Industrial Engineering Letters
ISSN 2224-6096 (Paper) ISSN 2225-0581 (online)
Vol.4, No.11, 2014

Effects of Radiation and Magnetic field on the flow and heat transfer of a nanofluid in a rotating frame

V. Sugunamma[1] J.V.Ramana Reddy [1] C.S.K.Raju[2] M. Jayachandra Babu[2] N. Sandeep[2*]
[1]Department of Mathematics, Sri Venkateswara University, Tirupati 517520, India.
[2]Fluid Dynamics Division, VIT University, Vellore, Tamil Nadu 632014, India.

Abstract
We analysed the flow and heat transfer characteristics of a nanofluid in porous medium bounded by a moving vertical semi-infinite permeable flat plate in presence of constant heat generation/absorption, radiation and chemical reaction in a rotating frame. The slip velocity is assumed to oscillate in time with constant frequency so that the solutions of the boundary layer are the same as oscillatory type. The dimensionless governing equations for this investigation are solved analytically using perturbation approximation. In this study two types of nanofluids, namely Cu -water and Cu -ethylene glycol are used and the heat transfer characteristics are analysed for different shapes of nano particles. The effect of various parameters on the flow and heat and mass transfer characteristics are discussed through graphs.
Key Words: Radiation, Rotation, Chemical Reaction, Convection, MHD.

Introduction:
Convective heat transfer in a nanofluid through porous medium bounded by an impulsively moving semi infinite permeable flat plate in presence of radiation, magneticfield, chemical reaction and rotation have received a lot of attention in the field of several industrial, scientific and engineering applications in recent years. This study is more important in industries such as hot rolling, melt spinning, extrusion etc. In particular heating or cooling fluids such as water, ethylene glycol and engine oil plays a crucial role in thermal management of high tech industries but they have poor thermal characteristics. To enhance the thermal conductivity of the fluid we can suspend a solid material of higher thermal conductivity in to the base fluid that mixed solvent is called a nanofluid.

(Choi,1995) was the first to introduce the word nanofluid that represents the fluid in which nano scale particles whose diameter is less than 100 nm. (Cheng and Minkowycz,1977) analysed the free convection over a vertical flat plate embedded in a porous medium, they used the boundary layer approximations and found the similarity solution for the problem. The natural convection about a vertical plate embedded in a porous medium by considering constant wall temperature and constant heat flux was discussed by (Kim and Vafai ,1989). They found the analytical solution for the boundary layer flow using the methods of matching asymptotes. (Glora and Zinolabedini,1987) solved a non similar problem of free convective heat transfer from a vertical plate embedded in a saturated porous medium with arbitrary varying surface temperature or heat flux. (Ranganathan and Viskanta ,1984), (Kumari and Glora,1997) presented an analysis for the combined convection along a non isothermal wedge in porous medium. All these studies are concerned with Newtonian fluid flows.

(Ece,2005) studied the similarity analysis for the laminar free convection boundary layer flow in presence of transverse magnetic field over a vertical down pointing cone with mixed thermal boundary conditions. He found the boundary layer velocity and temperature profiles for various values of magnetic parameter and Prandtl number. (Moran and Gaggioli ,1968) presented general systematic group formalism for similarity analysis. In this problem they reduced governing system of partial differential equations to a system of ordinary differential equations. (Eastman et al. ,1997) observed that Al_2O_3 -water and CuO -water with 5% nanoparticle volume fractions increases the thermal conductivity by 29% and 60% respectively. (Xie et al.,2002) reported that Al_2O_3 -ethylene glycol with 5% nano particle volume fraction enhanced thermal conductivity by 30%. (Parvin et al.,2012) studied variation of thermal conductivity on natural convection flow of water-alumina nanofluid in an annulus. They observed significant heat transfer enhancement due to the suspension of nano particles and it was accentuated by increasing the volume fraction of the nano particles and Prandtl number as well as large Grashof number. Control volume finite volume simulation by MHD forced and natural convection in a vertical channel with a heat generating pipe was analysed by (Nasrin and Alim ,2012). They indicated that the flow and thermal fields in a vertical channel depends on rate of heat transfer.

A detailed study of the natural convection of water based nano fluids in an inclined enclosure has been discussed by(Elif,2009). In this study, he investigated heat transfer enhancement using five different types of nano particles dispersed in water. The effect of interfacial layers in the enhanced thermal conductivity of nanofluids, given by (Yu and Choi,2003). Researchers(Hossain and Takhar,1996) analysed the effect of thermal radiation using the Rosseland diffusion approximation on mixed convection along a vertical plate with uniform free stream velocity and surface temperature. (Das,2012) analysed the influence of partial slip, thermal radiation and temperature dependent fluid properties on the MHD fluid flow and heat transfer over a flat plate with heat generation. (Magyari and Weidman,2006) discussed the heat transfer characteristics on a semi-infinite flat plate due to a uniform shear flow, both for the prescribed surface temperature and prescribed surface heat flux. It is worth pointing out that a uniform shear flow is driven by a viscous outer flow of rotational velocity whereas the classical Blasius flow is driven over the plate by an in viscid outer flow of irrotational velocity. (Hamad et al.,2011) studied MHD effects on free convection flow of a nanofluid past a vertical semi-infinite flat plate. (Sandeep and Sugunamma,2013) analyzed the effects of inclined magnetic field and radiation on free convective flow of dissipative fluid past a vertical plate through porous medium in presence of heat source. (Ghaly,2013) considered the thermal radiation effect on a steady flow, where as (Rapits and Massalas,1998) and (El-Aziz,2009) analyzed the unsteady case. (Sattar and Alam,1994) presented unsteady free convection and mass transfer flow of a viscous, incompressible, and electrically conducting fluid past a moving infinite vertical porous plate with thermal diffusion effect. Radiation convection interaction problems are found in consideration of the cooling of high temperature components, convection cells and their effect on radiation from stars, furnace design where heat transfer from surfaces occurs by parallel radiation and convection, the interaction of incident solar radiation with the earth's surface to produce complex free convection patterns and thus to complicate the art of weather forecasting and marine environment studies for predicting free convection patterns in oceans and lakes was discussed by (Siegel and Howell,1981). (Sandeep et. al, 2013) discussed about EG-Nimonic 80A nanofluid characteristics and they found heat transfer characteristics at different shapes of nano particles.

In this paper, our main objective is to extend the flow and heat transfer analysis by considering thermal radiation, chemical reaction and nano particle shape on boundary layer flow of a nanofluid past a moving vertical permeable flat plate in rotation frame. The governing equations are solved analytically using perturbation technique. Numerical results are reported for various values of physical parameters of interest and discussed graphically.

Mathematical formulation of the problem

We consider an unsteady three dimensional free convectional flow of an electrically conducting incompressible nanofluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium in the presence of buoyancy effect with chemical reaction, radiation and constant heat generation/absorption. The fluids are ethylene glycol and water based nanofluids containing two types of nano particles namely Cu (Copper), Al_2O_3 (Aluminium oxide). A uniform external magnetic field B_0 is taken to be acting along the z-axis. It is assumed that there is no applied voltage which implies the absence of an electric field. The flow is assumed to be in the x-axis direction which is taken along the plate in the upward direction and z-axis is normal to the plate. Also it is assumed that the whole system is rotated with a constant velocity **Ω** about z-axis. The fluid is assumed to be gray, absorbing emitting but not scattering medium. Due to semi-infinite plate surface assumption the flow variables are functions of z and time t only. The physical model of the problem is shown in figure 1.

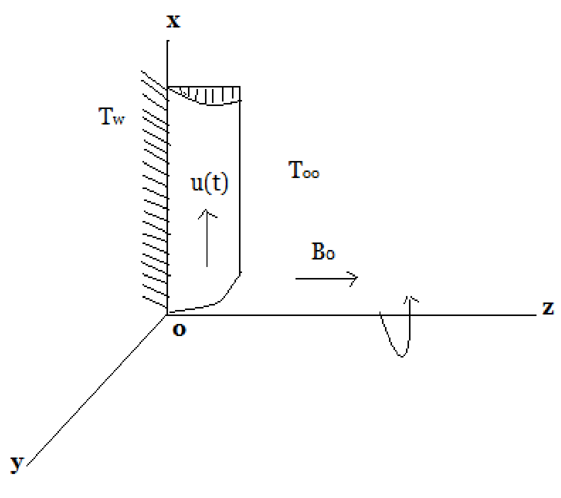

Fig.1 Physical Model of the problem

Under the above assumptions the governing equations of the flow is given by

$$\frac{\partial w}{\partial z}=0$$

(1)

$$\frac{\partial u}{\partial t}+w\frac{\partial u}{\partial z}-2\Omega v=\frac{1}{\rho_{nf}}\left[\mu_{nf}\frac{\partial^2 u}{\partial z^2}+(\rho\beta)_{nf}g(T-T_\infty)+(\rho\beta^*)_{nf}g(C-C_\infty)-\frac{\mu_f u}{k}-\sigma B_0^2 u\right]$$

(2)

$$\frac{\partial v}{\partial t}+w\frac{\partial v}{\partial z}+2\Omega u=\frac{1}{\rho_{nf}}\left[\mu_{nf}\frac{\partial^2 v}{\partial z^2}-\frac{\mu_f v}{k}-\sigma B_0^2 v\right]$$

(3)

$$\frac{\partial T}{\partial t}+w\frac{\partial T}{\partial z}=\alpha_{nf}\frac{\partial^2 T}{\partial z^2}+\frac{Q_0}{(\rho_{cp})_{nf}}(T-T_\infty)-\frac{1}{(\rho_{cp})_{nf}}\frac{\partial q_r}{\partial z}$$

(4)

$$\frac{\partial C}{\partial t}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}+K_l(C-C_\infty)$$

(5)

The boundary conditions for the problem are given by

$$u=0, v=0, T=T_\infty, C=C_\infty \text{ for } t\le 0 \text{ and for any } z$$

$$u=U_r\left\{1+\frac{\varepsilon}{2}(e^{\mathrm{int}}+e^{-\mathrm{int}})\right\}, v=0, T=T_\infty, C=C_\infty\ t>0 \text{ ,z=0.}$$

$$z=0\ u\to 0, v\to 0, T\to T_\infty, C\to C_\infty \ as\ z\to\infty$$

(6)

Where U_r is the uniform reference velocity and ε is the small constant quantity.
The effective density of the nanofluid is given by

$$\rho_{nf}=(1-\phi)\rho_f+\phi\rho_s$$

(7)

where ϕ is the solid volume fraction of nanoparticles. Thermal diffusivity of the nanofluid is

$$\alpha_{nf}=\frac{k_{nf}}{(\rho_{cp})_{nf}}$$

(8)

Where the heat capacitance $(\rho_{cp})_{nf}$ of the nanofluid is obtained as

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

(9)

The effective thermal conductivity of the nanofluid according to Hamilton and Crosser [27] model is given by

$$\frac{k_{nf}}{k_f}=\left(\frac{k_s+(n_p-1)k_f-\phi(n_p-1)(k_f-k_s)}{k_s+(n_p-1)k_f+\phi(k_f-k_s)}\right)$$

(10)

The thermal expansion coefficient of the nano fluid is given by

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

(11)

Also the effective dynamic viscosity of the nanofluid given as

$$\mu_{nf}=\frac{\mu_f}{(1-\phi)^{2.5}}$$

(12)

where n_p is the empirical shape factor for nanoparticle. In particular $n_p = 3$ for spherical shaped nano particles and $n_p = 3/2$ for cylindrical shaped nanoparticals. ϕ is the solid volume fraction of the nano particles k is thermal conductivity. Here the subscript $nf, f \; and \; s$ represents the thermo physical properties of nanofluid, base fluid and solid nanoparticals respectively.
By using Rosseland approximation the radiative heat flux leads to

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

(13)

Where $\sigma^* and \; k^*$ are Stefan-Boltzmann constant and the mean absorption coefficient respectively.

$$(q_r)_y = -4a^*\sigma^*(T_\infty^4 - T^4)$$

(14)

If the temperature differences are within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature, then expanding T^4 in Taylors series about T_∞ and neglecting higher order terms we get

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4$$

(15)

The continuity equation (1) gives

$$w = -w_0$$

(16)

where w_0 represents the normal velocity at the plate which is positive for suction and negative for injection.
Let us introduce the following non-dimensional variables

$$u' = \frac{u}{U_r}, v' = \frac{v}{U_r}, \; z' = \frac{zU_r}{v_f}, \; t' = \frac{tU_r^{\;2}}{v_f},$$

$$n' = \frac{nv_f}{U_r^{\;2}}, \; \theta = \frac{(T - T_\infty)}{(T_w - T_\infty)}, \psi = \frac{(C - C_\infty)}{(C_w - C_\infty)}$$

$$L = \frac{\beta_f^{\;*}}{\beta_f}\frac{(C_w - C_\infty)}{(T_w - T_\infty)}, N = \frac{k_{nf}}{k_f} + \frac{4F}{3}, S = \frac{w_0}{U_r}$$

$$R = \frac{2\Omega v_f}{U_r^2}, M = \frac{B_0}{U_r}\sqrt{\frac{\sigma v_f}{\rho_f}}, \Pr = \frac{v_f}{\alpha_f}, Sc = \frac{v_f}{D_B}$$

$$Q = \frac{Q_0 v_f^2}{U_r^2 k_f}, F = \frac{4\sigma^* T_\infty^3}{kk^*}, K = \frac{kU_r^2}{v_f^2}, Kr = \frac{K_l v_f}{U_r^2}$$

(17)

where v_f is the kinematic viscosity of nanofluid. By substituting Eq.(17) into Eqs. (2) to (5) yields the following dimensionless equations (dropping primes)

$$\left[1 - \phi + \phi\left(\frac{\rho_s}{\rho_f}\right)\right]\left(\frac{\partial u}{\partial t} - S\frac{\partial u}{\partial z} - Rv\right) =$$

$$\frac{1}{(1-\phi)^{2.5}}\frac{\partial^2 u}{\partial z^2} + \left[1 - \phi + \phi\frac{(\rho\beta)_s}{(\rho\beta)_f}\right]\theta \quad (18)$$

$$+\left[1 - \phi + \phi\frac{(\rho\beta^*)_s}{(\rho\beta^*)_f}\right]L\psi - \left(M^2 + \frac{1}{K}\right)u$$

$$\left[(1-\phi)+\phi\left(\frac{\rho_s}{\rho_f}\right)\right]\left(\frac{\partial v}{\partial t}-S\frac{\partial v}{\partial z}+Ru\right)= \frac{1}{(1-\phi)^{2.5}}\frac{\partial^2 v}{\partial z^2}-\left(M^2+\frac{1}{K}\right)v \qquad (19)$$

$$\left[(1-\phi)+\phi\frac{(\rho C_p)_s}{(\rho C_p)_f}\right]\left(\frac{\partial \theta}{\partial t}-S\frac{\partial \theta}{\partial z}\right)= \frac{1}{\Pr}\left[N\frac{\partial^2 \theta}{\partial z^2}+Q\theta\right] \qquad (20)$$

$$\left(\frac{\partial \psi}{\partial t}-S\frac{\partial \psi}{\partial z}\right)=\frac{1}{Sc}\frac{\partial^2 \psi}{\partial z^2}+Kr\,\psi \qquad (21)$$

Where

R is the rotational parameter, M is the magnetic field parameter, $\Pr$ is the Prandtl number, S is the suction $(S>0)$ /injection $(S<0)$ parameter. K is the permeability of the porous medium, Q heat source parameter, F is the radiation parameter, Sc is Smidth Number and Kr is the chemical reaction parameter.

The velocity characteristic U_r is defined as $U_r=\left[g\beta_f(T_w-T_\infty)\nu_f\right]^{\frac{1}{3}}$

Also the boundary conditions (6) become

$$u=0, v=0, \theta=0,\ \psi=0\ \ for\ t\le 0$$
$$u=\left\{1+\frac{\varepsilon}{2}(e^{\text{int}}+e^{-\text{int}})\right\}, v=0, \theta=1,\ \psi=1\ for\ t>0\ and\ z=0$$
$$u\to 0, v\to 0, \theta\to 0, \psi\to 0\ \ as\ \ z\to\infty$$

(22)

we now simplify equations (18) and (19) by putting the fluid velocity in the complex form as $V=u+iv$ and get

$$\left[(1-\phi)+\phi\left(\frac{\rho_s}{\rho_f}\right)\right]\left(\frac{\partial V}{\partial t}-S\frac{\partial V}{\partial z}+iRV\right)=\frac{1}{(1-\phi)^{2.5}}\frac{\partial^2 V}{\partial z^2}+\left[1-\phi+\phi\frac{(\rho\beta)_s}{(\rho\beta)_f}\right]\theta+\left[1-\phi+\phi\frac{(\rho\beta^*)_s}{(\rho\beta^*)_f}\right]L\psi-\left(M^2+\frac{1}{K}\right)V \qquad (23)$$

Also the boundary conditions (22) become

$$V=0, \theta=0,\ \psi=0\ \ for\ t\le 0\ and\ \ for\ any\ z.$$
$$V=\left\{1+\frac{\varepsilon}{2}(e^{\text{int}}+e^{-\text{int}})\right\}, \theta=1,\ \psi=1\ for\ t>0\ and\ z=0. \qquad (24)$$
$$V\to 0, \theta\to 0, \psi\to 0\ \ as\ \ z\to\infty.$$

Analytical solutions

To find the analytical solutions of the system of partial differential equations (20), (21) and (23) in the neighbourhood of the plate under the boundary conditions (24), we express V, θ and ψ as

$$V(z,t)=V_0+\frac{\varepsilon}{2}\left[e^{\text{int}}V_1(z)+e^{-\text{int}}V_2(z)\right] \qquad (25)$$

$$\theta(z,t)=\theta_0+\frac{\varepsilon}{2}\left[e^{\text{int}}\theta_1(z)+e^{-\text{int}}\theta_2(z)\right] \qquad (26)$$

$$\psi(z,t)=\psi_0+\frac{\varepsilon}{2}\left[e^{\text{int}}\psi_1(z)+e^{-\text{int}}\psi_2(z)\right] \tag{27}$$

for $\varepsilon(1)$. Invoking the above equations (25) to (27) into the equations (20),(21) and (23) and equating the harmonic and non Harmonic terms and neglecting the higher order terms of ε^2, we obtain the following set of equations.

Zeroth order Equations are:

$$V_0''+S_1V_0'-B_1V_0+J_2(1-\phi)^{2.5}\theta_0+J_3(1-\phi)^{2.5}\psi_0L=0 \tag{28}$$

$$N\theta_0''+Pr\,S\,J_4\theta_0'+Q\theta_0=0 \tag{29}$$

$$\psi_0''+S\,Sc\,\psi_0'+Kr\,Sc\,\psi_0=0 \tag{30}$$

First order Equations are:

$$V_1''+S_1V_1'-B_2V_1+J_2\theta_1+J_3L\,\psi_1=0 \tag{31}$$

$$N\theta_1''+\Pr S\,J_4\theta_1'-(\Pr J_4\,in-Q)\theta_1=0 \tag{32}$$

$$\psi_1''+S\,Sc\,\psi_1'+Sc\,(Kr-in)\,\psi_1=0 \tag{33}$$

Second order Equations are:

$$V_2''+S_1V_2'-B_3V_1+J_2\theta_2+J_3L\,\psi_2=0 \tag{34}$$

$$N\theta_2''+\Pr S\,J_4\theta_2'+(\Pr J_4\,in+Q)\theta_2=0 \tag{35}$$

$$\psi_2''+S\,Sc\,\psi_2'+Sc\,(Kr+in)\,\psi_2=0 \tag{36}$$

Where Primes denotes differentiation with respect to z .The corresponding boundary conditions can be written as

$$V_0=1,\theta_0=1,\psi_0=1,V_1=1,\theta_1=0,\psi_1=0$$

$$V_2=1,\theta_2=0,\psi_2=0\quad at\; z=0 \tag{37}$$

$$V_0\to 0,\theta_0\to 0,\psi_0\to 0,V_1\to 0,\theta_1\to 0,\ \psi_1\to 0$$

$$V_2\to 0,\theta_2\to 0,\psi_2\to 0\ as\ z\to\infty \tag{38}$$

Solving the equations from (28) to (38) with the boundary conditions (37) and (38), we obtain the expressions for the velocity, temperature and concentration as follows

$$V(z,t)=(1-A_1-A_2)e^{-D_1z}+A_1e^{-m_1z}+A_2e^{-m_2z}+\frac{\varepsilon}{2}\left\{e^{\text{int}}e^{-D_2z}+e^{-\text{int}}e^{-D_3z}\right\} \tag{39}$$

$$\theta(z,t)=e^{-m_2z} \tag{40}$$

$$\psi(z,t)=e^{-m_1z} \tag{41}$$

Where

$$m_1=\frac{S\,Sc+\sqrt{(S\,Sc)^2-4\,Kr\,Sc}}{2},m_2=\frac{\frac{\Pr S\,J_4}{N}+\sqrt{\left(\frac{\Pr S\,J_4}{N}\right)^2-4\frac{Q}{N}}}{2},$$

$$J_1=\left[(1-\phi)+\phi\left(\frac{\rho_s}{\rho_f}\right)\right],J_4=\left[(1-\phi)+\phi\left(\frac{(\rho C_p)_s}{(\rho C_p)_f}\right)\right]$$

$$J_2=\left[1-\phi+\phi\left(\frac{(\rho\beta)_s}{(\rho\beta)_f}\right)\right],J_3=\left[1-\phi+\phi\left(\frac{(\rho\beta^*)_s}{(\rho\beta^*)_f}\right)\right],S_1=S\,J_1(1-\phi)^{2.5},$$

$$R_1=R\,J_1(1-\phi)^{2.5},n_1=n\,J_1(1-\phi)^{2.5},$$

$$M_1=\left(M^2+\frac{1}{K}\right)(1-\phi)^{2.5}, B_1=M_1+iR_1, B_2=M_1+i(R_1+n_1), B_3=M_1+i(R_1-n_1),$$

$$A_1=\frac{-J_3(1-\phi)^{2.5}L}{\left(m_1^2-S_1m_1-B_1\right)}, A_2=\frac{-J_2(1-\phi)^{2.5}}{\left(m_2^2-S_1m_2-B_1\right)}, D_1=\frac{S_1+\sqrt{S_1^2+4B_1}}{2}, D_2=\frac{S_1+\sqrt{S_1^2+4B_2}}{2},$$

$$D_3=\frac{S_1+\sqrt{S_1^2+4B_3}}{2}.$$

Results and Discussion

In order to get the physical insight into the flow problem, comprehensive numerical results are presented graphically for various values of parameters that describe the flow characteristics. In the numerical calculus we have used the data presented in Table 1 for the thermophysical properties of the fluid and the nano particles. Following Sandeep et al. [26], we considered the range of nano particle volume fraction $0 \le \phi \le 0.2$.

The Prandtl Numbers of the base fluids Ethylene Glycol(EG) and water kept constant at 203 and 6.785 and we are chosen $nt=\pi/2, \varepsilon=0.05, n=10$ .In present study we analysed the results for different shape of nano particles. That is $n_p=3, n_p=3/2$ for spherical and cylindrical shaped nanoparticles respectively. The parameters ϕ, Q, R, S, F, K, M, Sc and Kr are varied over a range, which are listed in the figures legends.

Table 1 Thermophysical Properties of Ethylene Glycol, Water and nanoparticles

Physical properties	EG	Water	Cu
$\rho(kg/m^3)$	1115	997.1	8933
$C_p(J/Kg\,K)$	2386	4179	385
$k(W/mK)$	0.2499	0.613	400
$\beta\times10^{-5}(1/K)$	3.41	21	1.67

Fig. 1 shows the effect the permeability parameter K on velocity profiles of Cu-Water and Cu-EG nanofluids. It is clear that the increase in K leads to increase in the velocity of the nanofluid on the porous wall and so enhance the momentum boundary layer thickness. It is obvious that the velocity profiles of Cu-Water nanofluid is effective compared to Cu-EG nanofluid.

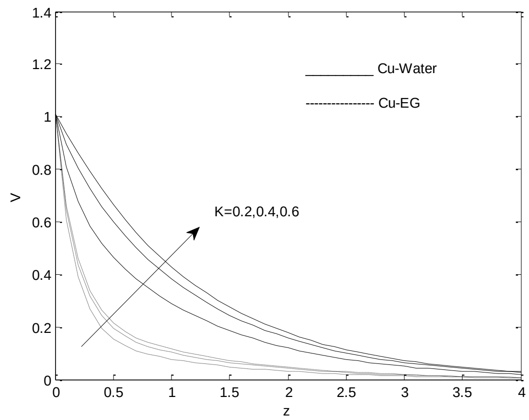

Fig.1 Velocity profiles for different values of K when $\phi=0.02, F=1, R=0.3, t=0.1, M=1,$ $Kr=0.5, Sc=0.2, Q=5$ and $S=5$

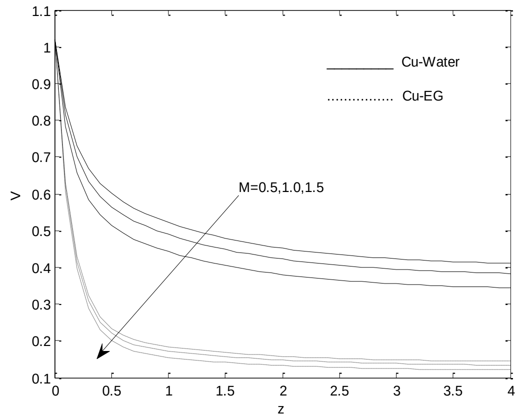

Fig.2 Velocity profiles for different values of M when $\phi = 0.1, F = 1, R = 0.3, t = 0.1, \mathrm{K} = 0.1,$ $Kr = 0.5, \mathrm{Sc} = 0.2, Q = 5$ and $S = 5$

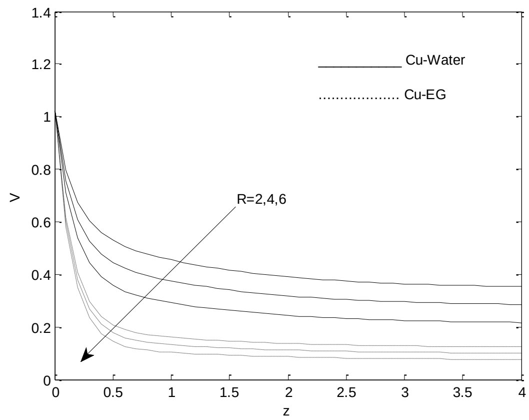

Fig.3 Velocity profiles for different values of R when $\phi = 0.1, F = 1, \mathrm{M} = 1, t = 0.1, \mathrm{K} = 0.1,$ $Kr = 0.5, \mathrm{Sc} = 0.2, Q = 5$ and $S = 5$

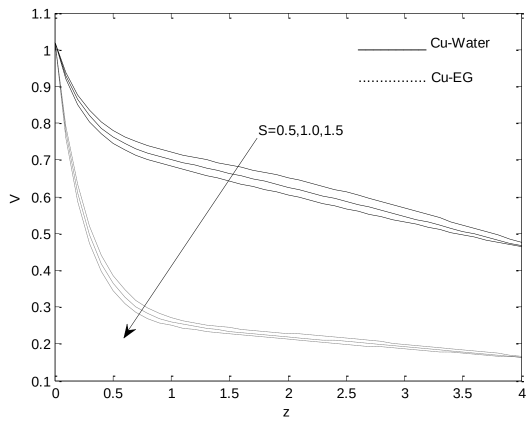

Fig.4 Velocity profiles for different values of S (>0) when $\phi = 0.1, F = 1, \mathrm{M} = 1, t = 0.1, \mathrm{K} = 0.1,$ $Kr = 0.5, \mathrm{Sc} = 0.2, Q = 5$ and $R = 0.3$

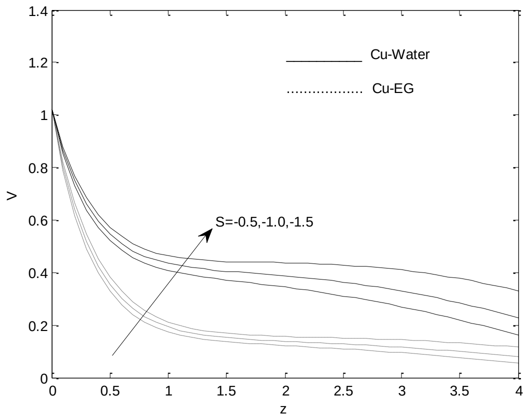

Fig.5 Velocity profiles for different values of S (<0 when $\phi=0.1, F=1, \mathrm{M}=1, t=0.1, \mathrm{K}=0.1,$ $Kr=0.5, \mathrm{Sc}=0.2, Q=5$ and $R=0.3$

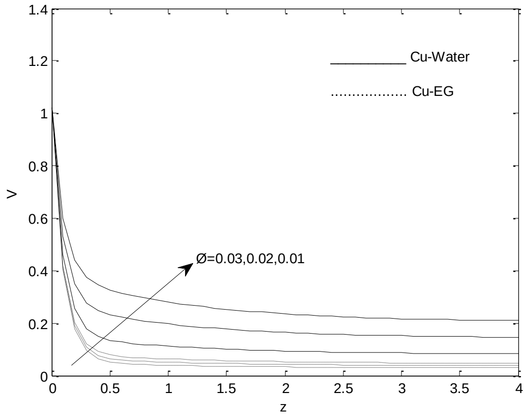

Fig.6 Velocity profiles for different values of ϕ when $S=5, F=1, \mathrm{M}=1, t=0.1, \mathrm{K}=0.1,$ $Kr=0.5, \mathrm{Sc}=0.2, Q=5$ and $R=0.3$

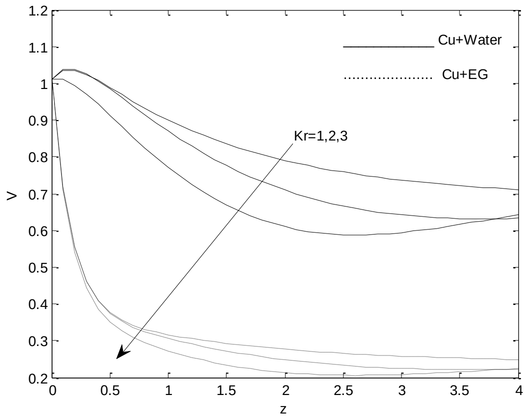

Fig.7 Velocity profiles for different values of Kr when $S=5, F=1, \mathrm{M}=1, t=0.1, \mathrm{K}=0.1,$ $\phi=0.1, \mathrm{Sc}=0.2, Q=5$ and $R=0.3$

 www.iiste.org

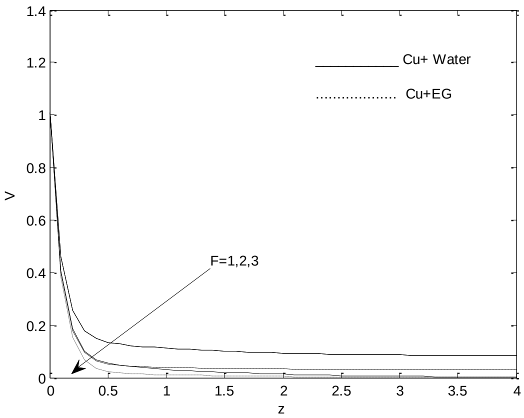

Fig.8 Velocity profiles for different values of F when $S = 5, \mathrm{Kr} = 0.5, \mathrm{M} = 1, t = 0.1, \mathrm{K} = 0.1,$ $\phi = 0.1, \mathrm{Sc} = 0.2, Q = 5$ and $R = 0.3$

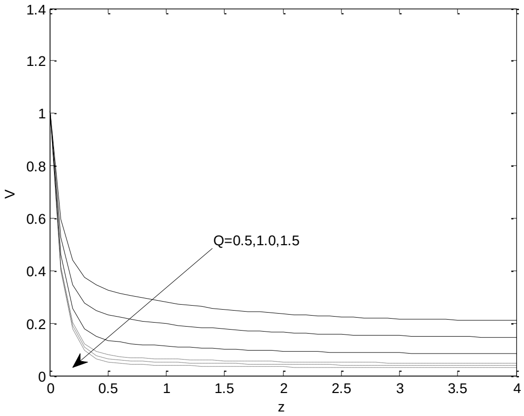

Fig.9 Velocity profiles for different values of Q when $S = 5, \mathrm{Kr} = 0.5, \mathrm{M} = 1, t = 0.1, \mathrm{K} = 0.1,$ $\phi = 0.1, \mathrm{Sc} = 0.2, \mathrm{F} = 1$ and $R = 0.3$

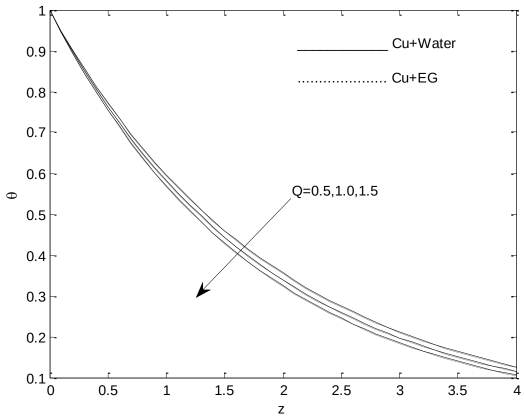

Fig.10 Temperature profiles for different values of Q when $S = 5, \mathrm{Kr} = 0.5, \mathrm{M} = 1, t = 0.1, \mathrm{K} = 0.1,$ $\phi = 0.1, \mathrm{Sc} = 0.2, \mathrm{F} = 1$ and $R = 0.3$

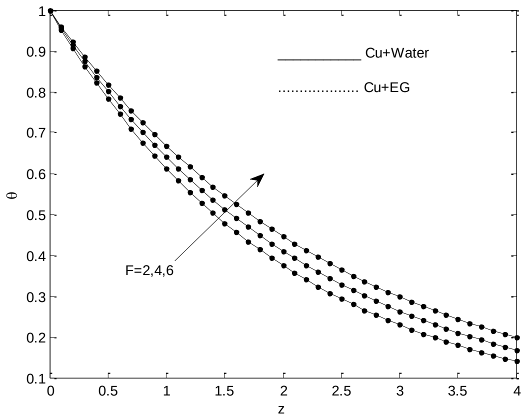

Fig.11 Temperature profiles for different values of F when $S=5, \mathrm{Kr}=0.5, \mathrm{M}=1, t=0.1, \mathrm{K}=0.1,$ $\phi=0.1, \mathrm{Sc}=0.2, \mathrm{R}=0.3$ and $Q=5.$

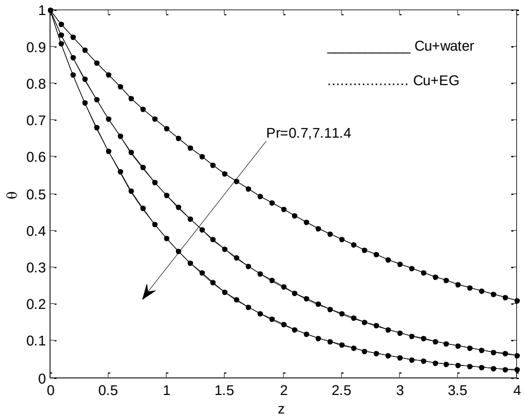

Fig.12 Temperature profiles for different values of Pr when $S=5, \mathrm{Kr}=0.5, \mathrm{M}=1, t=0.1, \mathrm{K}=0.1,$ $\phi=0.1, \mathrm{Sc}=0.2, \mathrm{F}=1$ and $Q=5.$

Fig. 2 depicts the effect of magneticfield parameter on velocity profiles. It is evident that the velocity profiles decreases with increase in magneticfield strength. The effect of magnetic field on an electrically conducting fluid give rise a resistive type force called Lorentz force. This force have tendency to slow down the motion of the fluid in the boundary layer. In addition, it observed that the effect of M is more on Cu-EG nanofluid compared to Cu-Water nanofluid.

Fig. 3 illustrates the influence of rotation parameter on velocity profiles. For both Cu-Water and Cu-EG it is observed that increasing in R tends to decrease in velocity across the boundary layer and so decrease the momentum boundary layer thickness. As like previous cases rotation effect is more on Cu-EG nanofluid compared to Cu-Water.

Figs. 4 and 5 display the effect of suction/injection parameter on the fluid velocity for both Cu-water and Cu-EG nanofluids. From figures it is observed that the velocity of the fluid across the boundary layer decreases by increase in suction parameter S (>0) but it is reverse in case of injection parameter S (<0).It is interesting to note that when S<0 ,the velocity profiles of Cu-Water nanofluid follows the Cu-EG nanofluid profiles for large values of z. It is evident that influence of suction parameter S (>0) is more effective on Cu-Water nanofluid compared to Cu-EG nanofluid.

Fig. 6 illustrates the effect of velocity profiles for different values of the volume fraction parameter ϕ. It is clear that the velocity profiles decreases with increase in nanopartical volume fraction parameter ϕ . This is due to fact that the increase in volume fraction causes the increase in thermal boundary layer thickness.Fig. 7 depicts the velocity profiles for different values of chemical reaction parameter Kr. It is evident that increase in chemical reaction parameter causes the decrease in velocity profiles for both Cu-Water and Cu-EG nanofluids. It is interesting to note that for higher values of z the velocity profiles fluxgates and takes reverse action after certain time.

Fig. 8 shows the effect of radiation parameter on velocity profiles of the fluid. The increase in thermal radiation causes the decrease in velocity profiles across the boundary layer. This is due to fact that a decrease in the values of F means that decrease in the Rosseland radiation absorptiveness.

This causes the increase in boundary layer thickness. It is prominent to mention here the effect of radiation is similar on both Cu-Water and Cu-EG nanofluids.

Fig. 9 represents the velocity profiles for different values of heat source parameter .From the graphs it is clear that there is a decrease in velocity profiles of the fluid an increase in Q. This is because when heat is absorbed, the buoyancy forces decrease which retard the flow rate and thereby give raise to a decrease in velocity profiles. Fig. 10 depicts the temperature profiles for different values of heat source parameter. It is clear that increase in heat source parameter decreases the temperature of the fluid. It is due to the fact that heat absorption dominates the heat generation.Fig. 11 illustrates the effect of radiation parameter on temperature profiles. It is clear that increase in radiation parameter causes the increase in fluid temperature for both nanofluids.Fig.12 illustrates the effect of Prandtl number on temperature profiles. It is observed that the increase in Prandtl number causes the decrease the fluid temperature for Cu-water and Cu-EG nanofluids.

Conclusions

We analysed the flow and heat transfer characteristics of a nanofluid in porous medium bounded by a moving vertical semi-infinite permeable flat plate in presence of constant heat generation/absorption, radiation and chemical reaction in a rotating frame. The dimensionless governing equations for this investigation are solved analytically using perturbation approximation. In this study two types of nanofluids, namely Cu-water and Cu-ethylene glycol are used and the heat transfer characteristics are analysed for different shapes of nano particles. The effect of various parameters on the flow and heat and mass transfer characteristics are discussed and we observed the

1. Velocity and temperature profiles of the fluid are more influenced by Radiation and Magneticfield parameters.
2. Suction parameter and chemical reaction parameter helps to reduce the velocity of the fluid and these parameters effect is high on Cu-EG nano fluid.
3. Shape of the nano particle does not shown any significant difference in velocity and temperature profiles of the fluid.
4. Decrease in nano particle shape enhances the velocity profiles of the fluid.
5. Increase in rotation causes the decrease in velocity profiles of the fluid.

References

[1] choi S.U.S,(1995), “Enhancing thermal conductivity of fluids with nano particles”, *Devels Appls Non Newtoniann flows*, 66, 99-105.

[2] Cheng P, Minkowycz W.J,(1977), “ Free convection about a vertical flat plate embedded in a porous medium with application to heat transfer from a dike*”. J Geophysics Res* ,82,2040–2044.

[3] Kim S.J, Vafai K.,(1989), “Analysis of natural convection about a vertical plate embedded in a porous medium”. *Int J Heat Mass Transfer* 32, 665–677.

[4]Gorla R.S.R,.Zinolabedini A, (1987),”Free convection from a vertical plate with nonuniform surface temperature and embedded in a porous medium”.*Trans ASME J Energy Resour Technol*.109, , 26-30.

[5]Ranganathan. P, Viskanta. R,(1984), “Mixed convection boundary layer flow along a vertical surface in a porous medium”. *Numer Heat Transf*,7, 305-317.

[6] Kumari M, Gorla R.S.R(1997) ,”Combined convection along a non-isothermal wedge in a porous medium”. *Heat Mass Transf*, 32, 393-398.

[7] Ece M.C, (2005),”Free convection flow about a cone under mixed thermal boundary conditions and a magnetic field”, *Appl. Math. Model.* 29 , 1121–1134.

[8] Moran M.J, Gaggioli R.A,(1968),” Similarity analysis via group theory”, *AIAA J*. 6 ,2014–2016.

[9]Moran M.J, Gaggioli R.A,(1968),” Reduction of the number of variables in systems of partial differential equations with auxiliary conditions”, *SIAM J. Appl.Math.* 16 , 202–215.

[10]Eastman J.A, Choi S.U.S., Li S, Thompson L.J,(1997),” Enhanced thermal conductivity through the development of nanofluids”, *Proceeding of the Symposium on Nanophase and Nanocomposite Materials II, Materials Research Society*, vol.457, USA, pp. 3–11.

[11] Xie.H, Wang J., Xi. T, Liu .Y, Ai.F, Wu .Q,(2002), “Thermal conductivity enhancement of suspensions containing nanosized alumina particles”, *J. Appl. Phys.* 91 , 4568–4572.

[12]Parvin.S,Nasrin R,Alim M.A,Hossain N.F,Chamkha A.J,(2012)”Thermal conductivity variation on natural convection flow of water–alumina nanofluid in an annulus”, *Int. J. Heat Mass Transfer*, 55, 5268–5274.

[13] Nasrin R, Alim M.A,(2012)," Control volume finite element simulation of MHD forced and natural convection in a vertical channel with a heat-generating pipe", *Int. J.Heat Mass Transfer* 55, 2813–2821.
[14] Elif BO:(2009)," Natural convection of water-based nanofluids in an inclined enclosure with a heat source". I*nt J Thermal Sci* 48, 2063–2073.
[15] Yu W, Choi SUS,(2003),"The role of interfacial layers in the enhanced thermal conductivity of nanofluids a renovated Maxwell model". *J Nanopart Res* 5, 167–171.
[16] Hossain M.A, Takhar H.S, (1996),"Radiation effects on mixed convection along a vertical plate with uniform surface temperature", *Heat Mass Transfer* 31 , 243–248.
[17] Das K ,(2012),"Impact of thermal radiation on MHD slip flow over a flat plate with variable fluid properties". *Heat Mass Transfer,* 48 , 767–778.
[18] Magyari E, Weidman PD: (2006),"Heat transfer on a plate beneath an external uniform shear flow". *Int J Therm Sci* 45, 110-115.
[19] Hamada M.A.A, Pop I, Md Ismail A.I,(2011)" Magnetic field effects on free convection flow of a nanofluid past a vertical semi-infinite flat plate", *Nonlinear Analysis: RealWorld Applications* 12, 1338–1346.
[20] Sandeep N and Sugunamma V, (2013)"Effect of Inclined Magnetic Field on Unsteady Free Convective Flow of Dissipative Fluid past a Vertical Plate". *World Applied Sciences Journal* 22 (7),975-984.
[21] Ghaly, A.Y.,(2002)"Radiation effect on a certain MHD free convection flow". *Chasos, Solitons Fractal* 13, 1843–1850.
[22] Rapits A., Massalas C.V,(1998),"Magnetohydrodynamic flow past a plate by the presence of radiation". *Heat and Mass Transf*. 34, 107–109.
[23] Aziz El, (2009),"Radiation effect on the flow and heat transfer over an unsteady stretching surface. Int. Commu. *Heat and Mass Transf.* 36, 521–524.
[24] Sattar M.A, Alam,M. M.(1994),"Thermal diffusion as well as transpiration effects on MHD free convection and mass transfer flow past an accelerated vertical porous plate". *Indian J.of Pure App. Math*. 25, 679–688.
[25] Siegel R, and Howell J. R, (1981),"Thermal radiation heat transfer, Series in thermal and fluid engineering". *Hemisphere Publishing Corporation. United State of America*.
[26]. Sandeep N, Sugunamma V and Mohan Krishna P,(2013)," Effects of Radiation on an Unsteady Natural Convective Flow of a EG-Nimonic 80a Nanofluid Past an Infinite Vertical Plate". *Advances in Physics Theories and Applications,* Vol.23, 36-43.