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Numerical Analysis of Hybrid Nanofluid Flow Over a Nonlinear Stretching Sheet with Viscous Dissipation, Joule Heating Effects

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ABSTRACT

The main objective of this article is to explore magnetohydrodynamic hybrid nanofluid flow past a stretching sheet. Mathematical model is developed by revisiting the work done by previous study and extended the same model for hybrid nanofluid flow scenario with viscous dissipation, joule heating and thermal radiation effects. Choosing appropriate similarity variables governing equations are transformed into system of ordinary differential equation and thereby solved by using shooting mechanism. Impact of various physical parameters on momentum, temperature and concentration profiles are shown through graphs. Important engineering quantities like skin friction coefficient, Nusselt number etc. are computed and discussed. In order to verify the code, the computed results are compared with existing literature and acceptable convergence notified in obtained results. Comparative analysis for mono particle nanofluid and hybrid nanofluid is explained for all flow parameters.

1. Introduction

Over the past decade research on heat transfer enhancement with the help of nanofluid has been increased expeditiously. As an upgraded version of nanofluid the researchers developed a new form of nanofluid in which dissimilar nanoparticle mixture will be suspended into base fluid. In many industrial processes the qualitative output depends on how quickly heat transfer takes place. Regular fluid like water, Ethylene Glycol etc. do not have high heat transfer capacity. As an alternate researcher started adding nanoparticles to base fluids to increase the thermal properties of the base fluids.

Hybrid nanofluids are widely used in many industrial processes quoted by Shah and Ali [2] where heat transfer rate is crucial such as nuclear reactor, parabolic geometry based solar collectors, heat exchangers, polymer extrusion, cooling/heating chambers and so on. This attracted many researchers to switch over their studies from mono particle nanofluid to Hybrid nanofluid. Devi and Devi [3] studied thermal behaviour of $Cu - Al_2O_3$ with water as base fluid. Their results indicate that notable heat transfer improvement can be achieved with hybrid nanofluid instead of mono particle

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nanofluid. Devi and Devi [4] explored hybrid nano fluid flow over permeable stretching sheet and concluded that hybrid nano fluids are better improvement over nanofluids. Cattaneo-Christov heat flux impact $TiO_2 - Cuo/EG$ was investigated by Jamshed and Aziz [5] and proved that spherical shaped nano particles have highest rate heat transfer as compared to hexagon, platelet type nanoparticles Ghadikolaei *et al.,* [6] studied squeezing flow with $C_2H_6O_2 - H_2O$ hybrid base fluid suspended with $Fe_3O_4 - Ag$ nano particles. Ghadikolaei *et al.,* [7] studied $TiO_2 - Cu$ hybrid nanofluid stagnation point flow over a stretching sheet. Recently Ahmed *et al.,* [8] examined $Fe_3O_4 - Ag$ impact on flow between two riga plates. Manjunatha *et al.,* [9] used Runge- kutta fourth order method to study variable viscosity effect on stretching sheet with hybrid nano particles. Besides these above said works numerous theoretical and experimental works can be observed in literature related to hybrid nanofluid [2,10-13,27-30].

Nano fluid flow and heat transport phenomenon plays key role in many industrial processes like polymer extrusion, cooling of nuclear reactors, Drawing of wires through quiescent liquid [14-19]. Due to these applications many researchers investigated nanofluid flow over nonlinear stretching sheet. Naramgari and Sulochana [20] discussed about suction injection impact on stretching sheet. A power law model nanofluid flow is reported by Dhanai *et al.,* [21]. Makinde and Aziz [22] explained boundary layer flow past a stretching surface with convective boundary conditions. Recently Waini *et al.,* [23] discussed mixed convective hybrid nanofluid flow over vertical stretching sheet in porous media with copper and alumina nanoparticles dispersed into base fluid water. Yashkun *et al.,* [24] studied thermophysical characteristics of copper-alumina hybrid nano particles over permeable stretching/shrinking surface. Most recently, Tlili *et al.,* [25] reported three dimensional hybrid nanofluid flow and heat transfer characteristics with alumina alloy material.

Closely observing the above cited research works in hybrid nanofluid, to the best of our knowledge no work has been reported on nonlinear stretching sheet with hybrid nanoparticles The main objective of this communication is to extend the research work by embedding viscous dissipation, joule heating and thermal radiation effects and to analyse heat transport phenomena of hybrid nanofluid [1].

2. Mathematical Model

We have considered a two dimensional steady, incompressible, magneto hydro dynamic hybrid nanofluid flows over a nonlinear stretching sheet. The sheet is stretched along the x-axis with velocity $u_w(x) = cx^n$ where $c > 0$. Physical model of fluid flow problem is depicted through Figure 1. Uniform magnetic field B_0 is applied in the direction of y-axis. The stretching sheet velocity is assumed to be is constant. The temperature near the wall is T_w and T_∞, C_∞ indicates temperature, concentration away from the sheet. The Thermophysical properties are considered as given in Table 1. With these assumptions the governing equations of fluid flow with the above assumption can be expressed in the following form.

$$u_x + u_y = 0 \tag{1}$$

$$\rho_{hnf}\{uu_x + vu_y\} = \mu_{hnf}u_{yy} - \sigma_{hnf}{B_0}^2u \tag{2}$$

$$(\rho c_p)_{hnf}\{uT_x + vT_y\} = k_{hnf}T_{yy} + \tau\left[D_B C_y T_y + \frac{D_T}{T_\infty}(T_y)^2\right] - (q_r)_y + \upsilon_{hnf}\left(\frac{\partial u}{\partial y}\right)^2 + \sigma_{hnf}B(x)^2u^2 \tag{3}$$

$$\{uC_x + vC_y\} = D_B C_{yy} + \frac{D_T}{T_\infty}T_{yy} \tag{4}$$

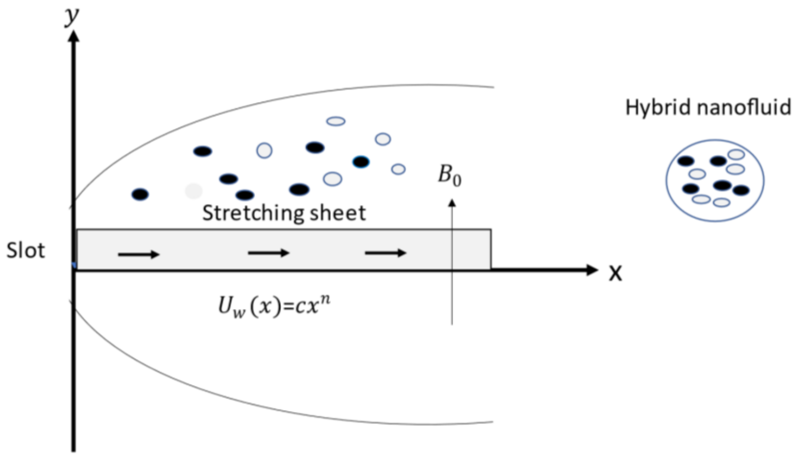

Fig. 1. Geometry of the Problem

The imposed boundary conditions on governing Eq. (1) to Eq. (4) are

$$u = U_w \,, v = v_w \,, T = T_w \,, C = C_w \text{ at } y = 0, \quad u \to 0 \,, T \to T_\infty \,, C \to C_\infty \text{ as } y \to \infty \tag{5}$$

Here u, v indicates horizontal and vertical velocity components respectively, T being temperature and C is the nano particles volume fraction, $\tau = \frac{(\rho c)_p}{(\rho c)_f}$ here $(\rho c)_p$ is the notation used to indicate effective heat capacitance of the nanoparticles, $(\rho c)_f$ is the heat capacity of the base fluid, ν is the kinematic viscosity, D_B and D_T are Brownian, thermophoretic diffusion coefficients, k is permeability parameter. The Thermophysical properties of nanoparticles and base fluid is given in Table 2. By using Roseland nonlinear thermal radiation approximation, the radiative heat flux q_r is written as

$$q_r = \frac{-4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} = \frac{-16\sigma^*}{3k^*}T_\infty^3\frac{\partial T}{\partial y}$$

where σ^*, k^* are Stefan Boltzmann constant, mean absorption coefficient respectively.

Introducing similarity transformations [26]

$$\eta = y\sqrt{\frac{c(n+1)}{2\nu}}x^{\frac{n-1}{2}}, u = axf'(\eta), v = \sqrt{\frac{c\nu(n+1)}{2}}x^{\frac{n-1}{2}}\left[f(\eta) + \frac{n-1}{n+1}\eta f'(\eta)\right] \quad \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty}, \phi(\eta) = \frac{C-C_\infty}{C_w-C_\infty} \tag{6}$$

The flow governing Eq. (2) to Eq. (4) reduces to the following forms

$$f''' + \left[1 - \phi_2\left\{(1-\phi_1) + \phi_1\left(\frac{\rho_{s1}}{\rho_f}\right)\right\} + \phi_2\left(\frac{\rho_{s2}}{\rho_f}\right)\right]\left(ff'' - \frac{2n}{n+1}f'^2\right) - (1-\phi_1)^{2.5}(1-\phi_2)^{2.5}Mf' = 0 \tag{7}$$

$$\left[\frac{\frac{khnf}{kf}+R}{Pr}\right]\theta'' + \left[1 - \phi_2\left\{(1-\phi_1) + \phi_1\left(\frac{(\rho c_p)_{s1}}{(\rho c_p)_f}\right)\right\} + \phi_2\left(\frac{(\rho c_p)_{s2}}{(\rho c_p)_f}\right)\right]f\theta' + \dot{N}b\theta'\varphi' + Nt\theta'^2 + Ecf''^2 + EcMf'^2 = 0 \tag{8}$$

$$\varphi'' + Lef\varphi' + \frac{Nt}{Nb}\theta'' = 0 \tag{9}$$

Non-dimensional forms of Boundary conditions (5) are

$$f(0) = S, f'(0) = 1, \theta(0) = 1,\ \varphi(0) = 1$$
$$f'(\eta) \to 0\ , \theta(\eta) \to 0, \phi(\eta) \to 0 \text{ as } \eta \to \infty \tag{10}$$

Here $f_w = \frac{v_w}{\sqrt{av}}, Nt = \frac{\tau D_T(T_w - T_\infty)}{\alpha T_\infty}, Nb = \frac{\tau D_B C_\infty}{\alpha}, R = \frac{16\sigma^* {T_\infty}^3}{(\rho c_p)_{nf} 3\alpha k^*}, M = \frac{\sigma {B_0}^2}{a\rho_f}$.

where $Pr = \frac{\nu}{\alpha}$ is the Prandtl number, Nb is Brownian motion parameter, Nt is thermophoresis parameter, M is magnetic field parameter, f_w is suction injection parameter.

Table 1
Thermo Physical properties on Nanofluid and Hybrid Nanofluid [7]

Property	Nanofluid	Hybrid Nanofluid
Viscosity (μ)	$\frac{\mu_f}{(1-\emptyset)^{2.5}}$	$\frac{\mu_f}{(1-\emptyset_1)^{2.5}(1-\emptyset_2)^{2.5}}$
Density (ρ)	$(1-\emptyset_1)\rho_f + \emptyset_1\rho_s$	$(1-\emptyset_2)\{(1-\emptyset_1)\rho_f + \emptyset_1\rho_{s1}\} + \emptyset_2\rho_{s2}$
Heat Capacity (ρc_p)	$(1-\emptyset_1)(\rho c_p)_f + \emptyset_1(\rho c_p)_s$	$(1-\emptyset_2)\{(1-\emptyset_1)(\rho c_p)_f + \emptyset_1(\rho c_p)_s\} + \emptyset_2(\rho c_p)_{s2}$
Thermal conductivity (k)	$\frac{k_{nf}}{k_f} = \frac{k_s + (m-1)k_f - (m-1)\phi(k_f - k_s)}{k_s + (m-1)k_f + (m-1)\phi(k_f - k_s)}$	$\frac{k_{hnf}}{k_f} = \frac{k_{s2} + (m-1)k_{bf} - (m-1)\phi_2(k_{bf} - k_{s2})}{k_{s2} + (m-1)k_{bf} + (m-1)\phi_2(k_{bf} - k_s)}$ Where, $\frac{k_{bf}}{k_f} = \frac{k_{s1} + (m-1)k_f - (m-1)\phi_1(k_f - k_{s1})}{k_{s1} + (m-1)k_f + (m-1)\phi_1(k_f - k_{s1})}$

Table 2
Thermo physical properties of nano particles and base fluid [6]

Type of particle	$\rho(kg/m\hat{}3)$	$C_p(J/kgK)$	K(W/mK)	$\sigma(S/m)$
Ag	10490	235	429	6.3X 10^7
MOS_2	5060	397.21	904.4	2.09X10^-5
H_2O	997.1	4179	0.613	0.05

3. Results and Discussion

In this section we discussed the impact of various flow parameters on momentum, temperature and volume fraction concentration profiles. The governing equations are solved by using shooting method. The program is verified with some limiting assumptions of the work done by Mabood *et al.,* [1]. Comparative results are presented in Table 3 and acceptable convergence observed for computed results.

Table 3
Comparison of Skin friction, Nusselt and Sherwood numbers for regular fluid case

M	Mabood *et al.,* [1]			Present Results		
	$-f''(0)$	$-\theta'(0)$	$-\varphi'(0)$	$-f''(0)$	$-\theta'(0)$	$-\varphi'(0)$
0.0	1.10102	1.06719	1.07719	1.10142	1.06712	1.07685
0.5	1.30989	1.04365	1.01090	1.30991	1.04364	1.01087
1.0	1.48912	1.02337	0.95495	1.48912	1.02337	0.95494

Figure 2 represents the effect of magnetic parameter on a velocity profile. From this figure it is evident that increasing M values reduces the velocity due to retarding force which is known as Lorentz force. Figure 3 displays the impact of suction parameter on a velocity profile and it is clear that a decrement in velocity profile is seen. Figure 4 depicts the impact of injection parameter on velocity profile and it is seen that velocity increases. Figure 5 represents the impact of thermal radiation (R) on temperature profile. For higher values of radiation (R) more heat is generated in nanofluid flow due to energy transformation and thickness of boundary layer. Figure 6 depicts the temperature profile for suction parameter. Here we noticed that temperature decreases with increase in values of S. Impact of thermophoresis parameter on temperature profile is shown in Figure 7, which clearly shows increasing trend in temperature profile. Brownian motion effect on temperature profile is shown in Figure 8, it is clear that the increase in Brownian motion parameter results in increase in temperature profile. Figure 9 portrays the impact of Lewis number on temperature profile. For higher values of Lewis number temperature distribution increases. Figure 10 is plotted to analyse the impact of Eckert number (EC) on temperature distribution. Usually, Eckert number is ratio of raising kinetic energy thus enhances the nano thermal energy transformation. So, temperature profile is increasing function of Eckert number (EC). Impact of thermophoresis parameter on concentration profile is shown in Figure 11, which clearly shows increasing trend in concentration profile. Brownian motion effect on concentration profile is shown in Figure 12, it is clear that the increase in Brownian motion parameter results in increase in concentration profile. In order to analyse the behaviour of some quantities of engineering interests viz., the local skin friction co-efficient $C_f Re_x^{\frac{-1}{2}}$, the local Nusselt number $N_u Re_x^{\frac{-1}{2}}$ and the local Sherwood number $ShRe_x^{\frac{-1}{2}}$, effects of various flow parameters on these three quantities have been computed and presented in Table 4 to Table 6.

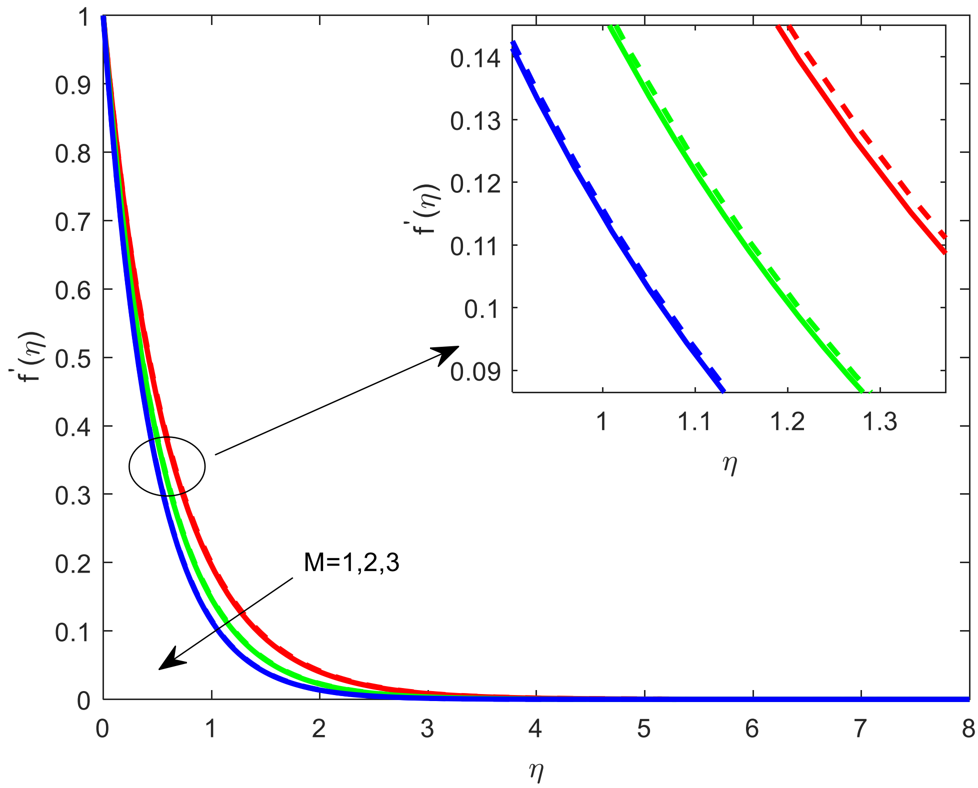

Fig. 2. Velocity profile for magnetic field parameter

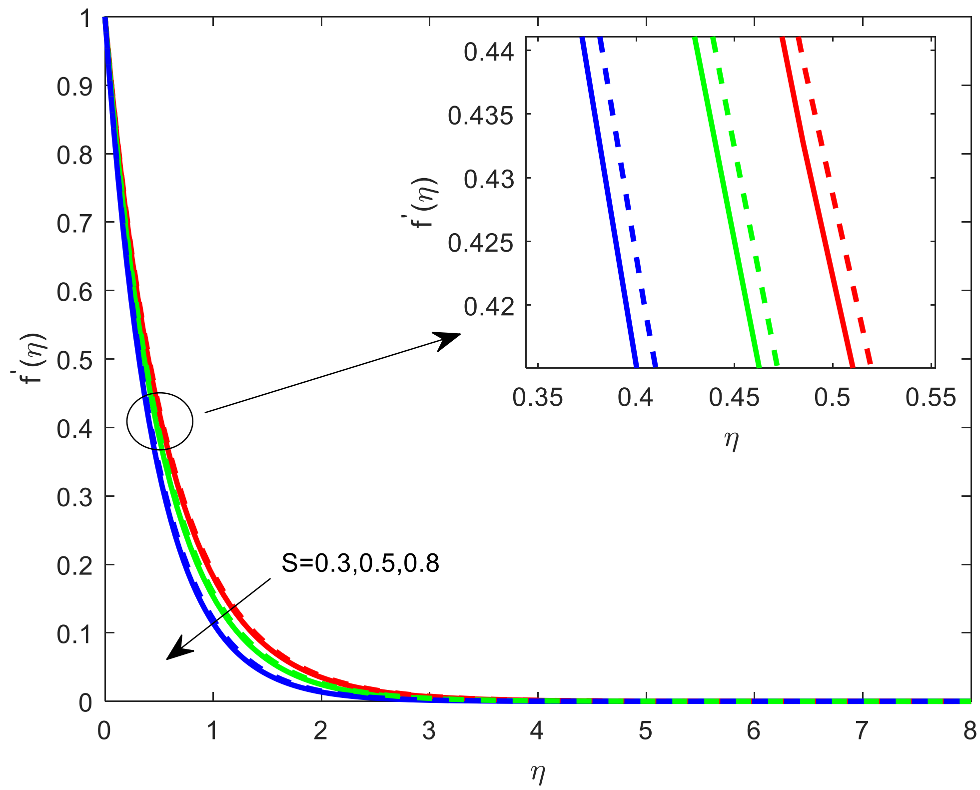

Fig. 3. Velocity profile for suction parameter

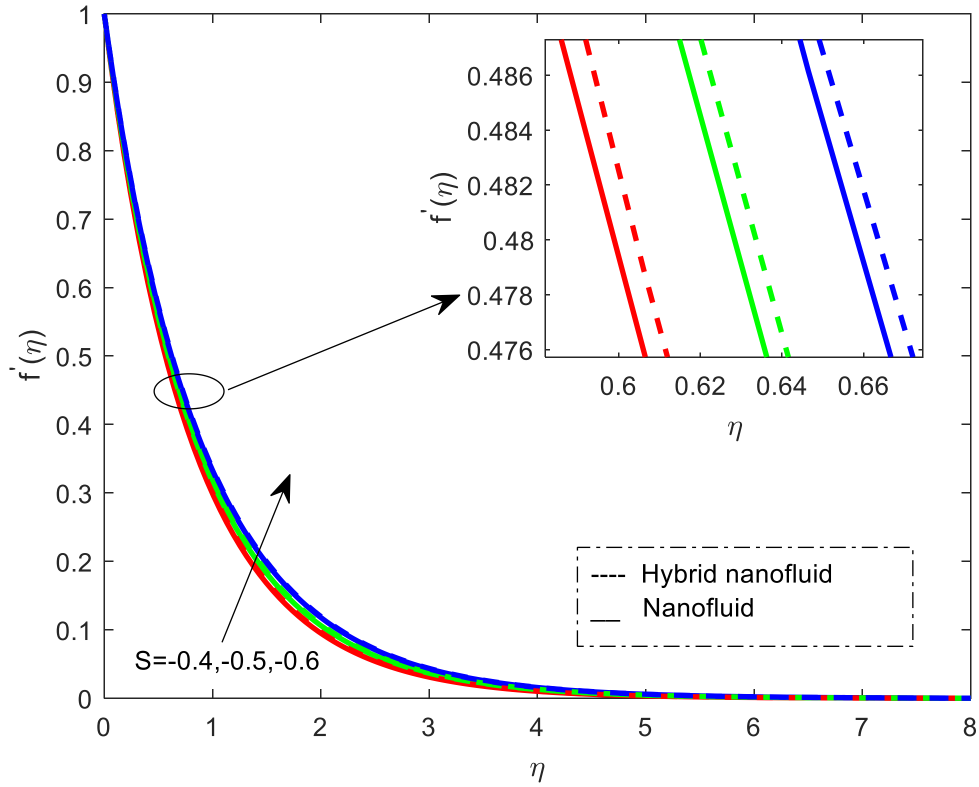

Fig. 4. Velocity profile for injection parameter

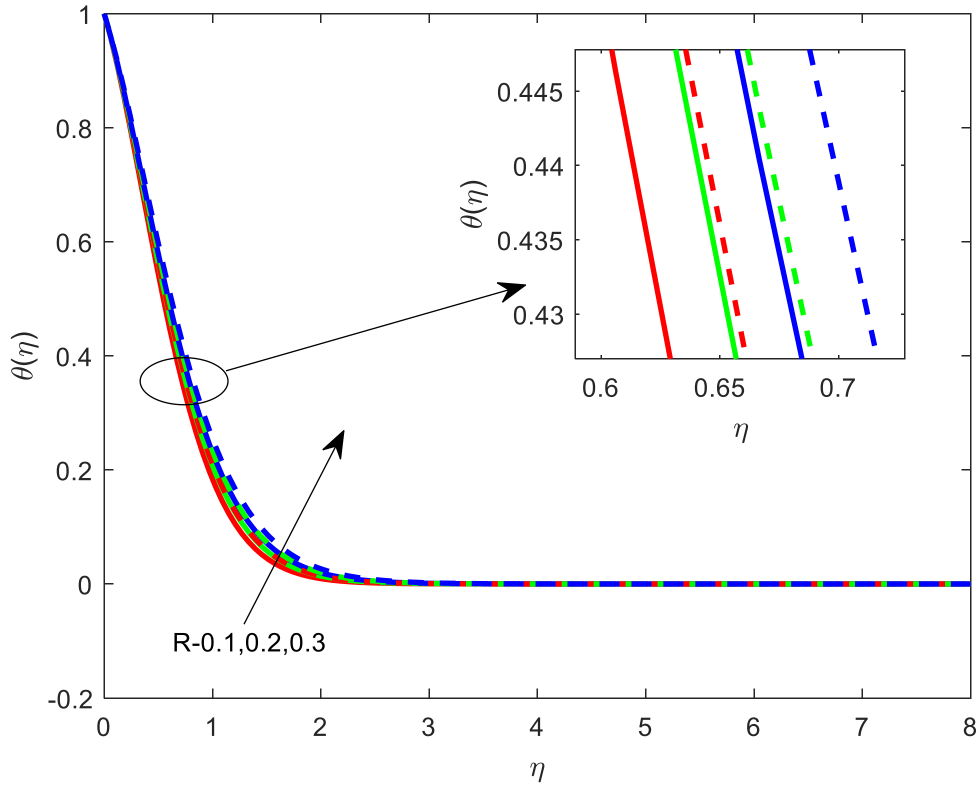

Fig. 5. Temperature profile for radiation parameter

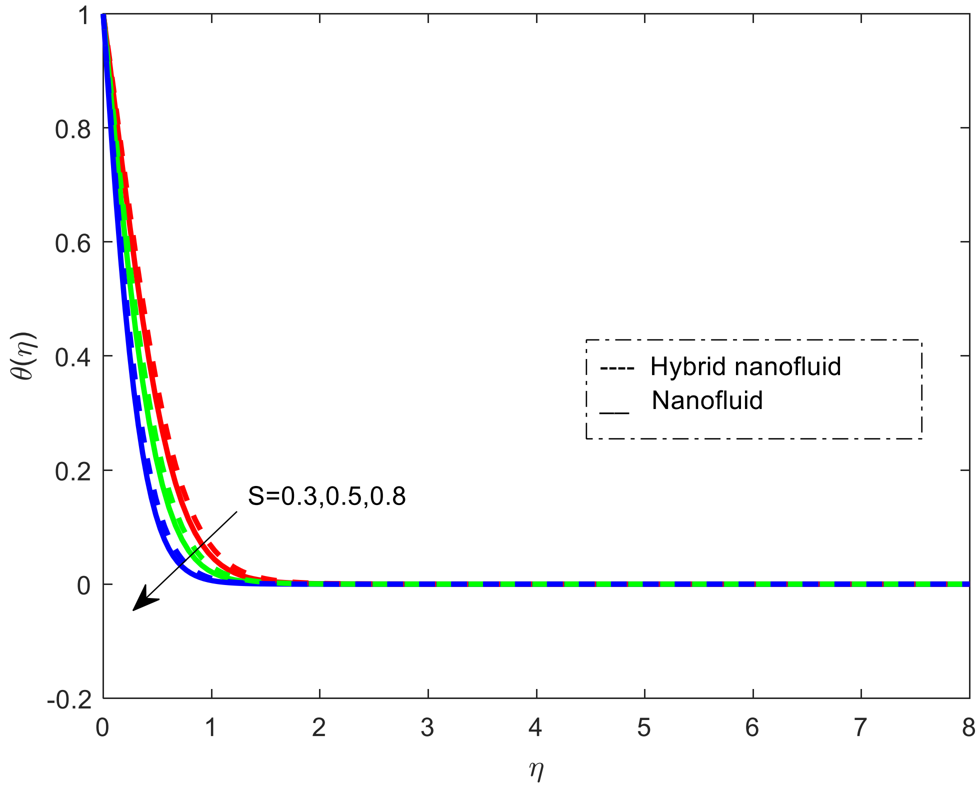

Fig. 6. Temperature profile for suction parameter

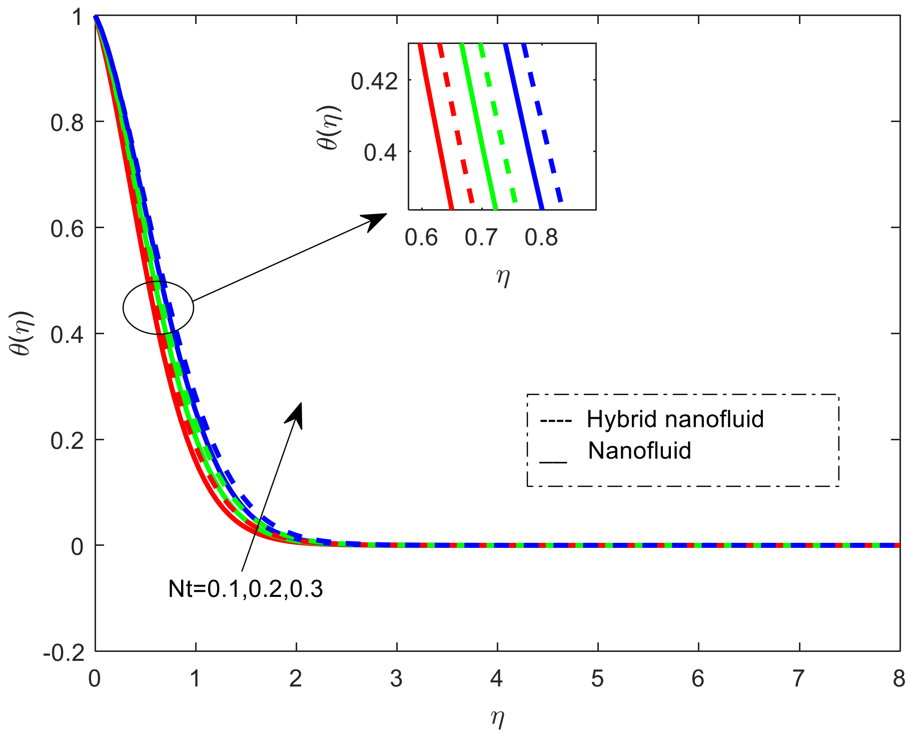

Fig. 7. Temperature profile for thermophoresis parameter

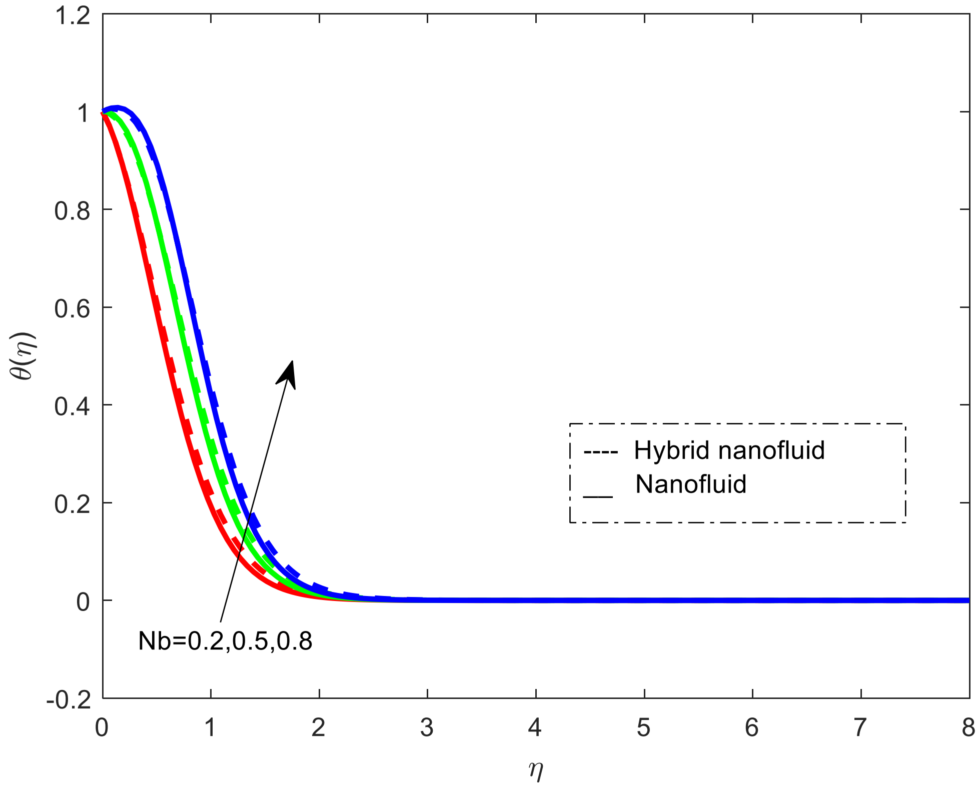

Fig. 8. Temperature profile for Brownian motion parameter

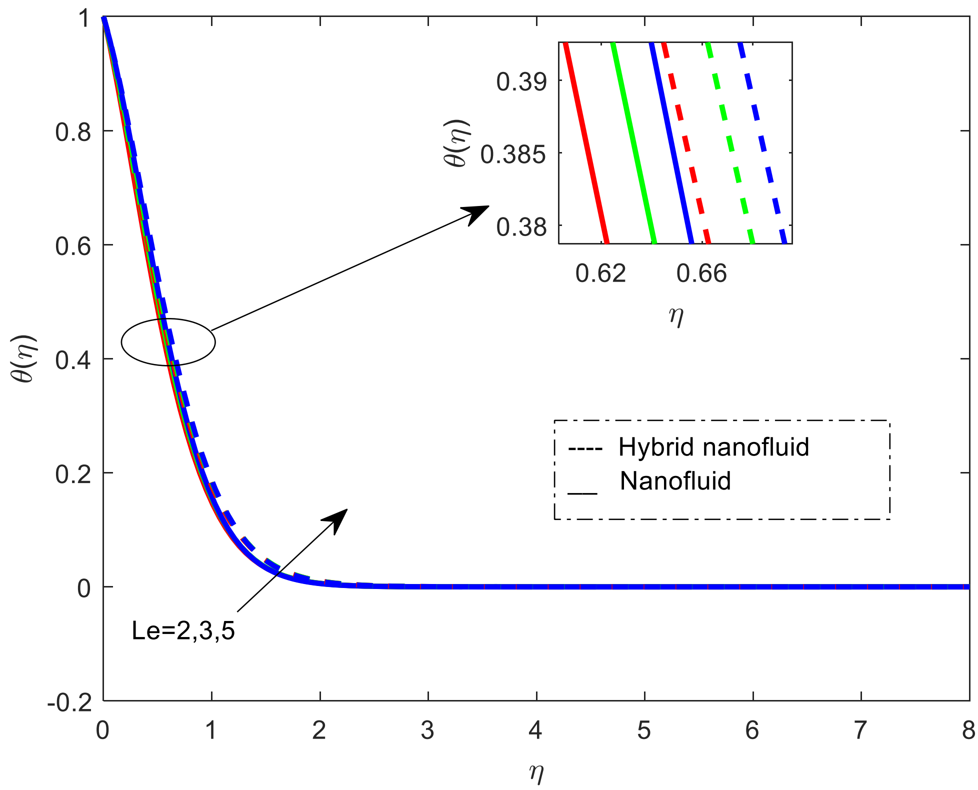

Fig. 9. Temperature profile for Lewis number

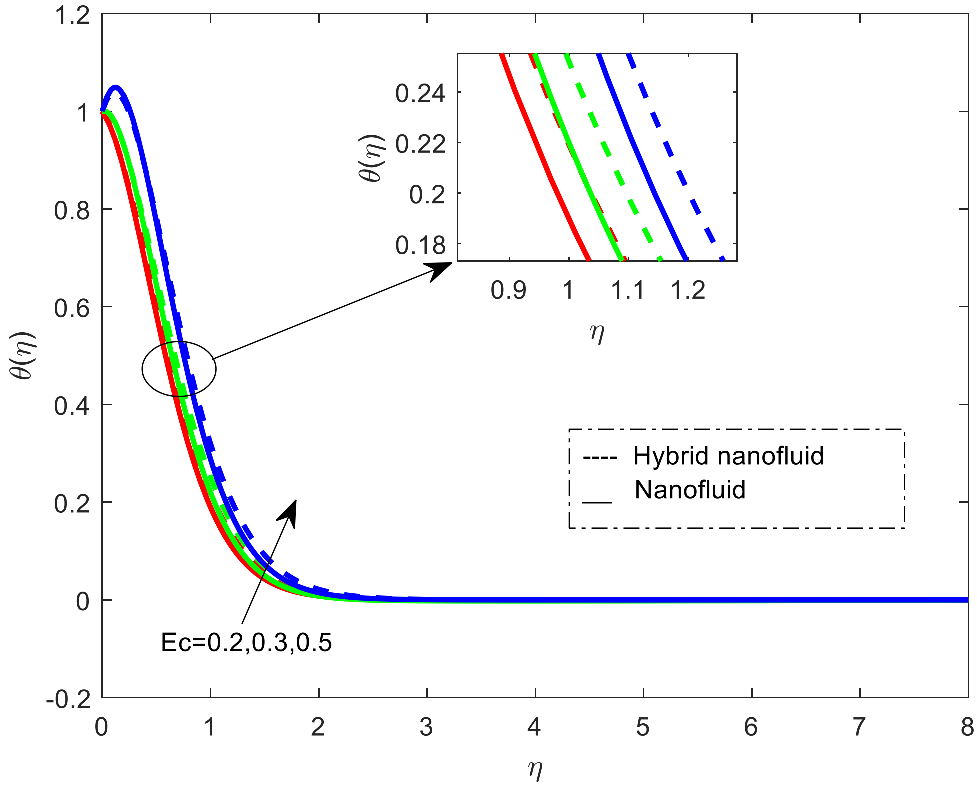

Fig. 10. Temperature profile for Eckert number

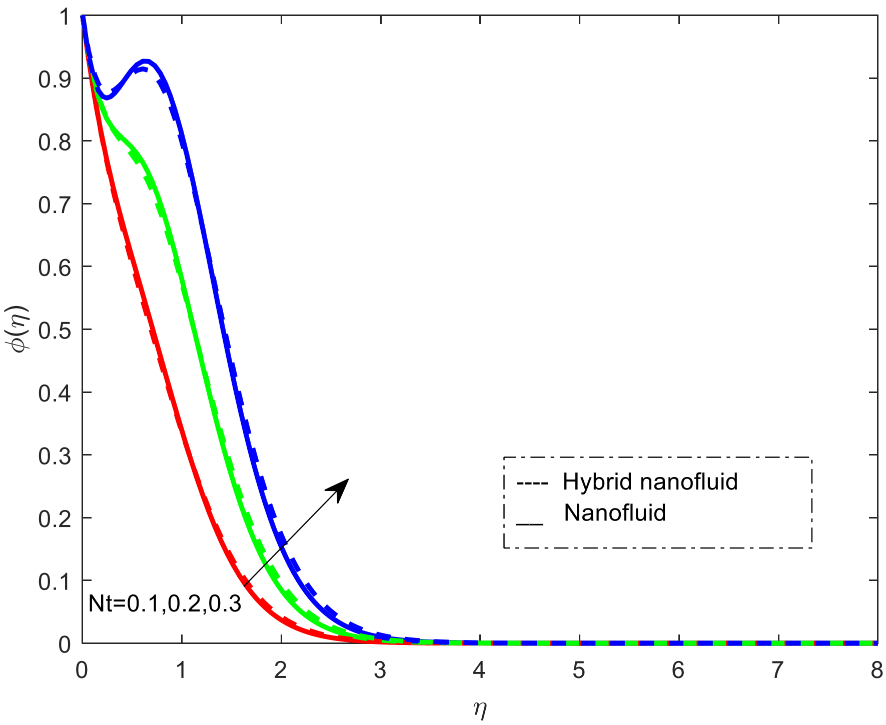

Fig. 11. Concentration profile for thermophoresis number

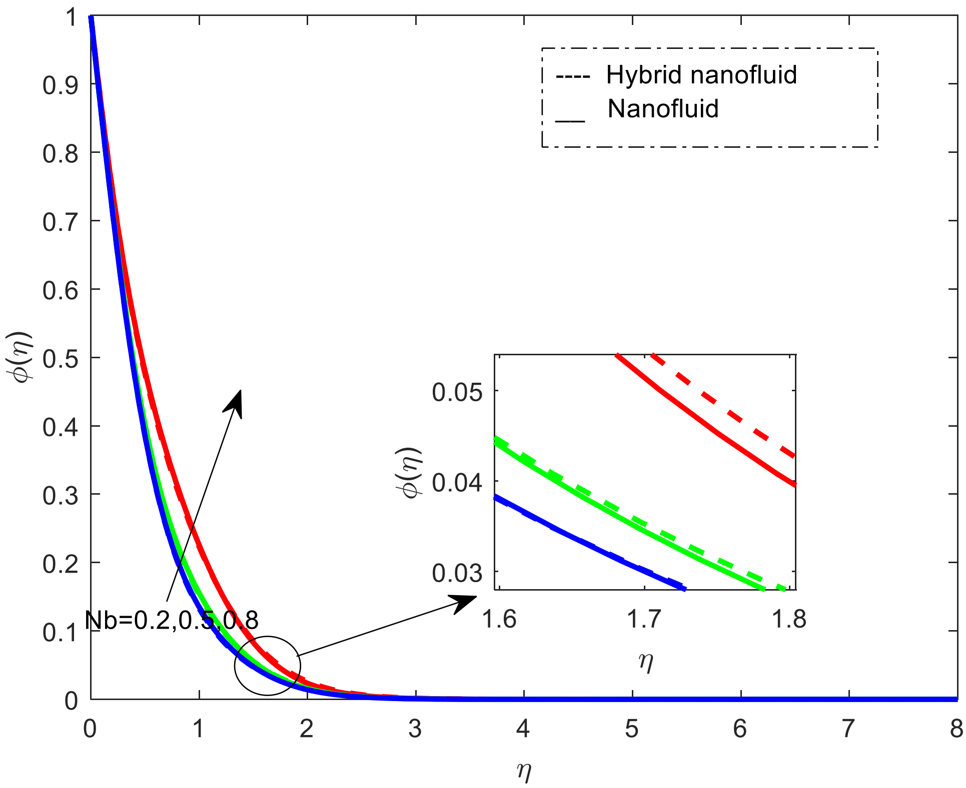

Fig. 12. Concentration profile for Brownian motion parameter

Table 4
Skin friction coefficient values for various parameters

M	R	S	$C_f Re_x^{\frac{-1}{2}}$	
			Ag	$Ag-MoS_2$
1			2.69040	2.94620
2			3.13805	3.45039
3			3.52896	3.88931
	0.1		1.52800	1.50582
	0.2		1.52800	1.50582
	0.3		1.52800	1.50582
		0.3	2.81246	3.05847
		0.5	3.09332	3.35612
		0.8	3.55599	3.84570
		-0.5	2.01559	2.20989
		-1	1.92481	2.11261
		-2	1.83931	2.02084

Table 5
Nusselt number computations for various parameters

M	R	S	Ec	Le	Nt	$N_u Re_x^{\frac{-1}{2}}$	
						Ag	$Ag - MOS_2$
1						0.63522	0.71085
2						0.36702	0.42701
3						0.12740	0.17595
	0.1					0.63682	0.62500
	0.2					0.62998	0.61625
	0.3					0.62110	0.60631
		0.3				1.72945	1.82304
		0.5				2.45192	2.54519
		-1				-0.01884	0.02683
		-2				-0.11217	-0.08202
			0.2			0.64029	0.63175
			0.3			0.27838	0.30437
				2		0.80649	0.77459
				3		0.72797	0.70673
					0.2	0.49212	0.50138
					0.3	0.37657	0.39764

Table 6
Sherwood number computations for various parameters

Le	Ec	Nb	Nt	$ShRe_x^{\frac{-1}{2}}$	
				Ag	$Ag - MOS_2$
2				0.17345	0.18789
3				0.56714	0.57057
	0.2			1.13434	1.12514
	0.3			1.36021	1.32724
		0.2		1.43665	1.41900
		0.5		1.50430	1.49766
			0.1	1.21676	1.19867
			0.2	1.17375	1.10556

4. Conclusion

A numerical study of MHD flow of hybrid nanofluid was carried out. A stretching sheet with Joule heating and viscous dissipation effect was considered. Appropriate similarity transformations were introduced to convert governing equations into ordinary differential equations and then solved using shooting method. The results showed the impact of various physical parameters on momentum, temperature and concentration profiles. The results were presented in the form of Tables and graphs. Some of the engineering quantities like Nusselt number, Skin friction co-efficient, Sherwood number, Lewis number, Eckert number were analysed and discussed.

I. The fluid velocity decreases with magnetic field (M) & Suction parameter whereas for injection parameter it increases.
II. The fluid temperature increases for radiation parameter while decreases for Suction parameter.
III. The fluid temperature and concentration increase for Brownian motion parameter.
IV. The fluid temperature and concentration increase for Thermophoresis parameter.
V. The fluid temperature increases for Lewis number and Eckert number.

VI. The Skin friction co-efficient increases for magnetic parameter and this increase is more for hybrid nanofluid compared to mono particle based nanofluid.

VII. The Skin friction co-efficient increases as suction parameter increases, is more for hybrid nanofluid than mono particle based nanofluid and decreases as injection parameter decreases, is less for single nanofluid than hybrid nanofluid.

VIII. Nusselt number decreases for increase in Lewis number and is less for hybrid nanofluid than single nanofluid.

IX. Sherwood number decreases as thermophoresis increases, and is lower for hybrid nanofluid as compared to mono particle based nanofluid.

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