

Fersadou, I., Kahalerras, H., & El Ganaoui, M. (2015). MHD mixed convection and entropy generation of a nanofluid in a vertical porous channel. *Computers & Fluids, 121*, 164-179.

Forchheimer, P. (1901). Water Movement Through Soil: *Zeitschrift des Vereines Deutscher Ingenieure,* v. 45.

Ganesh, N. V., Hakeem, A. A., & Ganga, B. (2018). Darcy–Forchheimer flow of hydromagnetic nanofluid over a stretching/shrinking sheet in a thermally stratified porous medium with second order slip, viscous and Ohmic dissipations effects. *Ain Shams Engineering Journal*, *9*(4), 939-951.

Gaunt, P. (1986). Magnetic viscosity and thermal activation energy. *Journal of Applied Physics, 59*(12), 4129-4132.

Genick Bar-Meir (2013). *Basics of Fluid Mechanics*. Chicago, www.potto.Org / downloads.php

Ghadikolaei, S., Hosseinzadeh, K., & Ganji, D. (2018). Investigation on three dimensional squeezing flow of mixture base fluid (ethylene glycol-water) suspended by hybrid nanoparticle (Fe3O4-Ag) dependent on shape factor. *Journal of Molecular Liquids, 262*, 376-388.

Ghosh, S., Mukhopadhyay, S., & Vajravelu, K. (2016). Dual solutions of slip flow past a nonlinearly shrinking permeable sheet. *Alexandria Engineering Journal*, *55*(2), 1835-1840.

Godson, L., Raja, B., Lal, D. M., & Wongwises, S. J. (2010). Experimental investigation on the thermal conductivity and viscosity of silver-deionized water nanofluid. *Experimental Heat Transfer*, *23*(4), 317-332.

Gorla, R. S. R., & Kumari, M. (2012). Mixed convection flow of a non-Newtonian nanofluid over a non-linearly stretching sheet. *Journal of Nanofluids*, *1*(2), 186-195.

Gupta, P., & Gupta, A. (1977). Squeezing flow between parallel plates. *Wear*, *45*(2), 177-185.

Hamid, A., Khan, M., & Khan, U. (2018). Thermal radiation effects on Williamson fluid flow due to an expanding/contracting cylinder with nanomaterials: dual solutions. *Physics Letters A, 382*(30), 1982-1991.

Hamid, A., & Khan, M. (2018). Impacts of binary chemical reaction with activation energy on unsteady flow of magneto-Williamson nanofluid. *Journal of Molecular Liquids*, *262*, 435-442.

Hamilton, R. L., Crosser, O. (1962). Thermal conductivity of heterogeneous two-component systems. *Industrial & Engineering chemistry fundamentals*, *1*(3), 187-191.

Haq, R. U., Nadeem, S., Khan, Z., Noor, (2015). MHD squeezed flow of water functionalized metallic nanoparticles over a sensor surface. *Physica E: Low-dimensional Systems and Nanostructures*, *73*, 45-53.

Harikrishnan, S., & Kalaiselvam, S. (2012). Preparation and thermal characteristics of CuO–oleic acid nanofluids as a phase change material. *Thermochimica Acta*, *533*, 46-55.

Harris, S., Ingham, D., & Pop, I. (2009). Mixed convection boundary-layer flow near the stagnation point on a vertical surface in a porous medium: Brinkman model with slip. *Transport in Porous Media*, *77*(2), 267-285.

Ha, S. N. (2001). A nonlinear shooting method for two-point boundary value problems. *Computers & Mathematics with Applications*, *42*(10-11), 1411-1420.

Hayat, T., Muhammad, K., Farooq, M., & Alsaedi, A. (2016a). Unsteady squeezing flow of carbon nanotubes with convective boundary conditions. *J PloS One*, *11*(5).

Hayat, T., Muhammad, T., Al-Mezal, S., & Liao, S. (2016b). Darcy-Forchheimer flow with variable thermal conductivity and Cattaneo-Christov heat flux. *International Journal of Numerical Methods for Heat & Fluid Flow, 26*(8), 2355-2369.

Hayat, T., Zahir, H., Mustafa, M., & Alsaedi, A. (2016c). Peristaltic flow of Sutterby fluid in a vertical channel with radiative heat transfer and compliant walls: A numerical study. *Results in Physics, 6*, 805-810.

Hayat, T., Waqas, M., Shehzad, S., & Alsaedi, A. (2016d). Stretched flow of Carreau nanofluid with convective boundary condition. *Pramana*, *86*(1), 3-17.

Hayat, T., Haider, F., Muhammad, T., & Alsaedi, A. (2017a). Darcy-Forchheimer flow with Cattaneo-Christov heat flux and homogeneous-heterogeneous reactions. *PloS one*, *12*(4), e0174938.

Hayat, T., Haider, F., Muhammad, T., & Alsaedi, A. (2017b). On Darcy-Forchheimer flow of viscoelastic nanofluids: A comparative study. *Journal of Molecular Liquids, 233*, 278-287.

Hayat, T., Saif, R. S., Ellahi, R., Muhammad, T., & Ahmad, B. (2017c). Numerical study for Darcy-Forchheimer flow due to a curved stretching surface with Cattaneo-Christov heat flux and homogeneous-heterogeneous reactions. *Results in Physics, 7*, 2886-2892.

Hayat, T., Khan, M., Imtiaz, M., & Alsaedi, A. (2017d). Squeezing flow past a Riga plate with chemical reaction and convective conditions. *journal of Molecular Liquids, 225*, 569-576.

Hayat, T., Qayyum, S., Waqas, M., & Ahmed, B. (2017e). Influence of thermal radiation and chemical reaction in mixed convection stagnation point flow of Carreau fluid. *Results in Physics, 7*, 4058-4064.

Hayat, T., Aziz, A., Muhammad, T., & Alsaedi, A. (2017f). Darcy–Forchheimer three-dimensional flow of Williamson nanofluid over a convectively heated nonlinear stretching surface. *Communications in Theoretical Physics, 68*(3), 387.

Hayat, T., Zubair, M., Waqas, M., Alsaedi, A., & Ayub, M. (2017g). Importance of chemical reactions in flow of Walter-B liquid subject to non-Fourier flux modeling. *Journal of Molecular Liquids, 238*, 229-235.

Hayat, T., Khan, M. I., Waqas, M., Alsaedi, A., & Yasmeen, T. (2017h). Diffusion of chemically reactive species in third grade fluid flow over an exponentially stretching sheet considering magnetic field effects. *Chinese Journal of Chemical Engineering, 25*(3), 257-263.

Hayat, T., Ayub, S., Alsaedi, A., Tanveer, A., & Ahmad, B. (2017i). Numerical simulation for peristaltic activity of Sutterby fluid with modified Darcy's law. *Results in Physics, 7*, 762-768.

Hayat, T., Ahmad, S., Ijaz Khan, M., & Alsaedi, A. (2018a). Modeling Chemically Reactive Flow of Sutterby Nanofluid by a Rotating Disk in Presence of Heat Generation/Absorption. *Communications in Theoretical Physics, 69*(5), 569. doi:10.1088/0253-6102/69/5/569

Hayat, T., Ullah, S., Khan, M. I., & Alsaedi, A. (2018b). On framing potential features of SWCNTs and MWCNTs in mixed convective flow. *Results in Physics, 8*, 357-364.

Hayat, T., Haider, F., Muhammad, T., & Alsaedi, A. (2018c). Numerical study for Darcy-Forchheimer flow of nanofluid due to an exponentially stretching curved surface. *Results in Physics, 8*, 764-771.

Hayat, T., Rafique, K., Muhammad, T., Alsaedi, A., & Ayub, M. (2018d). Carbon nanotubes significance in Darcy-Forchheimer flow. *Results in Physics, 8*, 26-33.

Hayat, T., Afzal, S., Khan, M. I., & Alsaedi, A. (2019a). Irreversibility aspects to flow of Sutterby fluid subject to nonlinear heat flux and Joule heating. *Applied Nanoscience*, 1-12.

Hayat, T., Ullah, I., Waqas, M., & Alsaedi, A. (2019b). Attributes of activation energy and exponential based heat source in flow of Carreau fluid with cross-diffusion effects. *Journal of Non-Equilibrium Thermodynamics, 44*(2), 203-213.

Hewitt, G. F., Shires, G. L., & Bott, T. R. (1994). *Process heat transfer* (Vol. 113): CRC press Boca Raton.

Hsiao, K.-L. (2017). To promote radiation electrical MHD activation energy thermal extrusion manufacturing system efficiency by using Carreau-Nanofluid with parameters control method. *Energy, 130*, 486-499.

Huminic, A., Huminic, G., Fleaca, C., Dumitrache, F., & Morjan, I. (2015). Thermal conductivity, viscosity and surface tension of nanofluids based on FeC nanoparticles. *Powder Technology, 284*, 78-84.

Idrees, M., Rehman, S., Shah, R. A., Ullah, M., & Abbas, T. (2018). A similarity solution of time dependent MHD liquid film flow over stretching sheet with variable physical properties. *Results in Physics*, *8*, 194-205.

Imran, N., Javed, M., Sohail, M., Thounthong, P., & Abdelmalek, Z. (2020). Theoretical exploration of thermal transportation with chemical reactions for sutterby fluid model obeying peristaltic mechanism. *Journal of Materials Research and Technology*, *9*(4), 7449-7459.

Incropera, F. P., Lavine, A. S., Bergman, T. L., & DeWitt, D. P. (2007). *Fundamentals of heat and mass transfer*. Los Angeles: Wiley.

Iqbal, S., Raj, C., Michael, J., Irfan, A. J. D. J. o. N., & Biostructures. (2017). a comparative investigation of Al_2O_3/H_2O, SiO_2/ H_2O and ZrO_2/ H_2O nanofluid for heat transfer applications. *Digest Journal of Nanomaterials & Biostructures 12*(2).

Irfan, M., & Khan, M. (2019). Simultaneous impact of nonlinear radiative heat flux and Arrhenius activation energy in flow of chemically reacting Carreau nanofluid. *Applied Nanoscience*, 1-12.

Irfan, M., Khan, W., Khan, M., & Gulzar, M. M. (2019a). Influence of Arrhenius activation energy in chemically reactive radiative flow of 3D Carreau nanofluid with nonlinear mixed convection. *Journal of Physics and Chemistry of Solids, 125*, 141-152.

Irfan, M., Khan, M., Khan, W., & Ahmad, L. (2019b). Influence of binary chemical reaction with Arrhenius activation energy in MHD nonlinear radiative flow of unsteady Carreau nanofluid: dual solutions. *Applied Physics A, 125*(3), 179.

Irfan, M., Khan, W. A., Khan, M., & Waqas, M. (2020). Evaluation of Arrhenius activation energy and new mass flux condition in Carreau nanofluid: dual solutions. *Applied Nanoscience*, *10*(12), 5279-5289.

Jain, N., & Timol, M. (2015). Similarity solutions of quasi three dimensional power law fluids using the method of satisfaction of asymptotic boundary conditions. *Alexandria Engineering Journal*, *54*(3), 725-732.

Jamil, M., Ahmed, A., & Khan, N. A. (2020). Some exact traveling wave solutions of MHD Maxwell fluid in porous medium. *International Journal of Applied and Computational Mathematics, 6*(3), 1-18.

Jang, S. P., & Choi, S. U. (2006). Cooling performance of a microchannel heat sink with nanofluids. *Applied Thermal Engineering, 26*(17-18), 2457-2463.

Jawad, M., Shah, Z., Islam, S., Bonyah, E., & Khan, A. Z. (2018). Darcy-Forchheimer flow of MHD nanofluid thin film flow with Joule dissipation and Navier's partial slip. *Journal of Physics Communications, 2*(11), 115014.

Jeong, J., Li, C., Kwon, Y., Lee, J., Kim, S. H., & Yun, R. (2013). Particle shape effect on the viscosity and thermal conductivity of ZnO nanofluids. *International Journal of Refrigeration, 36*(8), 2233-2241.

John, D., & Anderson, J. R. (1995). *Computational fluid dynamics: the basics with applications*. P. Perback, International ed., Published, 4-30.

Jusoh, R., Nazar, R., & Pop, I. (2018). Magnetohydrodynamic rotating flow and heat transfer of ferrofluid due to an exponentially permeable stretching/shrinking sheet. *Journal of Magnetism and Magnetic Materials, 465*, 365-374.

Kamali, R., Binesh, A. (2010). Numerical investigation of heat transfer enhancement using carbon nanotube-based non-Newtonian nanofluids. *International Communications in Heat and Mass Transfer, 37*(8), 1153-1157.

Kandasamy, R., Loganathan, P., & Arasu, P. P. (2011). Scaling group transformation for MHD boundary-layer flow of a nanofluid past a vertical stretching surface in the presence of suction/injection. *Nuclear Engineering and Design, 241*(6), 2053-2059.

Kandasamy, R., Muhaimin, I., & Rosmila, A. (2014). The performance evaluation of unsteady MHD non-Darcy nanofluid flow over a porous wedge due to renewable (solar) energy. *Renewable Energy, 64*, 1-9.

Kandasamy, R., & Muhammad, R. (2016). Thermal radiation energy on squeezed MHD flow of Cu, Al2O3 and CNTs-nanofluid over a sensor surface. *Alexandria Engineering Journal, 55*(3), 2405-2421.

Kandasamy, R., Altaie, H. S., & Zaimuddin, I. N. B. (2016). Irregular response of nanofluid flow subject to chemical reaction and shape parameter in the presence of variable stream conditions. *Alexandria Engineering Journal, 55*(3), 2485-2495.

Kandasamy, R., Mohammad, R., Zailani, N. A. B. M., & Jaafar, N. F. B. (2017). Nanoparticle shapes on squeezed MHD nanofluid flow over a porous sensor surface. *Journal of Molecular Liquids, 233*, 156-165.

Karniadakis, G., Beskok, A., & Aluru, N. (2006). *Microflows and nanoflows: fundamentals and simulation* (Vol. 29): Springer Science & Business Media.

Khaled, A.-R., & Vafai, K. (2004). Hydromagnetic squeezed flow and heat transfer over a sensor surface. *International Journal of Engineering Science 42*(5-6), 509-519.

Khan, M., & Hashim. (2015). Boundary layer flow and heat transfer to Carreau fluid over a nonlinear stretching sheet. *AIP Advances, 5*(10), 107203.

Khan, M., Malik, M., Salahuddin, T., & Khan, I. (2016). Heat transfer squeezed flow of Carreau fluid over a sensor surface with variable thermal conductivity: a numerical study. *Results in physics, 6*, 940-945.

Khan, M., & Hafeez, A. (2017). A review on slip-flow and heat transfer performance of nanofluids from a permeable shrinking surface with thermal radiation: dual solutions. *Chemical Engineering Science, 173*, 1-11.

Khan, M., Azam, M., Alshomrani, A. (2017a). Effects of melting and heat generation/absorption on unsteady Falkner-Skan flow of Carreau nanofluid over a wedge. *International Journal of Heat and Mass Transfer, 110*, 437-446.

Khan, M., Azam, M., & Alshomrani, A. (2017b). On unsteady heat and mass transfer in Carreau nanofluid flow over expanding or contracting cylinder with convective surface conditions. *Journal of Molecular Liquids, 231*, 474-484.

Khan, M., Alshomrani, A. S., & Haq, R. U. (2018a). Investigation of dual solutions in flow of a non-Newtonian fluid with homogeneous–heterogeneous reactions: critical points. *European Journal of Mechanics-B/Fluids, 68,* 30-38.

Khan, M., Irfan, M., Ahmad, L., & Khan, W. (2018b). Simultaneous investigation of MHD and convective phenomena on time-dependent flow of Carreau nanofluid with variable properties: dual solutions. *Physics Letters A, 382*(34), 2334-2342.

Khan, M. I., Qayyum, S., Hayat, T., Waqas, M., Khan, M. I., & Alsaedi, A. (2018c). Entropy generation minimization and binary chemical reaction with Arrhenius activation energy in MHD radiative flow of nanomaterial. *Journal of Molecular Liquids, 259*, 274-283.

Khan, M., Irfan, M., & Khan, W. (2018d). Thermophysical properties of unsteady 3D flow of magneto Carreau fluid in the presence of chemical species: a numerical approach. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 40*(2), 108.

Khan, M., Hussain, A., Malik, M., Salahuddin, T., & Aly, S. (2019a). Numerical analysis of Carreau fluid flow for generalized Fourier's and Fick's laws. *Applied Numerical Mathematics, 144*, 100-117.

Khan, M. I., Alsaedi, A., Qayyum, S., Hayat, T., & Khan, M. I. (2019b). Entropy generation optimization in flow of Prandtl–Eyring nanofluid with binary chemical reaction and Arrhenius activation energy. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 570*, 117-126.

Khan, S. U., Waqas, S. H., Shehzad, S. A., & Imran, M. (2019c). Theoretical analysis of tangent hyperbolic nanoparticles with combined electrical MHD, activation energy and Wu's slip features: a mathematical model. *Physica Scripta*.

Khan, W., Sultan, F., Ali, M., Shahzad, M., Khan, M., & Irfan, M. (2019d). Consequences of activation energy and binary chemical reaction for 3D flow of Cross-nanofluid with radiative heat transfer. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *41*(1), 4.

Khan, M. I., Irfan, M., Khan, W. A., Waqas, M., & Rashid, S. (2020a). Activation energy analysis in entropy optimized reactive flow. *Applied Nanoscience*, 1-11.

Khan, M. I., Afzal, S., Hayat, T., Waqas, M., & Alsaedi, A. (2020b). Activation energy for the Carreau-Yasuda nanomaterial flow: Analysis of the entropy generation over a porous medium. *Journal of Molecular Liquids, 297*, 111905.

Khan, M., El Shafey, A. M., Salahuddin, T., & Khan, F. (2020c). Chemically Homann stagnation point flow of Carreau fluid. *Physica A: Statistical Mechanics and its Applications*, *551*, 124066.

Kim, H. J., Lee, S.-H., Lee, J.-H., & Jang, S. P. (2015). Effect of particle shape on suspension stability and thermal conductivities of water-based bohemite alumina nanofluids. *Energy*, *90*, 1290-1297.

Kumar, K. G., Gireesha, B., Krishanamurthy, M., & Rudraswamy, N. (2017). An unsteady squeezed flow of a tangent hyperbolic fluid over a sensor surface in the presence of variable thermal conductivity. *Results in Physics, 7,* 3031-3036.

Kumar, R. K., Kumar, G. V., Raju, C., Shehzad, S., & Varma, S. (2018). Analysis of Arrhenius activation energy in magnetohydrodynamic Carreau fluid flow through improved theory of heat diffusion and binary chemical reaction. *Journal of Physics Communications, 2*(3), 035004.

Kumaresan, E., Kumar, A. V., & Kumar, B. R. (2017). An exact solution on unsteady MHD free convection chemically reacting silver nanofluid flow past an exponentially accelerated vertical plate through porous medium. *14th International Conference on Science, Engineering and Technology*. VIT University, Vellore, Tamil Nadu, India: IOP Conference Series, Materials Science and Engineering, **263** (06).

Kundu, P. K., Cohen, I. M., & Dowling, D. R. (2008). *Fluid mechanics*, 4th edn New York. *NY:* Academic Press.

Lambers, J. V. (2011). Mat 461/561: numerical analysis II.

Lee, S., Choi, S.-S., Li, S., and, & Eastman, J. (1999). Measuring thermal conductivity of fluids containing oxide nanoparticles. " ASME. *J. Heat Transfer*, 121(2), 280–289

Li, C. H., & Peterson, G. J. (2006). Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). *Journal of Applied Physics, 99*(8), 084314.

Lu, D., Ramzan, M., Ullah, N., Chung, J. D., & Farooq, U. (2017). A numerical treatment of radiative nanofluid 3D flow containing gyrotactic microorganism with anisotropic slip, binary chemical reaction and activation energy. *Scientific Reports, 7*(1), 1-22.

Lu, D., Ramzan, M., ul Huda, N., Chung, J. D., & Farooq, U. (2018). Nonlinear radiation effect on MHD Carreau nanofluid flow over a radially stretching surface with zero mass flux at the surface. *Scientific Reports, 8*(1), 3709.

Lu, D., Mohammad, M., Ramzan, M., Bilal, M., Howari, F., & Suleman, M. (2019). MHD Boundary Layer Flow of Carreau Fluid over a Convectively Heated

Bidirectional Sheet with Non-Fourier Heat Flux and Variable Thermal Conductivity. *Symmetry, 11*(5), 618.

MacDevette, M. (2013). *Heat transfer analysis of nanofluids and phase change materials.* Universitat Politècnica de Catalunya. Facultat de Matemàtiques i Estadítica:Ph.D thesis

Maheshwary, P., Handa, C., & Nemade, K. J. (2017). A comprehensive study of effect of concentration, particle size and particle shape on thermal conductivity of titania/water based nanofluid. *Applied Thermal Engineering*, *119*, 79-88.

Mahmood, M., Asghar, S., Hossain, M. (2007). Squeezed flow and heat transfer over a porous surface for viscous fluid. *Heat and Mass Transfer*, *44*(2), 165-173.

Majeed, A., Zeeshan, A., & Noori, F. (2019). Numerical study of Darcy-Forchheimer model with activation energy subject to chemically reactive species and momentum slip of order two. *AIP Advances*, *9*(4), 045035.

Malik, M. (2017). Application of shooting method on MHD thermally stratified mixed convection flow of non-Newtonian fluid over an inclined stretching cylinder. *Fifteenth Asian Congress of Fluid Mechanics.* Malaysia: Journal of Physics: Conference Series, *822*(1), 012012.

Mansur, S., Ishak, A., & Pop, I. (2015). The magnetohydrodynamic stagnation point flow of a nanofluid over a stretching/shrinking sheet with suction. *PLoS one*, *10*(3), e0117733.

Maxwell, J. (1873). *A Treatise on Electricity and Magnetism.* In: Oxford, UK. Clarendon Press, Vol. 1

Menzinger, M., & Wolfgang, R. (1969). The meaning and use of the Arrhenius activation energy. *Angewandte Chemie International Edition in English, 8*(6), 438-444.

Meraj, M., Shehzad, S., Hayat, T., Abbasi, F., & Alsaedi, A. (2017). Darcy-Forchheimer flow of variable conductivity Jeffrey liquid with Cattaneo-Christov heat flux theory. *Applied Mathematics and Mechanics, 38*(4), 557-566.

Merkin, J. H. (1986). On dual solutions occurring in mixed convection in a porous medium. *Journal of engineering Mathematics, 20*(2), 171-179.

Mohamed, R. A., Rida, S. Z., Arafa, A. A. M., & Mubarak, M. S. (2019). Heat and Mass Transfer in an Unsteady Magnetohydrodynamics Al_2O_3–Water Nanofluid

Squeezed Between Two Parallel Radiating Plates Embedded in Porous Media With Chemical Reaction. *Journal of Heat Transfer, 142*(1).

Mousavisani, S., Khalesi, J., Golbaharan, H., Sepehr, M., Ganji, D. (2019). Influence of inclined Lorentz forces through a porous media on squeezing Cu-H_2o nanofluid in the presence of heat source/sink. *International Journal of Numerical Methods for Heat & Fluid Flow*, 30(5)2563-2581.

Muhammad, N., Nadeem, S., & Mustafa, T. (2017a). Squeezed flow of a nanofluid with Cattaneo–Christov heat and mass fluxes. *Results in Physics*, *7*, 862-869.

Muhammad, T., Alsaedi, A., Shehzad, S. A., & Hayat, T. (2017b). A revised model for Darcy-Forchheimer flow of Maxwell nanofluid subject to convective boundary condition. *Chinese Journal of Physics*,*55*(3), 963-976.

Mukhopadhyay, S. (2013). Effects of thermal radiation and variable fluid viscosity on stagnation point flow past a porous stretching sheet. *Meccanica*, *48*(7), 1717-1730.

Murshed, S., Leong, K., & Yang, C. J. (2005). Enhanced thermal conductivity of TiO_2—water based nanofluids. *International Journal of Thermal Sciences*, *44*(4), 367-373.

Muskat, M.(1938). The flow of homogeneous fluids through porous media. *Soil Science*, *46*(2), 169.

Mustafa, M., Hayat, T., & Obaidat, S. J. M. (2012). On heat and mass transfer in the unsteady squeezing flow between parallel plates. *Meccanica*, *47*(7), 1581-1589.

Mustafa, M., Mushtaq, A., Hayat, T., & Ahmad, B. (2014). Nonlinear radiation heat transfer effects in the natural convective boundary layer flow of nanofluid past a vertical plate: A numerical study. *PloS One, 9*(9), e103946.

Mustafa, M., Sultan, A., & Rahi, M. (2019). Pressure-driven flow of Cross fluid along a stationary plate subject to binary chemical reaction and Arrhenius activation energy. *Arabian Journal for Science and Engineering, 44*(6), 5647-5655.

Myers, T. G., Ribera, H., Cregan, V., (2017). Does mathematics contribute to the nanofluid debate? *Journal of Heat and Mass Transfer, 111*, 279-288.

Na, T. Y., & Hansen, A. G. (1967). Similarity solutions of a class of laminar three-dimensional boundary layer equations of power law fluids. *International Journal of Non-Linear Mechanics, 2*(4), 373-385.

Naganthran, K., Nazar, R., & Pop, I. (2019a). A study on non-Newtonian transport phenomena in a mixed convection stagnation point flow with numerical simulation and stability analysis. *The European Physical Journal Plus, 134*(3), 1-14.

Naganthran, K., Nazar, R., & Pop, I. (2019b). Effects of heat generation/absorption in the Jeffrey fluid past a permeable stretching/shrinking disc. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *41*(10), 414.

Nasir, S., Shah, Z., Islam, S., Bonyah, E., & Gul, T. (2019). Darcy Forchheimer nanofluid thin film flow of SWCNTs and heat transfer analysis over an unsteady stretching sheet. *AIP Advances, 9*(1), 015223.

Nayak, M., Agbaje, T., Mondal, S., Sibanda, P., & Leach, P. J. (2020). Thermodynamic effect in Darchy–Forchheimer nanofluid flow of a single-wall carbon nanotube/multi-wall carbon nanotube suspension due to a stretching/shrinking rotating disk: Buongiorno two-phase model. *Journal of Engineering Mathematics,120*(1), 43-65.

Nawaz, M. (2020). Role of hybrid nanoparticles in thermal performance of Sutterby fluid, the ethylene glycol. *Physica A: Statistical Mechanics and its Applications*, *537*, 122447.

Nield, D. A., & Bejan, A. (2006). *Convection in porous media* (Vol. 3): Springer.

Ovsiannikov, L. V. e. (2014). *Group analysis of differential equations*: Academic press.

Pang, C., Jung, J.-Y., Lee, J. W., Kang, Y. T. (2012). Thermal conductivity measurement of methanol-based nanofluids with Al_2O_3 and SiO_2 nanoparticles. *International Journal of Heat and Mass Transfer*, *55*(21-22), 5597-5602.

Park, S. S., Kim, N. J. (2014). Influence of the oxidation treatment and the average particle diameter of graphene for thermal conductivity enhancement. *Journal of Industrial and Engineering Chemistry*, *20*(4), 1911-1915.

Paul, G., Pal, T., Manna, I. (2010). Thermo-physical property measurement of nano-gold dispersed water based nanofluids prepared by chemical precipitation technique. *Journal of Colloid and Interface Science*, *349*(1), 434-437.

Pop, I., Naganthran, K., Nazar, R., & Ishak, A. (2017). The effect of vertical throughflow on the boundary layer flow of a nanofluid past a stretching/shrinking sheet: a revised model. *International Journal of Numerical Methods for Heat & Fluid Flow, 27*(9), 1910-1927.

Prandtl, L. J. (1904). On fluid motions with very small friction. *Verhldg, 3*, 484-491.

Ramesh, G., Kumar, K. G., Chamkha, A. J., Gorla, R. S. R. (2019a). Effects of chemical reaction and activation energy on a Carreau nanoliquid past a permeable surface under zero mass flux conditions. *Proceedings of the Institution of Mechanical Engineers, Part N:* Journal of Nanomaterials, Nanoengineering and Nanosystems, *234*(1-2), 47-57.

Ramesh, K., Ojjela, O., & Nareshkumar, N. (2019b). Second law analysis in radiative mixed convective squeezing flow of Casson fluid between parallel disks with Soret and Dufour effects. *Heat Transfer—Asian Research, 48*(4), 1483-1500.

Rana, P., Shukla, N., Bég, O. A., & Bhardwaj, A. (2019). Lie group analysis of nanofluid slip flow with Stefan Blowing effect via modified Buongiorno's Model: entropy generation analysis. *Differential Equations and Dynamical Systems*, 1-18.

Rana, S., & Nawaz, M. (2019). Investigation of enhancement of heat transfer in Sutterby nanofluid using Koo-Kleinstreuer and Li (KKL) correlations and Cattaneo-Christov heat flux model. *Physica Scripta*.

Rashidi, M., Momoniat, E., Ferdows, M., & Basiriparsa, A. (2014). Lie group solution for free convective flow of a nanofluid past a chemically reacting horizontal plate in a porous media. *Mathematical Problems in Engineering, 2014*.

Rehman, K. U., Malik, A. A., Malik, M., Tahir, M., & Zehra, I. (2018). On new scaling group of transformation for Prandtl-Eyring fluid model with both heat and mass transfer. *Results in physics, 8*, 552-558.

Rieutord, M. (2014). *Fluid dynamics: an introduction*, Toulous: Springer.

Rogers, S. A., Park, J. D., & Lee, C.-W. J. (2019). Instantaneous dimensionless numbers for transient nonlinear rheology. *Rheologica Acta*, 1-18.

Roşca, A. V., & Pop, I. (2013). Flow and heat transfer over a vertical permeable stretching/shrinking sheet with a second order slip. *International Journal of Heat and Mass Transfer, 60*, 355-364.

Roşca, N. C., & Pop, I. (2017). Axisymmetric rotational stagnation point flow impinging radially a permeable stretching/shrinking surface in a nanofluid using Tiwari and Das model. *Scientific Reports, 7,* 40299.

Saba, F., Ahmed, N., Hussain, S., Khan, U., Mohyud-Din, S. T., & Darus, M. (2018a). Thermal analysis of nanofluid flow over a curved stretching surface suspended by carbon nanotubes with internal heat generation. *Applied Sciences*, *8*(3), 395.

Saba, F., Ahmed, N., Khan, U., Waheed, A., Rafiq, M., & Mohyud-Din, S. T. (2018b). Thermophysical analysis of water based (Cu–Al2O3) hybrid nanofluid in an asymmetric channel with dilating/squeezing walls considering different shapes of nanoparticles. *Applied Sciences*, *8*(9), 1549.

Sabir, Z., Imran, A., Umar, M., Zeb, M., Shoaib, M., & Raja, M. A. Z. (2020). A numerical approach for two-dimensional Sutterby fluid flow bounded at a stagnation point with an inclined magnetic field and thermal radiation impacts. *Thermal Science*, (00), 186-186.

Sadiq, M. A., Waqas, M., Hayat, T., & Alsaedi, A. (2019). Modeling and analysis of Maxwell nanofluid considering mixed convection and Darcy–Forchheimer relation. *Applied Nanoscience*, *9*(5), 1155-1162.

Salahuddin, T., Malik, M. Y., Hussain, A., Bilal, S., Awais, M., & Khan, I. (2017). MHD squeezed flow of Carreau-Yasuda fluid over a sensor surface. *Alexandria Engineering Journal*, *56*(1), 27-34.

Sajid, T., Sagheer, M., Hussain, S., & Bilal, M. (2018). Darcy-Forchheimer flow of Maxwell nanofluid flow with nonlinear thermal radiation and activation energy. *AIP Advances*, *8*(3), 035102.

Sajid, T., Tanveer, S., Sabir, Z., & Guirao, J. L. G. (2020). Impact of activation energy and temperature-dependent heat source/sink on maxwell–sutterby fluid. *Mathematical Problems in Engineering, 2020*.

Schlichting, H., & Gersten, K. (2016). *Boundary-layer theory*. Bochum: Springer.

Schowalter, W. R. (1978). *Mechanics of non-Newtonian fluids*: Pergamon Press.

Schwichtenberg, J. (2015). *Physics from Symmetry*: Karlsruhe, Springer.

Seyhan, M., Altan, C. L., Gurten, B., & Bucak, S. (2017). The effect of functionalized silver nanoparticles over the thermal conductivity of base fluids. *AIP Advances*, *7*(4), 045101.

Shah, S., Hussain, S., & Sagheer, M. (2016). MHD effects and heat transfer for the UCM fluid along with Joule heating and thermal radiation using Cattaneo-Christov heat flux model. *AIP Advances, 6*(8), 085103.

Shah, Z., Tassaddiq, A., Islam, S., Alklaibi, A., & Khan, I. (2019). Cattaneo–Christov Heat Flux Model for Three-Dimensional Rotating Flow of SWCNT and MWCNT Nanofluid with Darcy–Forchheimer Porous Medium Induced by a Linearly Stretchable Surface. *Symmetry*, *11*(3), 331.

Shehzad, S., Abbasi, F., Hayat, T., & Alsaedi, A. (2016). Cattaneo-Christov heat flux model for Darcy-Forchheimer flow of an Oldroyd-B fluid with variable conductivity and non-linear convection. *Journal of Molecular Liquids*, *224*, 274-278.

Shahzad, M., Sun, H., Sultan, F., Khan, W. A., Ali, M., & Irfan, M. (2019). Transport of radiative heat transfer in dissipative Cross nanofluid flow with entropy generation and activation energy. *Physica Scripta*, *94*(11), 115224.

Shamshuddin, M., Mishra, S., Bég, O. A., Kadir, A. (2019). Viscous dissipation and joule heating effects in non-Fourier MHD squeezing flow, heat and mass transfer between Riga plates with thermal radiation: variational parameter method solutions. *Arabian Journal for Science and Engineering*, *44*(9), 8053-8066.

Shampine, L. F., Kierzenka, J., & Reichelt, M. W. (2000). Solving boundary value problems for ordinary differential equations in MATLAB with bvp4c. *Tutorial notes*, *2000*, 1-27.

Shampine, L. F., Gladwell, I., Shampine, L., & Thompson, S. (2003). *Solving ODEs with matlab*. Cambridge university press.

Sharifpur, M., Tshimanga, N., Meyer, J. P., Manca, O. (2017). Experimental investigation and model development for thermal conductivity of α-Al2O3-glycerol nanofluids. *International Communications in Heat and Mass Transfer, 85*, 12-22.

Sheikholeslami, M., & Ganji, D. J. (2016). Nanofluid convective heat transfer using semi analytical and numerical approaches: a review. *Journal of the Taiwan Institute of Chemical Engineers*, *65*, 43-77.

Singh, P., Radhakrishnan, V., & Narayan, K. (1990). Squeezing flow between parallel plates. *Ingenieur-Archiv*, *60*(4), 274-281.

Sreenivasulu, P., Poornima, T., Malleswari, B., Reddy, N. B., & Souayeh, B. (2020). Viscous dissipation impact on electrical resistance heating distributed Carreau nanoliquid along stretching sheet with zero mass flux. *The European Physical Journal Plus*, *135*(9), 1-25.

Su, X., Yin, Y. (2019). Effects of an inclined magnetic field on the unsteady squeezing flow between parallel plates with suction/injection. *Journal of Magnetism and Magnetic Materials*, *484*, 266-271.

Subhashini, S., & Sumathi, R. (2014). Dual solutions of a mixed convection flow of nanofluids over a moving vertical plate. *International Journal of Heat and Mass Transfer, 71*, 117-124.

Sultan, F., Khan, W., Ali, M., Shahzad, M., Irfan, M., & Khan, M. (2019). Theoretical aspects of thermophoresis and Brownian motion for three-dimensional flow of the cross fluid with activation energy. *Pramana*, *92*(2), 21.

Sundar, L. S., Hortiguela, M. J., Singh, M. K., Sousa, A. C. (2016a). Thermal conductivity and viscosity of water based nanodiamond (ND) nanofluids: an experimental study. *International Communications in Heat and Mass Transfer*, *76*, 245-255.

Sundar, L. S., Singh, M. K., & Sousa, A. C. (2016b). Enhanced thermal properties of nanodiamond nanofluids. *Chemical Physics Letters*, *644*, 99-110.

Sutterby, J. L. (1965). Laminar converging flow of dilute polymer solutions in conical sections. II. *Transactions of the Society of Rheology, 9*(2), 227-241.

Sutterby, J. (1966). Laminar converging flow of dilute polymer solutions in conical sections: Part I. Viscosity data, new viscosity model, tube flow solution. *AIChE Journal*, *12*(1), 63-68.

Timmons, J., Falzone, G., Balonis, M., Bauchy, M., & Sant, G. (2018). Anomalous variations in the viscous activation energy of suspensions induced by fractal structuring. *Journal of Colloid and Interface Science, 530*, 603-609.

Timofeeva, E. V., Routbort, J. L., & Singh, D. J. (2009). Particle shape effects on thermophysical properties of alumina nanofluids. *Journal of Applied Physics*, *106*(1), 014304.

Tiwari, R. K., Das, M. K. (2007). Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids. *International Journal of heat and Mass transfer*, *50*(9-10), 2002-2018.

Tie-Gang, F., Ji, Z., & Shan-Shan, Y. (2009). Viscous flow over an unsteady shrinking sheet with mass transfer. *Chinese Physics Letters*, *26*(1), 014703.

Uddin, M. J., Yusoff, N. M., Bég, O. A., & Ismail, A. I. (2013). Lie group analysis and numerical solutions for non-Newtonian nanofluid flow in a porous medium with internal heat generation. *Physica Scripta*, *87*(2), 025401.

Uddin, Z., & Harmand, S. (2013). Natural convection heat transfer of nanofluids along a vertical plate embedded in porous medium. *Nanoscale Research Letters*, *8*(1), 64.

Ullah, I., Waqas, M., Hayat, T., Alsaedi, A., Khan, M. I. (2019). Thermally radiated squeezed flow of magneto-nanofluid between two parallel disks with chemical reaction. *Journal of Thermal Analysis and Calorimetry*, *135*(2), 1021-1030.

Vajravelu, K., Sarojamma, G., Sreelakshmi, K., & Kalyani, C. (2017). Dual solutions of an unsteady flow, heat and mass transfer of an electrically conducting fluid over a shrinking sheet in the presence of radiation and viscous dissipation. *International Journal of Mechanical Sciences*, *130*, 119-132.

Waini, I., Ishak, A., & Pop, I. (2019). Unsteady flow and heat transfer past a stretching/shrinking sheet in a hybrid nanofluid. *International Journal of Heat and Mass Transfer*, *136*, 288-297.

Waini, I., Ishak, A., & Pop, I. (2020). Squeezed hybrid nanofluid flow over a permeable sensor surface. *Mathematics*, *8*(6), 898.

Wang, X.-Q., & Mujumdar, A. S. (2007). Heat transfer characteristics of nanofluids: a review. *International journal of Thermal Sciences*, *46*(1), 1-19.

Waqas, M., Khan, M. I., Hayat, T., & Alsaedi, A. (2017). Numerical simulation for magneto Carreau nanofluid model with thermal radiation: a revised model. *Computer Methods in Applied Mechanics and Engineering*, *324*, 640-653.

Waqas, M., Naz, S., Hayat, T., Khan, M. I., & Alsaedi, A. (2019). Hydromagnetic Carreau nanoliquid in frames of dissipation and activation energy. *Communications in Theoretical Physics*, *71*(12), 1416.

Weidman, P. D., Kubitschek, D. G., & Davis, A. M. J. (2006). The effect of transpiration on self-similar boundary layer flow over moving surfaces. *International journal of engineering science*, *44*(11-12), 730-737.

Wen, D., Ding, Y. (2004). Effective thermal conductivity of aqueous suspensions of carbon nanotubes (carbon nanotube nanofluids). *Journal of Thermophysics and Heat Transfer,18*(4), 481-485.

White, F. M., & Corfield, I. (2006). *Viscous fluid flow* (Vol. 3): McGraw-Hill New York.

Xie, H., Yu, W., & Chen, W. (2010). MgO nanofluids: higher thermal conductivity and lower viscosity among ethylene glycol-based nanofluids containing oxide nanoparticles. *Journal of Experimental Nanoscience, 5*(5), 463-472.

Yoo, D.-H., Hong, K., & Yang, H.-S. (2007). Study of thermal conductivity of nanofluids for the application of heat transfer fluids. *Thermochimica Acta*, *455*(1-2), 66-69.

Yu, W., Xie, H., Chen, L., & Li, Y. (2009). Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid. *Thermochimica Acta*, *491*(1-2), 92-96.

Yu, W., Xie, H., Li, Y., & Chen, L. (2011). Experimental investigation on thermal conductivity and viscosity of aluminum nitride nanofluid. *Particuology*, *9*(2), 187-191.

Zaib, A., Rashidi, M., Chamkha, A., & Mohammad, N. (2018). Impact of nonlinear thermal radiation on stagnation-point flow of a Carreau nanofluid past a nonlinear stretching sheet with binary chemical reaction and activation energy. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *232*(6), 962-972.

Zaimi, K., Ishak, A., & Pop, I. (2014a). Boundary layer flow and heat transfer over a nonlinearly permeable stretching/shrinking sheet in a nanofluid. *Scientific Reports, 4,* 4404.

Zaimi, K., Ishak, A., & Pop, I. (2014b). Flow past a permeable stretching/shrinking sheet in a nanofluid using two-phase model. *Plos One, 9*(11), e111743.

Zhu, H., Zhang, C., Liu, S., Tang, Y., & Yin, Y. (2006). Effects of nanoparticle clustering and alignment on thermal conductivities of Fe_3O_4 aqueous nanofluids. *Applied Physics Letters*, *89*(2), 023123.