Influence of non-uniform heat source/sink on MHD nanofluid flow over a moving vertical plate in porous medium

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Abstract- We investigated the influence of magneticfield, radiation and non-uniform heat source/sink on nanofluid flow over a moving vertical plate in porous medium.We considered two types of nanofluids namely Cu-Ethylene glycol, Ag-Ethylene glycol. The governing partial differential equations of the flow are transformed to ordinary differential equations using similarity transformations and then solved numerically by using shooting technique. The effects of various non-dimensional governing parameters on velocity, temperature and concentration profiles are discussed and presented through graphs. Also, the skin friction, local Nusselt and Sherwood numbers are discussed and given for tabular form for two nanofluids separately.

Index terms: MHD, Radiation, Nanofluid, Non-uniform heat source/sink, Convection, Soret, Suction.

◆

1 INTRODUCTION

The innovation of Nanofluid started with Choi [1] at ANL laboratory. They are nanometer sized particles and have a less uniform dispersion in the inflexible articles. Nanofluids are vital applications in science and technology, cancer homeotherapy, industrial applications like polymer, plastic and building sciences. Fluid flow past moving vertical plate also having huge applications in science and engineering, aerodynamics, due to these reason researchers are very believed in this field. MHD nanofluid flow past a moving vertical plate in porous medium with radiation and soret effects was analyzed by Raju et al.[2]. Sandeep et al.[3] examined an unsteady convective natural flow of a nanofluid through an infinite vertical plate in the presence of radiation. Mohan Krishna et al.[4] elaborated this work by chosen heat source effect with various nanofluids. Mixed convection flow of nanofluids through a moving vertical plate in presence of suction/injection was illustrated using similarity method by Subhashini and Sumathi[5].

An unsteady three dimensional viscous boundary layer flow of a continuously stretching sheet was discussed numerically by Bachok et al.[6] and concluded that dual solution exists in presence of unsteadiness parameter. Azizah et al.[7] considered the suction effect of an unsteady heat transfer analysis of nanofluid through a continuously shrinking surface and concluded that flow reaction takes place predominant role in type of nanofluid.

MHD two-dimensional stagnation point flow of steady incompressible nanofluid through a stretching cylinder was analyzed by Akbar et al.[13]. Zhang et al.[14] discussed the MHD flow and heat transfer analysis of nanofluid through a flat plate in porous medium with radiation and first order chemical reaction. Unsteady MHD pseudo-plastic nanofluid flow and heat transfer in a finite thin film past a stretching surface in presence of internal heat generation was investigated by Lin et al.[15]. In this paper they considered the three types nanofluids and concluded that increasing in nanoparticle volume fraction decreases the nanofluid film thickness. Faroogh et al.[16] studied the natural and mixed convection of nanofluid in a square cavity with two phase simulation. An unsteady heat transfer analysis on hiemenz flow of nanofluid through a porous wedge due to solar energy radiation and heat source/sink effect with stream condition was illustrated by Mohamad et al.[17]. They concluded that the temperature is significantly impact on the porosity of wedge sheet. Hiemenz flow and heat transfer analysis of nanofluid through a porous wedge surface in presence of suction/injection due to solar energy was depicted by kandasamy et al.[18]. Nadeem et al.[19] discussed the heat transfer analysis of a second grade non-newtonian nanofluid towards a stretching sheet in presence of non-orthogonal stagnation point. An unsteady heat and mass transfer analysis of MHD nanofluid flow through a parallel stretching surface in a rotating system was studied

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by Hasan et al.[20]. Sandeep et al.[21] discussed the convective MHD fluid flow over a vertical plate in the presence of radiation and chemical reaction. Krunal et al.[21] presented the lattice Boltzmann simulation of natural convection in an open ended square cavity with partially heating.

By taking all the above studies into consideration in this study we reported onthe magneticfiled, radiation and non-uniform heat source/sink effects of a nanofluid flow through a moving vertical plate in porous medium. We considered two types of nanofluids namely Cu-Ethylene glycol, Ag-Ethylene glycol. The governing partial differential equations of the flow are transformed to ordinary differential equations by using similarity transformation and then solved numerically.

2Mathematical Formulation

Consider anincompressible, steady, two-dimensional, laminar mixed convection boundary layer flow of a nanofluid over a moving vertical plate in porous medium. The fluid is Ethylene glycol based nanofluid containing different types of nanoparticles.A variable magneticfield $B(x)$ is applied to the flow, Soret, non-uniform heat source/sink and radiation effects are taken into account. The nanoparticles spherical shape and size are assumed to be uniform. Moreover, it is assumed that the base fluid and nanoparticles are in thermal equilibrium and no slip occurs between them.The governing boundary layer equations as per above assumptions can be expressed as

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

$$\rho_{nf}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu_{nf}\frac{\partial^2 u}{\partial y^2}+g(\rho\beta)_{nf}(T-T_\infty) \tag{2}$$

$$-\sigma B^2(x)u-\frac{\mu_f}{k'}u,$$

$$(\rho c_p)_{nf}\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k_{nf}\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}-q''' \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2}, \tag{4}$$

With the boundary conditions

$$u=u_w=b\,,v=v_w\,,T=T_w,C=C_w \text{ at } y=0,$$

$$u\to a\,,T\to T_\infty,C\to C_\infty \text{ as } y\to\infty, \tag{5}$$

Where u and v are the velocity components in the x, y directions , ρ_{nf} and μ_{nf} are the density and the dynamic viscosity of the nanofluid respectively, β_{nf} is the coefficient of the thermal expansion of the nanofluid, g is the acceleration due to gravity, T is the nano-fluid temperature, $B=B_0\sqrt{U/x}$, is the induced magnetic field, $k'=k_0x/U$ is the permeability of the porous medium, q_r is the radiative heat flux, $(\rho c_p)_{nf}$ is the heat capacitance of nano-fluid and k_{nf} is the effective thermal conductivity of nanofluid, D_m is the coefficient of the mass diffusivity, T_m is the mean fluid temperature, k_T is the thermal diffusion ratio, where a, b are constants corresponds to the plate velocity and the free stream velocity. Where $v_w(x)>0$ for injection and $v_w(x)<0$ for suction, T, C are the temperature and concentration of the nanofluid.The nanofluid constants are given by

$$(\rho\beta)_{nf}=(1-\phi)(\rho\beta)_f+\phi(\rho\beta)_s,$$

$$(\rho c_p)_{nf}=(1-\phi)(\rho c_p)_f+\phi(\rho c_p)_s,$$

$$\frac{k_{nf}}{k_f}=\frac{(k_s+2k_f)-2\phi(k_f-k_s)}{(k_s+2k_f)+\phi(k_f-k_s)},$$

$$\rho_{nf}=(1-\phi)\rho_f+\phi\rho_s,\quad \mu_{nf}=\frac{\mu_f}{(1-\phi)^{2.5}}, \tag{6}$$

Where ϕ is the nanoparticle volume fraction. The subscripts f and s refer to fluid and solid fraction properties respectively.

The radiative heat flux q_r under Rosseland approximation has the form

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{7}$$

where σ^* is the Stefan-Boltzmann constant and k^* is the mean absorption coefficient. The temperature differences within the flow are assumed to be sufficiently small such that T^4 may be expressed as a linear function of temperature. Expanding T^4 using Taylor series and neglecting higher order terms yields

$$T^4\cong 4T_\infty^{\;3}T-3T_\infty^{\;4} \tag{8}$$

We now employ the similarity transformation as

$$\eta = \sqrt{U / v_f x}\, y,\ \psi(x,y) = \sqrt{v_f x U}\, f(\eta),$$

$$\theta(\eta) = T - T_\infty / T_w - T_\infty \quad , \phi(\eta) = C - C_\infty / C_w - C_\infty \ (9)$$

Where $\psi(x,y)$ is the stream function that satisfies the continuity equation (1) and $U = a + b$ is the composite velocity.

$$u = \frac{\partial \psi}{\partial y} = Uf'(\eta),$$

$$v = \frac{\partial \psi}{\partial x} = -1/2\sqrt{v_f U / x}\left(f(\eta) - \eta f'(\eta) \right)$$

(10)Using equations (5)-(10) theequations (2)-(4) reduced to the ordinary differential equations is of the form

$$\frac{1}{(1-\phi)^{2.5}} f''' + \frac{1}{2}\left(1 - \phi + \phi \frac{\rho_s}{\rho_f}\right) ff'' + \left(1 - \phi + \phi \frac{(\rho\beta)_s}{(\rho\beta)_f}\right)\lambda\theta - (M + K) f' = 0 \qquad (11)$$

$$\frac{1}{\Pr}\left(\frac{k_{nf}}{k_f} + R_a\right)\theta'' + \frac{1}{2}\left(1 - \phi + \phi \frac{(\rho c_p)_s}{(\rho c_p)_f}\right) f\theta' - A^* f' - B^*\theta = 0 \qquad (12)$$

$$\phi'' - 2Scf'\phi + Scf\phi' + ScSr\theta'' = 0 \qquad (13)$$

The transformed boundary conditions are

$$f(\eta) = S,\ f'(\eta) = \varepsilon,\ \theta(\eta) = 1,\ \phi(\eta) = 1 \text{ at } \eta = 0,$$
$$f'(\eta) = 1 - \varepsilon,\ \theta(\eta) = 0,\ \phi(\eta) = 0 \text{ as } \eta \to \infty, \ (14)$$

Where primes denotes differentiation with respect to η, $v_w(x) = -1/2\sqrt{Uv_f / x}\, S$, S is the suction for $S > 0$ and $S < 0$ for injection , $M = \sigma B_0^{\ 2} / \rho_f u_0$ is the magnetic field parameter, $K = \upsilon_f / ak_0$ is porosity parameter, $\Pr = \upsilon_f / \alpha_f$ is the Prandtl number, $R_a = 16\sigma^* T_\infty^3 / 3k^* k_f$ is the radiation parameter, $Sr = D_m k_T (T_w - T_\infty) / T_m (C_w - C_\infty) \nu_f$ is the soret number, $Sc = \upsilon_f / D_m$ is the Schmidt number, A^*, B^* are internal heat generation/absorption coefficient respectively. λ Is the mixed convection parameter, which are given by $\lambda = Gr_x / \mathrm{Re}_x^{\ 2}$ and $\varepsilon = U_w / U$ .Here $Gr_x = g\beta_f (T_w - T_\infty) x^3 / \nu_f^{\ 2}$ is local Grashof number and $\mathrm{Re}_x = Ux / \nu_f$ is the Reynolds number.

The physical quantities of interest are the local skin friction coefficient, the wall heat transfer coefficient and mass transfer coefficients are given by

$$(1-\phi)^{5/2} Cf_x \mathrm{Re}_x^{\ 1/2} = f''(0), \qquad (15)$$

$$\frac{k_f}{k_{nf}} Nu_x \mathrm{Re}_x^{\ -1/2} = -\theta'(0), \qquad (16)$$

$$Sh_x \mathrm{Re}_x^{\ -1/2} = -\phi'(0), \qquad (17)$$

3. Results and Discussion

The system of nonlinear ordinary differential equations (11) to (13) with the boundary conditions (14) are solved numerically using shooting method. The obtained resultsshows the influences of the non-dimensional governing parameters, namely volume fraction of nano particles ϕ ,radiation parameter R_a, suction parameter S, buoyancy parameter λ ,heat generation/absorption coefficients A^*, B^* on the flow, temperature and concentration profiles are discussed and presented graphically. Also, the friction factor and Nusselt and Sherwood numbers are discussed and given in tabular form for two nanofluids separately. For numerical results $\Pr = 6.2, Sc = 0.6, \phi = 0.1, M = 1, \lambda = 1, S = 1,$ $R = Sr = K = A^* = B^* = 0.2.$ These values are treated common in entire study except the varied values in respective figures and tables. Table 1 shows the thermophysical properties of Ethylene glycol and nano particles.

Table 1 Thermophysical properties of base fluid and different nanoparticles

	ρ $(Kg\, m^{-3})$	c_p $(J\, Kg^{-1} K^{-1})$	k $(Wm^{-1} K^{-1})$	β $10^{-5} K^{-1}$
EG	1114	2415	0.252	57
Cu	8933	385	400	1.67
Ag	10500	235	429	1.89

Figures 1, 2, and 3 are shows the velocity, temperature and concentration profiles for different values of nanoparticle volume fraction (ϕ). It is noticed from the figures that increase in the velocity, temperature and concentration profiles of the flow by increase in nanoparticles volume fraction. Generally increase in volume fraction of nanoparticles enhances the thermal conductivity. For this reason enhances the thermal boundary layer thickness along with momentum and concentration boundary layers.

Figures 4, 5 and 6 show the influence of radiation parameter (R_a) on velocity, temperature and concentration profiles for both Cu-EG and Ag-EG nanofluids. It noticed that increases in radiation parameter improve the velocity, temperature and concentration profiles. Also, noticed that Ag-EG nanofluid shown better enhancement in velocity and concentration profiles and Cu-EG nanofluid shown better enhancement in temperature profiles. Figures 7, 8 and 9 depicts the effect of thermal buoyancy parameter (λ) on velocity, temperature and concentration profiles for both Cu-EG and Ag-EG nanofluids. It is observed from the figures that enhances in the buoyancy parameter improves the velocity profiles and declines the temperature profiles. But it shows mixed performance in concentration profiles. The influence of suction parameter on velocity, temperature and concentration profiles is shown in Figures 10, 11 and 12. It is clear from the figures that increase in suction parameter reduces the velocity, temperature and concentration profiles. Generally increase in suction parameter it starts a pressure on the flow. Due to this reason reduces the velocity and temperature fields near the boundary and increases the far away from the boundary. The velocity, temperature and concentration for various values of non-uniform heat source/sink are displayed from figures 13 to 18. It is evident from figures that increase in non-uniform heat source/sink depreciates the velocity, temperature and concentration profiles of the flow.

Tables 2 and 3 represents the variation in Skin friction coefficient $(f''(0))$, Nusselt number $(-\theta'(0))$, Sherwood number $(-\phi'(0))$ for Cu-EG and Ag-EG nanofluids at different non-dimensional governing parameters. It is clear from the tables that increase in magnetic field parameter; porosityparameter enhances the friction factor and depreciates the heat and mass transfer rate. Increase in time and space dependent internal heat generation/absorption parameters (A* and B*), buoyancy parameter, suction parameter, enhances the heat and transfer rate for both Cu-EG and Ag-EG nanofluids. It is interesting to mention that increase in volume fraction of nanoparticles increases the friction rate and decreases the Nusselt, Sherwood numbers.Magneticfiled parameter and porosity parameter helps to enhance the mass transfer rate but decreases the skin friction coefficient and Nusselt number. Increase in Soret number and buoyancy parameter increases the friction factor and heat transfer rate but reduces the Sherwood number for both Cu-EG and Ag-EG nanofluids.

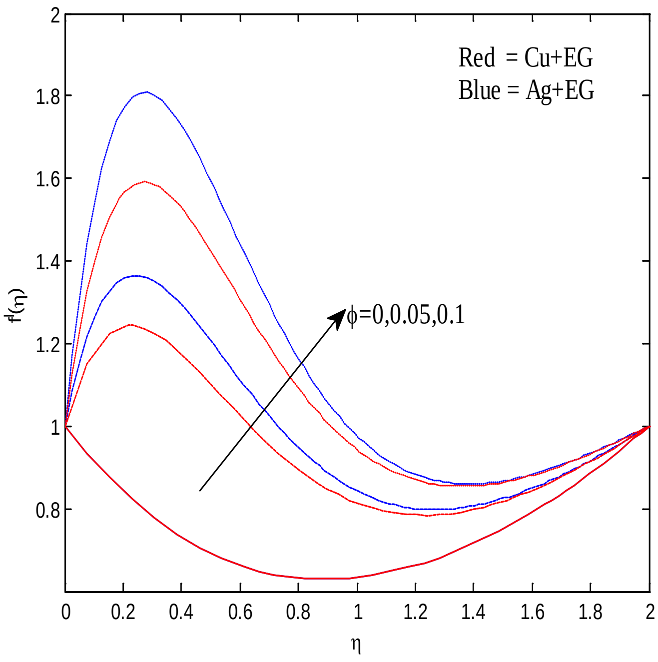

Fig.1 Velocity profiles for different values of ϕ

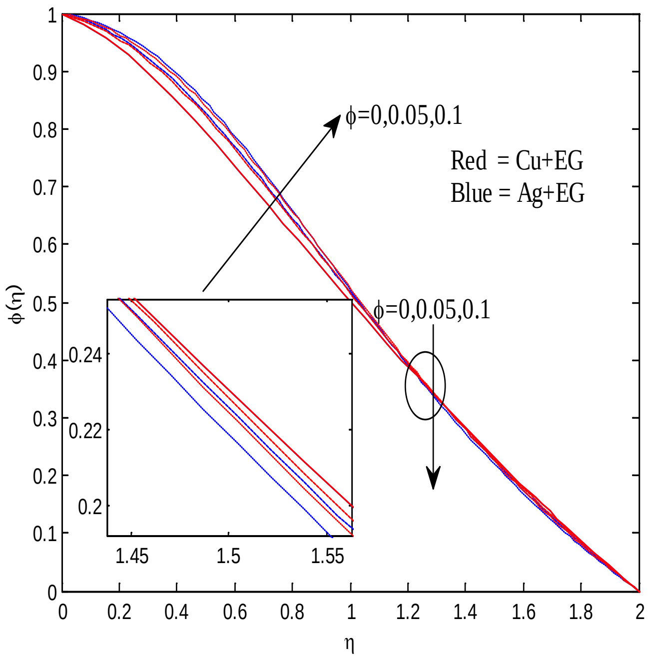

Fig.3 Velocity profiles for different values of ϕ

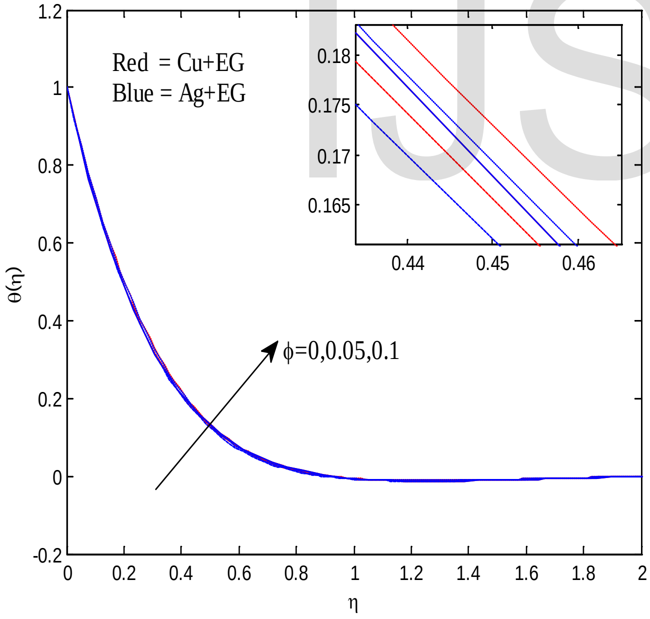

Fig.2 Temperature profiles for different values of ϕ

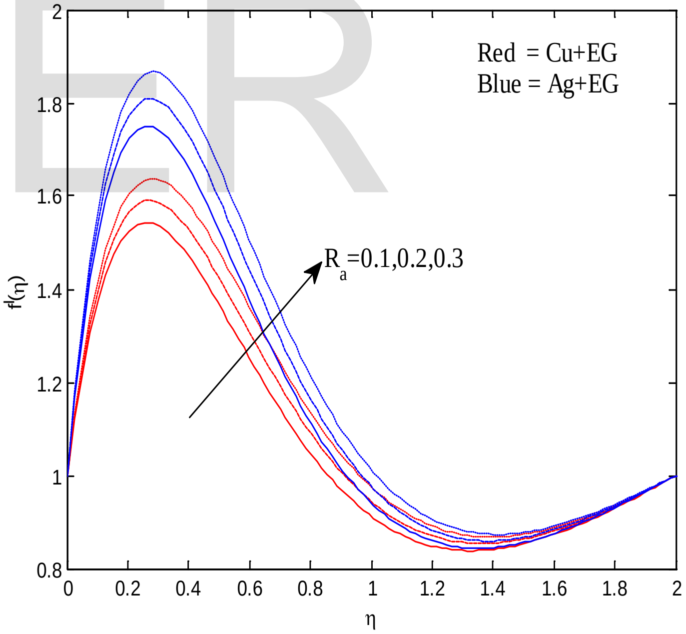

Fig.4 Velocity profiles for different values of R_a

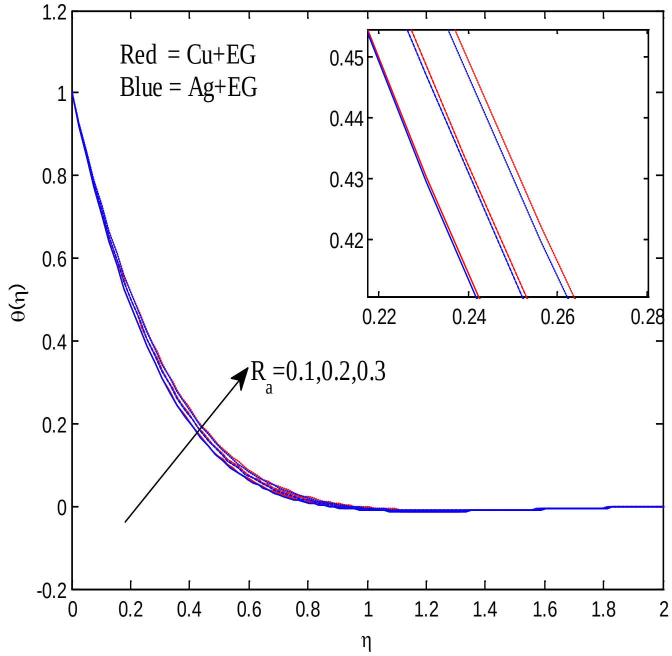

Fig.5 Temperature profiles for different values of R_a

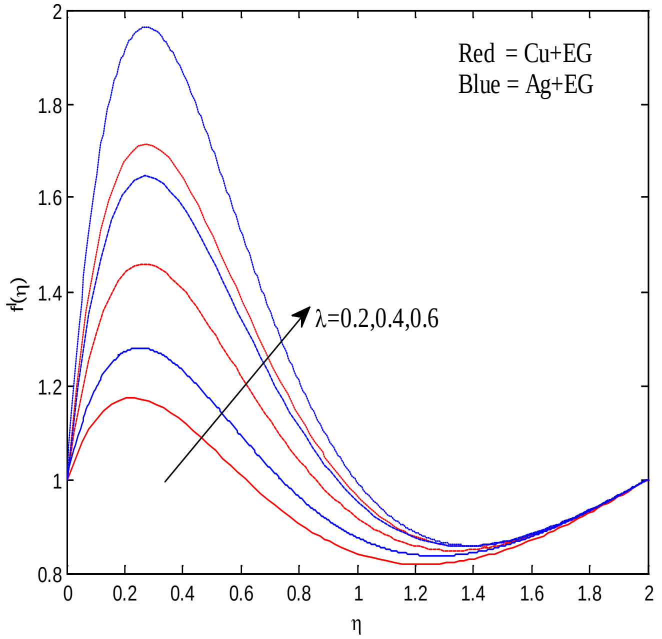

Fig.7 Velocity profiles for different values of λ

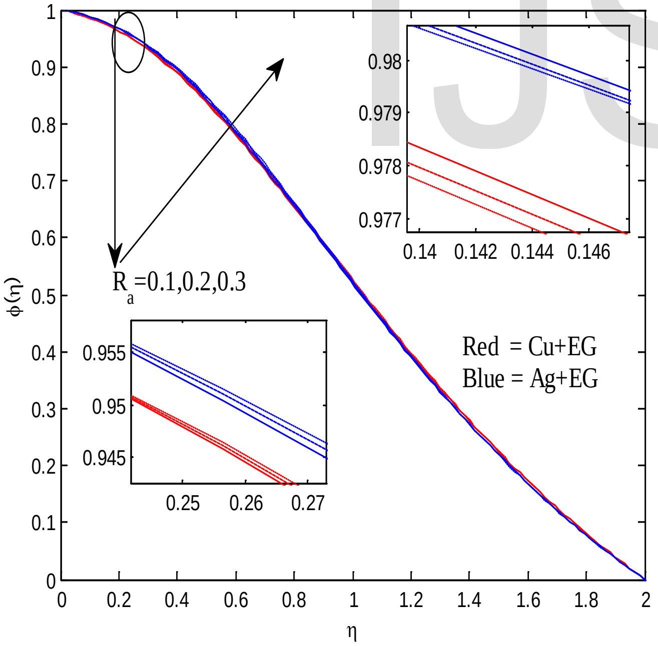

Fig.6 Concentration profiles for different values R_a

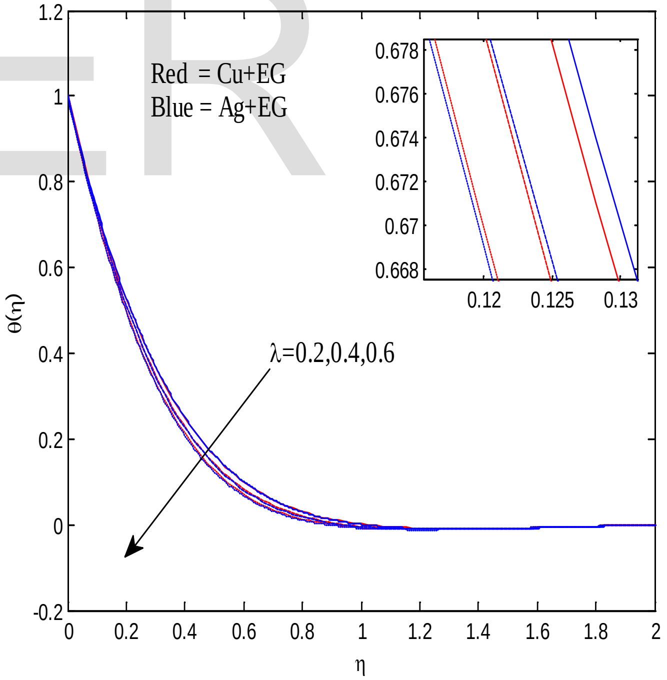

Fig.8 Temperature profiles for different values of λ

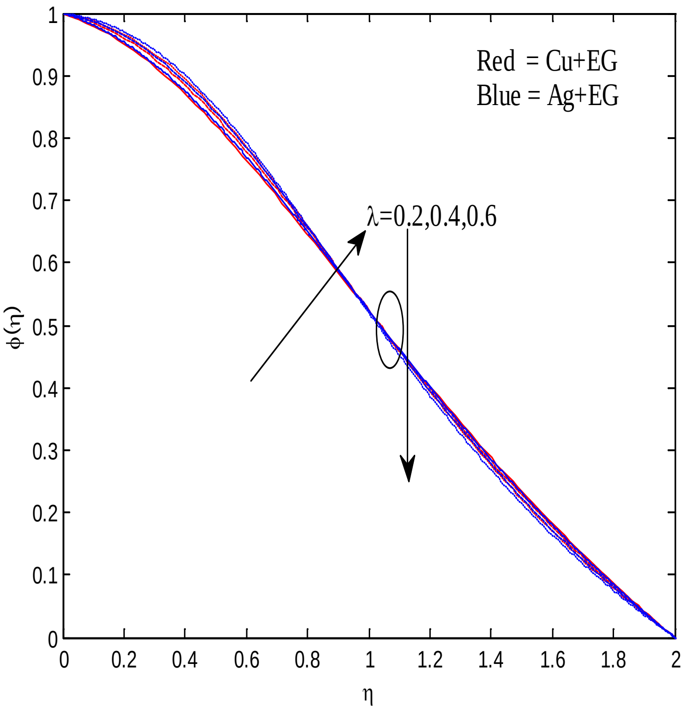

Fig.9Concentration profiles for different values λ

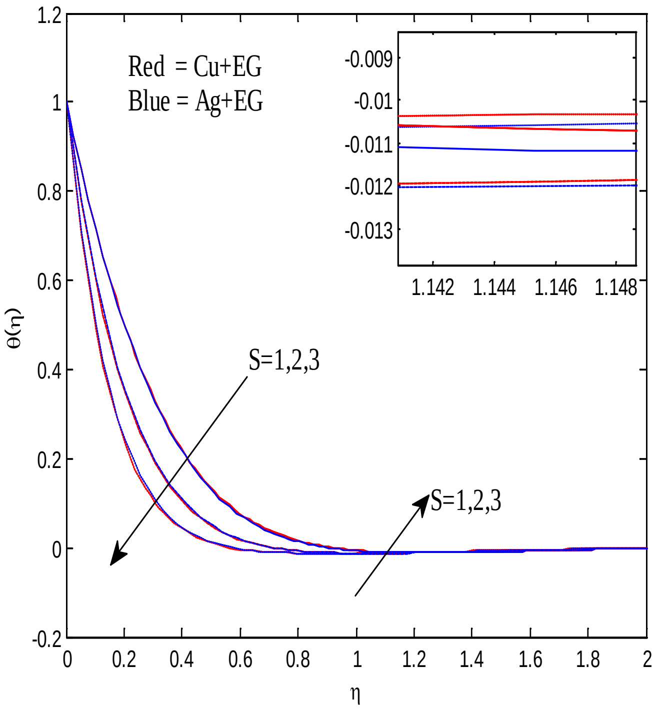

Fig.11 Temperature profiles for different values of S

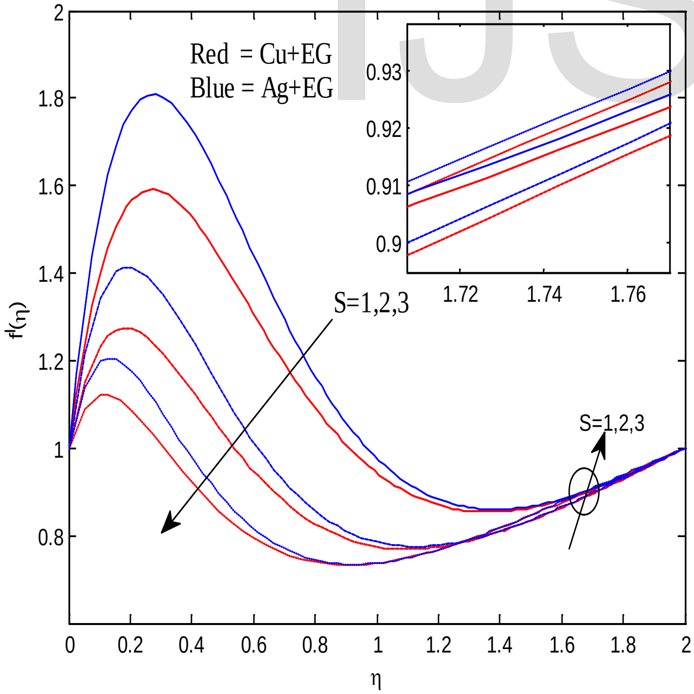

Fig.10 Velocity profiles for different values of S

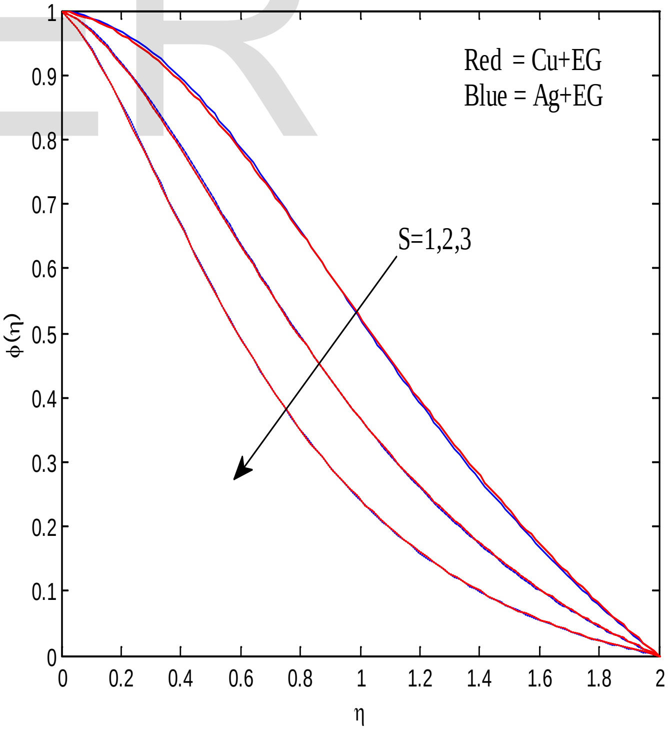

Fig .12 Concentration profiles for different values of S

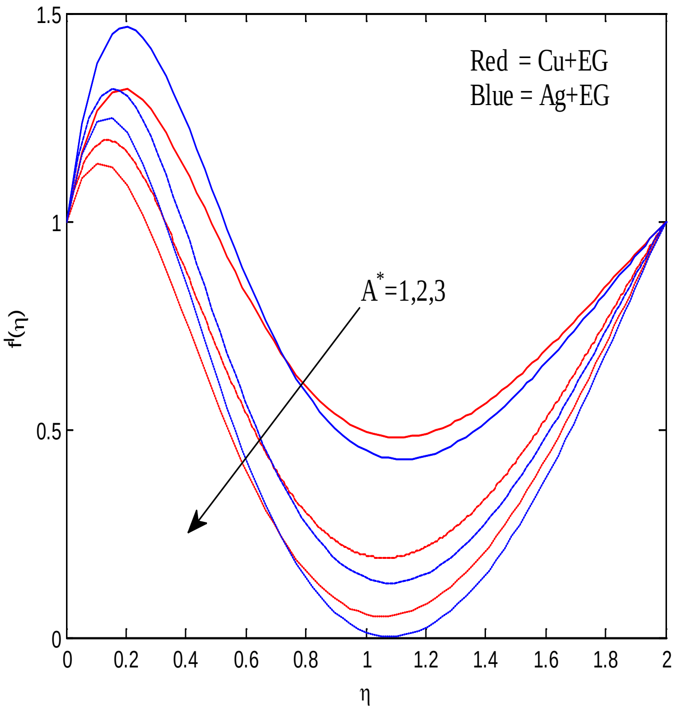

Fig.13 Velocity profiles for different values of A^*

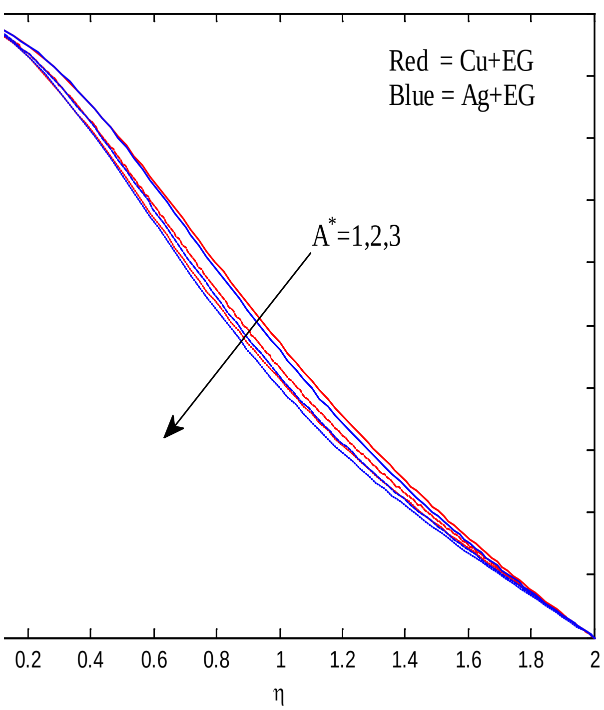

Fig.15 Concentration profiles for different values of A^*

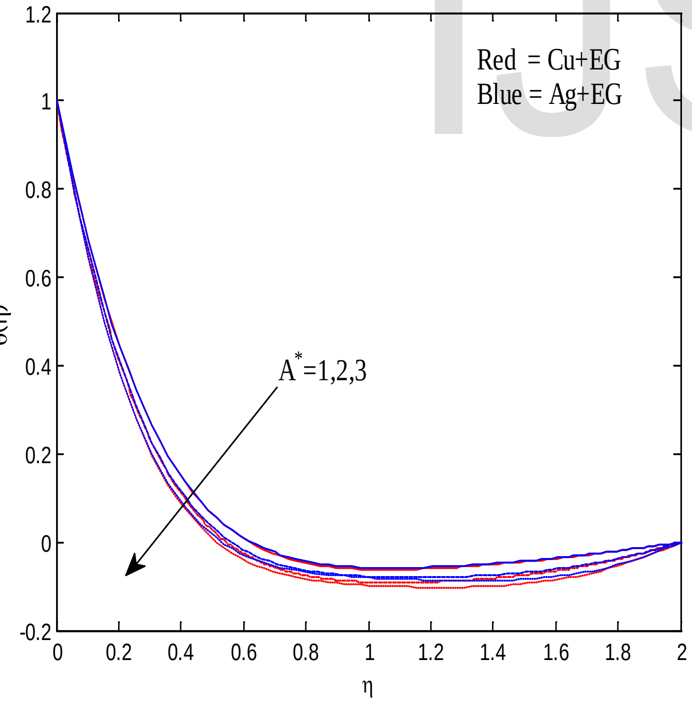

Fig.14 Velocity profiles for different values of A^*

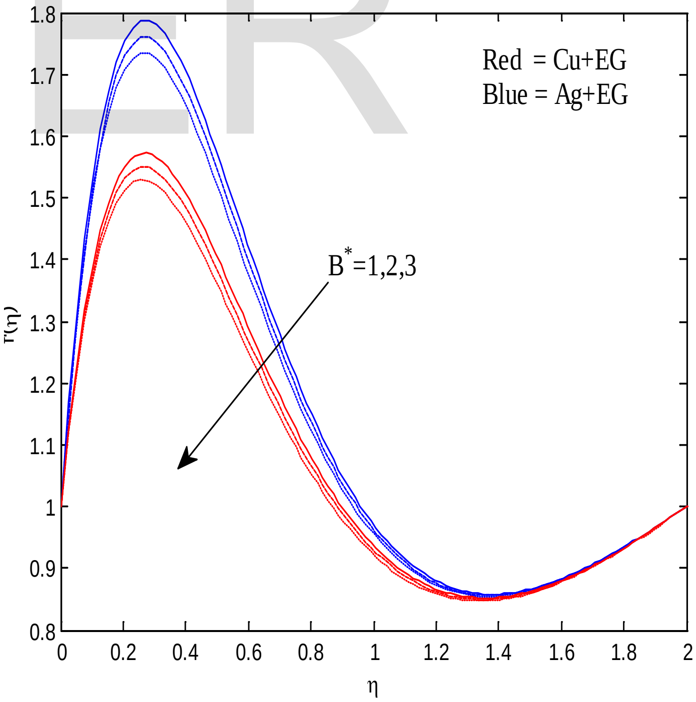

Fig.16 Velocity profiles for different values of B^*

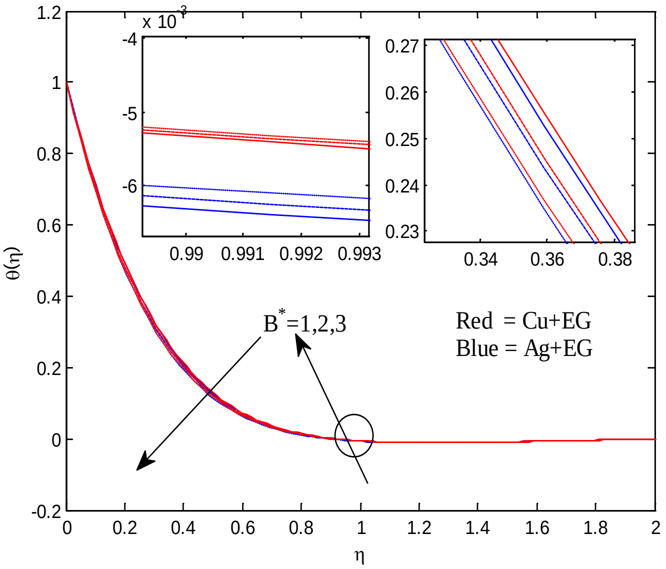

Fig.17 Temperature profiles for different values of B^*

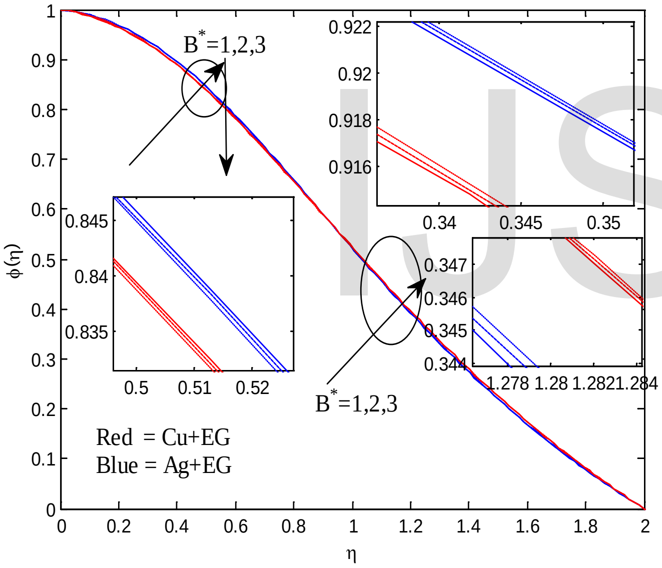

Fig.18 concentration profiles for different values of B^*

Conclusions

In this study we analyzed the influence of magnetic field, radiation and non-uniform heat source/sink parameters of a nanofluid flow over a moving vertical plate in porous medium by considering Cu-Ethylene glycol, Ag-Ethylene glycol nanofluids. The governing partial differential equations of the flow are transformed to ordinary differential equations by using similarity transformation and then solved using shooting technique. The effects of non-dimensional governing parameters namely volume fraction of nano particles, magneticfiled parameter, radiation parameter,soret number, heat generation/absorption coefficient, buoyancy parameter and porosity parameter on the flow, temperature and concentration profiles are discussed and presented graphically. Also, the friction factor and Nusselt and Sherwood numbers are discussed and given in tabular form for two nanofluids separately. The conclusions are as follows:

- Internal heat generation/absorption parameter, buoyancy parameter and suction parameters are enhances the heat transfer rate
- Magneticfiled parameter, porosity parameters effectively improves the mass transfer rate and reduces the friction factor.
- Increases in volume fraction of nanoparticles enhanced the velocity and temperature boundary layer along with skin friction coefficient; but mixed effect increase/decrease was seen in concentration boundary layer.
- Ag-EG nanofluid effectively increases the velocity boundary layer thickness compared with Cu-EG nanofluid.

erent values of B^*

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Table.2 Variation in $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ for Cu-EG nanofluid

M	R_a	A^*	B^*	λ	S	Sr	K	ϕ	$f''(0)$	$-\theta'(0)$	$\phi'(0)$
1	0.2	0.2	0.2	0.5	1	0.2	0.2	0.1	5.357107	3.102921	0.095141
2									4.765979	3.053127	0.134667
3									4.276918	3.011897	0.167408
	0.1								5.123133	3.257805	0.086715
	0.2								5.357107	3.102921	0.095141
	0.3								5.577497	2.966464	0.101902
		1							3.985691	3.496842	0.155508
		2							3.145908	3.792686	0.200367
		3							2.705016	4.018887	0.215888
			1						5.258213	3.205988	0.085844
			2						5.141047	3.330604	0.074531
			3						5.030461	3.450892	0.063546
				0.2					1.814733	2.955864	0.160038
				0.4					4.218414	3.059104	0.113171
				0.6					6.463129	3.143009	0.079570
					1				5.357107	3.102921	0.095141
					2				3.714104	4.833907	0.214291
					3				2.508406	6.749952	0.407987
						0.2			5.357107	3.102921	0.095141
						0.4			5.357107	3.102921	-0.156075
						0.6			5.357107	3.102921	-0.407291
							0.2		5.357107	3.102921	0.095141
							0.4		5.228590	3.092138	0.103666
							0.6		5.105648	3.081793	0.111869
								0	-0.903914	3.377609	0.187795
								0.05	2.574716	3.255166	0.126392
								0.1	5.357107	3.102921	0.095141

Table.3 Variation in $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ for Ag-EG nanofluid

M	R_a	A^*	B^*	λ	S	Sr	K	ϕ	$f''(0)$	$-\theta'(0)$	$\phi'(0)$
1	0.2	0.2	0.2	0.5	1	0.2	0.2	0.1	7.285251	3.091701	0.077375
2									6.666336	3.043878	0.113337
3									6.145899	3.003632	0.143766
	0.1								6.992534	3.240659	0.070505
	0.2								7.285251	3.091701	0.077375
	0.3								7.560524	2.960314	0.082799
		1							5.586898	3.476076	0.152026
		2							4.640369	3.766003	0.198984
		3							4.136218	3.999990	0.212019

			1						7.163033	3.192289	0.068447
			2						7.017558	3.314162	0.057578
			3						6.879600	3.432046	0.047010
				0.2					2.684234	2.916797	0.149271
				0.4					5.813571	3.040450	0.096667
				0.6					8.710264	3.138116	0.061084
					1				7.285251	3.091701	0.077375
					2				5.306372	4.724916	0.202315
					3				3.775469	6.549701	0.409802
						0.2			7.285251	3.091701	0.077375
						0.4			7.285251	3.091701	-0.163744
						0.6			7.285251	3.091701	-0.404863
							0.2		7.285251	3.091701	0.077375
							0.4		7.151699	3.081416	0.085062
							0.6		7.023405	3.071514	0.092496
								0	-0.903914	3.377609	0.187795
								0.05	3.655482	3.257419	0.111047
								0.1	7.285251	3.091701	0.077375

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