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Radiation and Soret Effects of MHD Nanofluid Flow over a Moving Vertical Moving Plate in Porous Medium

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Abstract
We analyzed the magneticfiled, radiation and soret effects of a nanofluid flow over a moving vertical plate in porous medium. We considered two types of nanofluids namely Cu-Ethylene glycol, CuO-Ethylene glycol. The governing partial differential equations of the flow are transformed to ordinary differential equations by using similarity transformation and then solved numerically. The effects of non-dimensional governing parameters namely volume fraction of nano particles, magneticfiled parameter, radiation parameter, soret number, 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.
Keywords: MHD, Radiation, Soret effect, Porous medium, Nanofluid.

1. Introduction

The revolution of nanofluids started with Choi (1995) at ANL laboratory. Nanofluids are suspended particles of fluid. They have a nanometer sized particles and they have a less uniform dispersion in the rigid particles. Nano fluids are crucial applications in science and technology, marine engineering, industrial application such plastic, polymer industries, cancer homeotherapy and building sciences. Flows through moving vertical flat plate also having enormous applications in the aerosols engineering, aerodynamics and civil engineering because of this reason researchers likely to this field. Laminar boundary layer flow of a nanofluid in the presence of flat surface was considered by Khan and Pop (2010). Bachok et al. (2010) investigated the Nanofluid through a steady boundary layer flow of a semi-infinite uniform free stream. In this paper they are concluded that the plate and free stream are in opposite line. Mixed convective nanofluid flow of a vertical horizontal plate with a porous medium was discussed Ahmad and Pop (2011). Enhanced characteristics of Nanofluid in a saturated porous medium with vertical plate in the presence of surface heat, solute and nanoparticle fluxes are considered by Khan and Aziz (2011). In this study they explained the enhanced characteristics of nanofluid along with power law of the surface fluxes. MHD convective flow of nanofluid through a linearly stretching layer illustrated by Hamad (2011). Sugunamma and Sandeep (2011) analyzed unsteady MHD raditive fluid flow in porous medium with constant heat fluix. Mixed convective boundary layer flow of a nanofluid in the presence of power dissipation was discussed by Gosselin and Silva (2004). The effect of thermal radiation on viscous nanofluid flow of a nonlinearly stretching sheet was discussed by Hady et al. (2012). They used logical shooting technique with RK method in this study. MHD stagnation point flow of a convective nanofluid through inflamed shrinking layer was scrutinized by Makinde et al. (2013). They narrated the impact of different controlling parameters and accomplish the correlation between the physical parameters and buoyancy effects .Haddad et al. (2012) analyzed the effects of Brownian and thermophoresis parameters in natural convective flow of a anofluid .They emphasize the results increase in volume fraction decrease in heat transfer coefficient and the heat transfer establishment is entirely conduction for higher value of volume fraction coefficient. Convective dripped Nanofluid flow of a non-isothermal vertical plate with porous medium was illustrated by Rama Subba Reddy et al. (2011). Sandeep et al. (2013) discussed radiation effects on unsteady natural convective flow of a nanofluid past an infinite vertical plate. Mohan Krishna et al. (2014) extended this work by considering heat source effect and different nanofluids. Sandeep et al. (2012) discussed radiation and chemical reaction effects of the MHD flow over a vertical plate.

Numerical investigation of convective and heat transfer characteristics of nanofluid through a vertical plate with convective boundary conditions were illustrated by Ibrahim and Shankar (2012). In this paper they used constant heat flux and heated boundary condition. Implicit Finite differences Analysis of a free MHD convective Nanofluid through a permeable vertical plate in the existence of suction or injection parameters are observed by Chamka and Aly (2010). Combined effect of convective nanofluid through a perpendicular plate with dripped porous medium is solved numerically by Kumari et al. (2012). Theoretical analysis of Nanofluid flow of heat transfer in the presence of dufour effects was discussed by Hussein and Mahmood (2012). They noticed that nanoparticles are passed from hot wall to cold wall in the effect of positive thermophoresis parameter and Dufour effect. Kameswaran et al. (2012) examined the Chemical reaction and Soret effect of convective nanofluid flow through a stretching or shrinking sheet in the presence of magnetic field and they concluded that decreases in wall heat transfer and mass transfer rates with increase in magnetic field. Double diffusive analysis of convective horizontal sheet in the presence of dripped porous medium is solved using

Galerkin approach by Kuznetsov and Nield (2010). Recently the resaerchers (Ramana Reddy et al., 2014, Mohankrishna et al., 2013, Sandeep et al.2013) analyzed the heat and momentum transfer characteristics at different channels by immersing the micro or millimeter sized particles in to base fluids.

To the authors' knowledge no studies has been reported on magneticfiled, radiation and soret effects of a nanofluid flow over a moving vertical plate in porous medium by considering Cu-Ethylene glycol, CuO-Ethylene glycol nanofluids. The governing partial differential equations of the flow are transformed to ordinary differential equations by using similarity transformation and then solved numerically. The effects of non-dimensional governing parameters namely volume fraction of nano particles, magneticfiled parameter, radiation parameter, soret number, 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.

2. Mathematical Formulation

Consider a steady, incompressible, 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. 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. A variable magneticfield $B(x)$ is applied to the flow, Soret and radiation effects are taken into account. The governing boundary layer equations as per above assumptions can be expressed as

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

$$\rho_{nf}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu_{nf}\frac{\partial^2 u}{\partial y^2}+g(\rho\beta)_{nf}(T-T_\infty)-\sigma B^2(x)u-\frac{\mu_f}{k'}u, \tag{2}$$

$$(\rho c_p)_{nf}\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k_{nf}\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y} \tag{3}$$

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

With the boundary conditions

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

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, $k'=k_0 x/U$ 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

$$(\rho\beta)_{nf}=(1-\phi)(\rho\beta)_f+\phi(\rho\beta)_s,\ (\rho c_p)_{nf}=(1-\phi)(\rho c_p)_f+\phi(\rho c_p)_s,$$
$$\frac{k_{nf}}{k_f}=\frac{(k_s+2k_f)-2\phi(k_f-k_s)}{(k_s+2k_f)+\phi(k_f-k_s)},\ \mu_{nf}=\frac{\mu_f}{(1-\phi)^{2.5}},\ \rho_{nf}=(1-\phi)\rho_f+\phi\rho_s, \tag{6}$$

Where ϕ is the nano particle 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

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

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

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

$$u = \frac{\partial \psi}{\partial y} = Uf'(\eta), \qquad v = \frac{\partial \psi}{\partial x} = -1/2\sqrt{v_f U / x}\left(f(\eta) - \eta f'(\eta)\right) \tag{10}$$

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

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

$$\frac{1}{\Pr}\left(\frac{k_{nf}}{k_f} + R\right)\theta'' + \frac{1}{2}\left(1 - \phi + \phi\frac{(\rho c_p)_s}{(\rho c_p)_f}\right) f\theta' = 0 \tag{12}$$

$$\phi'' - 2Scf'\phi + Scf\phi' + ScSr\theta'' = 0 \tag{13}$$

The transformed boundary conditions are

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

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, $R = 16\sigma^* T_\infty^3 / 3k^* k_f$ is the radiation parameter, $Sr = D_m k_T (T_w - T_\infty) / T_m (C_w - C_\infty) v_f$ is the soret number, $Sc = \upsilon_f / D_m$ is the Schmidt number, λ is the mixed convection parameter, which are given by $\lambda = Gr_x / \mathrm{Re}_x^{\ 2}$ and $\varepsilon = U_w / U$ .Here $Gr_x = g\beta_f (T_w - T_\infty) x^3 / v_f^{\ 2}$ is local Grashof number and $\mathrm{Re}_x = Ux / v_f$ 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

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

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

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

3. Results and Discussion

The system of nonlinear ordinary differential equations (11) to (13) with the boundary conditions (14) are solved numerically using bvp4c with MATLAB package. The results obtained shows the influences of the non dimensional governing parameters, namely volume fraction of nano particles ϕ, magneticfiled parameter M, radiation parameter R, soret number Sr, buoyancy parameter λ and porosity parameter K 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 we used $\Pr = 6.2, \mathrm{Sc} = 0.6, \phi = 0.1, R = Sr = K = 0.2, M = 1, \lambda = 0.5$ .These values are kept 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

	$\rho (Kg\, m^{-3})$	$c_p (J\, Kg^{-1}\, K^{-1})$	$k\,(Wm^{-1}\, K^{-1})$	$\beta 10^{-5}\, K^{-1}$
Ethylene Glycol	1114	2415	0.252	57
Copper (Cu)	8933	385	400	1.67
Copper Oxide (CuO)	6320	531.8	76.5	1.8

Figures 1, 2 and 3 depicts the effect of volume fraction of nano particles (ϕ) on velocity, temperature and concentration profiles for Cu-EG and CuO-EG nanofluids. It is observed from figures that increase in volume fraction of nano particles increases the velocity, temperature and concentration profiles of the flow. Generally increase in volume fraction of nano particles improves the thermal conductivity. These causes to improve the thermal boundary layer thickness along with velocity and concentration boundary layers. It is interesting to mention that the enhancement in temperature and concentration profiles of CuO-EG nanofluid is more than that of Cu-EG nanofluid. Figures 4, 5 and 6 represent the effect of magneticfield parameter (M) on velocity, temperature and concentration profiles for Cu-EG and CuO-EG nanofluids. It is clear from figures that a raise in the value of magneticfield parameter reduces the velocity and concentration profiles and enhances the temperature profiles. It is due to the fact that increase in magneticfield parameter develops the force opposite to the flow, is called Lorentz force. This force depreciates the velocity and concentration boundary layers and enhances the thermal boundary layer thickness. Due to this reason we seen enhancement in temperature profiles.

Figures 7, 8 and 9 illustrate the effect of porosity parameter (K) on velocity, temperature and concentration profiles for Cu-EG and CuO-EG nanofluids. We observed similar type of results as we seen for magneticfiled parameter. The increase in porosity parameter generates internal heat to the flow this causes to improve the temperature profiles. Due to the internal heat generation the particles near the wall moves to cooler areas that's why we noticed fall in concentration profiles. Figures 10, 11, and 12 shows the influence of radiation parameter (R) on velocity, temperature and concentration profiles for Cu-EG and CuO-EG nanofluids. It is noticed from figures that increase in radiation parameter improves the velocity, temperature and concentration profiles. Cu-EG nanofluid shown better enhancement in velocity and concentration profiles and CuO-EG nanofluid shown enhancement in temperature profiles.

The influence of soret number (Sr) on velocity, temperature and concentration profiles for Cu-EG and CuO-EG nanofluids are displayed in figures 13, 14 and 15 respectively. It is observed that increase soret number increases the concentration profiles of the flow. But it showed mixed performance in increase/decrease in velocity and temperature profiles. Figures 16, 17 and 18 illustrates the effect of thermal buoyancy parameter (λ) on velocity, temperature and concentration profiles for Cu-EG and CuO-EG nanofluids. It is evident from figures that increase in buoyancy parameter enhances the velocity and concentration profiles but depreciates the temperature profiles after certain level buoyancy parameter shown mixed performance in increase/decrease in temperature profiles.

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 CuO-EG nanofluids at different non-dimensional governing parameters. It is evident from tables that increase in volume fraction of nano particles, radiation parameter enhances the friction factor and depreciates the heat and mass transfer rate. 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 CuO-EG nanofluids.

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

ϕ	M	K	R	Sr	λ	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1						5.332786	2.885487	0.185931
0.2						9.338788	2.582982	0.137070
0.3						11.290326	2.277318	0.114528
	1					5.332786	2.885487	0.185931
	2					4.817211	2.855112	0.212511
	3					4.370021	2.828785	0.235049
		1				4.914172	2.860826	0.207553
		2				4.454926	2.833777	0.230816
		3				4.049620	2.809996	0.250794
			0.5			5.946060	2.538479	0.195669
			1.0			6.778529	2.152635	0.198317
			1.5			7.445206	1.897382	0.194175
				0.5		5.332759	2.885482	-0.151620
				1.0		5.332790	2.885490	-0.714240
				1.5		5.332790	2.885490	-1.276847
					0.1	-1.328382	2.574868	0.401070
					0.2	-1.170021	2.584787	0.393350
					0.3	-1.013303	2.594407	0.385937

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

ϕ	M	K	R	Sr	λ	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1						3.923567	2.835366	0.210276
0.2						7.171982	2.523694	0.157903
0.3						8.793106	2.218328	0.132052
	1					3.923567	2.835366	0.210276
	2					3.436760	2.804407	0.238658
	3					3.019233	2.777985	0.262186
		1				3.527820	2.810195	0.233415
		2				3.098237	2.782968	0.257802
		3				2.722123	2.759334	0.278355
			0.5			4.420799	2.486399	0.221986
			1.0			5.096272	2.099701	0.226725
			1.5			5.636284	1.845048	0.223846
				0.5		3.923567	2.835364	-0.128184
				1.0		3.923582	2.835369	-0.692303
				1.5		3.923583	2.835370	-1.256412
					0.1	-1.294069	2.577006	0.396723
					0.2	-1.173258	2.584657	0.390658
					0.3	-1.053409	2.592153	0.384785

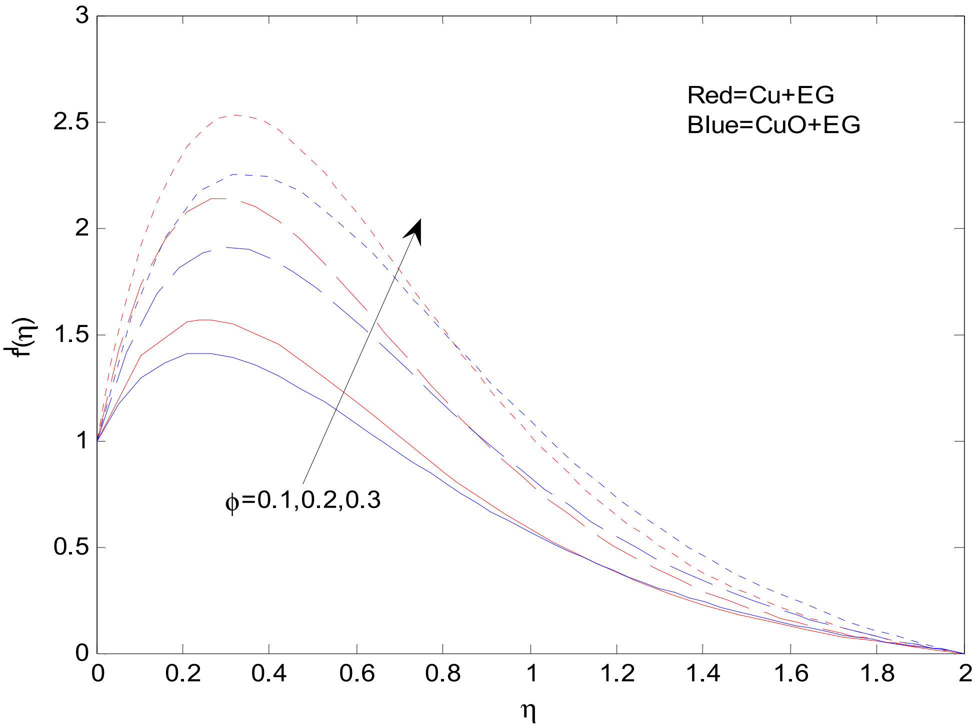

Figure.1 Velocity profiles for different values of ϕ

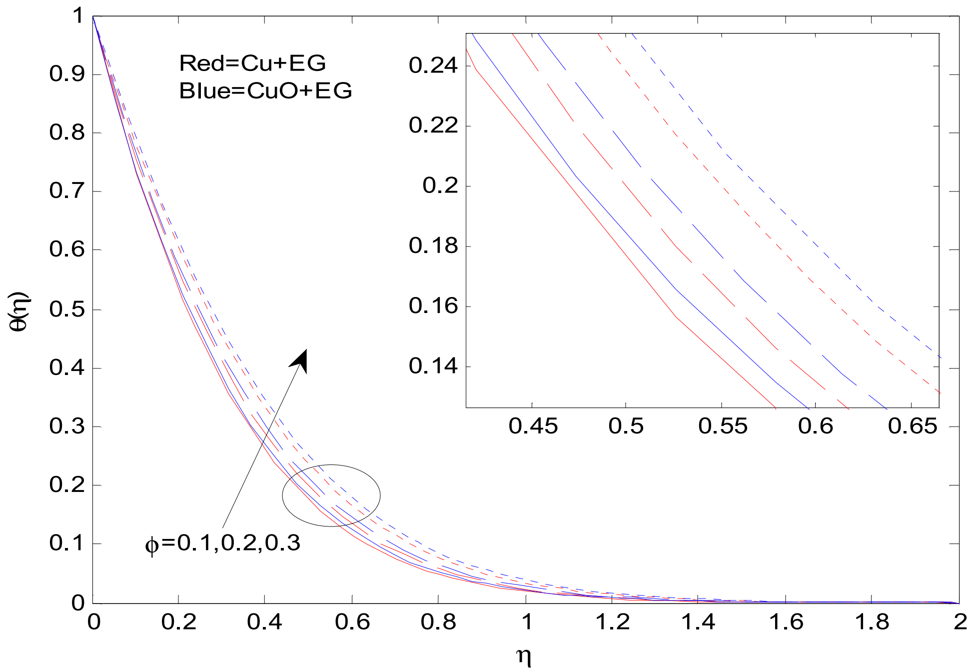

Figure.2 Temperature profiles for different values of ϕ

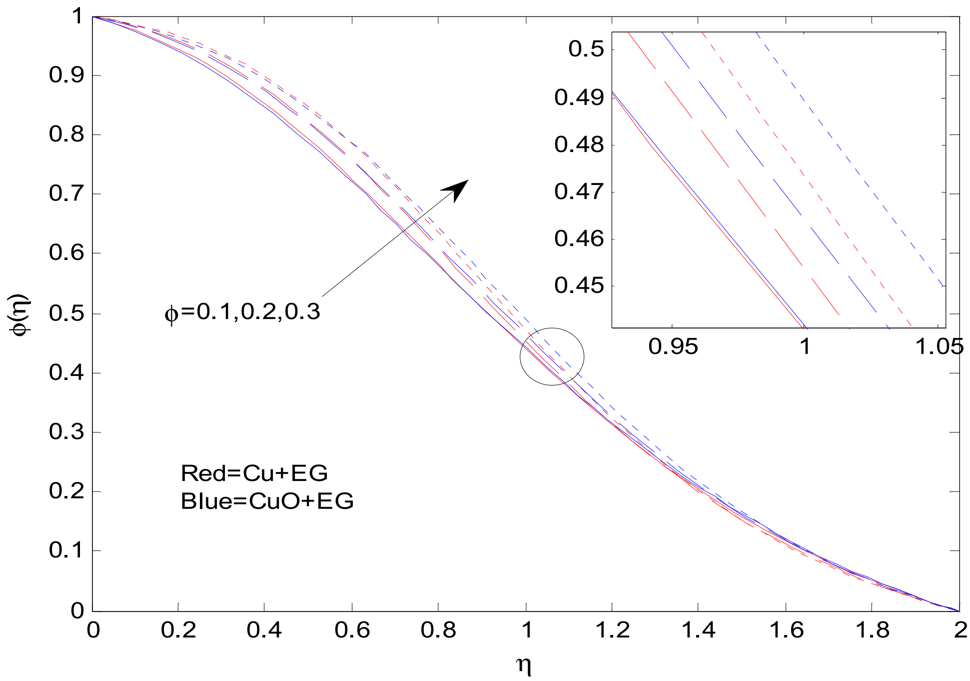

Figure.3 Concentration profiles for different values of ϕ

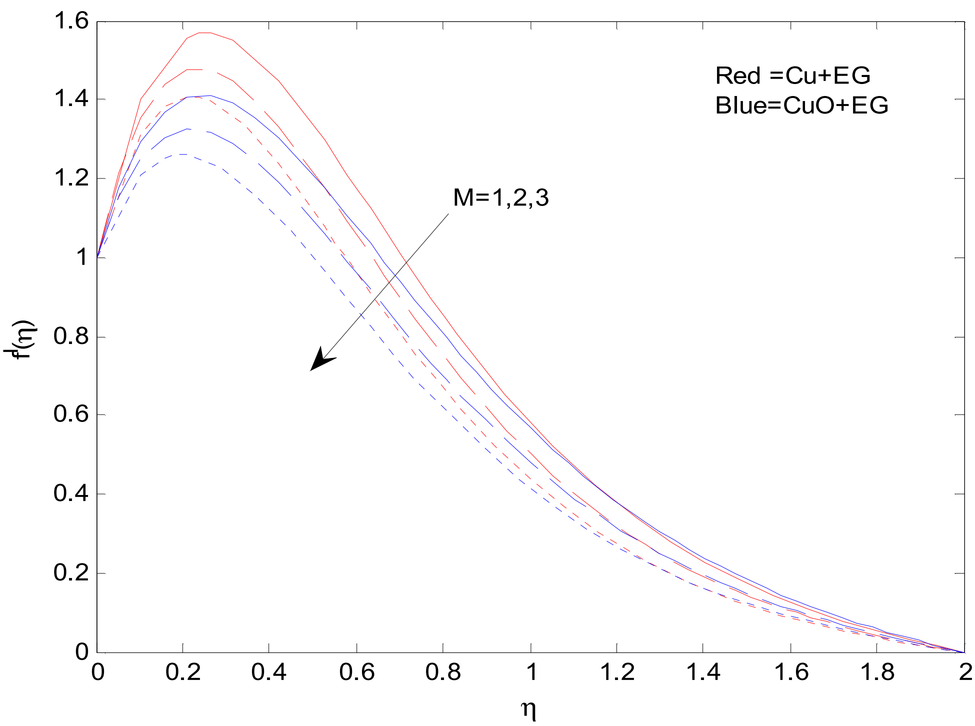

Figure.4 Velocity profiles for different values of M

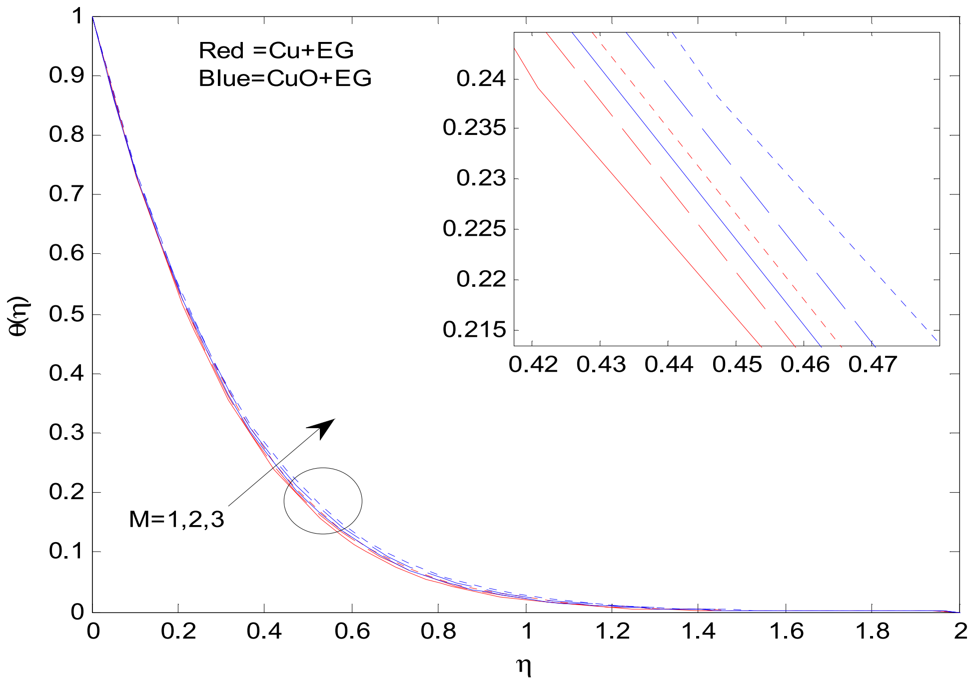

Figure.5 Temperature profiles for different values of M

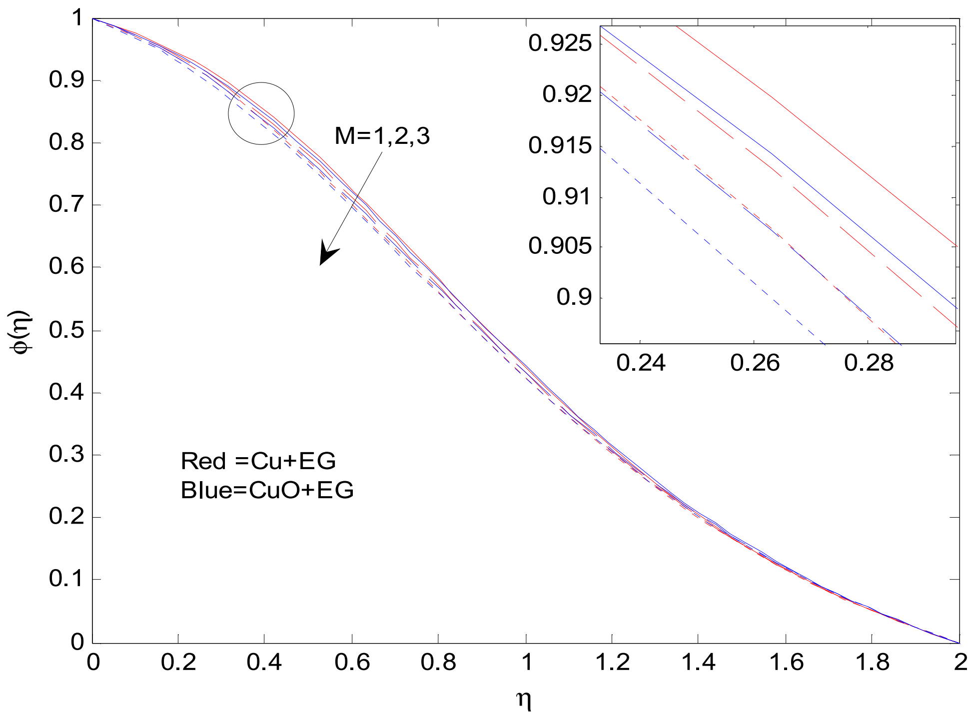

Figure.6 Concentration profiles for different values of M

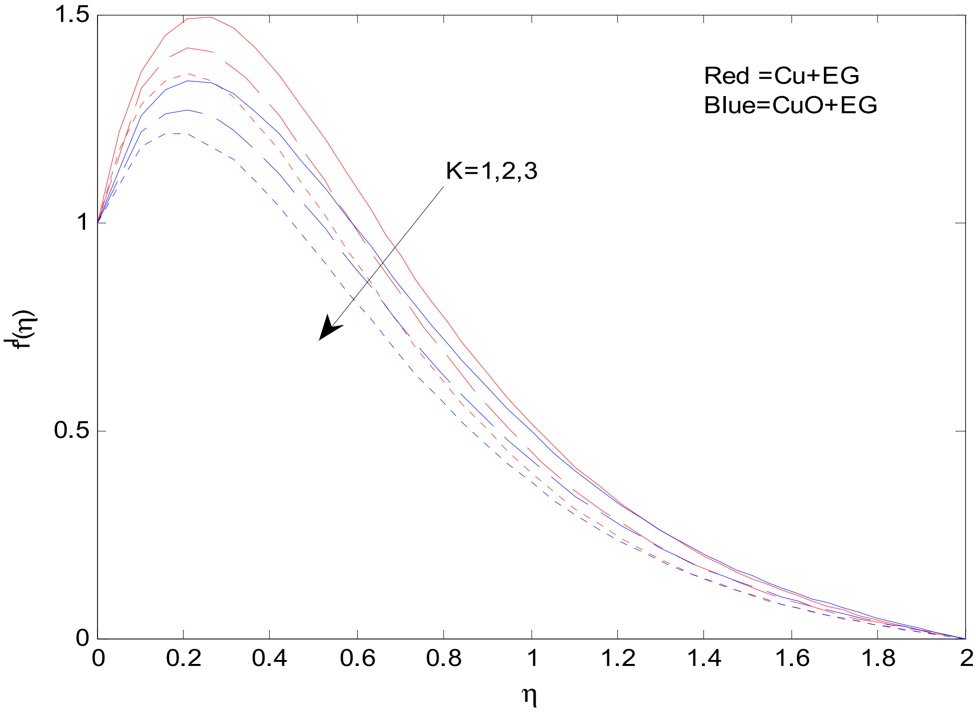

Figure.7 Velocity profiles for different values of K

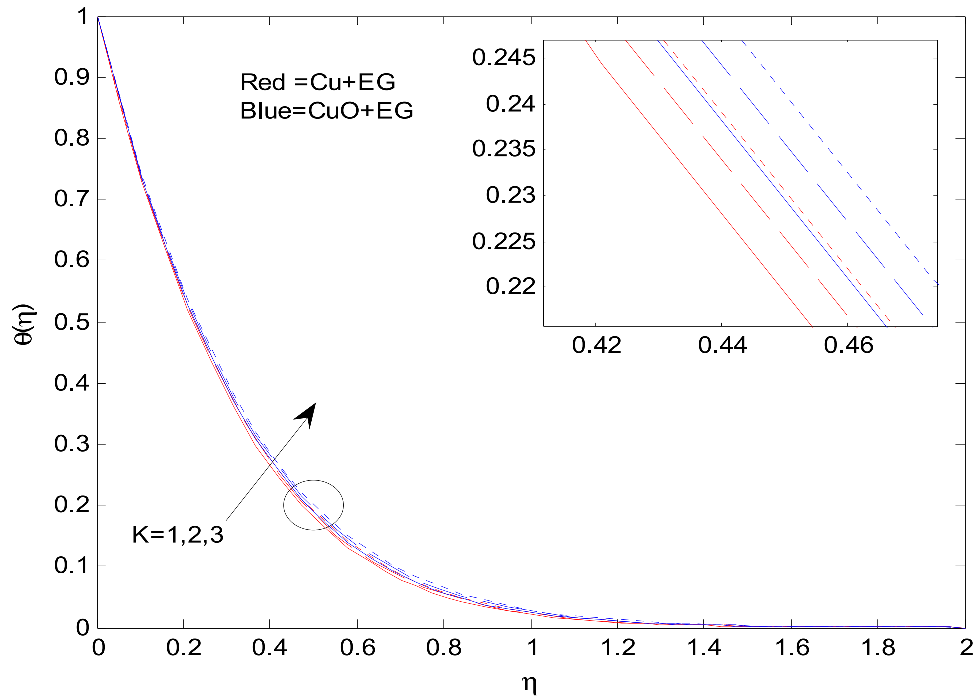

Figure.8 Temperature profiles for different values of K

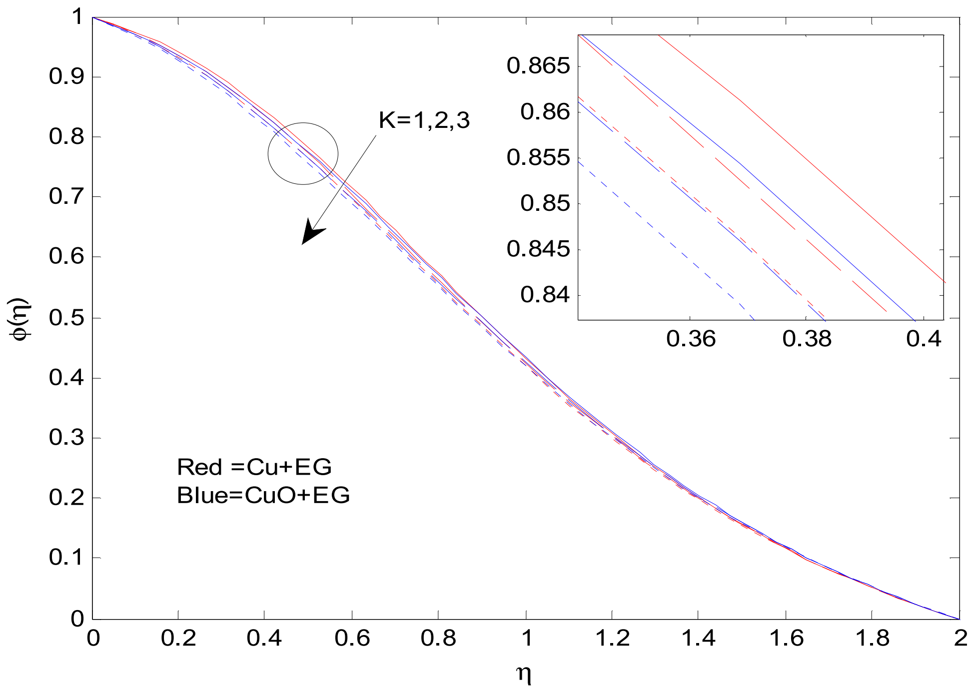

Figure.9 Concentration profiles for different values of K

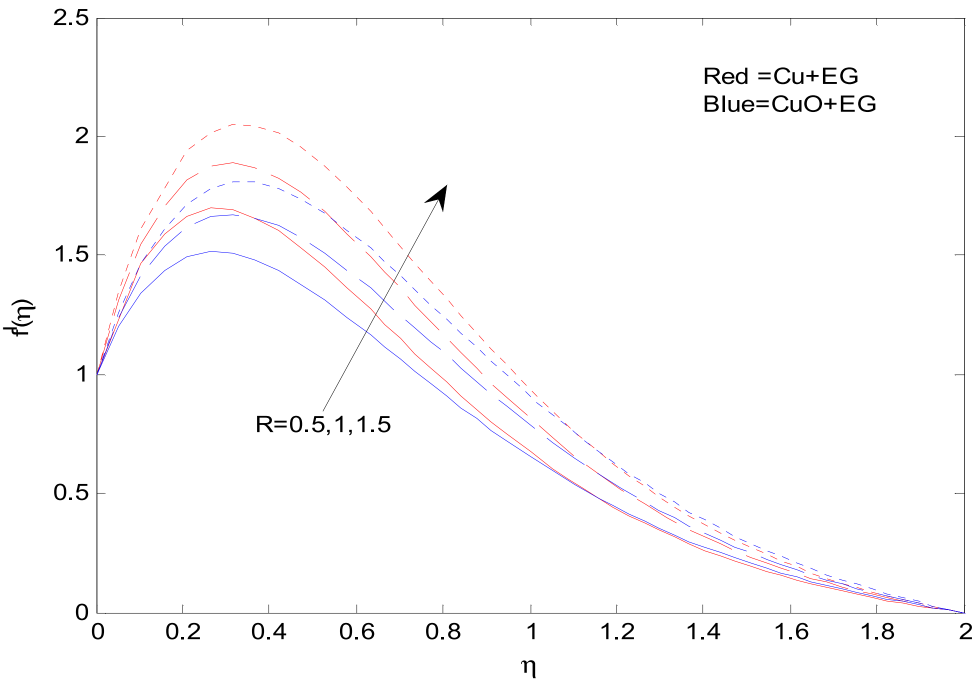

Figure.10 Velocity profiles for different values of R

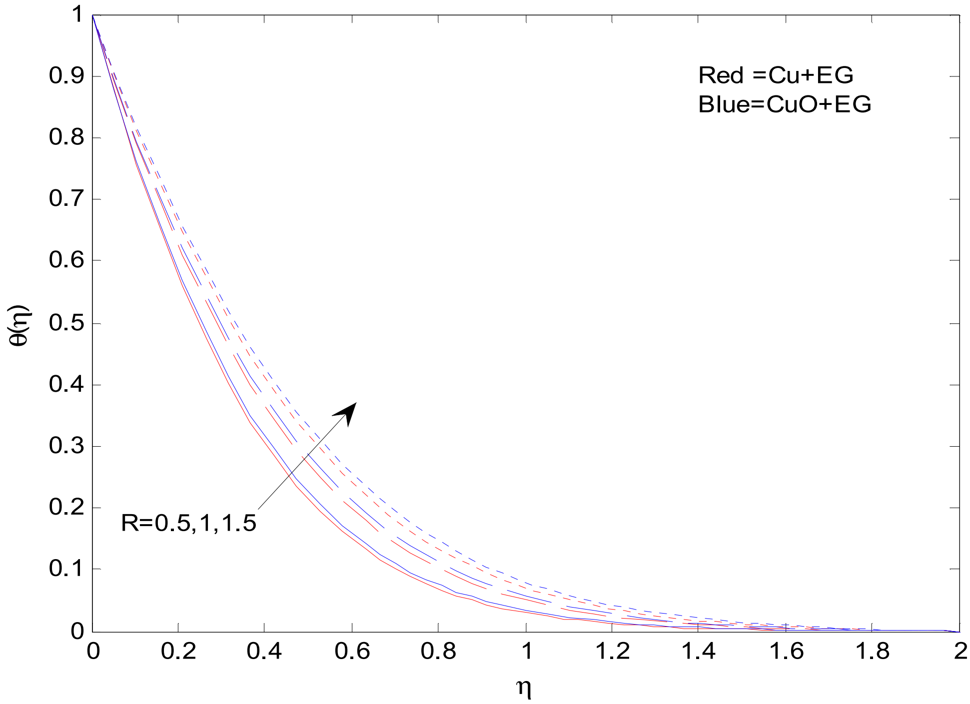

Figure.11 Temperature profiles for different values of R

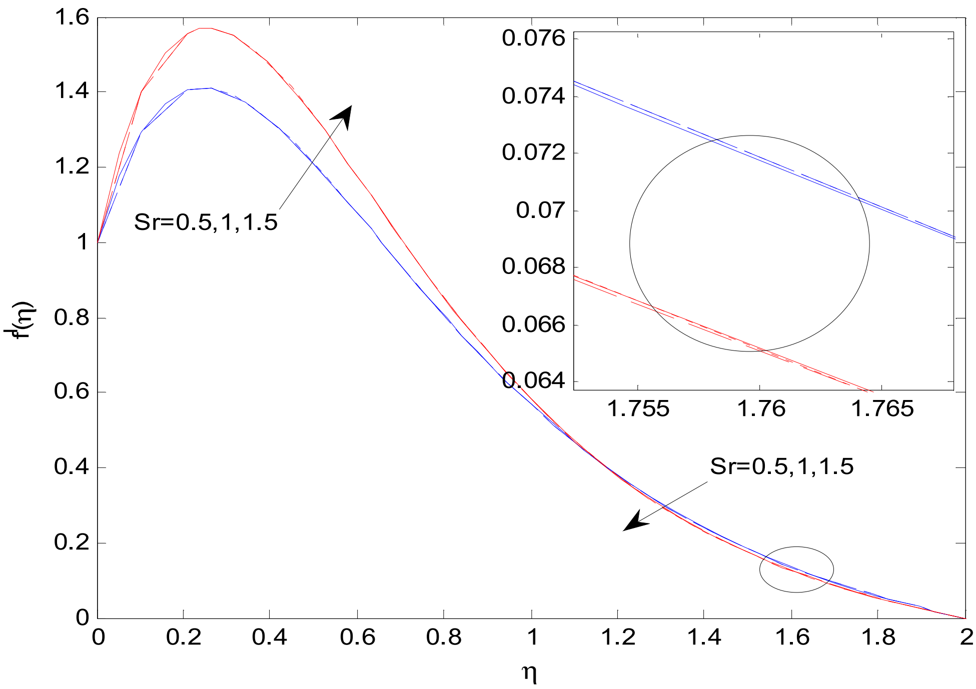

Figure.13 Velocity profiles for different values of Sr

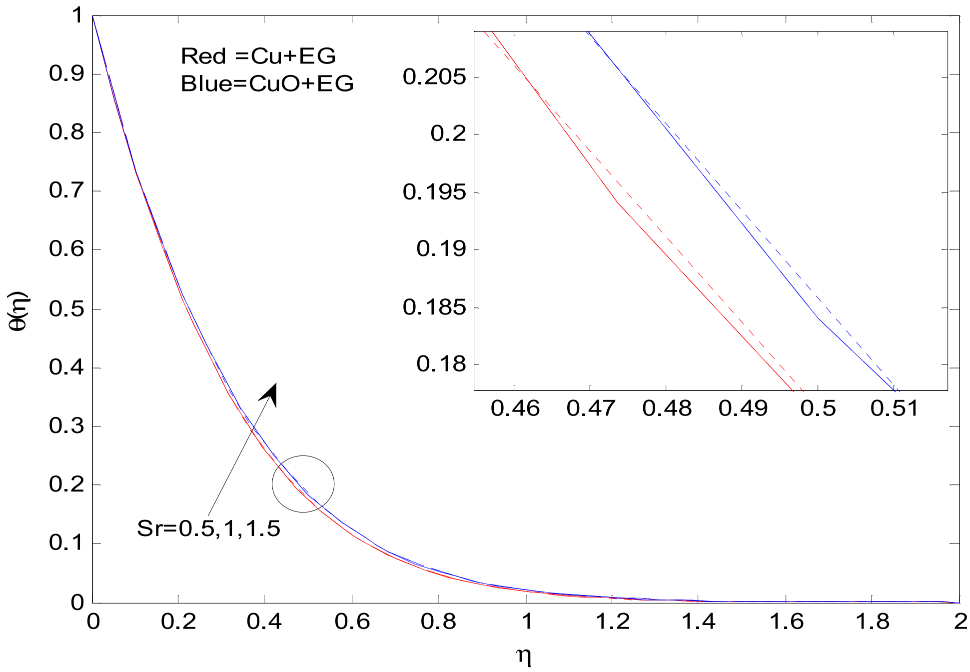

Figure.14 Temperature profiles for different values of Sr

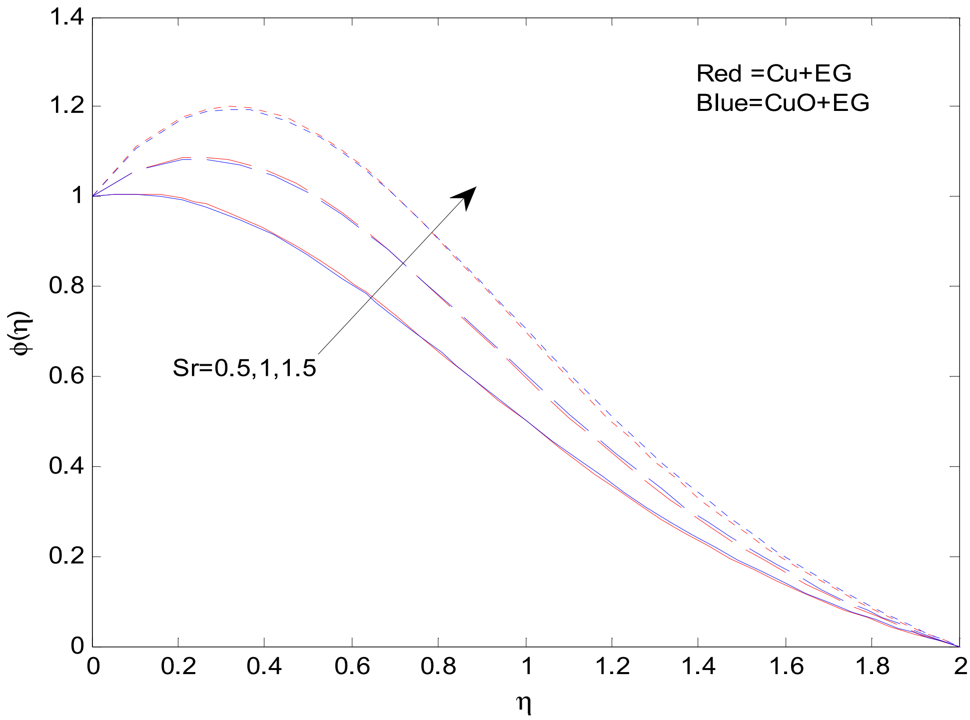

Figure.15 Concentration profiles for different values of Sr

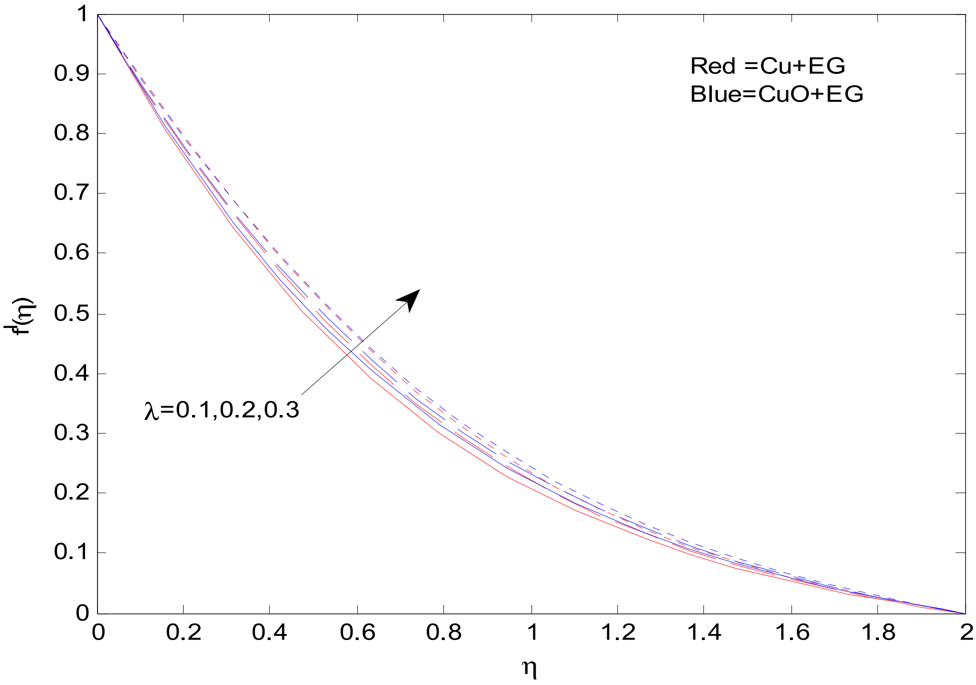

Figure.16 Velocity profiles for different values of λ

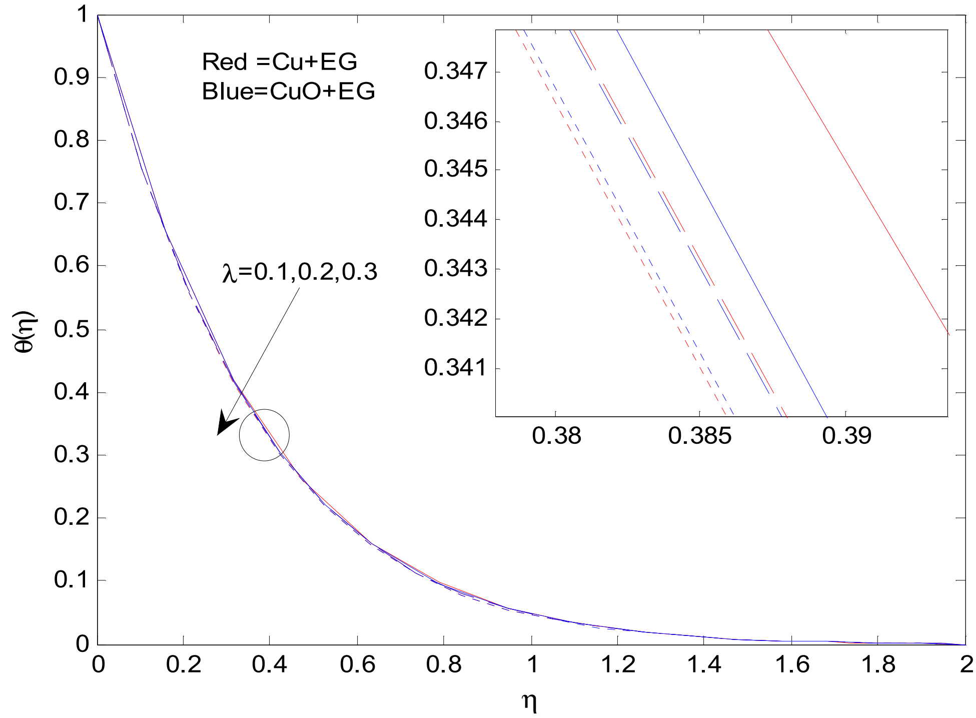

Figure.17 Temperature profiles for different values of λ

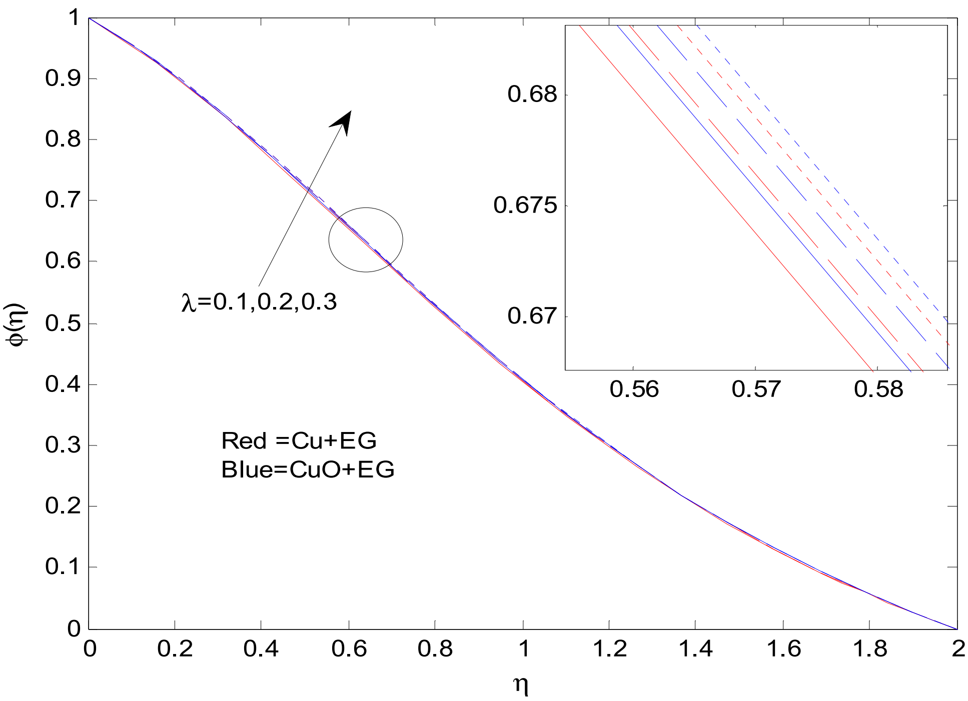

Figure.18 Velocity profiles for different values of λ

Conclusions

In this study we analyzed the influence of magneticfiled, radiation and soret parameters of a nanofluid flow over a moving vertical plate in porous medium by considering Cu-Ethylene glycol, CuO-Ethylene glycol nanofluids. The governing partial differential equations of the flow are transformed to ordinary differential equations by using similarity transformation and then solved numerically. The effects of non-dimensional governing parameters namely volume fraction of nano particles, magneticfiled parameter, radiation parameter, soret number, 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:

(i) CuO-Ethylene glycol nanofluid shows better heat transform performance compared to Cu-Ethylene glycol nanofluid.
(ii) Soret number and buoyancy parameters help to enhance the heat transfer rate.
(iii) Magneticfiled parameter, porosity parameters effectively improves the mass transfer rate and reduces the friction factor.
(iv) Increases in nonoparticle volume fraction enhance the velocity, temperature and concentration boundary layers along with skin friction coefficient
(v) Cu-EG nanofluid effectively increases the velocity boundary layer thickness compared with CuO-EG nanofluid.

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