Menemui Matematik (Discovering Mathematics) 47(3) (2025) 34-51

Menemui Matematik
(Discovering Mathematics)

journal homepage: https://persama.org.my/dismath/home

Stagnation Point Flow of Hybrid Nanofluid over a Non-linear Stretching/Shrinking Sheet in Porous Medium with Suction

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Received: 12 September 2025
Accepted: 8 November 2025

ABSTRACT

The focus of this research is to observe the porous medium presence with suction effects on the stagnation point flow and heat transfer in a hybrid nanofluid over nonlinear stretching/shrinking sheet. Silver (Ag) and Copper Oxide (CuO) nanoparticles are dispersed in pure water to create a hybrid nanofluid. The governing nonlinear partial differential equations are turned into a nonlinear ordinary differential equation by using similarity transformations. These resulting equations subjected to the boundary conditions are then solved numerically by implementing bvp4c function in MATLAB software. The flow and heat transfer characteristics were graphically illustrated and explained. The effects of the parameters are discussed for various values of the porous medium and suction parameter, nonlinear parameter and nanoparticle volume fraction parameter which represents in velocity profile and temperature profile with reduced skin friction coefficient and reduced heat transfer. The results indicate the existence of dual solutions for a given range of parameters. The presence of porous medium resulting in elevation of reduced skin friction coefficient and reduced heat transfer. Besides, the suction effects reduce energy losses. Thus, the heat transfer increases and decreases the boundary layer separation.

Keywords: Heat transfer, hybrid nanofluid, non-linear stretching/shrinking sheet, suction, porous medium

INTRODUCTION

Hybrid nanofluids have been considered a novel fluid since their initial development by researchers, resulting in limited literature on hybrid nanofluids over nonlinear stretching/shrinking surfaces. However, Anuar *et al*. (2020a) analyzed the numerical solution of stagnation point flow and heat transfer over a nonlinear stretching/shrinking sheet in a hybrid nanofluid, including a stability analysis. They found that the first solution indicates stable flow, while the second indicates unstable flow, with the nonlinear parameter delaying boundary layer separation. Dual solutions were found to exist for a certain range.

Gupta and Gupta (1977) extended Crane's (1970) problem to include heat and mass transfer with the effects of suction or blowing. Zeeshan and Majeed (2016) proposed a heat transfer analysis of Jeffery fluid flow over a stretching sheet with suction/injection and magnetic dipole effects. Raju *et al.* (2016) examined the effects of nonlinear thermal radiation on 3D Jeffrey fluid flow over a stretching/shrinking surface, considering homogeneous-heterogeneous reactions, a non-uniform heat source/sink, and suction/injection. Kamal *et al.* (2018) investigated stagnation-point flow and heat transfer over a permeable stretching/shrinking sheet with a heat source effect. Anuar *et al.* (2019) analyzed the effect of suction/injection on the stagnation point flow of hybrid open nanofluid over an exponentially shrinking sheet with stability analysis. Waini *et al.* (2019) researched hybrid nanofluid flow and heat transfer over a nonlinear permeable stretching/shrinking surface, finding that dual solutions exist with the shrinking/stretching parameter and an additional suction parameter. Anuar *et al.* (2020b) addressed hybrid nanofluid flow over a permeable moving surface under hydromagnetic and suction effects, showing that the skin friction coefficient and the local Nusselt number increase with increased suction/injection, but the local Nusselt number decreases as the heat source rises.

The literature indicates that many studies on the stagnation-point flow of hybrid nanofluid are based on a two-phase modeling framework, including the effects of suction or injection in the boundary layer of steady, laminar, and incompressible hybrid nanoparticles. Anuar *et al*. (2020a) provided insights into the impact of combining two nanoparticles' sizes and the heat transfer direction, along with the volume concentration of nanoparticles, on the evolution of velocity and temperature fields and key engineering quantities. Mahmood *et al.* (2024) investigated MHD stagnation point flow of a hybrid nanofluid over a stretching sheet, including effects of suction and viscous dissipation. They used a model-based comparative analysis and reported how suction and dissipative effects significantly influence velocity and thermal profiles of the hybrid nanofluid. Ghosh *et al.* (2024) studied and explained about the steady flow of a hybrid nanofluid due to a permeable shrinking sheet close to a stagnation region with suction/injection. Mahabaleshwar *et al.* (2024) presented an analytical solution for stagnation-point flow of a hybrid nanofluid which is Brinkman-type over a stretchable plate including wall suction and thermal radiation. Closed-form expressions which are incomplete error functions were obtained which they concluded that the presence of suction enhances cooling of the wall, increasing heat transfer. Low & Bachok (2024) examined stagnation point flow and heat transfer of a hybrid nanofluid over a stretching or shrinking cylinder, including suction/injection effects. They reported dual solution behaviors dependent on the suction parameter and shrinking/stretching dynamics and found that the hybrid nanofluid notably enhances heat transfer compared to regular nanofluids. Kaharuddin *et al.* (2025) analyzed steady stagnation-point flow and heat transfer with suction over a stretching/shrinking sheet embedded in a porous medium under thermal radiation. They discovered the existence of both dual and unique solutions depending on the velocity ratio parameter and showed that increasing suction and permeability enhances both the skin friction coefficient and the local Nusselt number, while higher Prandtl number and radiation parameter thin the thermal boundary layer.

The addition of a porous medium to the problem affects the rate of heat transfer because it alters the fluid velocity within the medium. Rosali *et al.* (2011) studied this and found that decreasing the porosity of the porous medium (increasing the permeability K expands the range of the parameter c for which solutions exist for the shrinking sheet. Vyas & Srivastava (2012) investigated scenarios where a sheet is placed at the bottom of a porous medium, which resists fluid flow and affects fluid stability. They observed lower suction rates compared to situations without a porous medium. They also noted that different porous materials require varying degrees of suction to control vorticity in the boundary layer. Pal & Mandal (2015) discovered that the skin friction coefficient increases with increased permeability of the porous medium for a shrinking sheet but decreases for a stretching sheet. Yasin *et al*. (2017) analyzed boundary layer flow and heat transfer past a permeable shrinking surface embedded in a porous medium with a second order slip condition. They found that applying a slip condition along with the presence of a porous medium extends the range of solutions. Additionally, they observed that the skin friction coefficient is higher under the no-slip condition compared to the slip condition. Mahabaleshwar & Hatami (2023) investigated the unsteady stagnation-point flow of a hybrid nanofluid over a stretching or shrinking sheet embedded in a porous medium, incorporating mass transpiration like suction/injection and chemical reactions. They used similarity transformations to reduce the governing PDEs into ODEs and derived analytical expressions for the velocity and concentration profiles. The study revealed that axial velocity decreases as the shrinking-sheet parameter increases (in both suction and injection cases) and concentration diminishes with increasing shrinking parameter and chemical reaction rate.

Bachok *et al.* (2023) studied the numerical computation of stagnation point flow and heat transfer over a nonlinear stretching or shrinking sheet in hybrid nanofluid with suction or injection effects. They found that there exist non-unique solutions at certain values of shrinking case ($\varepsilon \leq -1$) while unique solution exists at stretching case ($\varepsilon > -1$) for nonlinear stretching/shrinking surface. Besides that, they conclude that the presence of nonlinear suction parameter widens the range of solutions and delays the boundary layer separation. Hakim *et al.* (2023) studied stagnation-point flow and heat transfer over an exponentially stretching/shrinking sheet embedded in a porous medium with internal heat generation. They discovered dual solutions in the shrinking case ($\lambda < 0$) and a unique solution in the stretching case ($\lambda > 0$). Increasing the permeability parameter raised the skin friction coefficient and the local Nusselt number, whereas increasing heat generation reduced the Nusselt number while leaving skin friction unchanged. Reddy *et al.* (2024) investigated the magnetohydrodynamic stagnation point flow of a Williamson hybrid nanofluid (MoS_2–SiO_2/CMC–water) over a stretching sheet embedded in a porous medium, considering the effects of heat generation, thermal radiation, and chemical reaction. They found that the velocity profile increases with the porosity parameter and is higher for hybrid nanofluid compared to mono-nanofluid. Additionally, they observed that increasing thermal radiation and Biot number enhances the thermal boundary layer thickness, leading to higher fluid temperatures. Furthermore, the concentration profile decreases with an increase in the chemical reaction parameter, indicating a stronger reactant consumption effect in the flow field. Based on past studies, there is a noticeable lack of research on stagnation point flow of hybrid nanofluids over non-linear stretching or shrinking sheets embedded in porous medium with suction effects, indicating a significant gap that warrants further investigation. Therefore, motivated by the previous studies, we extend this work from Bachok *et al*. (2023) by exploring hybrid nanofluid flow at stagnation point over a non-linear stretching/shrinking sheet with the effects of suction in a porous medium using similarity transformation method.

METHODOLOGY

In this paper, we consider a two-dimensional stagnation point flow and heat transfer over a non-linear stretching/shrinking sheet in porous media with the presence of suction. Figure 1 shows the illustration of the flow problem. Silver (Ag) and copper oxide (CuO) are nano-sized particles and water as a base fluid. The thermophysical properties of hybrid nanofluids are given in Table 1 below, respectively. Both Ag and CuO are considered as we follow the model introduced by Bachok *et al.* (2023) and are among the most commonly used by many researches in previous studies.

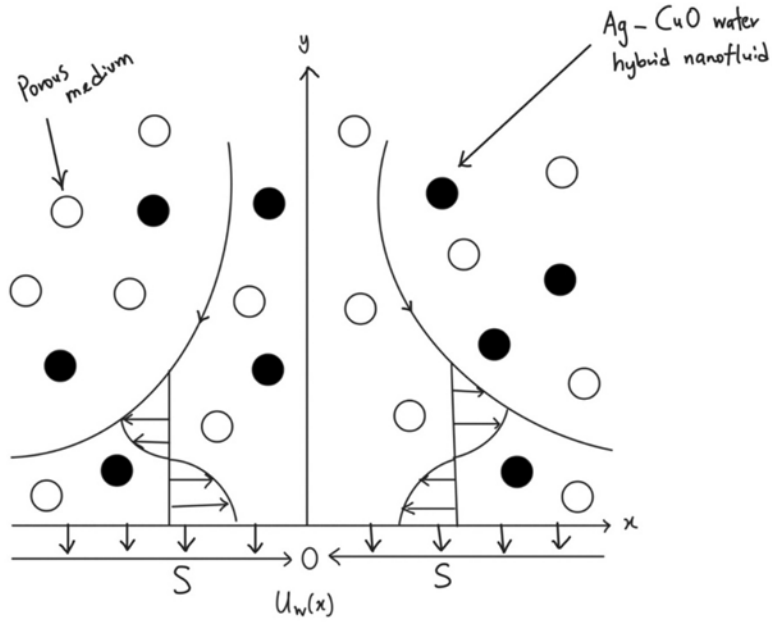

Figure 1: The physical model and coordinate system

The basic governing equations are constructed as below (Abu Bakar *et al*. (2021) and Bachok *et al.* (2023)):

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=U_\infty\frac{dU_\infty}{dx}+\frac{\mu_{hnf}}{\rho_{hnf}}\frac{\partial^2 u}{\partial y^2}-\frac{\mu_{hnf}\varepsilon}{\rho_{hnf}K}(u-U_\infty), \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{hnf}\frac{\partial^2 T}{\partial y^2}, \tag{3}$$

with the corresponding boundary conditions:

$$\begin{gathered} v=V_w(x), u=U_w(x), T=T_w \ \ at \ \ y=0 \\ u\rightarrow U_\infty(x), T\rightarrow T_\infty \ as \ \ y\rightarrow\infty \end{gathered} \tag{4}$$

where u and v are corresponding velocity components in x and y directions, T is the temperature of fluids.

Table 1: Thermophysical properties of hybrid nanofluids (Bachok *et al.,* 2023)

Properties	Formulations
Thermal diffusivity, α	$\alpha_{hnf}=\frac{k_{hnf}}{(\rho C_p)_{hnf}}$, where $\frac{k_{hnf}}{k_{nf}}=\frac{k_{s2}+2k_{nf}-2\varphi_2(k_{nf}-k_{s2})}{k_{s2}+2k_{nf}+2\varphi_2(k_{nf}-k_{s2})}$, $\frac{k_{nf}}{k_f}=\frac{k_{s1}+2k_f-2\varphi_1(k_f-k_{s1})}{k_{s1}+2k_f+2\varphi_1(k_f-k_{s1})}$
Dynamic viscosity, μ	$\mu_{hnf}=\frac{\mu_f}{(1-\varphi_1)^{2.5}(1-\varphi_2)^{2.5}}$
Density, ρ	$\rho_{hnf}=\varphi_2\rho_{s2}+(1-\varphi_2)[(1-\varphi_1)\rho_f+\varphi_1\rho_{s1}]$
Heat capacity	$\rho C_p=\varphi_2(\rho C_p)_{s2}+(1-\varphi_2)\left[(1-\varphi_1)(\rho C_p)_f+\varphi_1(\rho C_p)_{s1}\right]$

Here, φ_1 is copper oxide (CuO) nanoparticle and φ_2 is silver (Ag) nanoparticle. Nanofluid is formed by disseminating CuO in basic fluid such as water. Hybrid nanofluid is formed by disseminating CuO and Ag in basic fluid. To solve Eq. (1) to Eq. (3), the following similarities variables introduced by Malvandi *et al.* (2014) along with the boundary conditions, Eq. (4)

$$\eta=\left(\frac{(n+1)b}{2\nu_f}\right)^{\frac{1}{2}}yx^{\frac{n-1}{2}},\psi=\left(\frac{2b\nu_f}{n+1}\right)^{\frac{1}{2}}x^{\frac{n+1}{2}}f(\eta),T=(T_w-T_\infty)\theta(\eta)+T_\infty \quad (5)$$

where b is constant, n is non-linear parameter, η is the similarity variable, ψ represents the stream function, ν_f is the fluid kinematic viscosity. These similarities variables satisfy Eq. (1). It is defined as $u=\frac{\partial\psi}{\partial y}$ and $v=-\frac{\partial\psi}{\partial x}$.

Eq. (2) and Eq. (3) are transformed into following form

$$\frac{1}{A_1}\frac{(n+1)}{2}f'''(\eta)-m_1(f'(\eta)-1)+\frac{n+1}{2}f(\eta)f''(\eta)-n(f'^2(\eta)+1)=0 \quad (6)$$

$$\frac{k_{hnf}/\,k_f}{(\rho C_p)_{hnf}\,/\,(\rho C_p)_f}\frac{1}{Pr}\,\theta''(\eta)+f(\eta)\theta'(\eta)=0 \quad (7)$$

where $A_1=\frac{\nu_f}{\nu_{hnf}}$ is the viscosity coefficient, $m_1=\frac{\nu_{hnf}\varepsilon}{Kb}$ is porous media permeability parameter.

The boundary conditions are transformed into

$$f(0)=S,\theta(0)=1,f'(0)=\varepsilon, \quad (8)$$
$$f'(\eta)\to 1,\theta(\eta)\to 0\ as\ \eta\to\infty$$

where f' means differentiation with respect to η and S is suction parameter. For stretching ($\varepsilon > 0$) and shrinking ($\varepsilon < 0$) parameter, these parameters are represented as $\varepsilon = \frac{a}{b}$. The Prandtl number, Pr is $Pr = \frac{\nu}{\alpha}$.

The local skin friction and the local Nusselt number are

$$Re_x^{\frac{1}{2}} C_f = \frac{\mu_{hnf}}{\mu_f} \sqrt{\frac{n+1}{2}} f''(0), \qquad Re^{-\frac{1}{2}} Nu_x = -\frac{k_{hnf}}{k_f} \sqrt{\frac{n+1}{2}}\, \theta'(0) \tag{9}$$

where Re is local Reynold number denoted by $\frac{U_\infty x}{\nu_f}$.

RESULTS AND DISCUSSION

The effects of porous medium and suction in the case of stagnation point flow of hybrid nanofluid in stretching/shrinking sheet are discussed. The porous medium presence enables transportation of fluids and gases through it. The numerical result was generated by comparing the present results with the past research using the MATLAB built-in function bvp4c for several governing parameters. Table 2 shows the comparison values of reduced skin friction coefficient, $f''(0)$ and reduced heat transfer at the surface, $-\theta'(0)$ for current study and past research, Anuar *et al.* (2020a) and Bachok *et al.* (2023). Current results obtained compatible results with Anuar *et al.* (2020a) and Bachok *et al.* (2023) results. Thus, the present numerical have a good correlation with the prior studies.

Table 2: Comparison values of $f''(0)$ and $-\theta'(0)$ when $S = 0$, $\varphi_1 = \varphi_2 = 0, n = 1, Pr = 0.7, \varepsilon = -1.1, m_1 = 0$

Solutions	Anuar *et al.* (2020a)		Bachok *et al.* (2023)		Current results	
	f''(0)	-*θ'*(0)	*f''*(0)	-*θ'*(0)	*f''*(0)	-*θ'*(0)
First solution	1.18668	0.18283	1.18668	0.18283	1.18668	0.18283
Second solution	0.04923	0.00008	0.04923	0.00008	0.04923	0.00008

MATLAB built-in function bvp4c is used to solve Eq. (6) and Eq. (7) as well as the boundary conditions Eq. (8). Table 3 shows the Ag-CuO and water thermophysical characteristics (Bachok *et al*. 2023) and the range of parameters is also taken from Bachok *et al*. (2023). CuO-water nanofluid is created by disseminating 0.1 volume percent of CuO nanoparticle into water, φ_1 = 0.1 and φ_2 = 0. By distributing silver nanoparticles in nanofluid (CuO–water) with volume fractions $\varphi_1 = \varphi_2$ = 0.1, the required (Ag–CuO/water) hybrid nanofluid is created. Therefore, the nonlinear parameters, *n* are taken from 1 to 3. The suction values range between 0 to 0.2. The porous medium values are in the range of 0 to 0.3. Prandtl number, Pr is fixed at 6.2. According to Bachok *et al.*

(2023), there exists non-unique solutions at certain value of shrinking case ($\varepsilon \leq -1$), while unique solution exists at stretching case ($\varepsilon > -1$).

Table 3: Thermophysical properties of nanoparticles (Bachok *et al.*, 2023)

Physical Properties	Ag	CuO	Base fluid (water)
$-\rho(kg/m^{-3})$	10500	6320	997.1
$c_p(J/kgK)$	429	76.50	0.613
$k(W/mK)$	235	531.80	4179

Figures 2 and 3 show the presence of porous medium parameter, m_1 effects on the velocity profile, $f'(\eta)$ and temperature profile, $\theta(\eta)$ in the nonlinear (Ag-Cuo/water) hybrid nanofluid with nanoparticle volume fractions, $\varphi_1 = \varphi_2 = 0.1$ for shrinking case ($\varepsilon = -1.2$). The results clearly show that variation in m_1 cause observable changes in both profiles. The velocity profile, $f'(\eta)$ increases in the first solution but decreases for temperature profile, $\theta(\eta)$. For second solution, the velocity profile, $f'(\eta)$ decreases but increases for temperature profile, $\theta(\eta)$ when applying porous medium value in the range of 0 until 0.3. This confirms that the changes in velocity and temperature profiles are due to variations in the porous medium parameter, as porous medium influences the resistance to flow and heat transfer, thereby enabling transportation and storage of fluids.

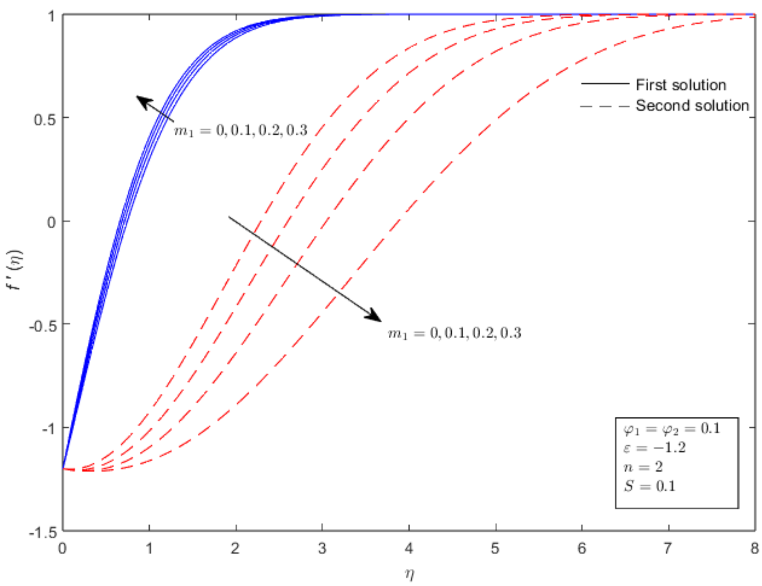

Figure 2: Velocity profiles for different m_1

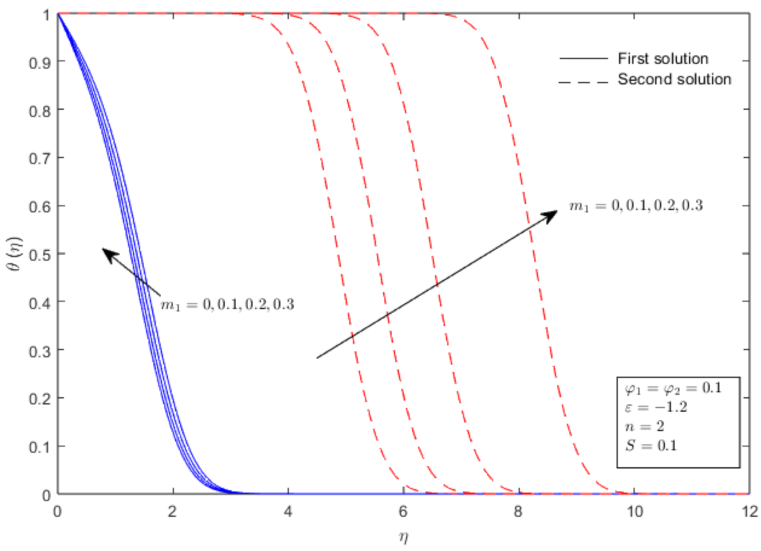

Figure 3: Temperature profiles for different m_1

Figures 4 and 5 illustrate the influences of porous medium on reduced skin friction coefficient, $f''(0)$ and reduced heat transfer rate at the surface, $-\theta'(0)$ with ε for different m_1 values. It shows that the existence of unique solution when $\varepsilon \geq -1$ and dual solution exists when $\varepsilon < -1$. The predictability of boundary layer separation resulting for no solution when $\varepsilon < \varepsilon_c$. Observation indicates that if the porous medium value increases, the critical value, ε_c decreases. The skin friction coefficient, $f''(0)$ decreases as the permeability parameter increases. The reduction of $f''(0)$ is attributed to the higher permeability enabling smoother movement of fluids within the pores in porous medium. Lower shear stress at the interface of fluid-solid caused by the easier passage of flow, particularly for shrinking cases that lead to an increase in skin friction. Besides that, the porous structure allows for increased interaction between the fluid and solid surface that influences the heat transfer dynamics resulting in increasing of reduced heat transfer, $-\theta'(0)$. Hence, when permeability parameter, m_1 increases, the reduced heat transfer, $-\theta'(0)$ increases.

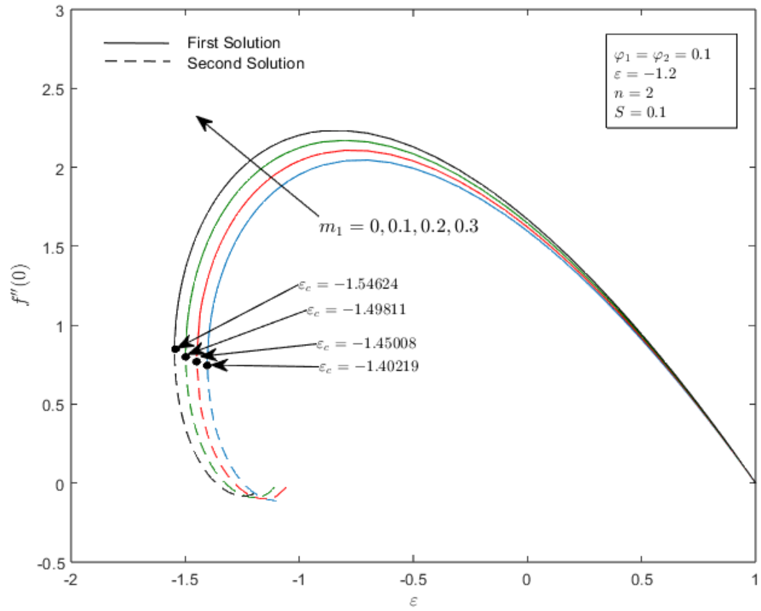

Figure 4: Variation of $f''(0)$ with ε for different m_1

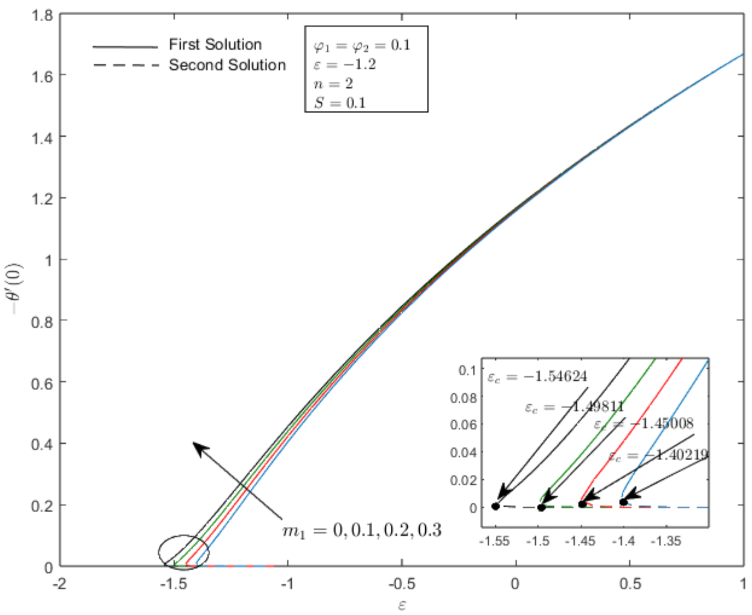

Figure 5: Variation of $-\theta'(0)$ with ε for different m_1

Figures 6 and 7 present the outcome of velocity profile, $f'(\eta)$ and temperature profile, $\theta(\eta)$ with suction, S. When the suction effect is applied in the range $0 \leq S \leq 0.2$ in first solution, the velocity profile, $f'(\eta)$ increases within the momentum boundary layer while decreases for second solution. The presence of suction $S = 0.1$ affects the range of duality to be widened. The temperature profile, $\theta(\eta)$ decreases as the thermal boundary layer thickness is thinning at the first solution and the second solution as the suction removes the warmer fluid adjacent to the wall, enhancing convective heat transfer.

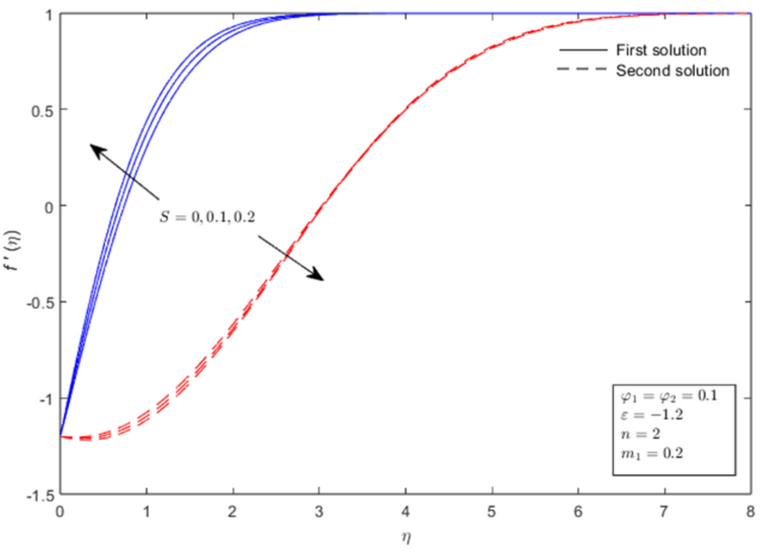

Figure 6: Velocity profiles for different S

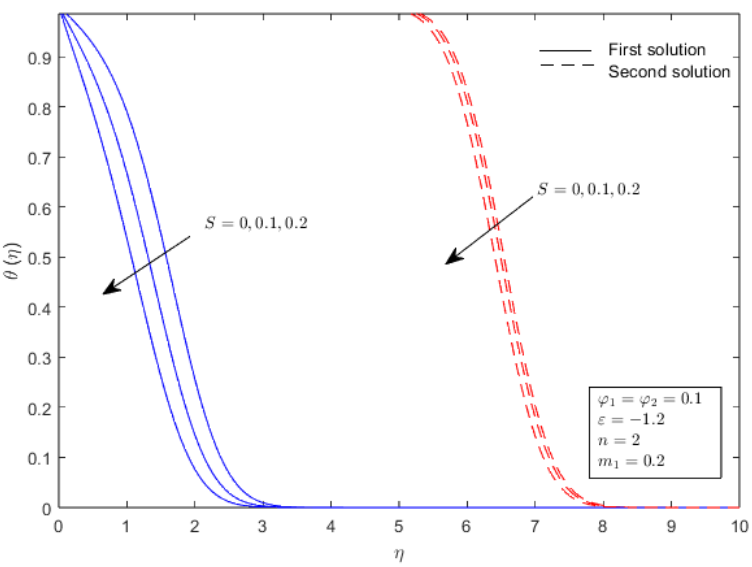

Figure 7: Temperature profiles for different S

Figures 8 and 9 show the results of reduced skin friction coefficient $f''(0)$ and reduced heat transfer rate at the surface $-\theta'(0)$ with ε for different S. It shows that the existence of unique solution when $\varepsilon \geq -1$ while the dual solution exists when $\varepsilon < -1$. There is no solution when $\varepsilon < \varepsilon_c$. The figures of $f''(0)$ and $-\theta'(0)$ are observed to be increasing when the values of S get higher for both solutions. The increasing value of S pushes the fluid into an empty space affecting the surface limit or in other word, suction creates a vacuum effect with addition of porous medium. As a result, more force is used to fluid flow, and more temperature will eventually rise. The increasing of $-\theta'(0)$ shows that suction induces a flow of fluid towards the surface, leading to higher velocities near the boundary that enhance heat transfer.

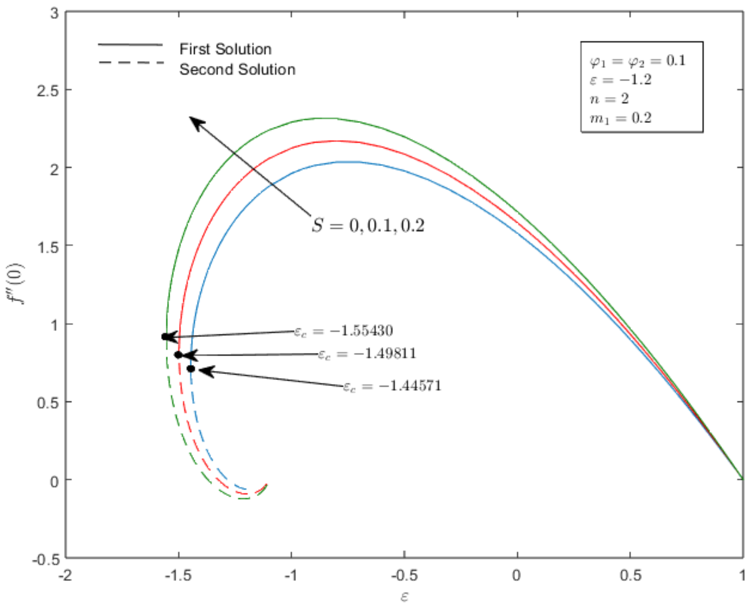

Figure 8: Variation of $f''(0)$ with ε for different S

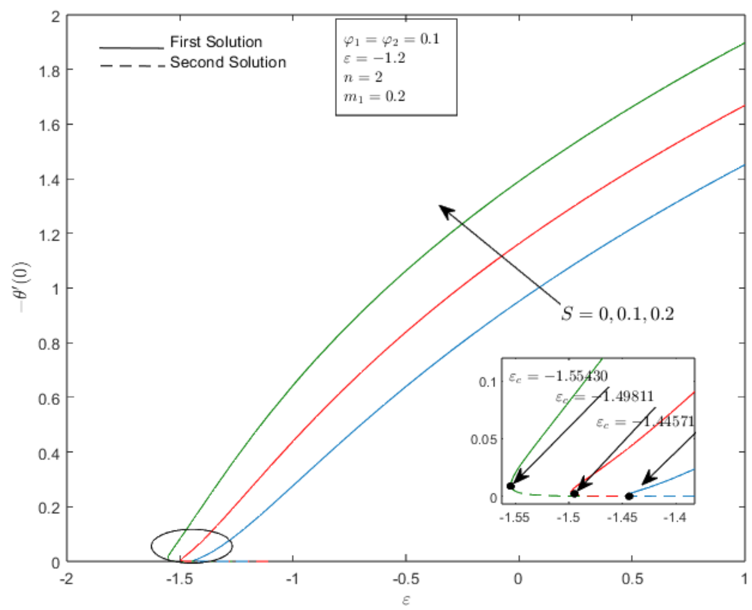

Figure 9: Variation of $-\theta'(0)$ with ε for different S

The graphical results focus on the different volume fractions of CuO nanoparticles in a certain range of φ_1. Therefore, Figures 10 and 11 present the outcome of CuO nanoparticles, φ_1 for a nonlinear stretching/shrinking case with porous medium, m_1 and suction, $S = 0.1$. When the value of CuO rises, the velocity profile, $f'(\eta)$ increases but decreases for temperature profile, $\theta(\eta)$ for first solution and second solution. Figures 12 and 13 shows the graphical results focus on the different volume fractions of Ag nanoparticles in a certain range of φ_2 for a nonlinear stretching/shrinking case with porous medium, m_1 and suction, $S = 0.1$. When Ag value increases in first solution, the velocity profile, $f'(\eta)$ decreases but temperature profile, $\theta(\eta)$ increases. For the second solution, the velocity profile increases but decreases for temperature profile.

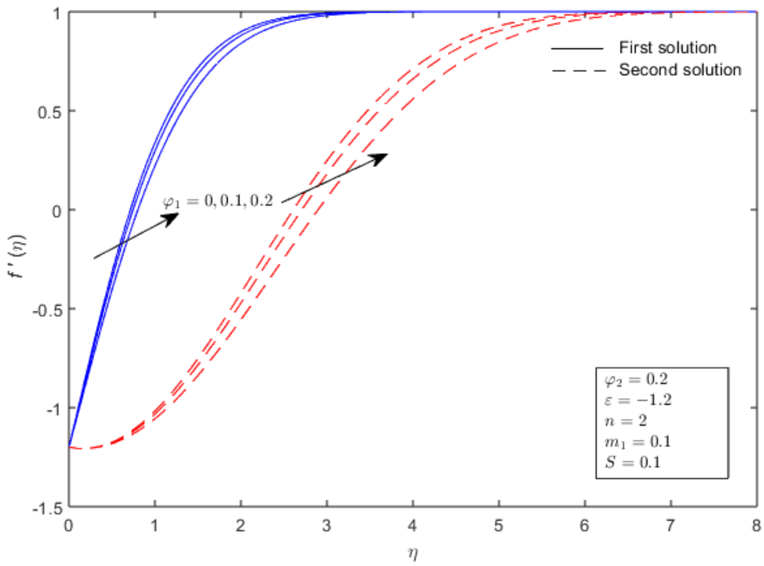

Figure 10: Velocity profiles for different φ_1

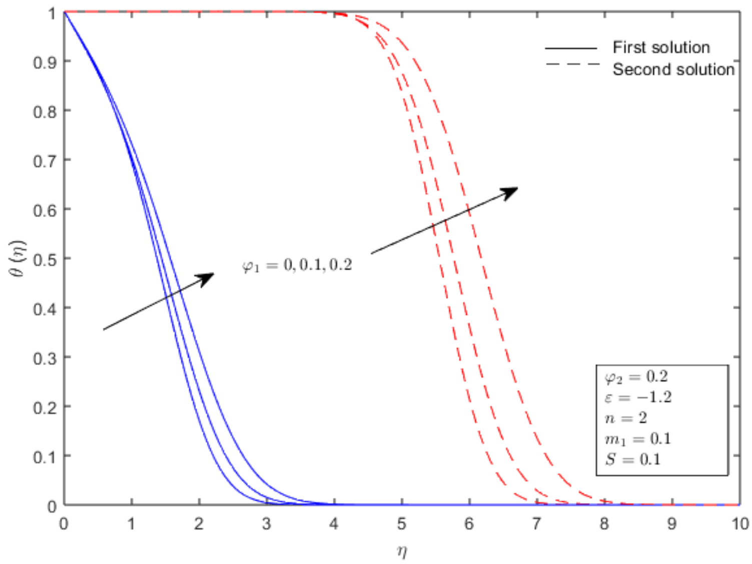

Figure 11: Temperature profiles for different φ_1

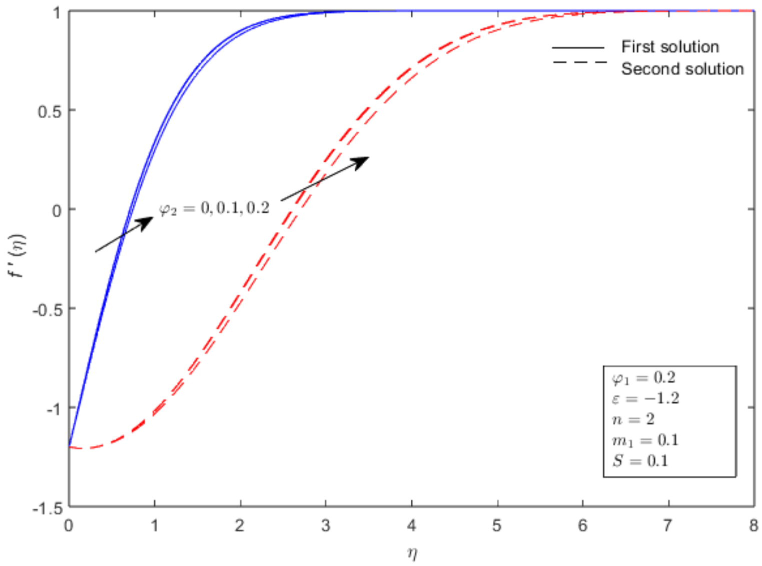

Figure 12: Velocity profiles for different φ_2

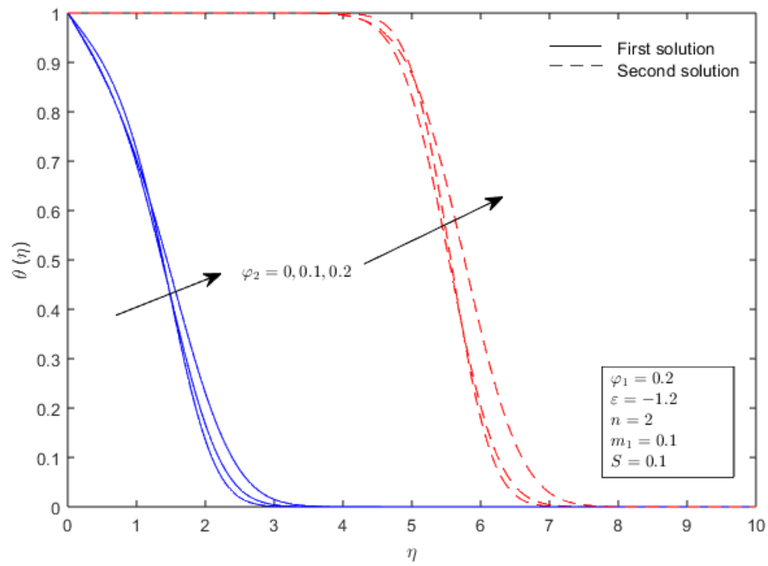

Figure 13: Temperature profiles for different φ_2

CONCLUSION

Stagnation point flow of hybrid nanofluid over a nonlinear stretching/shrinking sheet in porous medium with suction is discussed in this study. The comparison of current results obtained with previous results are analyzed. The effect of porous medium and suction on the reduced skin friction coefficient and reduced heat transfer, velocity profiles and temperature profiles have been discussed. The governing equations are converted to a system of nonlinear ODEs that be solved by using bvp4c in MATLAB. The findings of this study can be summarized as follows:

- For nonlinear stretching/shrinking surface, there exists dual solutions at certain values of shrinking case ($\varepsilon \leq -1$) while unique solution exists at stretching case ($\varepsilon > -1$).
- The presence of nonlinear suction parameter widens the range of solutions and delays the boundary layer separation.
- The presence of porous medium enables transportation and storage of fluids and the porous structure allows for increased interaction between the fluid and solid surface that influences the heat transfer dynamics resulting in increasing of reduced heat transfer, $-\theta'(0)$.
- The velocity and temperature profiles decrease in first and second solutions for both nanoparticles, CuO, φ_1 and Ag, φ_2.

ACKNOWLEDGEMENTS

We are grateful to the referee for his/her valuable comments and suggestions, which led to the improvement of this paper.

REFERENCES

Abu Bakar, S., Md Arifin, N., Khashi'ie, N. S., & Bachok, N. (2021). Hybrid nanofluid flow over a permeable shrinking sheet embedded in a porous medium with radiation and slip impacts. Mathematics, **9(8)**: 878.

Anuar, N. S., Bachok, N., Arifin, N. M., & Rosali, H. (2019). Effect of suction/injection on stagnation point flow of hybrid nanofluid over an exponentially shrinking sheet with stability analysis. CFD Letters, **11(12)**: 21-33.

Anuar, N. S., Bachok, N., Arifin, N. M., & Rosali, H. (2020a). Numerical solution of stagnation point flow and heat transfer over a nonlinear stretching/shrinking sheet in hybrid nanofluid: Stability analysis. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, **76(2)**: 85-98.

Anuar, N. S., Bachok, N., Turkyilmazoglu, M., Arifin, N. M., Rosali, H. (2020b). Analytical and stability analysis of MHD flow past a nonlinearly deforming vertical surface in carbon nanotubes, Alexandria Eng. J. **59 (1)**: 497–507.

Anwar, M. I., Khan, I., Hussanan, A., Salleh, M. Z., and Sharidan, S. (2013). Stagnation–point flow of a nanofluid over a nonlinear stretching sheet. World Applied Sciences Journal, 23:998–1006.

Anwar, M. I., Sharidan, S., Khan, I., and Salleh, M. Z. (2014). Magnetohydrodynamic and radiation effects on stagnation–point flow of nanofluid towards a nonlinear stretching sheet. Indian Journal of Chemical Technology, **21**:199–204.

Bachok, N., Ishak, A., Nazar, R., Pop, I. (2010) Flow and heat transfer at a general three-dimensional stagnation point in a nanofluid, Physica B: Condensed Matter, **405(24)**: 4914-4918.

Bachok, N., Ishak, A., Nazar, R., and Senu, N. (2013). Stagnation-point flow over a permeable stretching/shrinking sheet in a copper-water nanofluid, Boundary Value Problems 2013, no. 1: 39.

Bachok, N., Tajuddin, S. N. N., Anuar, N. S., & Rosali, H. (2023). Numerical Computation of Stagnation Point Flow and Heat Transfer over a Nonlinear Stretching/Shrinking Sheet in Hybrid Nanofluid with Suction/Injection Effects. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, **107(1)**: 80-86.

Çengel, Y. A. and Cimbala, J. M. (2016). Fluid Mechanics: Fundamentals and Applications. McGraw-Hill, New York.

Chaudhary, M. A., & Merkin, J. H. (1993). The effects of blowing and suction on free convection boundary layers on vertical surfaces with prescribed heat flux. Journal of Engineering Mathematics, **27(3)**: 265-292.

Crane, LJ. (1970). Flow past a stretching plate, Z. angew. Math. Phy. **21**:645–647.

Devi, S. P. A., Devi, S. S. U. (2016). Numerical investigation of hydromagnetic hybrid Cu-Al2O3/water nanofluid flow over a permeable stretching sheet with suction. Int. J. Nonlinear Sci. Numer. Simul. **17**: 249–257.

Fauzi, N. F., Ahmad, S. and Pop, I. (2015). Stagnation point flow and heat transfer over a nonlinear shrinking sheet with slip effects. Alexandria Engineering Journal 54, no. **4**: 929-934.

Ghosh, S., Mukhopadhyay, S., & Vajravelu, K. (2024). Hybrid nanofluid flow close to a stagnation point past a porous shrinking sheet. Waves in Random and Complex Media, **34(6)**: 6305-6321.

Goldstein, S. (1965). On backward boundary layers and flow in converging passages. Journal of Fluid Mechanics, **21(1)**: 33-45.

Gupta, P.S. & Gupta, A.S. (1977). Heat and mass transfer on a stretching sheet with suction or blowing, Can. J. Chem. Eng. **55**:744–746.

Hakim, K. N. A., Rosali, H., & Johari, M. A. M. (2023). Stagnation-point flow and heat transfer over an exponentially shrinking/stretching sheet in porous medium with heat generation. Mathematical Modeling and Computing, **10(4)**: 1260–1268.

Hamad, M.A.A., Ferdows, M. (2012). Similarity solution of boundary layer stagnation-point flow towards a heated porous stretching sheet saturated with a nanofluid with heat absorption/generation and suction/blowing: a Lie group analysis. Commun. Nonlinear Sci. Numer. Simul. **17**: 132–140.

Hayat, T., and Nadeem, S. (2017). Heat transfer enhancement with Ag–CuO/water hybrid nanofluid. Results in physics **7**: 2317-2324.

Hiemenz K., (1911). Die Grenzschicht an einem Dingler's Polytech **326**:321-324.

Jafarimoghaddam A., (2020). Numerical Analysis of the Nanofluids Flow near the Stagnation Point over a Permeable Stretching/Shrinking Wall: A New Modeling, Arabian Journal for Science and Engineering, (2020), 45(2), 1001-1015.

Japili, N., Rosali, H., & Bachok, N. (2022). Mhd stagnation point flow over a stretching or shrinking sheet in a porous medium with velocity slip. Mathematical modeling and computing, 9 (4), 852–832.

Kaharuddin, N. A. H., Rosali, H., & Rahmin, N. A. (2025). Effects of suction on steady boundary layer stagnation-point flow and heat transfer in porous medium towards a stretching/shrinking sheet with thermal radiation. Mathematical Modeling and Computing, 12(1), 40–48.

Kamal, F., Zaimi, K., Ishak, A. and Pop, I. (2018). Stability analysis on the stagnationpoint flow and heat transfer over a permeable stretching/shrinking sheet with heat source effect, International Journal of Numerical Methods for Heat & Fluid Flow, 28, No. 11, pp. 2650-2663.

Khan, U., Zaib, A., Ishak, A., (2021). Non-similarity solutions of radiative stagnation point flow of a hybrid nanofluid through a yawed cylinder with mixed convection, Alexandria Engineering Journal, 60(6), 5297-5309.

Low, X. E., & Bachok, N. (2024). Stagnation point flow and heat transfer of hybrid nanofluid over a stretching/shrinking cylinder with suction/injection effects. Journal of Advanced Research in Numerical Heat Transfer, 17(1), 14–28.

Mahabaleshwar, U. S., & Hatami, T. A. A. M. (2023). Analysis of a stagnation point flow with hybrid nanoparticles over a porous medium. Fluid Dynamics & Materials Processing, 19(2), 541–567.

Mahmood, Z., Duraihem, F. Z., As, A., & Khan, U. (2024). Model-based comparative analysis of MHD stagnation point flow of hybrid nanofluid over a stretching sheet with suction and viscous dissipation. Numerical Heat Transfer, 86(6), 1639–1660.

Malvandi, A., Hedayati, F., & Nobari, M. R. H. (2014). An analytical study on boundary layer flow and heat transfer of nanofluid induced by a non-linearly stretching sheet. Journal of Applied Fluid Mechanics, **7(2)**: 375-384.

Manjunatha, S., B. Ammani Kuttan, S. Jayanthi, Ali Chamkha, and B. J. Gireesha. (2019). Heat transfer enhancement in the boundary layer flow of hybrid nanofluids due to variable viscosity and natural convection. Heliyon 5, no. **4**: e01469.

Martin, J. M. and Boyd, I. D. (2009). Stagnation-point heat transfer near the continuum limit. Journal, **1**: 283-285.

Mat, N. A. A., Arifin, N. M., Nazar, R. M., and Ismail, F. (2012). Similarity solutions for the flow and heat transfer over a nonlinear stretching/shrinking sheet in a nanofluid. In AIP Conference Proceedings, **1450**: 165–172.

Miklavčič, M., & Wang, C. (2006). Viscous flow due to a shrinking sheet. Quarterly of Applied Mathematics, **64(2)**: 283-290.

Mukhopadhyay, S. (2013). Slip effects on MHD boundary layer flow over an exponentially stretching sheet with suction/blowing and thermal radiation. Ain Shams Engineering Journal, **4**:485–491.

Muneeshwaran M. Srinivasan G. Muthukumar P. Wang C. (2021). Role of hybrid nanofluid in heat transfer enhancement – A review. International Communications in Heat and Mass Transfer, 125.

Najib, N., Bachok, N., Arifin, N.M., Ali, F.M. (2018). Stability analysis of stagnationpoint flow in a nanofluid over a stretching/shrinking sheet with secondorder slip, Soret and Dufour effects: a revised model. Appl. Sci. **8**: 642.

Pal, D., & Mandal, G. (2015). Mixed convection–radiation on stagnation-point flow of nanofluids over a stretching/shrinking sheet in a porous medium with heat generation and viscous dissipation. Journal of Petroleum Science and Engineering, **126**: 16–25.

Pletcher, R. H. Tannehill, J. C. and Anderson, D. (2016). Computational Fluid Mechanics and Heat Transfer Third Edition. CRC Press, United States.

Prasad, K. V., Vajravelu, K. and Datti.P. S. (2010). Mixed convection heat transfer over a non-linear stretching surface with variable fluid properties. International Journal of non-linear Mechanics, 45, no. **3**: 320-330.

Raju, C.S.K., Sandeep, N., Gnaneswara Reddy, M. (2016). Effect of nonlinear thermal radiation on 3D Jeffrey fluid flow in the presence of homogeneousheterogeneous reactions, Int. J. Eng. Res. Africa, **21**: 52–68.

Rana, P., and Bhargava, R. (2012). Flow and heat transfer of a nanofluid over a nonlinear stretching sheet: A numerical study. Communication in Nonlinear Science and Numerical Simulation, **171**: 212-226.

Rana, Puneet, Ruchika Dhanai, and Lokendra Kumar. (2017). Radiative nanofluid flow and heat transfer over a non-linear permeable sheet with slip conditions and variable magnetic field: Dual solutions. Ain Shams Engineering Journal, **8(3)**: 341-352.

Rosali, H., Ishak, A., & Pop, I. (2011). Stagnation point flow and heat transfer over a stretching/shrinking sheet in a porous medium. International Communications in Heat and Mass Transfer, **38 (8)**: 1029–1032.

Sandeep, N., Sulochana, C., Isaac Lare, A., (2016). Stagnation-point flow of a Jeffrey nanofluid over a stretching surface with induced magnetic field and chemical reaction, Int. J. Eng. Res. Africa, **20**: 93–111.

Vinodkumar Reddy, M., Ajithkumar, M., Zafar, S. S. B., Faizan, M., Ali, F., & Lakshminarayana, P. (2024). Magnetohydrodynamic stagnation point flow of Williamson hybrid nanofluid via stretching sheet in a porous medium with heat source and chemical reaction. Proceedings of the institution of mechanical engineers, part E: Journal of Process Mechanical Engineering, 09544089241239583.

Vyas, P., & Srivastava, N. (2012). Radiative boundary layer flow in porous medium due to exponentially shrinking permeable sheet. International Scholarly Research Notices, 2012.

Waini, I., Ishak, A. and Pop, I. (2019). Hybrid nanofluid flow and heat transfer over a nonlinear permeable stretching/shrinking surface, International Journal of Numerical Methods for Heat & Fluid Flow, **29(9)**: 3110-3127.

Waini, I., Ishak, A., Groşan, T., & Pop, I. (2020). Mixed convection of a hybrid nanofluid flow along a vertical surface embedded in a porous medium. International Communications in Heat and Mass Transfer, **114**: 104565.

Wang, C. (2008). Stagnation flow towards a shrinking sheet. International Journal of Non-Linear Mechanics, **43 (5)**: 377–382. White, F. M. (2011). Fluid Mechanics, McGraw-Hill, New York, 7th Edition.

Yasin, M. H. M., Ishak, A., & Pop, I. (2017). Boundary layer flow and heat transfer past a permeable shrinking surface embedded in a porous medium with a secondorder slip: A stability analysis. Applied Thermal Engineering, **115**: 1407–1411.

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

Zeeshan, A., Majeed, A. (2016). Heat transfer analysis of Jeffery fluid flow over a stretching sheet with suction/injection and magnetic dipole effect, Alexandria Engineering Journal, **55(3)**: 2171-2181.