Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Radiation Effects on Inclined Magnetohydrodynamics Mixed Convection Boundary Layer Flow of Hybrid Nanofluids over a Moving and Static Wedge

Siti Shuhada Ishak[1], Nurul Nurfatihah Mazlan[1], Mohd Rijal Ilias[1,*], Roselah Osman[1], Abdul Rahman Mohd Kasim[2], Nurul Farahain Mohammad[3]

[1] School of Mathematical Sciences, College of Computing, Informatics and Media, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2] Centre for Mathematical Sciences, College of Computing & Applied Sciences, Universiti Malaysia Pahang, Lebuhraya Tun Razak, Gambang 26300, Pahang, Malaysia
[3] Department of Computational and Theoretical Sciences, Kulliyyah of Science, International Islamic University Malaysia, Bandar Indera Mahkota, 25200 Kuantan, Pahang, Malaysia

ARTICLE INFO

Article history:
Received 7 October 2022
Received in revised form 14 November 2022
Accepted 22 November 2022
Available online 30 November 2022

Keywords:
Magnetohydrodynamics; Mixed Convection; Hybrid Nanofluids; Radiation; Constant Wall Temperature

ABSTRACT

Nowadays, hybrid nanofluids play an important role in heat transfer systems. They are a good alternative to increase the efficiency of heat transfer and save the energy. Thermal radiation and mixed convection flow of hybrid nanofluids past a permeable moving and stationary wedge were studied in this research. This research uses water as a base fluid to investigate the effects of silver (Ag) and magnesium oxide (MgO) nanoparticles. Similarity transformation techniques are used to convert the partial differential equations of hybrid nanofluids to ordinary differential equations, which is then solved numerically by applying the implicit finite difference Keller box method. The results of the research are illustrated graphically to show the behavior of velocity and temperature profiles, as well as skin friction and Nusselt number. Increasing the parameters of the aligned magnetic field, magnetic field interaction, mixed convection, and wedge angle parameter results in higher velocity profiles but lower temperature profiles. As the radiation parameter and the nanoparticle volume fraction increase, the temperature rises and the velocity decreases. With the exception of the radiation parameter, the skin friction and Nusselt number increase as the alignment angle of the magnetic field, the interaction of the magnetic field, the mixed convection, the wedge angle parameter, and the volume fraction of nanoparticle Ag and MgO rise. As a result of these findings, the velocity profiles and Nusselt numbers of moving wedges are higher, but the temperature profiles and skin friction are lower than those of stationary and moving against flow wedges. In addition, a comparison with previously published research is presented, with excellent agreement discovered. The results of this research will contribute to the field of knowledge in mathematics by bringing additional information for mathematician interested in future research on hybrid nanofluids.

* *Corresponding author.*
E-mail address: mrijal@uitm.edu.my

https://doi.org/10.37934/araset.28.3.6884

1. Introduction

Nanotechnology is frequently viewed as the most promising technology of the twenty-first century [1]. The word "nanotechnology" refers to the application of nanoscale materials. Nanotechnology is an interdisciplinary subject that combines scientific domains such as biology, chemistry, physics, and engineering, resulting in a topic with unique applications [2]. Nanotechnologies encompass a broad variety of materials, manufacturing processes, and ideas that are used to construct and enhance many of the items that people use every day. It appears to be part of a new wave of scientific and engineering discoveries that will alter industries such as aerospace, energy, information technology, medical, national security, and transportation. It will enable the development of new goods that are more durable, lighter, and stronger. Buildings, bridges, ships, automobiles, and other constructions now employ different materials than they did in the past [3]. In addition, nanotechnology is defined as atomic, molecular, and macromolecular research and development in at least one dimension with a length range of one to one hundred nanometers.

In thermal engineering, heat transfer is a critical technological issue in many industrial and engineering domains. The change in temperature that occurs as a result of energy conversions from one part to another is referred to as heat transfer. The study of heat transfer in boundary layer flows is beneficial in a variety of technical applications, including transpiration cooling, oil thermal recovery, thrust bearing and radial diffuser design, and drag reduction [4]. Fluid are commonly employed as heat transporters in transportation systems and industrial operations, such as for heating and cooling. Choosing an adequate heat transfer fluid for heat dispersion is an important factor to consider when developing heat exchangers. One of the most important characteristics in heat transport is the Heat Transfer Fluid (HTF), which influences the size and cost of heat exchanger systems. Heat transfer potential of traditional HTFs such as water and oil is limited. There is a pressing need to create a new class of HTFs in order to save costs and meet the growing demand of industry and commerce.

Fortunately, breakthroughs in nanotechnology have allowed heat transfer technologies to become more efficient and cost effective. Nanoparticles are thought to be a new generation of materials with applications in heat transmission. Nanofluids is a new admixture formed as stated in Choi's theory [5]. According to Choi's theory, nanofluids is created by adding nanoscale particles to a base fluid. Choi also mentioned in the hypothesis that when comparing the base fluid to the nanofluids, the nanofluids have a higher thermal conductivity and have a greater effect on heat transfer enhancement. As a result, it is also widely acknowledged and accepted empirically and conceptually that dispersing nanoparticles in a liquid improves the thermophysical properties of the carrier fluid [6]. Nanofluids with high thermal conductivity even at low particle concentrations and low viscosity are suitable candidates for heat transfer applications [7]. Many experimental results in nanofluids thermal conductivity show a larger deviation from the effective medium theory of solid suspensions and the observed deviations are due to the various factors that contribute to nanofluids thermal conductivity [8,9]. The parameters that contribute to nanofluids thermal conductivity, according to Lenin *et al*., [10], can be separated into two categories based on the elements present in the nanofluids. Firstly, there are nanoparticle-related parameters to consider, such as particle concentration, shape and size. Next, their inherent thermophysical qualities, as well as factors related to the thermophysical properties of the base fluid, such as intrinsic thermal conductivity and viscosity, density, and heat capacity.

Hybrid nanofluids, on the other hand, are a relatively new type of nanofluids that can be made by suspending two or more types of nanoparticles in a base fluid, as well as hybrid (composite) nanoparticles. A hybrid material is a substance that combines the physical and chemical features of multiple materials in one homogeneous phase. Synthetic hybrid nanomaterials have unique physicochemical features not found in their individual components. The characteristics of these composites have been studied extensively by Li *et al*., [11], and hybrid materials including carbon nanotubes (CNTs) have been employed in electrochemical sensors, biosensors, and nanocatalysts [12]. Hybrid nanofluids are a type of nanotechnology that is rapidly expanding due to their potential applications in material science and engineering. Based on Setia *at el*., [13], by balancing the benefits and disadvantages of separate suspensions, hybrid nanofluids create considerable changes in heat transfer and pressure drop requirements, which can be attributed to a higher aspect ratio, a more suited thermal network, and the synergistic effect of nanoparticles. Long-term stability, manufacturing processes, selecting optimal nanoparticle combinations for synergistic effects, and the cost of nanofluids may be the most difficult problems, even beyond real implementations. Khashi'ie *et al*., [14] analyze the mixed convection of hybrid Cu-Al_2O_3/water along a static plate in a non-darcyan porous medium with thermal dispersion. They find that the temperature of the hybrid nanofluid decreases with increasing thermal dispersion and mixed convection parameters. While, Nayan *et al*., [15] explore the aligned magnetohydrodynamics (MHD) flow of a hybrid nanofluids through a porous media across a vertical plate. It is discovered that the velocity profiles increase and the temperature profiles decrease when the angle of aligned magnetic field, the interaction of magnetic parameter, and the local Grashof number increase, while the velocity profiles decrease and the temperature profiles increase when the porous parameter and volume fraction of nanoparticles parameter increase. Furthermore, the skin friction of Ag-CuO-water is lower than that of CuO-water, and the Nusselt number of Ag-CuO-water is higher than that of CuO-water.

MHD is the study of the magnetic characteristics and behaviour of electrically conducting fluids. Magneto-fluid dynamics or hydromagnetic is another name for it. Magneto refers to a magnetic field, while hydro refers to water and dynamics refers to movement. As a result, MHD is made up of liquid and magnetic properties, with the magnetic field influencing individual particles and rearranging their concentration in the fluid regime, which has a significant impact on heat transfer analysis [16]. Magnetic fluids, liquids, metals, and mixtures including water, salt, and other electrolytes are among the materials that can be studied using MHD. Using a sequence of Navier–Stokes equations and Maxwell's equations, Hannes Alfven was the first to propose the term MHD to characterise the flow behavior of a fluid having electromagnetic properties [17]. The study of MHD flow phenomena is important and has gotten a lot of attention because of its practical applications in a variety of industrial and engineering fields, such as fusion reactors, optical fibre fliters, crystal growth, metal casting, optical grafting, and the stretching of plastic sheets and metallurgical processes [18]. Once MHD interacts with an electrically conducive fluid, it produces a resistive form force that results in fluid particle motion resistance, which is known as Lorentz force. The Lorentz force increases proportionally with concentration and fluid temperature, delaying boundary layer separation. Nagendramma *et al*., [19] analyzed MHD heat and mass transfer flow through a stretching wedge with a transverse magnetic field, viscous dissipation, and wall slip with a convective boundary condition. Temperature is shown to increase as Eckert and Biot numbers increase and decrease as wedge angle decreases. Then, Ilias et al. [20] investigated a steady aligned MHD magnetic nanofluid flow past a static wedge with constant surface temperature. Fluid velocity increases with increasing inclination angle, magnetic parameter, and thermal buoyancy parameters, but decreases with increasing nanoparticle volume percentage. It has also been discovered that the magnetic parameter has a substantial influence on fluid velocity and temperature. Ilias *et al*., [21] explored the unsteady aligned MHD magnetic nanofluid flow past a wedge the same year. It has been discovered that the magnetic parameter and the unsteadiness parameter have a substantial influence on fluid velocity, temperature, skin friction, and heat transfer rates. In this way, several researchers did the investigation of MHD under different situations [23-29].

Thermal radiation is a process in which energy is emitted in all directions in the form of an electromagnetic wave directly from the radiated surface. The thermal radiation effect plays a critical role in the flow of various liquids and heat transfer from an engineering and physical standpoint. In engineering processes that demand a high operating temperature, thermal radiation has been proven to be advantageous. These include nuclear power plant design, gas turbine design, aeroplane design, space vehicle design, reliable equipment design and satellite design. The thermal radiation effect is important for efficiently controlling thermal boundary layer/altering thermal boundary layer structure and regulating the temperature of a system/altering heat transfer rate. Pal and Mandal [30] investigated the effect of radiative convection on the MHD flow of nanoliquid generated by a nonlinear boundary. According to Waqas *et al*., [31], thermal radiation improved the temperature distribution. They use an exponentially convected stretchable surface to investigate the MHD flow of Carreau nanoliquid and then Brownian motion and thermophoresis formulations and computations are presented. Cao and Baker [32] investigated heat transmission via radiation on the boundary layer through optical fluid past a vertical wall in a recent study on the impact of thermal radiation on fluid flow considering different geometries. Using the Rosseland diffusion approximation, the boundary-layer equations for natural convection–radiation flow over a vertical plate in optically dense fluid have been solved with first-order discontinuities at the wall. Nonlinear radiation was used to investigate the unsteady 2D slip flow of Carreau nanofluid past a static and/or moving wedge by Khan *et al*., [33]. For both shear thickening and shear thinning fluid, our research shows that temperature and the corresponding thermal boundary layer thickness are enhancing functions of the temperature ratio parameter. Furthermore, the velocity of a moving wedge is greater than that of a static wedge. Meanwhile, Pandey and Kumar [34] studied the effects of thermal radiation, viscous dissipation and chemical reaction on the MHD boundary layer flow of nanofluid by a wedge. The result shown that the thermal boundary layer thickness increases with an increase in magnetic field parameter. Then, concentration boundary layer width decreases as the chemical reaction parameter values increase, whereas the velocity profiles increase as the magnetic field parameter increases. Other researcher who studies on the effect of radiation were discuss in [35-36].

Furthermore, due to numerous applications in technology and industry, including as electronic gadgets, nuclear reactors, and pipeline transport, researchers are increasingly interested in investigating mixed convection flow in various types of fluid. The term "mixed convection" refers to the combination of free and forced convection. In general, convection is a heat transfer mechanism involving the movement of fluid from a hotter to a colder medium. Furthermore, free convection is a mixing motion caused by a density difference, whereas forced convection is a mixing motion caused by an external source. In their study of hybrid nanofluids flow in a porous medium of a vertical surface, Waini *et al*., [37] discovered that as the mixed convection parameter is reduced, the velocity distribution decelerates. According to Rostami *et al*., [38], a hybrid nanofluids made up of silicon dioxide (SiO2) and aluminium oxide (Al2O3) nano-size particles with water as the base fluid is analytically modelled to solve the problem of steady laminar MHD mixed convection boundary layer flow of a SiO2-Al2O3/water hybrid nanofluids near the stagnation point on a vertical permeable flat plate. Mishra *et al.*, [39] also looked at the flow of mixed convection MHD nanofluids across a wedge with a temperature-controlled heat source. When it comes to velocity, the magnetic field is more effective. The Brownian motion parameter increases temperature profiles while decreasing volume fractions profiles. Thermal radiation slows the passage of energy to the fluid, lowering the quantity of heat in the fluid.

The present study deals with the boundary layer flow of hybrid nanofluids in the presence of both MHD mixed convection and radiation parameter for constant wall temperature [40]. This type of flow has not yet been examined, to the best of the author's knowledge. The goal of this research is to expand the studies of Kotha *et al.*, [41] to the case of hybrid nanofluids, taking into account the effects of mixed convection and constant wall temperature. This is due to the fact that constant wall temperature and convective boundary condition are related to each other. Additionally, hybrid nanofluids have a higher thermal conductivity than nanofluids, and the presence of both MHD mixed convection and radiation parameters will aid in heat transfer in the medium. The model of Tiwari and Das [42] is employed in this study to deal with governing equations by including hybrid nanoparticles, such as silver (Ag) and magnesium oxide (MgO), with water as the base fluid.

2. Mathematical Formulation

The following assumptions and conditions are applied to the mathematical model:

- A two-dimensional laminar steady flow;
- Boundary layer approximation;
- Tiwari and Das model;
- Mixed convection of hybrid nanofluids;
- Magnetohydrodynamics (MHD);
- Radiations effects;
- Constant wall temperature.

A steady MHD mixed convection flow of hybrid nanofluids over a wedge in the presence of magnetic field and thermal radiation is considered as shown in Figure 1. It is assumed that hybrid nanoparticles is moving over the surface of a wedge with velocity $u_w(x) = U_w x^m$ and the free stream velocity $u_e(x) = U_\infty x^m$ where U_w and U_∞ are constant. $\Omega = \lambda\pi$ is the total angle of wedge, where $\lambda = \frac{2m}{m+1}$ which refers to angle parameter and m is the pressure gradient parameter. It is also assumed that the induced magnetic field caused by the motion of electrically conducting fluid is neglected, as it is very small compared to magnetic field. The flow is subjected to an aligned magnetic field with an acute angle, α and it is expressed as $B(x) = B_0 x^{\frac{m-1}{2}}$ and $B_0 \neq 0$ as a function of the distance from the origin.

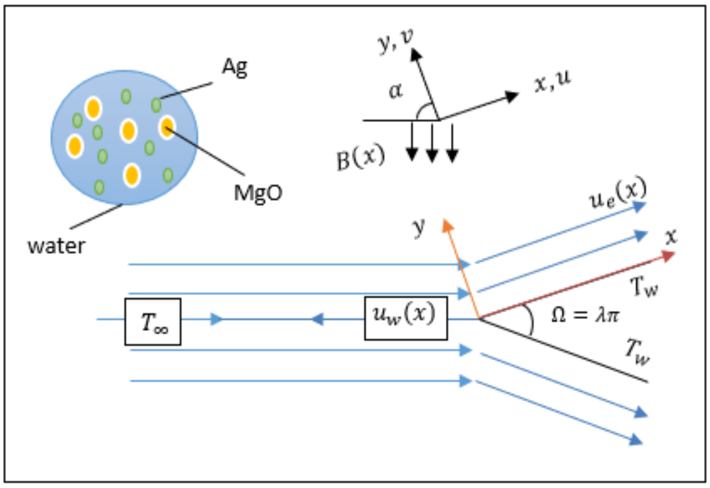


Fig. 1. Physical model of the problem and coordinate system

B_0 denotes the magnetic fluid's strength as well as the wedge's coordinates (x, y). The base fluid is considered to be water with hybrid nanoparticles of silver (Ag) and magnesium oxide (MgO) that are in thermal equilibrium. Assuming a two-dimensional and steady flow in the laminar boundary layer, the governing equations are given as follows [41]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=u_e\frac{\partial u_e}{\partial x}+\frac{\mu_{hnf}}{\rho_{hnf}}\frac{\partial^2 u}{\partial y^2}+\frac{\sigma B^2(x)}{\rho_{hnf}}\sin^2\alpha(u_e-u)+\frac{(\rho\beta)_{hnf}}{\rho_{hnf}}g(T-T_\infty)\sin\frac{\Omega}{2} \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{hnf}\frac{\partial^2 T}{\partial y^2}-\frac{1}{(\rho C_p)_{hnf}}\frac{\partial q_r}{\partial y} \tag{3}$$

While the boundary conditions used in this study are as follows:

$$\begin{aligned} &u=u_w(x), \quad v=0, \quad T=T_w \quad \text{at} \quad y=0 \\ &u\to u_e(x), \quad T\to T_\infty, \quad \text{as} \quad y\to\infty \end{aligned} \tag{4}$$

where u and v denote the velocity components in x- and y-directions respectively and α is an aligned magnetic field with an acute angle which is applied to the flow. σ is the electricity conductivity, T denotes the temperature of the hybrid nanofluids, T_w is the hot fluid at uniform temperature, T_∞ is the constant temperature of ambient cold fluid and g is the gravity acceleration.

As the radiation effect is implemented in the present model, the radiative heat flux, q_r is equated using the Rosseland approximation as follows [43]:

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{5}$$

where σ^* is the Stefan-Bolzmann constant and k^* is the absorption coefficient. Assuming that the difference in temperature within the flow is such that T^4 can be expressed as a linear combination of the temperature. Adapting the Taylor series and disregarding the higher-order terms, T^4 is expended about T_∞ to obtain $T^4 \approx 4T_\infty^3 T - 3T_\infty^4$. Then, the energy equation can be formulated as

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{1}{(\rho C_P)_{hnf}}\left(k_{hnf}+\frac{16\sigma^* T_\infty^3}{3k^*}\right)\frac{\partial^2 T}{\partial y^2} \tag{6}$$

The thermophysical relations of hybrid nanofluids are as follow [44].

$$\begin{aligned} &\rho_{hnf}=(1-\phi_2)\left[(1-\phi_1)\rho_f+\phi_1\rho_{S_1}\right]+\phi_1\rho_{S_2}, \\ &(\rho C_P)_{hnf}=(1-\phi_2)\left[(1-\phi_1)(\rho C_P)_f+\phi_1(\rho C_P)_{S_1}\right]+\phi_2(\rho C_P)_{S_2}, \\ &\mu_{hnf}=\frac{\mu_f}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}, \ \alpha_{hnf}=\frac{k_{hnf}}{(\rho C_P)_{hnf}}, \end{aligned} \tag{7}$$

$$\frac{k_{hnf}}{k_f}=\frac{k_{S_2}+2k_{bf}-2\phi_2\left(k_{bf}-k_{S_2}\right)}{k_{S_2}+2k_{bf}+\phi_2\left(k_{bf}-k_{S_2}\right)}\bullet\frac{k_{S_1}+2k_f-2\phi_1\left(k_f-k_{S_1}\right)}{k_{S_1}+2k_f+\phi_1\left(k_f-k_{S_1}\right)},$$

$$(\rho\beta)_{hnf}=\left[(1-\phi_2)\left((1-\phi_1)(\rho\beta)_f+\phi_1(\rho\beta)_{S_1}\right)\right]+\phi_2(\rho\beta)_{S_2}$$

where ϕ_1 is the volume fraction of nanoparticle Ag, ϕ_1 is the volume fraction of nanoparticles of MgO, ρ_f is the effective density of fluid, ρ_{S_1} is the effective density of Ag, ρ_{S_2} is the effective density of MgO, $(\rho C_P)_{hnf}$ is the heat capacity of the hybrid nanofluids, $(\rho C_P)_{S_1}$ is the heat capacity of the Ag, $(\rho C_P)_{S_2}$ is the heat capacity of the MgO, μ_f is the effective dynamic viscosity of fluid, k_{bf} is the thermal conductivity of the fluid, k_{S_1} is the thermal conductivity of Ag, k_{S_2} is the thermal conductivity of MgO, k_f is the thermal conductivity of fluid, $(\rho\beta)_{s_1}$ is the thermal expansion coefficient of Ag, $(\rho\beta)_{s_2}$ is the thermal expansion coefficient of MgO and $(\rho\beta)_{hnf}$ is the thermal expansion coefficient of hybrid nanofluids. Table 1 shows the thermophysical properties of silver nanoparticles, magnesium oxide nanoparticles and base fluid (water).

Table 1
Thermophysical properties of silver nanoparticles, magnesium oxide nanoparticles and base fuid water [45]

Properties	Ag (Silver)	MgO (Magnesium Oxide)	Base fluid (water)
$C_P\left(J/kgK\right)$	235	879	4179
$k\left(W/mK\right)$	429	30	0.613
$\rho\left(kg/m^3\right)$	10500	3580	997.1
$\beta\times10^{-3}$	5.4	3.36	21
Pr			6.20

The stream function $\psi\left(x,y\right)$presented below is used to satisfy the continuity equation in (1),

$$u=\frac{\partial\psi}{\partial y},\qquad v=-\frac{\partial\psi}{\partial x}, \tag{8}$$

To solve the governing equation in (1)-(3), the following similarity variable are introduced,

$$\eta=\left(\frac{(m+1)}{2x^2}\mathrm{Re}_x\right)^{\frac{1}{2}}y,\qquad \psi=\left(\frac{2v_f{}^2\,\mathrm{Re}_x}{m+1}\right)^{\frac{1}{2}}f(\eta),\qquad \theta=\frac{T-T_\infty}{T_w-T_\infty}, \tag{9}$$

where η is the similarity variable, $\mathrm{Re}_x=\frac{u_e x}{v_f}$ is the Reynolds number $v_f=\frac{\mu_f}{\rho_f}$ is kinematic viscosity, $f(\eta)$ and $\theta(\eta)$ is refer to the non-dimensional stream function and temperature, respectively.

By substituting (6), (7), (8) and (9) into (2) and (3), the following nonlinear ODEs of momentum and energy are obtained:

$$f'''(\eta)+A_1A_2\left[f(\eta)f''(\eta)+\lambda\left(1-\left(f'(\eta)\right)^2\right)\right]+$$
$$\left(2-\lambda\right)A_1M\sin^2\alpha(1-f'(\eta))+\left(2-\lambda\right)\left(A_1A_3\right)\lambda_T\theta\sin\frac{\Omega}{2}=0 \tag{10}$$

$$\left(1+\frac{4}{3}R\right)\theta''(\eta)+\frac{A_4+A_5\phi_2}{A_6}\Pr\theta'(\eta)f(\eta)=0 \tag{11}$$

The boundary condition derived by applying (4) are as follows:

$$\begin{aligned} &f(0)=0, \quad f'(0)=\varepsilon, \quad \theta(0)=1 \quad &\text{at} \quad \eta=0 \\ &f'(\eta)\to 1, \quad \theta(\eta)\to 0 \quad &\text{as} \quad \eta\to\infty \end{aligned} \tag{12}$$

where primes denote differentiation with respect to η, $\lambda=\frac{2m}{m+1}$ is wedge angle parameter, $M=\frac{\sigma B_0{}^2}{\rho_f U_\infty}$ is interaction of magnetic field parameter, $\lambda_T=\frac{g\beta_f(T_w-T_\infty)x}{u_e{}^2}$ is the mixed convection parameter, $R=\frac{16T_\infty^3\sigma^*}{k_{hnf}3k^*}$ is the radiation parameter, $Pr=\frac{(\mu C_P)_f}{k_f}$ is the Prandtl number and ε is the constant moving wedge parameter. The parameter λ_T must be constant and independent of x in order to obtain a valid similarity solution. Numerical findings are discussed using the skin friction coefficient, C_f at the plate's surface and the local Nusselt number, Nu_x which are specified as:

$$C_f=\frac{\tau_w}{\rho_f u_e{}^2}, \quad Nu_x=\frac{xq_w}{k_f(T_w-T_\infty)} \tag{13}$$

where τ_w is the shear tress or skin wall friction and q_w is the plate's heat flux, which are define as:

$$\tau_w=\mu_{hnf}\left(\frac{\partial u}{\partial y}\right)_{y=0}, \quad q_w=-k_{hnf}\left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{14}$$

By substituting (9) and (14) into (13), the solutions obtained are as follows:

$$\frac{C_f}{\mathrm{Re}_x^{-\frac{1}{2}}}=\sqrt{\frac{m+1}{2}}\frac{1}{A_1}f''(0), \qquad \frac{Nu_x}{\mathrm{Re}_x^{\frac{1}{2}}}=-\sqrt{\frac{m+1}{2}}\left(A_6\right)\theta'(0) \tag{15}$$

Where,

$$A_1=(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}$$

$$A_2=(1-\phi_2)\left[(1-\phi_1)+\phi_1\frac{\rho_{S_1}}{\rho_f}\right]$$

$$A_3=\left[(1-\phi_1)+\phi_1\frac{(\rho\beta_{S_1})}{(\rho\beta)_f}\right]+\phi_2\frac{(\rho\beta_{S_2})}{(\rho\beta)_f}$$

$$A_4=\left(1-\phi_2\right)\left[(1-\phi_1)+\phi_1\frac{(\rho C_p)_{S_1}}{(\rho C_p)_f}\right]$$

$$A_5=\phi_2\frac{(\rho C_p)_{S_2}}{(\rho C_p)_f}$$

$$A_6=\frac{k_{S_2}+2k_{bf}-2\phi_2(k_{bf}-k_{S_2})}{k_{S_2}+2k_{bf}-\phi_2(k_{bf}-k_{S_2})}\bullet\frac{k_{S_1}+2k_f-2\phi_1(k_f-k_{S_1})}{k_{S_1}+2k_f-\phi_1(k_f-k_{S_1})}$$

3. Numerical Solution

Eq. (10) and Eq. (11) will be numerically solved utilising an implicit difference scheme known as the Keller-Box method. This is an efficient scheme based on the finite difference method [46]. There are four steps to follow when utilising this method to solve the dimensionless governing equations, which are:

I. Reduce Eq. (10) and Eq. (11) to first-order equations.
II. Write the difference equations using central differences.
III. Linearize the resulting equations using the Newton's method, which is applied to the coefficient of matrix of the finite difference equations.
IV. Solve the linear system using block elimination and a block tri-diagonal factorization scheme.

4. Results and Discussion

The result describes the effects of the parameters on hybrid nanofluids in moving and static wedges. Graphs are used to show the velocity and temperature profiles of the hybrid nanofluids that are affected by the parameters, while tables are used to show the skin friction and Nusselt number that are impacted by the parameters. Table 2 shows the direct comparison in the term of skin friction coefficient that obtained in the present study with the numerical results reported by Watanabe [47], Khan *et al.*, [33], Yih [48], Mabood *et al.*, [49] and Kotha *et al.*,[41] to validate the validity and accuracy of the current analysis. The reported findings are in food accordance with those reported in previous study.

Table 2
Validation testing of skin friction coefficient for various value of m when $\alpha = M = \lambda_T = \lambda = \phi_1 = \phi_2 = R = 0$

m	Watanabe (1190)	Khan et al. (2015)	Yih (1998)	Mabood et al. (2021)	Kotha et al. (2019)	Present results
0	0.46960	0.4969	0.469600	0.469599988	0.46959999	0.469604
0.0141	0.50461	-	0.504614	0.504614318	0.50461432	0.504618
0.0435	0.58698	-	0.568978	0.568977764	0.56897776	0.568982
0.0909	0.65498	0.6550	0.654974	0.654993688	0.65497884	0.654983
0.1429	0.73200	-	0.73200	0.731998540	0.73199854	0.732003
0.2	0.80213	0.8021	0.802125	0.802125593	0.80212559	0.802131
0.3333	0.92777	0.9277	0.927653	0.802125593	0.92765359	0.927660
0.5	-	1.0389	-	1.038903483	-	1.038911
1	-	1.2326	1.232588	1.232587657	-	1.232598

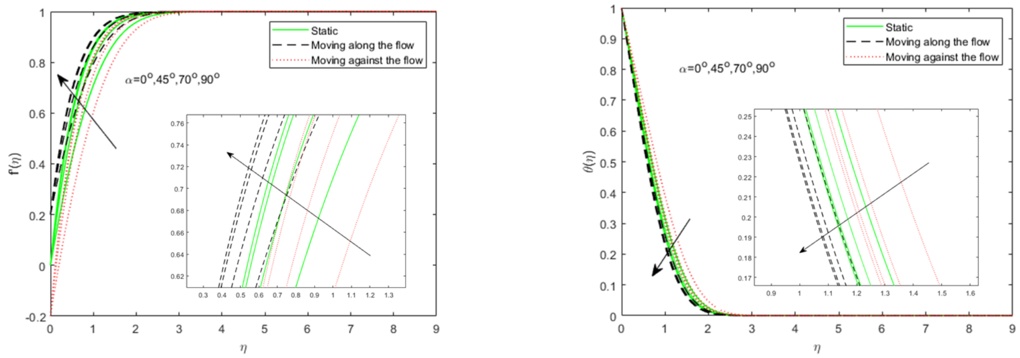
In order to study influences of the aligned angle magnetic field (α), the interaction of magnetic parameter (M), mixed convection parameter (λ_T), wedge angle parameter (λ), the volume fraction of nanoparticles (ϕ_1, ϕ_2) and the radiation parameter (R) on effect of radiation, the numerical results are graphically presented in Figure 2-7. The Prandtl number for mixed convection hybrid nanofluids is 6.2, and it is fitted to the nondimensional values as follows for numerical computational $\alpha = 90^0$, $M = 2$, $\lambda_T = 0.3$, $\lambda = 0.3333$, $\phi_1 = 0.1$, $\phi_2 = 0.1$ and $R = 0.5$.

Figure 2-7 demonstrate how velocity and temperature profiles change when $\alpha, M, \lambda_T, \lambda, \phi_1, \phi_2$ and R change at three condition which are at wedge moving along the flow, at static wedge and at wedge moving against the flow.

Figure 2(a) depicts the effect of α on velocity profiles considering all conditions of the wedge. It can be observed that all three wedge circumstances of static, moving along the flow, and moving against the flow same behavior of velocity profiles which is velocity profiles increase when α

increase. It also can be seen that, the momentum boundary layer reduce when α increase. The momentum boundary layer for hybrid nanofluids past a wedge with condition moving along the flow wedge is the highest followed by static and the lowest is moving against the flow.

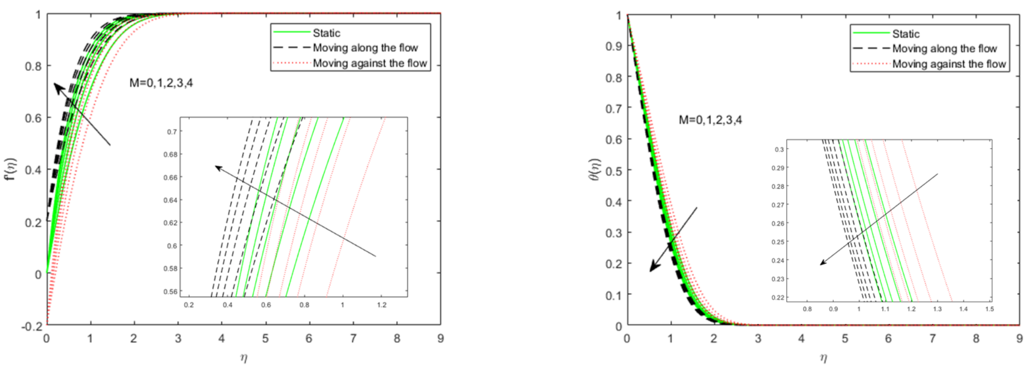
Figure 2(b) depicts the effect of α on temperature profiles considering the conditions of wedge. The temperature profiles for all three wedge circumstances of static, moving along the flow and moving against the flow decrease when α increase. This is due to the fact that as the magnetic field's inclination angle increases, the thermal boundary layer shrinks. When $\alpha = \frac{\pi}{2}$ behaves as a transverse magnetic field, the nanoparticles are attracted by the magnetic field as the aligned angle positions change.



(a) (b)

Fig. 2. Effects of α on (a) velocity profiles and (b) temperature profiles

Figure 3(a) represents the effect of M on velocity profiles considering all conditions of the wedge. It can be observed that all three wedge circumstances of static, moving along the flow, and moving against the flow same behavior of velocity profiles which is velocity profiles increase when M increase. When the value of M increases, the behavior of velocity shifts towards the vertical wedge, as seen in the diagram. Because the nanoparticles normally arrange in sequence as the M increases, this results in a decrease in the thickness of the momentum boundary layer. Based on the free stream velocity, the magnetic line moves as they pass through the wedge. M pushes the viscous force-decelerated fluid, which also counteracts the viscous effect. Besides that, the figure shows the velocity profiles for hybrid nanofluids past a wedge with condition moving along the flow wedge is the highest followed by static and the lowest is moving against the flow.



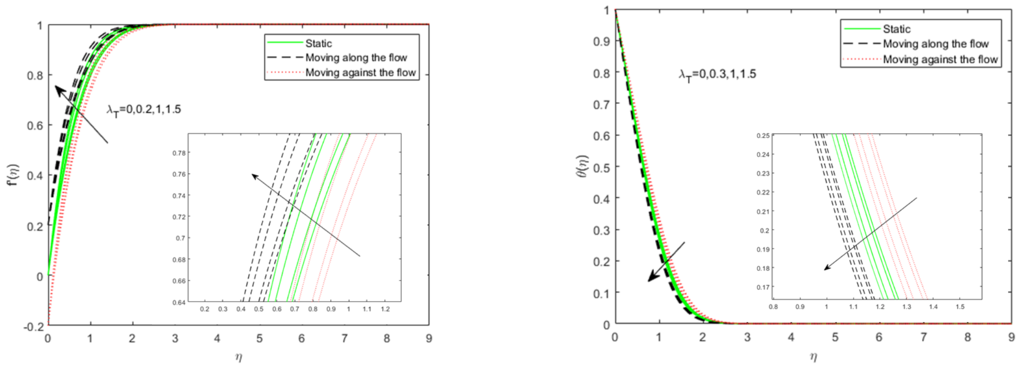
(a) (b)

Fig. 3. Effects of M on (a) velocity profiles (b) temperature profiles

Figure 3(b) displays the effect of M on temperature profiles considering the conditions of wedge. The temperature profiles for all three wedge circumstances of static, moving along the flow and moving against the flow decrease when M increase. This is due to the fact that the thermal boundary layer becomes thinner, increasing the rate of heat transfer. The temperature profiles for hybrid nanofluids past a wedge with condition moving against the flow wedge is the highest followed by static and the lowest is moving along the flow.

Figure 4(a) displays the effect of λ_T on velocity profiles considering all conditions of the wedge. It can be observed that all three wedge circumstances of static, moving along the flow, and moving against the flow same behavior of velocity profiles which is velocity profiles increase when λ_T increase. During this case, as λ_T parameter values increases, the thickness of the boundary layer is reduced. In terms of physics, this is due to the increased buoyancy force. From the figure above, the velocity profiles for hybrid nanofluids past a wedge with condition moving along the flow wedge is the highest followed by static and the lowest is moving against the flow.

Figure 4(b) displays the effect of λ_T on temperature profiles considering the conditions of wedge. The temperature profiles for all three wedge circumstances of static, moving along the flow and moving against the flow decrease when λ_T increase. This is due to the fact that the thermal boundary layer becomes thinner, increasing the rate of heat transfer. It also can be observed the temperature profiles for hybrid nanofluids past a wedge with condition moving against the flow wedge is the highest followed by static and the lowest is moving along the flow.

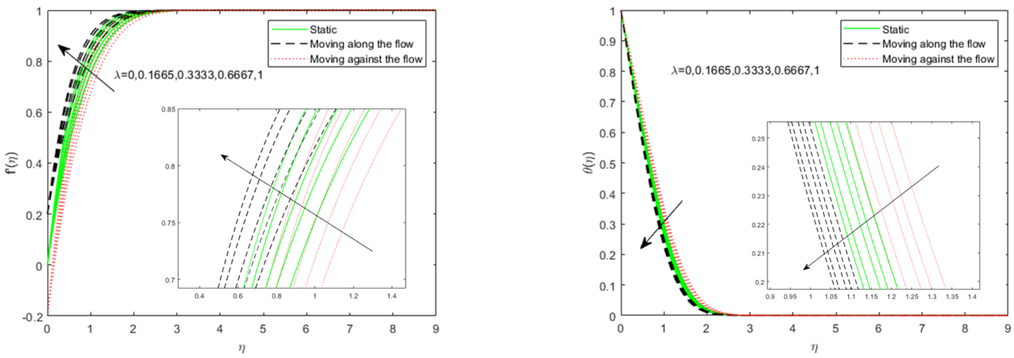


(a) (b)

Fig. 4. Effects of λ_T on (a) velocity profiles (b) temperature profiles

Figure 5(a) displays the effect of λ on velocity profiles considering all conditions of the wedge. It can be observed that all three wedge circumstances of static, moving along the flow, and moving against the flow same behavior of velocity profiles which is velocity profiles increase when λ increase. During this case, as λ parameter values increases, the thickness of the boundary layer is reduced. It shows that the nanofluids flow is accelerated. From the figure above, the velocity profiles for hybrid nanofluids past a wedge with condition moving along the flow wedge is the highest followed by static and the lowest is moving against the flow.

Figure 5(b) displays the effect of λ on temperature profiles considering the conditions of wedge. The temperature profiles for all three wedge circumstances of static, moving along the flow and moving against the flow decrease when λ increase. This is due to the fact that the thermal boundary layer becomes thinner, increasing the rate of heat transfer. It also can be observed the temperature profiles for hybrid nanofluids past a wedge with condition moving against the flow wedge is the highest followed by static and the lowest is moving along the flow.

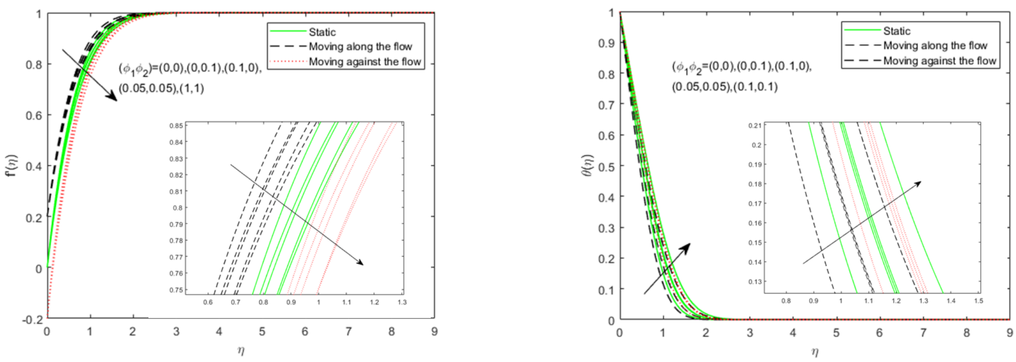


(a) (b)

Fig. 5. Effects of λ on (a) velocity profiles (b) temperature profiles

Figure 6(a) displays the effect of (ϕ_1, ϕ_2) on velocity profiles considering all conditions of the wedge. Based on Figure 6(a), the growth in (ϕ_1, ϕ_2) makes a decrease in the velocity profiles for all conditions wedge and increase in the momentum boundary layer thickness. This is accompanied by an increase in viscosity, which causes the velocity to decrease. Besides, it is clear from the figure that the velocity profiles for hybrid nanofluids past a wedge with condition moving along the flow wedge is the highest followed by static and the lowest is moving against the flow.

Figure 6(b) displays the effect of (ϕ_1, ϕ_2) on temperature profiles considering the conditions of wedge. The temperature profiles for all three wedge circumstances of static, moving along the flow and moving against the flow increase when (ϕ_1, ϕ_2) increase. By increasing the values of volue fraction, the rate of heat transfer increase, and consequently, the temperature field upsurges. An increase of the nanoparticles volume fraction may physically disperse more energy hence raises the temperature consequently. The influence of the increment in (ϕ_1, ϕ_2) also enhance the boundary layer thickness. Based on the figure, it is observed the temperature profiles for hybrid nanofluids past a wedge with condition moving against the flow wedge is the highest followed by static and the lowest is moving along the flow.

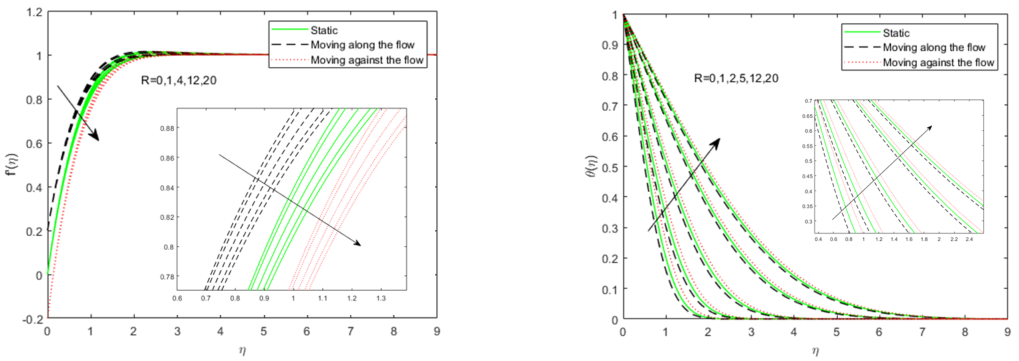


(a) (b)

Fig. 6. Effects of (ϕ_1, ϕ_2) on (a) velocity profiles (b) temperature profiles

Figure 7(a) displays the effect of R on velocity profiles considering all conditions of the wedge. Based on Figure 7(a), the growth in R makes a decrease in the velocity profiles for all conditions wedge and increase in the momentum boundary layer thickness. This could occur because an increase in the radiation parameter strengthens the thermal boundary layer. Besides, it is clear from the figure that the velocity profiles for hybrid nanofluids past a wedge with condition moving along the flow wedge is the highest followed by static and the lowest is moving against the flow.

Figure 7(b) displays the effect of R on temperature profiles considering the conditions of wedge. The temperature profiles for all three wedge circumstances of static, moving along the flow and moving against the flow increase when R increase. As a result of the increase in the radiation factor, the width of the thermal boundary layer increases as well, because the Rosseland radiation absorptive factor decreases. As a consequence, the separation of heat flux radiation q_r increases, while the coefficient of absorption decreases. Therefore, radiation heat transfer to the fluid increases, and fluid temperature increases as well. Based on the figure, it is observed the temperature profiles for hybrid nanofluids past a wedge with condition moving against the flow wedge is the highest followed by static and the lowest is moving along the flow.



(a) (b)

Fig. 7. Effects of R on (a) velocity profiles (b) temperature profiles

Table 3 below shows the numerical value of skin friction coefficient at different values of parameter $\alpha, M, \lambda_T, \lambda, \phi_1, \phi_2$ and R for all conditions of wedge. Meanwhile, Table 4 below shows the numerical value of Nusselt number at different values of parameter $\alpha, M, \lambda_T, \lambda, \phi_1, \phi_2$ and R for all conditions of wedge.

As shown in Table 3, the skin friction coefficient and Nusselt number increase as $\alpha, M, \lambda_T, \lambda, \phi_1, \phi_2$ and R increases. The highest skin friction is for the moving against the flow wedge whereas the highest Nusselt number is for the moving along the flow wedge.

Table 3
Variation of skin friction and Nusselt numberat different dimensionless parameters for moving and static wedge

α	M	λ_T	λ	ϕ	R	Skin Friction			Nusselt Number		
						Against the flow $\varepsilon=-0.2$	Static $\varepsilon=0$	Along the flow $\varepsilon=0.2$	Against the flow $\varepsilon=-0.2$	Static $\varepsilon=0$	Along the flow $\varepsilon=0.2$
0^o	2	0.3	0.3333	$\phi_1=0.1$, $\phi_2=0.1$	0.5	1.815201	1.674143	1.465026	1.043670	1.235088	1.407365
45^o						2.719878	2.375811	1.991337	1.176571	1.326521	1.468751
70^o						3.245362	2.796611	2.315181	1.235934	1.370501	1.500076
90^o						3.389526	2.912980	2.405378	1.250555	1.381554	1.508092
45^o	0	0.3	0.3333	$\phi_1=0.1$, $\phi_2=0.1$	0.5	1.815201	1.674143	1.465026	1.043670	1.235088	1.407365
	1					2.312712	2.055065	1.747908	1.122544	1.287996	1.442184
	2					2.719878	2.375811	1.991337	1.176571	1.326521	1.468751
	3					3.073148	2.658062	2.208118	1.217588	1.356747	1.490178
	4					3.389526	2.912980	2.405378	1.250555	1.381554	1.508092
45^o	2	0	0.3333	$\phi_1=0.1$, $\phi_2=0.1$	0.5	2.589467	2.254453	1.877618	1.158244	1.311179	1.455751
		0.3				2.719878	2.375811	1.991337	1.176571	1.326521	1.468751
		1				3.015510	2.652394	2.251578	1.216334	1.360222	1.497588

		1.5				3.220190	2.844912	2.433488	1.242559	1.382731	1.517046
45^o	2	0.3	0	$\phi_1 = 0.1$, $\phi_2 = 0.1$	0.5	2.337674	2.016083	1.665988	1.113598	1.275349	1.428262
			0.1665			2.543378	2.209857	1.841699	1.148580	1.303740	1.450736
			0.3333			2.719878	2.375811	1.991337	1.176571	1.326521	1.468751
			0.6667			2.990606	2.629717	2.217555	1.216466	1.358910	1.494087
45^o	2	0.3	0.3333	$\phi_1 = 0$, $\phi_2 = 0$	0.5	1.863941	1.601468	1.323589	0.861562	0.986894	1.107732
				$\phi_1 = 0$, $\phi_2 = 0.1$		2.181699	1.882597	1.561460	0.992573	1.131921	1.265686
				$\phi_1 = 0.1$, $\phi_2 = 0$		2.355666	2.054028	1.719505	1.031163	1.165318	1.292857
				$\phi_1 = 0.05$, $\phi_2 = 0.05$		2.256848	1.957755	1.631535	1.015818	1.152644	1.283372
				$\phi_1 = 0.1$, $\phi_2 = 0.1$		2.719878	2.375811	1.991337	1.176571	1.326521	1.468751
45^o	2	0.3	0.3333	$\phi_1 = 0.1$, $\phi_2 = 0.1$	0	2.536555	2.202371	1.833809	1.348457	1.575992	1.790978
					1	2.548032	2.214921	1.847041	1.027971	1.148071	1.261909
					4	2.562153	2.230139	1.863093	0.722320	0.777169	0.828993
					12	2.575665	2.244559	1.878281	0.492838	0.517060	0.539783
					20	2.581721	2.251007	1.885076	0.404697	0.420508	0.435290

4. Conclusions

The effects of thermal radiation and heat transfer on boundary layer flow of hybrid nanofluids across a static and moving wedge were explored in this study. A nonlinear PDE is converted to an ODE and numerically solved using the Keller Box method in Fortran software utilising the similarity approach. The constant wall temperature are considered as boundary conditions. The following are the findings of this study:

I. The velocity profiles increase as the values α, M, λ_T and λ are increased. Increasing (ϕ_1, ϕ_2) and R causes the velocity profiles to decrease.
II. The temperature profiles decreases with increasing values of α, M, λ_T and λ while increasing the values of (ϕ_1, ϕ_2) and R increases the temperature profiles.
III. Skin friction and Nusselt number increase as $\alpha, M, \lambda_T, \lambda$ and (ϕ_1, ϕ_2) increase, with the exception of R.

The study also indicated that for all parameters, the wedge with condition moving along the flow has the highest velocity profiles and highest Nusselt number, but the lowest temperature profiles and lowest skin friction. Meanwhile, the wedge with condition moving against the flow has the lowest velocity profiles and lowest Nusselt number, but the highest temperature profiles and highest skin friction.

Acknowledgement
The authors extend their appreciation to Universiti Teknologi MARA Shah Alam for funding this work through Geran Penyelidikan UMP-IIUM-UiTM Sustainable Research Collaboration 2020 under grant number 600-RMC/SRC/5/3 (016/2020).

References
[1] Anderson, Ben. "Hope for nanotechnology: anticipatory knowledge and the governance of affect." *Area* 39, no. 2 (2007): 156-165. https://doi.org/10.1111/j.1475-4762.2007.00743.x.
[2] Kulzer, Florian, and Michel Orrit. "Single-molecule optics." *Annu. Rev. Phys. Chem.* 55 (2004): 585-611. https://doi.org/10.1146/annurev.physchem.54.011002.103816
[3] Ahmed, Mahmoud Salem. "Nanofluid: new fluids by nanotechnology." In *Thermophysical Properties of Complex Materials*. IntechOpen, 2020. https://doi.org/10.5772/intechopen.86784
[4] Attia, Hazem Ali. "Stagnation point flow and heat transfer of a micropolar fluid with uniform suction or

blowing." *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 30, no. 1 (2008): 51-55. https://doi.org/10.1590/s1678-58782008000100008
[5] Choi, S. US, and Jeffrey A. Eastman. *Enhancing thermal conductivity of fluids with nanoparticles*. No. ANL/MSD/CP-84938; CONF-951135-29. Argonne National Lab.(ANL), Argonne, IL (United States), 1995. https://www.osti.gov/servlets/purl/196525
[6] Uddin, M. J., A. Sohail, O. Anwar Bég, and AI Md Ismail. "Numerical solution of MHD slip flow of a nanofluid past a radiating plate with Newtonian heating: a lie group approach." *Alexandria Engineering Journal* 57, no. 4 (2018): 2455-2464. https://doi.org/10.1016/j.aej.2017.03.025
[7] Raja, M., R. Vijayan, P. Dineshkumar, and M. Venkatesan. "Review on nanofluids characterization, heat transfer characteristics and applications." *Renewable and sustainable energy reviews* 64 (2016): 163-173. https://doi.org/10.1016/j.rser.2016.05.079
[8] Wen, Dongsheng, Guiping Lin, Saeid Vafaei, and Kai Zhang. "Review of nanofluids for heat transfer applications." *Particuology* 7, no. 2 (2009): 141-150. https://doi.org/10.1016/j.partic.2009.01.007
[9] Das, Sarit Kumar, Stephen US Choi, and Hrishikesh E. Patel. "Heat transfer in nanofluids—a review." *Heat transfer engineering* 27, no. 10 (2006): 3-19. https://doi.org/10.1080/01457630600904593
[10] Lenin, Ramanujam, Pattayil Alias Joy, and Chandan Bera. "A review of the recent progress on thermal conductivity of nanofluid." *Journal of Molecular Liquids* 338 (2021): 116929. https://doi.org/10.1016/j.molliq.2021.116929
[11] Li, Yanjiao, Simon Tung, Eric Schneider, and Shengqi Xi. "A review on development of nanofluid preparation and characterization." *Powder technology* 196, no. 2 (2009): 89-101. https://doi.org/10.1016/j.powtec.2009.07.025
[12] Guo, Shaojun, Shaojun Dong, and Erkang Wang. "Gold/platinum hybrid nanoparticles supported on multiwalled carbon nanotube/silica coaxial nanocables: preparation and application as electrocatalysts for oxygen reduction." *The Journal of Physical Chemistry C* 112, no. 7 (2008): 2389-2393. https://doi.org/10.1021/jp0772629
[13] Setia, Hema, Ritu Gupta, and R. K. Wanchoo. "Thermophysical Properties of TiO 2-Water Based Nanofluids.In *AIP Conference Proceedings*, vol. 1393, no. 1, pp. 267-268. American Institute of Physics, 2011. https://doi.org/10.1063/1.3653712
[14] Khashi'ie, Najiyah Safwa, Norihan Md Arifin, Ezad Hafidz Hafidzuddin, Nadihah Wahi, and Mohd Rijal Ilias. "Magnetohydrodynamics (MHD) flow and heat transfer of a doubly stratified nanofluid using Cattaneo-Christov model." *Universal Journal of Mechanical Engineering* 7, no. 4 (2019): 206-214. DOI: 10.13189/ujme.2019.070410
[15] Nayan, Asmahani, Nur Izzatie Farhana Ahmad Fauzan, Mohd Rijal Ilias, Shahida Farhan Zakaria, and Noor Hafizah Zainal Aznam. "Aligned Magnetohydrodynamics (MHD) Flow of Hybrid Nanofluid Over a Vertical Plate Through Porous Medium." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 92, no. 1 (2022): 51-64. https://doi.org/10.37934/arfmts.92.1.5164
[16] Sudarsana, Ali J. Reddy, P. Chamkha, and Ali Al-Mudhaf. "MHD heat and mass transfer flow of a nanofluid over an inclined vertical porous plate with radiation and heat generation/absorption." *Advanced Powder Technology* 28, no. 3 (2017): 1008-1017. https://doi.org/10.1016/j.apt.2017.01.005
[17] Narender, Ganji, Kamatam Govardhan, and Gobburu Sreedhar Sarma. "Magnetohydrodynamic stagnation point on a Casson nanofluid flow over a radially stretching sheet." *Beilstein Journal of Nanotechnology* 11, no. 1 (2020): 1303-1315. https://doi.org/10.3762/bjnano.11.114
[18] Daniel, Yahaya Shagaiya, Zainal Abdul Aziz, Zuhaila Ismail, and Faisal Salah. "Thermal radiation on unsteady electrical MHD flow of nanofluid over stretching sheet with chemical reaction." *Journal of King Saud University-Science* 31, no. 4 (2019): 804-812. https://doi.org/10.1016/j.jksus.2017.10.002
[19] Nagendramma, V., K. Sreelakshmi, and G. Sarojamma. "MHD heat and mass transfer flow over a stretching wedge with convective boundary condition and thermophoresis." *Procedia Engineering* 127 (2015): 963-969. https://doi.org/10.1016/j.proeng.2015.11.444
[20] Ilias, Mohd Rijal, Noraihan Afiqah Rawi, Noor Hidayah Mohd Zaki and Sharidan Shafie. "Aligned MHD Magnetic Nanofluid Flow Past a Static Wedge." International Journal of Engineering & Technology (2018): n. pag. DOI:10.14419/ijet.v7i3.28.20960
[21] Ilias, Mohd Rijal, Ismail N. S'aidah, W. S. Esah, and C. Hussain. "Unsteady aligned MHD boundary layer flow of a magnetic nanofluid over a wedge." *International Journal of Civil Engineering and Technology (IJCIET)* 9 (2018): 794-810.
[22] Bosli, Fazillah, Alia Syafiqa Suhaimi, Siti Shuhada Ishak, Mohd Rijal Ilias, Amirah Hazwani Abdul Rahim, and Anis Mardiana Ahmad. "Investigation of Nanoparticles Shape Effects on Aligned MHD Casson Nanofluid Flow and Heat Transfer with Convective Boundary Condition." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 91, no. 1 (2022): 155-171. https://doi.org/10.37934/arfmts.91.1.155171
[23] Rosaidi, Nor Alifah, Nurul Hidayah Ab Raji, Siti Nur Hidayatul Ashikin Ibrahim, and Mohd Rijal Ilias. "Aligned

Magnetohydrodynamics Free Convection Flow of Magnetic Nanofluid over a Moving Vertical Plate with Convective Boundary Condition." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 93, no. 2 (2022): 37-49. https://doi.org/10.37934/arfmts.93.2.3749

[24] Ilias, Mohd Rijal, Noraihan Afiqah Rawi, and Sharidan Shafie. "Natural convection of ferrofluid from a fixed vertical plate with aligned magnetic field and convective boundary condition." *Malaysian Journal of Fundamental and Applied Sciences* 13, no. 3 (2017).

[25] Nura'in Nabilah Noranuar, Wan, Ahmad Qushairi Mohamad, Sharidan Shafie, Ilyas Khan, Mohd Rijal Ilias, and Lim Yeou Jiann. "Analysis of Heat Transfer in Non-Coaxial Rotation of Newtonian Carbon Nanofluid Flow with Magnetohydrodynamics and Porosity Effects." *Nanostructured Materials-Classification, Growth, Simulation, Characterization, and Devices*.

[26] Ismail, M. A., N. F. Mohamad, M. R. Ilias, and S. Shafie. "MHD Effect on Unsteady Mixed Convection Boundary Layer Flow past a Circular Cylinder with Constant Wall Temperature." In *Journal of Physics: Conference Series*, vol. 890, no. 1, p. 012054. IOP Publishing, 2017. doi :10.1088/1742-6596/890/1/012054

[27] Ismail, M. A., N. F. Mohamad, M. R. Ilias, and S. Shafie. "MHD Effect on Unsteady Mixed Convection Boundary Layer Flow past a Circular Cylinder with Constant Wall Temperature." In *Journal of Physics: Conference Series*, vol. 890, no. 1, p. 012054. IOP Publishing, 2017. doi :10.1088/1742-6596/890/1/012054

[28] Ismail, Nur Suhaida Aznidar, Ahmad Sukri Abd Aziz, Mohd Rijal Ilias, and Siti Khuzaimah Soid. "Mhd boundary layer flow in double stratification medium." In *Journal of Physics: Conference Series*, vol. 1770, no. 1, p. 012045. IOP Publishing, 2021. doi:10.1088/1742-6596/1770/1/012045

[29] Ilias, Mohd Rijal, Nur Sa'aidah Ismail, Nurul Hidayah Ab Raji, Noraihan Afiqah Rawi, and Sharidan Shafie. "Unsteady aligned MHD boundary layer flow and heat transfer of a magnetic nanofluids past an inclined plate." *International Journal of Mechanical Engineering and Robotics Research* 9, no. (2020). https://doi.org/10.18178/ijmerr.9.2.197-206

[30] Pal, Dulal, and Gopinath Mandal. "Hydromagnetic convective–radiative boundary layer flow of nanofluids induced by a non-linear vertical stretching/shrinking sheet with viscous–Ohmic dissipation." *Powder Technology* 279 (2015):674. https://doi.org/10.1016/j.powtec.2015.03.043

[31] Waqas, M., M. Ijaz Khan, T. Hayat, and A. Alsaedi. "Numerical simulation for magneto Carreau nanofluid model with thermal radiation: a revised model." *Computer Methods in Applied Mechanics and Engineering* 324 (2017): 640-653. https://doi.org/10.1016/j.cma.2017.06.012

[32] Cao, Kang, and John Baker. "Non-continuum effects on natural convection–radiation boundary layer flow from a heated vertical plate." *International Journal of Heat and Mass Transfer* 90 (2015): 26-33.https://doi.org/10.1016/j.ijheatmasstransfer.2015.05.014

[33] M. Khan, M. Azam and A. S. Alshomrani, Unsteady slip flow of Carreau nanofluid over a wedge with nonlinear radiation and new mass flux condition, Results in Physics, 7 (2017) 2261-2270. https://doi.org/10.1016/j.rinp.2017.06.038

[34] A. K. Pandey and M. Kumar, Chemical reaction and thermal radiation effects on boundary layer flow of nanofluid over a wedge with viscous and Ohmic dissipation, St. Petersburg Polytechnical University J.: Physics and Mathematics, 3 (2017) 322-332. https://doi.org/10.1016/j.spjpm.2017.10.008

[35] Berrehal, Hamza, and Abdelaziz Maougal. "Entropy generation analysis for multi-walled carbon nanotube (MWCNT) suspended nanofluid flow over wedge with thermal radiation and convective boundary condition." *Journal of Mechanical Science and Technology* 33, no. 1 (2019): 459-464. DOI 10.1007/s12206-018-1245-y

[36] Ullah, Imran, Sharidan Shafie, and Ilyas Khan. "MHD Mixed convection flow of Casson fluid over a moving wedge saturated in a porous medium in the presence of chemical reaction and convective boundary conditions." *Journal of Science and Technology* 9, no. 3 (2017).

[37] Waini, Iskandar, Anuar Ishak, Teodor Groşan, and Ioan Pop. "Mixed convection of a hybrid nanofluid flow along a vertical surface embedded in a porous medium." *International Communications in Heat and Mass Transfer* 114 (2020): 104565. https://doi.org/10.1016/j.icheatmasstransfer.2020.104565

[38] Rostami, Mohammadreza Nademi, Saeed Dinarvand, and Ioan Pop. "Dual solutions for mixed convective stagnation-point flow of an aqueous silica–alumina hybrid nanofluid." *Chinese journal of physics* 56, no. 5 (2018): 2465-2478.https://doi.org/10.1016/j.cjph.2018.06.013

[39] Mishra, P., M. R. Acharya, and S. Panda. "Mixed convection MHD nanofluid flow over a wedge with temperature-dependent heat source." *Pramana* 95, no. 2 (2021): 1-12. https://doi.org/10.1007/s12043-021-02087-z

[40] Pandey, Alok Kumar, and Manoj Kumar. "Chemical reaction and thermal radiation effects on a boundary layer flow of nanofluid over a wedge with viscous and Ohmic dissipation." *St. Petersburg Polytechnical University Journal: Physics and Mathematics* 10, no. 4 (2017): 54-72. https://doi.org/10.1016/j.spjpm.2017.10.008

[41] Kotha, G., Kukkamalla, K., & Ibrahim, S. (2018). Effect of thermal radiation on engine oil nanofluid flow over a permeable wedge under convective heating. *Multidiscipline Modeling in Materials and Structures*, *15*(1), 187–205. https://doi.org/10.1108/mmms-03-2018-0047

[42] Tiwari, Raj Kamal, and Manab Kumar Das. "Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids." *International Journal of heat and Mass transfer* 50, no. 9-10 (2007): 2002-2018. https://doi.org/10.1016/j.ijheatmasstransfer.2006.09.034

[43] Kandasamy, R., I. Muhaimin, and A. K. Rosmila. "The performance evaluation of unsteady MHD non-Darcy nanofluid flow over a porous wedge due to renewable (solar) energy." *Renewable Energy* 64 (2014): 1-9. https://doi.org/10.1016/j.renene.2013.10.019

[44] Mabood, F., and A. T. Akinshilo. "Stability analysis and heat transfer of hybrid Cu-Al2O3/H2O nanofluids transport over a stretching surface." *International Communications in Heat and Mass Transfer* 123 (2021): 105215. https://doi.org/10.1016/j.icheatmasstransfer.2021.105215

[45] Anuar, Nur Syazana, Norfifah Bachok, and Ioan Pop. "Influence of buoyancy force on Ag-MgO/water hybrid nanofluid flow in an inclined permeable stretching/shrinking sheet." *International Communications in Heat and MassTransfer* 123 (2021): 105236. https://doi.org/10.1016/j.icheatmasstransfer.2021.105236

[46] Rafique, Khuram, Muhammad Imran Anwar, Masnita Misiran, Ilyas Khan, and El-Sayed M. Sherif. "The implicit Keller Box scheme for combined heat and mass transfer of Brinkman-type micropolar nanofluid with Brownian motion and thermophoretic effect over an inclined surface." *Applied Sciences* 10, no. 1 (2019): 280. https://doi.org/10.3390/app10010280

[47] Watanabe, T. "Thermal boundary layers over a wedge with uniform suction or injection in forced flow." *Acta Mechanica* 83, no. 3 (1990): 119-126. https://doi.org/10.1007/bf01172973

[48] Yih, K. A. "Uniform suction/blowing effect on forced convection about a wedge: uniform heat flux." *Acta Mechanica* 128, no. 3 (1998): 173-181. https://doi.org/10.1007/bf01251888

[49] Mabood, Fazle, Anum Shafiq, Waqar Ahmed Khan, and Irfan Anjum Badruddin. "MHD and nonlinear thermal radiation effects on hybrid nanofluid past a wedge with heat source and entropy generation." *International Journal of Numerical Methods for Heat & Fluid Flow* (2021). https://doi.org/10.1108/hff-10-2020-0636