SEMARAK ILMU PUBLISHING

CFD Letters

Journal homepage:
https://semarakilmu.com.my/journals/index.php/CFD_Letters/index
ISSN: 2180-1363

The Effect of MHD on Marangoni Boundary Layer of Hybrid Nanofluid Flow Past a Permeable Stretching Surface

Nur Nazirah Abdullah[1], Ahmad Nazri Mohamad Som[2], Norihan Md Arifin[1,3,*], Aniza Ab Ghani[1]

[1] Department of Mathematics and Statistics, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2] Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[3] Institute for Mathematical Research, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 15 August 2022
Received in revised form 14 October 222
Accepted 16 November 2022
Available online 1 May 2023

Keywords:
Hybrid nanofluid; magnetic; Marangoni; permeable stretching surface; shooting method

ABSTRACT

Numerous researchers studied on the properties of hybrid $Cu - Al_2O_3$/water nanofluid in order to have better thermal efficiency that could be used in industrial applications. Therefore, the present study accentuates the effect of MHD on Marangoni boundary layer of hybrid $Cu - Al_2O_3$/water nanofluid flow over a stretching surface. Furthermore, the governing boundary layer equations which is partial differential equations (PDEs) are transformed into a set of ordinary differential equations (ODEs) using similarity transformations. Then, these problems are solved numerically using shooting method through Maple software. It is shows that the rate of heat transfer decreases with the increase in magnetic parameter. The velocity and temperature profiles, as well as local Nusselt number are observed with the specific parameter namely, magnetic parameter, nanoparticles volume fraction and suction. By increasing the volume fraction for copper and magnetic parameter, the velocity profiles decrease while the temperature profiles increase.

1. Introduction

The boundary layer theory plays a vital role in the diverse area of engineering and scientific applications. Most of the problems in engineering sciences are nonlinear, particularly some of heat transfer problems. An enormous amount of research work has been invested in the study of nonlinear boundary value problems [1-7]. Hybrid nanofluid has been introduced and mathematically studied as it is promising better heat transfer performance in fulfilling industrial demand. Hybrid nanofluids are new kinds of nanofluid that are formed by the combination of two different nanoparticles in the base fluid. There are two ways to produce hybrid nanofluid: dispersing different types of nanoparticles in the base fluid or dispersing hybrid nanoparticles in the base fluid. The base fluids may be water, oil, and ethylene glycol. Meanwhile, the nanoparticle materials are copper (Cu), Silver (Ag), Aluminium Oxide (Al_2O_3), Titanium dioxide (TiO_2), and Copper Oxide (CuO). The preparation methods of hybrid nanofluid were discussed in detail using base fluid by Sarkar *et al.*,

* *Corresponding author.*
E-mail address: norihana@upm.edu.my (Norihan Md Arifin)

https://doi.org/10.37934/cfdl.15.5.6573

[8]. They observed that proper hybridization improves the thermal efficiency and heat transfer performance of the hybrid nanofluid. Similarly, Sidik *et al.*, [9] also showed a similar conclusion where the hybrid nanofluid has better thermal conductivity compared to simple nanofluid and base fluid. The potential of Al_2O_3-water nanofluid can enhance the performance of a single slope solar application by increasing the solid volume fraction of nanoparticles (Rashidi *et al.*, [10]). Gupta *et al.*, [11] analyzed the synthesis and thermophysical properties of the hybrid nanofluid. According to the study, the thermophysical properties could be affected by the types of nanoparticles, solid volume fraction, base fluid, particle size, and shape. Huminic and Huminic [12] investigated both experimentally and numerically regarding the working of hybrid nanofluid in heat transfer applications. Several reviews in hybrid nanofluid on boundary layer flow are available in this literature for further reading: (see [13-19])

Furthermore, the dissipative layers that occur between the liquid-liquid or liquid-gas interfaces are known as Marangoni boundary layers. Marangoni flow is induced by a surface tension gradient at the interface of immiscible fluid which is an important physical phenomenon under a microgravity environment due to the increased importance of surface forces and greater extensions and interfaces. Marangoni convection flow also significant in daily life uses such as coating flow technology, film drainage in emulsions, foams, microfluidics, and surfactant replacement therapy for neonatal infants. Al-Mdallal *et al.,* [20] analyzed Marangoni radiative effects of hybrid nanofluid over a flat surface with the existence of magnetic field. Three different types of hybrid nanofluid were used such as alumina-silicon dioxide/water $(Al_2O_3 - SiO_2)$, alumina-titanium dioxide/water $(Al_2O_3 - TiO_2/H_2O)$ and titanium dioxide-silicon dioxide/water $(TiO_2 - SiO_2/H_2O)$. Aly and Ebaid [21] studied Marangoni boundary layer flow in a hybrid nanofluid embedded in a porous medium over a surface in the presence of a magnetic field and thermal radiation. In this study, the velocity field decreased with an increasing Cu volume fraction and magnetic field. Meanwhile, the temperature field vice versa. Khashi'ie *et al.*, [22] numerically investigated the thermal Marangoni convection flow of a hybrid nanofluid over a stretching/shrinking sheet. They concluded that heat transfer rate enhanced with an increasing Cu volume fraction in shrinking flow and Marangoni parameter in stretching flow. Recently, Wahid *et al.,* [23] numerically investigated the Marangoni hybrid nanofluid boundary layer flow embedded in a porous medium over a permeable infinite stretching/shrinking disk. They observed that the local Nusselt number in shrinking surface increased with an increasing Cu volume fraction and porosity.

In the present study, due to the mentioned literature, we are inspired to further the investigation the Marangoni boundary layer flow of hybrid $Cu - Al_2O_3$/water nanofluid past a permeable stretching surface with the effects of magnetic field, also to extend the study by Khashi'ie *et al.*, [22] that only considered the hybrid nanofluid in the absence of magnetic field. The hybridization between Al_2O_3 and Cu nanoparticles in water is emphasized, where the volume fraction of Al_2O_3 is set to be fixed, meanwhile the volume fraction of Cu is set to be varied accordingly. Therefore, a numerical investigation is executed towards this model, in which the main highlight is to determine the influence of the control parameter towards the separation of the boundary layer.

2. Problem Formulation

A steady two-dimensional MHD Marangoni hybrid nanofluid flow past a permeable stretching sheet is investigated. The fluid flow is assumed to be incompressible and laminar, with the presence of the base fluid particles in thermal equilibrium. Further, Cartesian coordinate system, (x, y) is applied (Figure 1). The velocity of the sheet is $u_w(x) = ax$ where $a > 0$. Meanwhile, the temperature of the sheet is $T_w(x) = T_\infty + T_0\left(\frac{x}{L}\right)^2$ where T_∞, and T_0 are the ambient fluid and characteristic temperature, respectively while L is the characteristic length. Furthermore, the main agent for flow induction is a surface temperature gradient that developed the surface tension. The surface tension (σ) is taken to be linearly function of temperature, according to Devi and Devi [24]:

$$\sigma = \sigma_0[1 - \gamma_T(T - T_\infty)]\,, \gamma_T = -\frac{1}{\sigma_0}\frac{\partial\sigma}{\partial T} \tag{1}$$

where $\boldsymbol{\gamma_T}$ is the coefficient of temperature surface tension and $\boldsymbol{\sigma_0}$ is the surface tension at the interface and $\boldsymbol{\sigma_0 > 0}$. it is also assumed that a uniform magnetic field, $\boldsymbol{B_0}$, is applied in the normal to the surface direction.

The governing boundary layer equations for a nanofluid can be written in the Cartesian coordinates (x, y) as given by Devi and Devi [24]:

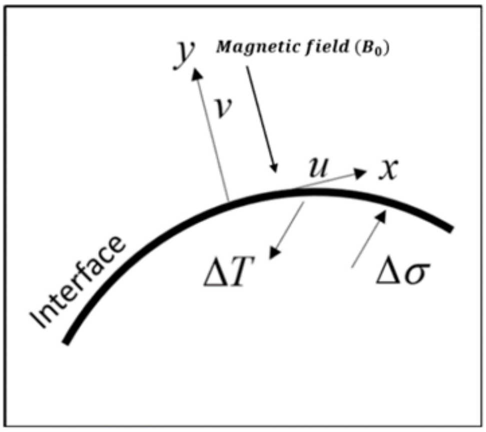

Fig. 1. A physical model of the problem

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \tag{2}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\mu_{hnf}}{\rho_{hnf}}\frac{\partial^2 u}{\partial y^2} - \frac{\sigma_{hnf}}{\rho_{hnf}}B_0^2 u. \tag{3}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k_{hnf}}{(\rho C_p)_{hnf}}\frac{\partial^2 T}{\partial y^2}. \tag{4}$$

subject to the boundary conditions

$$v = v_0,\ \ \mu_{hnf}\frac{\partial u}{\partial y}|_{y=0} = \lambda\frac{\partial \sigma}{\partial y}|_{y=0} =$$

$$\lambda\frac{\partial \sigma}{\partial T}\frac{\partial T}{\partial x}|_{y=0}, \quad T = T_w(x) \text{ at } y = 0,$$

$$u \to 0, \quad T \to T_\infty, \text{ as } \quad y \to \infty. \tag{5}$$

Here u and v are the velocity components of the hybrid nanofluid in the x and y directions, respectively, T is the temperature of the hybrid nanofluid and v_0 is the constant mass flux velocity and λ is the constant parameter. Further, μ_{hnf}, ρ_{hnf}, k_{hnf}, and $(\rho C_p)_{hnf}$ are the dynamic viscosity, density, thermal conductivity, and heat capacity of the hybrid nanofluid, which the correlations are given in Table 1. The subscript of f and n refer to the properties of the water and nanoparticles, separately. The thermal and physical characteristics for water and nanoparticles are given in Table 2. The following dimensionless variables are introduced for similarity solutions of Eq. (2) to Eq. (4) as well as boundary conditions (5) as follows:

Table 1
The physical properties of nanofluid and hybrid nanofluid (Devi and Devi [24])

Properties	Hybrid nanofluid
Density	$\rho_{hnf} = (1-\phi_2)\begin{bmatrix}(1-\phi_1)\rho_f \\ +\phi_1\rho_{s1}\end{bmatrix} + \phi_2\rho_{s2}$
Heat Capacity	$(\rho C_p)_{hnf} = (1-\phi_2)\begin{bmatrix}(1-\phi_1)(\rho C_p)_f \\ +\phi_1(\rho C_p)_{s1}\end{bmatrix} + \phi_2(\rho C_p)_{s2}$
Dynamic viscocity	$\frac{\mu_{hnf}}{\mu_f} = \frac{1}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}$
Thermal conductivity	$\frac{k_{hnf}}{k_{bf}} = \left[\frac{k_{s2}+2k_{bf}-2\phi_2(k_{bf}-k_{s2})}{k_{s2}+2k_{bf}+\phi_2(k_{bf}-k_{s2})}\right]$ where $\frac{k_{bf}}{k_f} = \left[\frac{k_{s1}+2k_f-2\phi_1(k_f-k_{s1})}{k_{s1}+2k_f+\phi_1(k_f-k_{s1})}\right]$

Table 2
Thermophysical properties for the nanoparticles and water (Khanafer *et al.,* [25] and Oztop and Abu-Nada [26])

Physical properties	Water	Al_2O_3	Cu
$\rho(kg/m^3)$	997.1	3970	8933
$C_p(J/kgK)$	4179	765	385
$k(W/mK)$	0.6130	40	400

$$u = axf'(\eta),\ \ v = -\sqrt{av_f}f(\eta),\ \ \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty},\ \ \eta = y/\sqrt{v_f/a}, \tag{6}$$

where prime denotes differentiation with respect to η. Thus, we have

$$v_0 = -\sqrt{av_f}S, \tag{7}$$

where S is the constant mass flux velocity.

Substituting (6) into (3) and (4), we obtain the following ordinary (similarity) differential equations,

$$\lambda_1 f''' - M\lambda_3 f' + \lambda_2(ff'' - f'^2) = 0. \tag{8}$$

$$\frac{1}{Pr}\frac{\lambda_4}{\lambda_5}\theta'' + f\theta' - 2f'\theta = 0. \tag{9}$$

Here$\lambda_1 = \frac{\mu_{hnf}}{\mu_f}$, $\lambda_2 = \frac{\rho_{hnf}}{\rho_f}$, $\lambda_3 = \frac{\sigma_{hnf}}{\sigma_f}$, $\lambda_4 = \frac{k_{hnf}}{k_f}$, $\lambda_5 = \frac{(\rho C_p)_{hnf}}{(\rho C_p)_f}$, $Pr = \frac{(C_p \mu)_f}{k_f}$ is the Prandtl number and M is the magnetic field parameter.

The non-dimensional boundary conditions are

$$f(0) = S, f''(0) = -2Ma\lambda(1-\phi_1)^{2.5}(1-\phi_2)^{2.5},$$
$$\theta(0) = 1 \text{ at } \eta = 0, \quad (10)$$
$$f'(\eta) \to 0, \ \theta(\eta) \to 0, \quad \text{as}\ \eta \to \infty$$

where in the case of, if $S > 0$ is the suction and $S < 0$ is the injection, and $Ma = \frac{\sigma_0 \gamma_T T_0}{L^2 a \sqrt{a \rho_f \mu_f}}$ represents the Marangoni parameter.

Furthermore, physical quantities of interest in this study is local Nusselt number, Nu_x, which is defined as:

$$Nu_x = \frac{x q_w}{k_f (T_w - T\_\infty)}, \quad (11)$$

where q_w is the surface heat flux and the term is written as:

$$q_w = -k_{hnf}\left(\frac{\partial T}{\partial y}\right)_{y=0}, \quad (12)$$

Using (6), (11) and (12), we get

$$Re_x^{-1/2} Nu_x = \frac{k_{hnf}}{k_f}[-\theta'(0)].$$

Where $Re_x = U_w(x)x/v_f$ is the local Reynolds number.

3. Results and Discussion

The nonlinear ordinary differential Eq. (8) and Eq.(9) subject to the boundary conditions (10) were solved numerically using shooting method through Maple software to analyze the different physical parameters, such as magnetic parameter M, Copper (Cu) volume fraction ϕ_2 and the constant mass transfer parameter S with $S > 0$ for suction, and $S < 0$ for injection. Effects of these physical parameters are highlighted in Figure 2 to Figure 6. Table 3 shows the comparison values of $f''(0)$ and $\theta'(0)$ for Cu-water with both $Ma = 1$, and $M = 0$ for the different values of ϕ where $\phi = 0.1$ and $\phi = 0.2$. From the Table 3, the present results show a good agreement with the previous result obtained numerically by Khashi'ie *et al.,* [22] and Sastry *et al.,* [26]. Table 4 represent the numerical data for local Nusselt number, $Re_x^{-1/2} Nu_x$ for various values of M and S when $Pr = 6.2, Ma = 1, \lambda = 1, \phi_1 = 0.1$ and $\phi_2 = 0.09$. It is observed that the local Nusselt number $Re_x^{-1/2} Nu_x$ is decreasing as the values of magnetic parameter M increasing. However, the suction case (when $S > 0$) produces an increase in local Nusselt number $Re_x^{-1/2} Nu_x$. Meanwhile, the local Nusselt number $Re_x^{-1/2} Nu_x$ is decreasing when $S < 0$ (injection).

Table 3
Comparison values of $f''(0)$ and $\theta'(0)$ for Cu-water with $Ma = 1, M = 0, \lambda = 1, S = 0$ and $\phi_1 = 0$

	ϕ	0.1	0.2
Present	$f''(0)$	-1.53687	-1.14487
	$\theta'(0)$	-3.40680	-2.58854
Khashi'ie *et al.,* [19]	$f''(0)$	-1.53687	-1.14487
	$\theta'(0)$	-3.40694	-2.58874
Sastry *et al.,* [24]	$f''(0)$	-1.53687	-3.40361
	$\theta'(0)$	-2.58874	-2.58644

Table 4
Values of local Nusselt number, $Re_x^{-1/2} Nu_x$ for various values of $M = 0,1,2$ and $S = -0.5,0,0.5$ when $Pr = 6.2,\ Ma = 1,\ \lambda = 1,\ \phi_1 = 0.1,$ and $\phi_2 = 0.09$

S	M	$Re_x^{-1/2} Nu_x$
-0.5	0	3.429572
	1	2.789934
	2	2.308835
0	0	4.374033
	1	3.735512
	2	3.265533
0.5	0	5.778110
	1	5.279899
	2	4.942785

Figure 2 and Figure 2 3 show the velocity and temperature profile with the enlargement of the magnetic parameter M. The fluid velocity declines while the temperature profiles escalates when the magnetic parameter M increases. Theoretically, the velocity profiles decreases while the temperature profiles increase with increasing of magnetic parameter M. Furthermore, increasing of magnetic parameter caused the induced Lorentz force increased in the boundary layer. Consequently, an enlargement of the Lorentz force resists the fluid flow and reduces the fluid motion. As a result, the temperature increases. Figure 4 and Figure 5 illustrate influence of Copper (Cu) volume fraction ϕ_2 on the velocity and temperature profiles, respectively. It is observed that the velocity decreases with an increase in Copper (Cu) volume fraction ϕ_2. Meanwhile, the temperature profile vice versa. Figure 6 display the velocity and temperature profiles for selected values of $S > 0$ (suction) and $S < 0$ (injection) when $\phi_1 = 0.1$ and $\phi_2 = 0.09$, respectively. These figures show that the fluid injection ($S < 0$) has more tendency to increase both fluid velocity and temperature profiles as well as the thickness of the thermal boundary layer. Nevertheless, the velocity and temperature profiles tend to decrease when ($S > 0$) for suction cases.

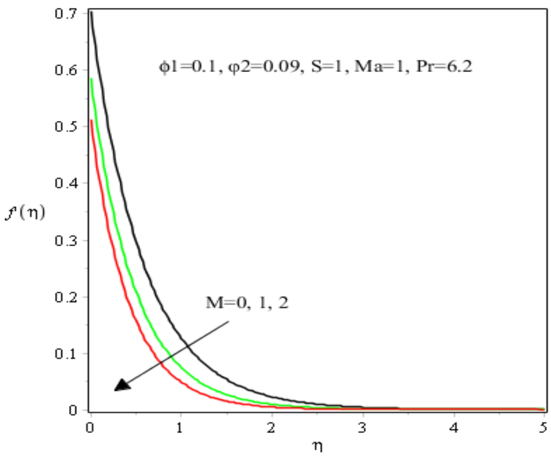

Fig. 2. Variation of $f'(\eta)$ with η for several values of magnetic parameter M

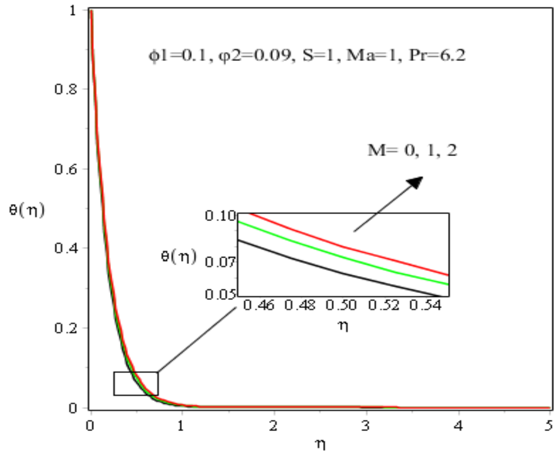

Fig. 3. Variation of $\theta(\eta)$ with η for several values of magnetic parameter M

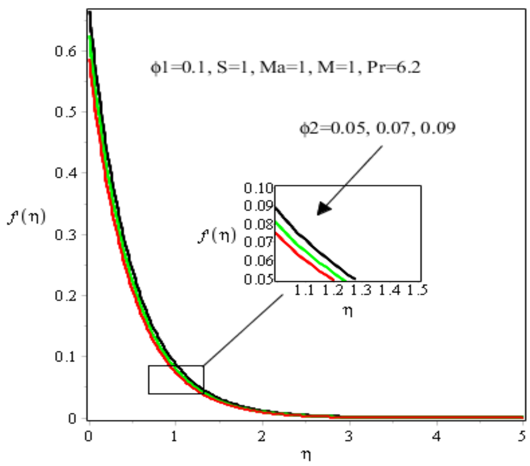

Fig. 4. Variation of $f'(\eta)$ with η for several values of Cu volume fraction ϕ_2

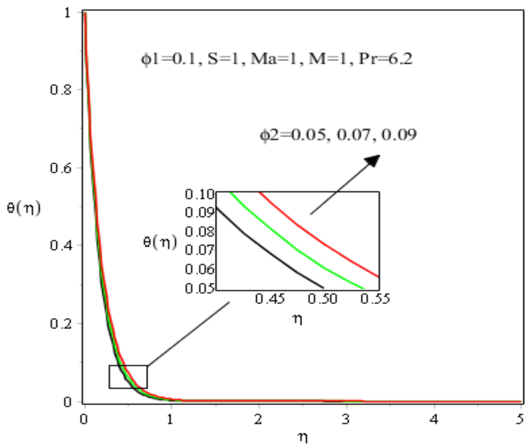

Fig. 5. Variation of $\theta(\eta)$ with η for several values of Cu volume fraction ϕ_2

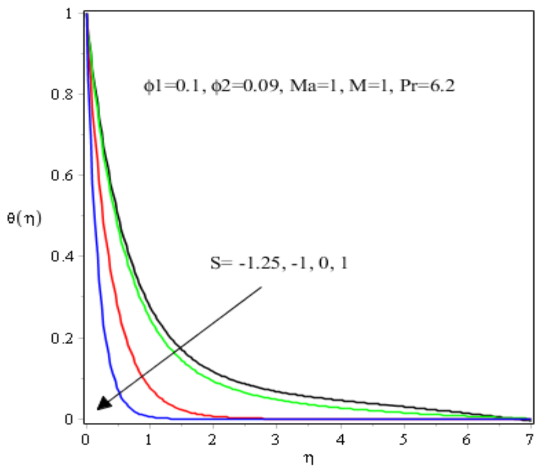

Fig. 6. Variation of $\theta(\eta)$ for values of $S >$ 0 (suction) and $S <$ 0 (injection)

4. Conclusions

In this study, hybrid $Cu - Al_2O_3$/water nanofluid contributes to the enhancement of heat transfer performances. Hybrid $Cu - Al_2O_3$/water nanofluid consists of combination of nanoparticles and leads to better thermal conductivity compared to simple nanofluid and base fluid. The effects of magnetic parameter, Cu volume fraction, and suction as well as local Nusselt number are studied in this present work. The similarity transformation was used to transform the governing partial differential equations into a nonlinear ordinary differential equation and then numerically solved by using shooting method through Maple software. The conclusions of present work are as follows:

i. The local Nusselt number are decreasing when $(S < 0)$ and the values of magnetic parameter M increasing. Meanwhile, the local Nusselt number is increasing when $(S > 0)$.
ii. As the magnetic parameter M and Cu volume fraction enhances, the velocity profiles decrease while the temperature profiles increase.
iii. Both velocity and temperature profiles declined with the increment of suction parameter, $(S > 0)$ while for injection (when $S < 0$), both velocity and temperature profiles escalate.

Acknowledgement
This research was funded by a grant from Universiti Putra Malaysia (GP-GPB 9711400).

References
[1] Ali, F. M., R. Nazar, N. M. Arifin, and I. Pop. "Unsteady shrinking sheet with mass transfer in a rotating fluid." *International Journal for Numerical Methods in Fluids* 66, no. 11 (2011): 1465-1474. https://doi.org/10.1002/fld.2325
[2] Shen, Ming, Fei Wang, and Hui Chen. "MHD mixed convection slip flow near a stagnation-point on a nonlinearly vertical stretching sheet." *Boundary value problems* 2015, no. 1 (2015): 1-15. https://doi.org/10.1186/s13661-015-0340-6
[3] Najib, Najwa, Norfifah Bachok, Norihan Md Arifin, and Fadzilah Md Ali. "Stability analysis of stagnation-point flow in a nanofluid over a stretching/shrinking sheet with second-order slip, soret and dufour effects: A revised model." *Applied Sciences* 8, no. 4 (2018): 642. https://doi.org/10.3390/app8040642
[4] Nadeem, Sohail, M. Riaz Khan, and Arif Ullah Khan. "MHD stagnation point flow of viscous nanofluid over a curved surface." *Physica Scripta* 94, no. 11 (2019): 115207. https://doi.org/10.1088/1402-4896/ab1eb6
[5] Ghosh, Sudipta, and Swati Mukhopadhyay. "Stability analysis for model-based study of nanofluid flow over an exponentially shrinking permeable sheet in presence of slip." *Neural Computing and Applications* 32 (2020): 7201-7211. https://doi.org/10.1007/s00521-019-04221-w
[6] Khan, Ansab Azam, Khairy Zaimi, Suliadi Firdaus Sufahani, and Mohammad Ferdows. "MHD flow and heat transfer of double stratified micropolar fluid over a vertical permeable shrinking/stretching sheet with chemical reaction and heat source." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 21, no. 1 (2020): 1-14. https://doi.org/10.37934/araset.21.1.114
[7] Mahat, Rahimah, Muhammad Saqib, Imran Ulah, Sharidan Shafie, and Sharena Mohamad Isa. "MHD Mixed Convection of Viscoelastic Nanofluid Flow due to Constant Heat Flux." *Journal of Advanced Research in Numerical Heat Transfer* 9, no. 1 (2022): 19-25.
[8] Sarkar, Jahar, Pradyumna Ghosh, and Arjumand Adil. "A review on hybrid nanofluids: recent research, development and applications." *Renewable and Sustainable Energy Reviews* 43 (2015): 164-177. https://doi.org/10.1016/j.rser.2014.11.023
[9] Sidik, Nor Azwadi Che, Isa Muhammad Adamu, Muhammad Mahmud Jamil, G. H. R. Kefayati, Rizalman Mamat, and G. Najafi. "Recent progress on hybrid nanofluids in heat transfer applications: a comprehensive review." *International Communications in Heat and Mass Transfer* 78 (2016): 68-79. https://doi.org/10.1016/j.icheatmasstransfer.2016.08.019

[10] Gupta, Munish, Vinay Singh, Satish Kumar, Sandeep Kumar, Neeraj Dilbaghi, and Zafar Said. "Up to date review on the synthesis and thermophysical properties of hybrid nanofluids." *Journal of cleaner production* 190 (2018): 169-192. https://doi.org/10.1016/j.jclepro.2018.04.146
[11] Rashidi, Saman, Shima Akar, Masoud Bovand, and Rahmat Ellahi. "Volume of fluid model to simulate the nanofluid flow and entropy generation in a single slope solar still." *Renewable Energy* 115 (2018): 400-410. https://doi.org/10.1016/j.renene.2017.08.059
[12] Huminic, Gabriela, and Angel Huminic. "Hybrid nanofluids for heat transfer applications–a state-of-the-art review." *International Journal of Heat and Mass Transfer* 125 (2018): 82-103. https://doi.org/10.1016/j.ijheatmasstransfer.2018.04.059
[13] Khashi'ie, Najiyah Safwa, Norihan Md Arifin, Ioan Pop, Roslinda Nazar, Ezad Hafidz Hafidzuddin, and Nadihah Wahi. "Flow and heat transfer past a permeable power-law deformable plate with orthogonal shear in a hybrid nanofluid." *Alexandria Engineering Journal* 59, no. 3 (2020): 1869-1879. https://doi.org/10.1016/j.aej.2020.05.029
[14] Khashi'ie, Najiyah Safwa, Ezad Hafidz Hafidzuddin, Norihan Md Arifin, and Nadihah Wahi. "Stagnation point flow of hybrid nanofluid over a permeable vertical stretching/shrinking cylinder with thermal stratification effect." *CFD Letters* 12, no. 2 (2020): 80-94.
[15] Faizal, Nur Faizzati Ahmad, Norihan Md Ariffin, Yong Faezah Rahim, Mohd Ezad Hafidz Hafidzuddin, and Nadihah Wahi. "MHD and slip effect in micropolar hybrid nanofluid and heat transfer over a stretching sheet with thermal radiation and non-uniform heat source/sink." *CFD Letters* 12, no. 11 (2020): 121-130. https://doi.org/10.37934/cfdl.12.11.121130
[16] Teh, Yuan Ying, and Adnan Ashgar. "Three dimensional MHD hybrid nanofluid Flow with rotating stretching/shrinking sheet and Joule heating." *CFD Letters* 13, no. 8 (2021): 1-19. https://doi.org/10.37934/cfdl.13.8.119
[17] Wahid, Nur Syahirah, Norihan Md Arifin, Najiyah Safwa Khashi'ie, Ioan Pop, Norfifah Bachok, and Mohd Ezad Hafidz Hafidzuddin. "Flow and heat transfer of hybrid nanofluid induced by an exponentially stretching/shrinking curved surface." *Case Studies in Thermal Engineering* 25 (2021): 100982. https://doi.org/10.1016/j.csite.2021.100982
[18] Alsaedi, A., K. Muhammad, and T. Hayat. "Numerical study of MHD hybrid nanofluid flow between two coaxial cylinders." *Alexandria Engineering Journal* 61, no. 11 (2022): 8355-8362. https://doi.org/10.1016/j.aej.2022.01.067
[19] Kumar, T. Prasanna. "Heat Transfer of SWCNT-MWCNT Based Hybrid Nanofluid Boundary Layer Flow with Modified Thermal Conductivity Model." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 92, no. 2 (2022): 13-24. https://doi.org/10.37934/arfmts.92.2.1324
[20] Al-Mdallal, Qasem M., N. Indumathi, B. Ganga, and AK Abdul Hakeem. "Marangoni radiative effects of hybrid-nanofluids flow past a permeable surface with inclined magnetic field." *Case Studies in Thermal Engineering* 17 (2020): 100571. https://doi.org/10.1016/j.csite.2019.100571
[21] Aly, Emad H., and Abdelhalim Ebaid. "MHD Marangoni boundary layer problem for hybrid nanofluids with thermal radiation." *International Journal of Numerical Methods for Heat & Fluid Flow* 31, no. 3 (2021): 897-913. https://doi.org/10.1108/HFF-05-2020-0245
[22] Khashi'Ie, Najiyah Safwa, Norihan Md Arifin, Ioan Pop, Roslinda Nazar, Ezad Hafidz Hafidzuddin, and Nadihah Wahi. "Thermal Marangoni flow past a permeable stretching/shrinking sheet in a hybrid Cu-Al." *Sains Malaysiana* 49, no. 1 (2020): 211-222. https://doi.org/10.17576/jsm-2020-4901-25
[23] Wahid, Nur Syahirah, Norihan Md Arifin, Najiyah Safwa Khashi'ie, and Ioan Pop. "Marangoni hybrid nanofluid flow over a permeable infinite disk embedded in a porous medium." *International Communications in Heat and Mass Transfer* 126 (2021): 105421. https://doi.org/10.1016/j.icheatmasstransfer.2021.105421
[24] Devi, SP Anjali, and S. Suriya Uma Devi. "Numerical investigation of hydromagnetic hybrid Cu–Al2O3/water nanofluid flow over a permeable stretching sheet with suction." *International Journal of Nonlinear Sciences and Numerical Simulation* 17, no. 5 (2016): 249-257. https://doi.org/10.1515/ijnsns-2016-0037
[25] Khanafer, Khalil, Kambiz Vafai, and Marilyn Lightstone. "Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids." *International journal of heat and mass transfer* 46, no. 19 (2003): 3639-3653. https://doi.org/10.1016/S0017-9310(03)00156-X
[26] Oztop, Hakan F., and Eiyad Abu-Nada. "Numerical study of natural convection in partially heated rectangular enclosures filled with nanofluids." *International journal of heat and fluid flow* 29, no. 5 (2008): 1326-1336. https://doi.org/10.1016/j.ijheatfluidflow.2008.04.009