Advances in Physics Theories and Applications
ISSN 2224-719X (Paper) ISSN 2225-0638 (Online)
Vol.23, 2013

Effects of Radiation on an Unsteady Natural Convective Flow of a EG-Nimonic 80a Nanofluid Past an Infinite Vertical Plate

N.Sandeep [1]*, Dr.V.Sugunamma [2] , P.Mohan Krishna [3]
[1] Division of fluid dynamics (SAS), VIT University, Vellore, Tamil Nadu, India.
[2,3] Department of Mathematics, S.V.University, Tirupati, A.P., India.
Email:sandeep@vit.ac.in

Abstract
In this study, we analyse the effects of thermal radiation on unsteady natural convective flow of a nanofluid past an impulsively started infinite vertical plate. The nanofluid contains heat treatable nickel chromium iron alloy (Nimonic 80A) nanoparticles with Ethylene Glycol as base fluid. The partial differential equations governing the flow are solved numerically by MATALB pde solver package. The effects of various parameters on velocity and temperature profiles, as well as Nusselt number and Skin friction coefficient are examined and presented graphically .It is found that rate of heat transfer increases by increase in thermal radiation and change of particle shape. Also we observed that the decrease in radiation parameter leads to fall the value of skin friction coefficient. Shape of nanoparticles doesn't effects velocity of the fluid.
Key Words: Heat transfer, Nanofluids, Thermal radiation, free convection, Volume fraction.

1. Introduction

Nanofluid is made by adding nanoparticles and a surfactant into a base fluid can greatly enhance thermal conductivity and convective heat transfer. The diameters of nanoparticles are usually less than 100 nm which improves their suspension properties. Unsteady natural convection flow of a nanofluid past an impulsively infinite vertical plate in presence of radiation have received a lot of attention in the field of several industrial,Scientific and engineering areas as the design of pertinent equipment involve processes occurring at high temperatures. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. Convective flows with radiation are also encountered in many industrial processes such as heating and cooling of chambers, energy processes, evaporation from large reservoirs, solar power technology and space vehicle re-entry.

Researchers Hossain and Takhar [1] 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. Kuznetsov and Nield [2] studied the natural convective boundary layer flow of a nanofluid past an infinite vertical plate by considering thermophoresis and Brownian motion of nanoparticles. Boundary layer flow of a nanofluid over a permeable stretching/shrinking sheet was studied theoretically by Bachok et al [3].

Thermal radiation of a gray fluid which is emitting and absorbing radiation in a non-scattering medium was discussed by Hossain et al [4]. Das [5] studied the influence of partial slip, thermal radiation and temperature dependent fluid properties on the hydro-magnetic fluid flow and heat transfer over a flat plate with heat generation. Partial slip effects on boundary layer flow past a permeable exponential stretching sheet in presence of thermal radiation was analysed by Mukhopadhyay et al. [6]. Mehrdad Moosavi et al. [7] investigated thermophysical properties of poly (ethylene glycol) binary mixtures at different temperatures. Cheng and Minkowycz [8] discussed similarity solutions for free convective heat transfer from a vertical plate in a fluid saturated porous medium. Gorla and Tornabene [9] and Gorla and Zinolabedini [10] solved the non similar problem of free convective heat transfer from a vertical plate embedded in a saturated porous medium with an arbitrarily varying surface temperature or heat flux. On the other hand, recently, heat transfer problems for boundary layer flow concerning with a convective boundary condition were investigated by Aziz [11].

Yao et al. [12] have recently investigated the heat transfer of a viscous fluid flow over a permeable stretching/shrinking sheet with a convective boundary condition. Magyari and Weidman [13] analysed 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. [14] discussed Magnetic field effects on free convection flow of a nanofluid past a vertical semi-infinite flat plate.

To the author's knowledge, no studies have been communicated so far with regard to radiation effects on an unsteady natural convective flow of a nanofluid past an infinite vertical plate. The objective of this paper is to analyze the effect of radiation on transient natural convective flow of Ethylene Glycol-Nimonic 80A nanofluid past an infinite vertical plate. The unsteadiness is caused by the impulsive motion of the vertical plate. The present study is of immediate application to all those processes which are highly affected with heat enhancement concept

2. Mathematical Formulation

Consider an unsteady, incompressible, two dimensional flow of a nanofluid past an impulsively started infinite vertical plate. The flow is considered along x-axis, which is taken along the plate in the vertically upward direction and the y-axis is measured normal to the surface of the plate. At time $t' \leq 0,$ the plate and the fluid are at the same temperature. At time $t' > 0$, the plate is given an impulsive motion in the vertically upward direction with the constant velocity u_0. The surface of the plate is maintained at a constant temperature T_w higher than the temperature T_∞ of the ambient nanofluid. The fluid is Ethylene Glycol based nanofluid containing Nimonic 80A nano particles. In this study, nanofluids are assumed to behave as single phase fluids with local thermal equilibrium between the base fluid and the nano particles suspended in them so that no slip occurs between them. A schematic representation of physical model and coordinate system is depicted in Fig. 1. The thermophysical properties of the nanofluids are given in Table 1 .The basic unsteady momentum and thermal energy equations according to the model for nanofluids given by Tiwari and Das [15] satisfying Boussinesq approximation [16] in the presence of radiation are as follows:

$$\rho_{nf} u_{t'} = \mu_{nf} u_{yy} + (\rho\beta)_{nf} g(T - T_\infty) \quad (1)$$

$$(\rho C_p)_{nf} T_{t'} = k_{nf} T_{yy} - (q_r)_y \quad (2)$$

Boundary conditions for the problem are

$$t' \leq 0, \quad u = 0, \quad T = T_\infty, \text{ for all } y$$
$$t' > 0, \quad u = u_0, \ T = T_w, \quad \text{for } y = 0,$$
$$u \to 0, T \to T_\infty, \text{ as } y \to \infty, \quad (3)$$

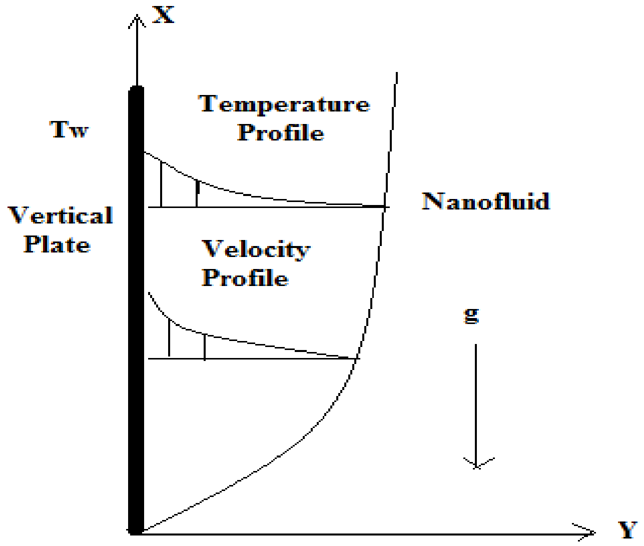

Fig. 1. Physical Model of the problem

Where u is the velocity along x- axis, ρ_{nf} is the effective density of the nanofluid, μ_{nf} is the effective dynamic viscosity of the nanofluid, $(\rho\beta)_{nf}$ is the thermal expansion of the nanofluid , $(\rho C_p)_{nf}$ is the heat capacitance, g is the acceleration due to gravity , k_{nf} is the thermal conductivity of the nanofluid , q_r is the radiative heat flux.

For nanofluids the expressions of density ρ_{nf} , thermal expansion coefficient $(\rho\beta)_{nf}$ and heat capacitance $(\rho C_p)_{nf}$ are given by

$$\left.\begin{aligned} \rho_{nf} &= (1-\varphi)\rho_f + \varphi\rho_p \\ (\rho\beta)_{nf} &= (1-\varphi)(\rho\beta)_f + \varphi(\rho\beta)_p \\ (\rho C_p)_{nf} &= (1-\varphi)(\rho C_p)_f + \varphi(\rho C_p)_p \end{aligned}\right\} \tag{4}$$

The effective thermal conductivity of the nanofluid according to Hamilton and Crosser [17] model is given by

$$k_{eff} = k_f \left(\frac{k_p + (n-1)k_f - \varphi(n-1)(k_f - k_p)}{k_p + (n-1)k_f + \varphi(k_f - k_p)} \right) \tag{5}$$

Where n is the empirical shape factor for nanoparticle .In particular n=3 for spherical shaped nano particles and n=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 p represents the thermo physical properties of nanofluid, base fluid and solid nanoparticals respectively.

By using Rosseland approximation [18] the radiative heat flux leads to

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

Where σ^* *and* k^* are Stefan-Boltzmann constant and the mean absorption coefficient respectively.

$$(q_r)_y = -4a^*\sigma^*(T_\infty^4 - T^4) \tag{7}$$

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

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

In view of equations 6-8 and introducing the following non dimensional variables in equations 1-3

$$U = \frac{u}{u_0},\ Y = \frac{yu_0}{\nu_f},\ t = \frac{t' u_0^2}{\nu_f}\ \Pr = \frac{\nu_f}{\alpha_f}$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty},\ Gr = \frac{g\beta(T_w - T_\infty)\nu_f}{u_0^3}, \tag{9}$$

The governing equations reduces to

$$U_t = AU_{YY} + B\theta \tag{10}$$

$$\theta_t = C\theta_{YY} - D\theta \tag{11}$$

The corresponding dimensionless boundary conditions are

$$\begin{aligned} &t \le 0,\quad U = 0,\quad \theta = 0 \quad \text{for all } Y \\ &t > 0 \quad U = 1,\ \theta = 1 \quad \text{for } Y = 0 \\ &\qquad U \to 0,\ \theta \to 0 \text{ as } Y \to \infty \end{aligned} \tag{12}$$

Where $A = \dfrac{\rho_f}{\left((1-\varphi)\rho_f + \varphi\rho_p\right)(1-\varphi)^{2.5}}$ (13)

$$B = \left(\frac{\rho_f\left((\rho\beta)_f(1-\varphi) + \varphi(\rho\beta)_p\right)}{(\rho\beta)_f\left(\rho_f(1-\varphi) + \varphi\rho_p\right)} \right) \tag{14}$$

$$C=\left(\frac{(\rho C_p)_f k_{nf}}{\Pr k_f\left((\rho C_p)_f(1-\varphi)+\varphi(\rho C_p)_p\right)}\right) \tag{15}$$

$$D=\frac{R(\rho C_p)_f}{\left((\rho C_p)_f(1-\varphi)+\varphi(\rho C_p)_p\right)} \tag{16}$$

3. Results and discussion

The partial differential equations (10) and (11) subjects to the boundary conditions (12) were solved numerically by using MATLAB pde solver package. We consider Nimonic 80A nano particles with Ethylene Glycol as the base fluid. Table 1 shows the thermophysical Properties of Ethylene Glycol and Nimonic 80A.

Table 1: Thermophysical Properties of Ethylene Glycol and Nimonic 80A

	Ethylene Glycol	**Nimonic 80A**
$\rho(Kg/m^3)$	1115	8190
$C_p(J/KgK)$	2386	448
$k(W/mK)$	0.2499	112
β/K	3.41×10^{-3}	1.27×10^{-5}

The Prandtl number of the base fluid (EG) is kept constant at 203 and the nanoparticles volume fractions considered in the range $0\le\varphi\le0.4$.

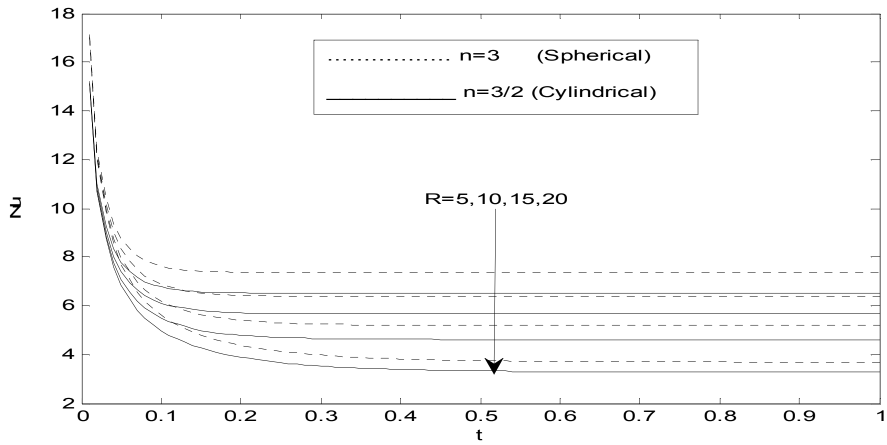

Fig.2 Variation of Nusselt number (Nu) against time t for different values of Radiation parameter R. When Gr=2, $\varphi=0.2$

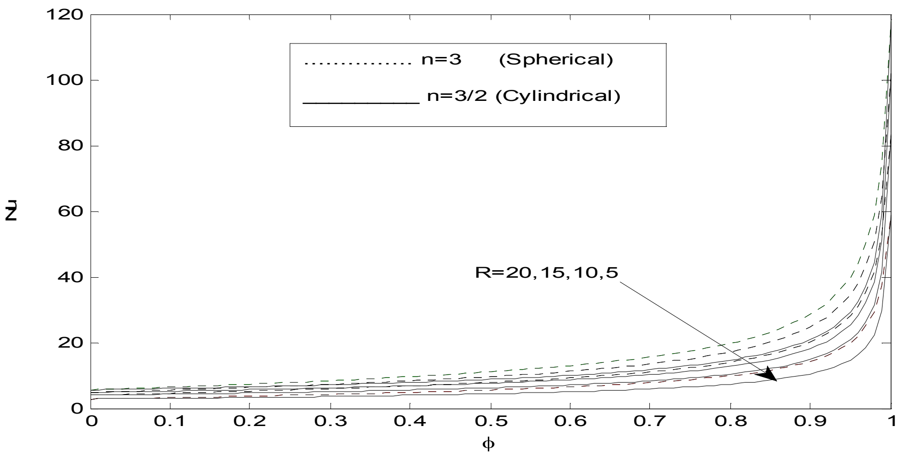

Fig.3 Variation of Nusselt number (Nu) against volume fraction φ for different values of Radiation parameter R. When Gr=2.

Fig. 2 shows the variation of Nusselt number (Nu) when $\varphi = 0.2$ for different values of Radiation parameter R and at different particle shapes. It can be seen that increasing of radiation parameter increases rate of heat transfer and it is interesting to note that spherical shaped nano particles improved the heat transfer rate compare to cylindrical shaped nanoparticles. Fig. 3 shows the effect of radiation parameter on Nusselt number against φ , we observed that the increase in radiation parameter causes a linear decrease in heat transfer rate along with decrease in volume fraction. But in this case also Spherical shaped nano particles causes the increase of heat transfer rate compared to cylindrical shaped particles.

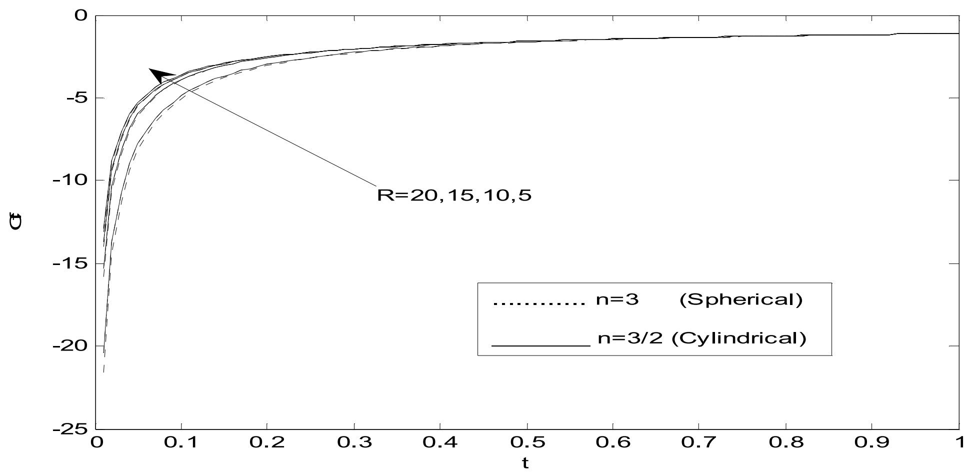

Fig.4 Variation of skin friction (C_f) for different values of Radiation parameter R. When Gr=10

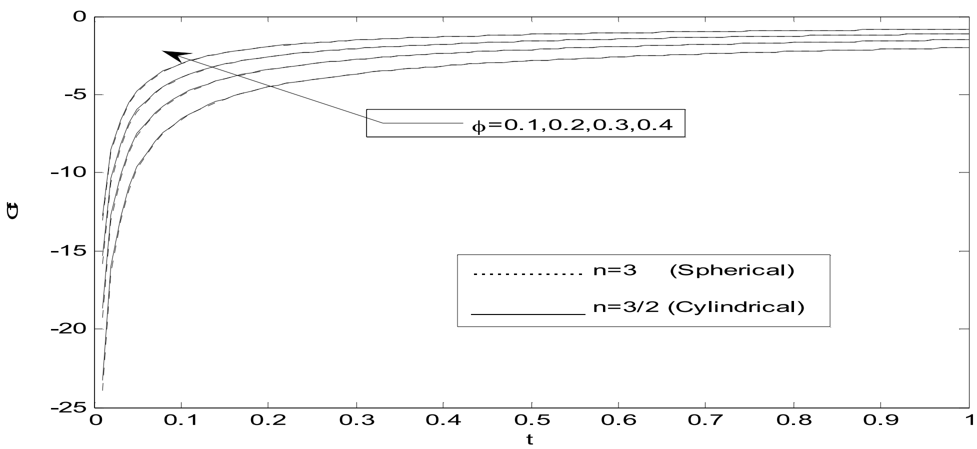

Fig.5 Variation of skin friction (C_f) for different values of Volume fraction φ .When Gr=10.

Figs. 4 and 5 illustrate the change in skin friction coefficient (C_f) with time t for different values of radiation parameter (R) and volume fraction (φ) for both spherical and cylindrical shaped nanoparticles. It is noticed that the decrease in radiation parameter, increase in volume fraction effects the decrease in skin friction coefficient and in both figures spherical shaped nanoparticles causes the slight decrease in skin friction coefficient compared to cylindrical shaped nanoparticles.

It is observed from Figs. 2, 3, 4 and 5 that the Nusselt number and Skin friction are more influenced by radiation, volume fraction and nano particle shape.

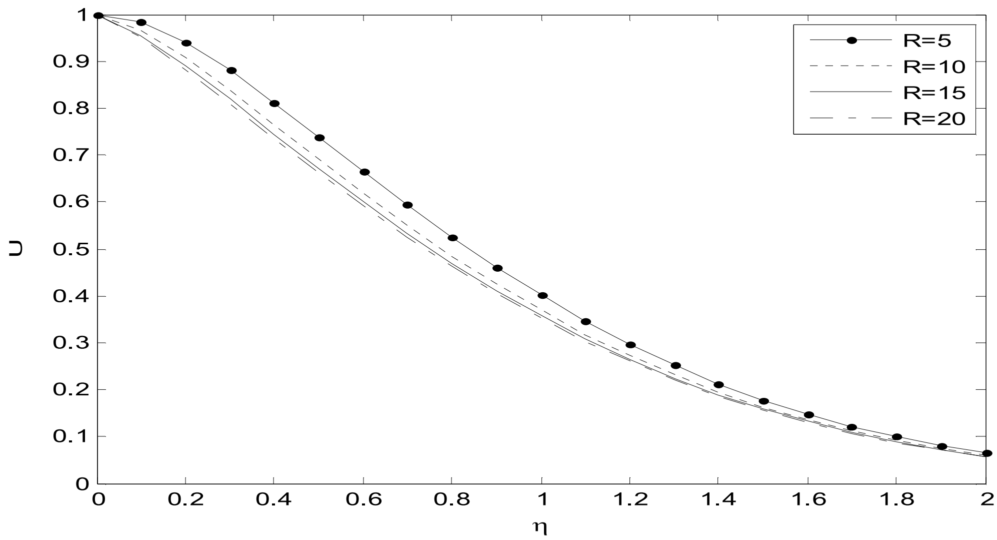

Fig.6 Variation of Velocity profiles (U) for different values of Radiation parameter R.When Gr=10,t=0.6,n=3,n=3/2. $\varphi = 0.2$

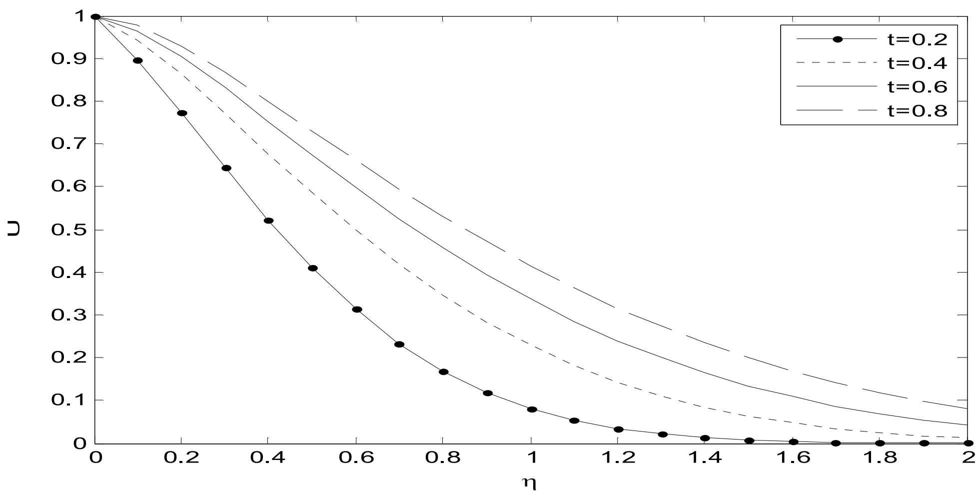

Fig.7 Variation of Velocity profiles (U) for different values of time t.
When Gr=10, ,n=3,n=3/2.R=10, $\varphi = 0.2$

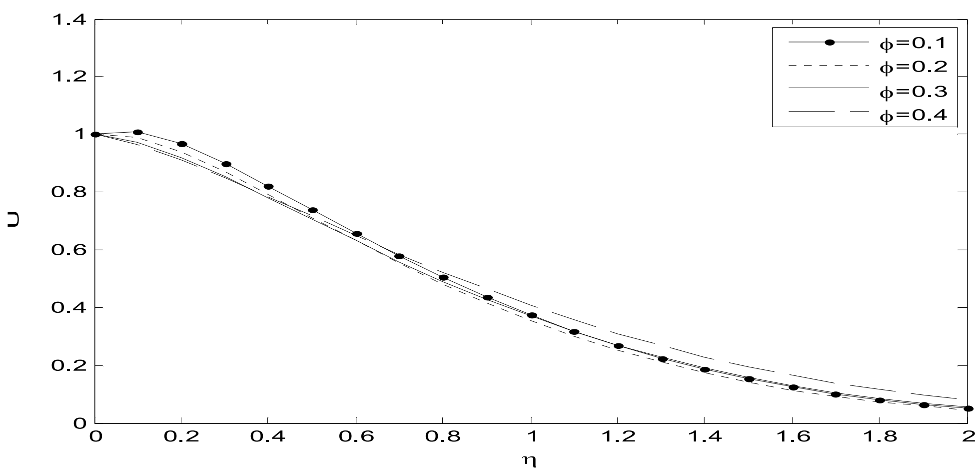

Fig.8 Variation of Velocity profiles (U) for different values of Volume fraction φ
When Gr=10, ,n=3,n=3/2.R=10, t=0.6

Fig. 6 displays the variation on velocity profiles for different values of thermal radiation parameter and it is found that increase in radiation parameter causes the decrease in velocity and from Fig. 7 it is observed that decrease in time interval slowdown the velocity of the fluid. Fig. 8 exhibits the influence of volume fraction on velocity profiles .When the volume fraction of the nanoparticles increases from 0.1 to 0.4, the velocity profiles decrease near the boundary layer, while they increase outside the boundary layer. It is interesting to notice that shape of nanoparticle doesn't shown any effect on velocity profile of EG-Nimonic 80A nanofluid. That is the reason we didn't highlight the value of n in Figs. 6, 7 and 8.

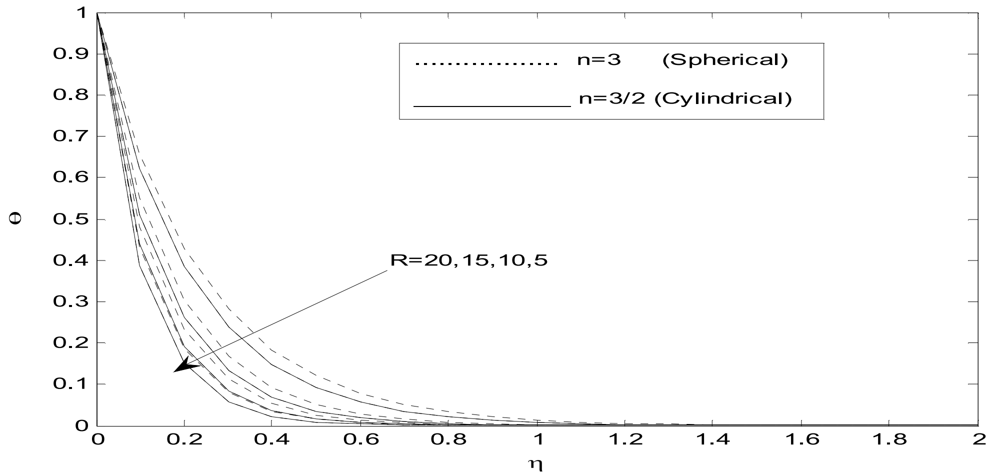

Fig.9 Variation of Temperature profiles for different values of R
When Gr=10, ,n=3,n=3/2. t=0.6, $\varphi = 0.2$

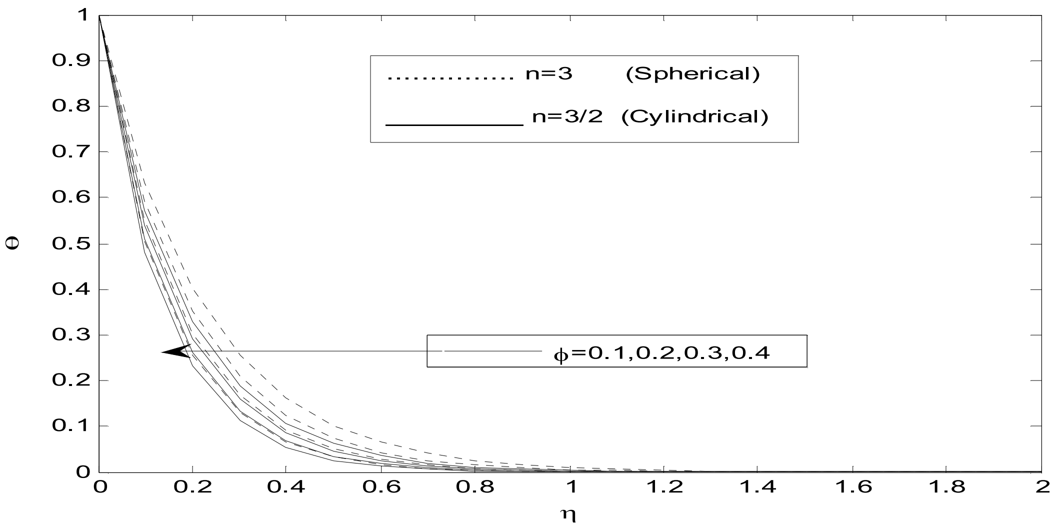

Fig.9 Variation of Temperature profiles for different values of φ
When Gr=10,n=3,n=3/2. t=0.6, R=10

The temperature profiles of nanofluid for different values of radiation parameter and volume fraction are presented in Figs. 9 and 10.It is observed that the surface temperature increases with decrease of radiation parameter, this is due to the fact that the effect of radiation decreases the rate of energy transport to the fluid. But it is reversed in the case of volume fraction as shown in Fig. 10 .But in both cases spherical shaped nanoparticles causes the increase in temperature compared to cylindrical shaped nano particles.

4. Conclusions

The effects of radiation heat transfer on an unsteady natural convective flow of nanofluids past an infinite vertical plate using Rosseland approximation for the radiative heat flux are analyzed. The governing partial differential equations are solved by MATLAB pde solver. The effects of the nanoparticle volume fraction, thermal radiation parameter R and time t on the flow and heat transfer characteristics are determined for EG-Nimonic80A nanofluid.

The conclusions are as follows:

1. The variations of the Nusselt number and Skin friction are more influenced by radiation, volume fraction and shape of the nano particle.
2. The dimensionless surface velocity of the nanofluid does not affected by the shape of the nano particle.
3. An increase in time increases the fluid velocity.
4. The increase in volume fraction of nanoparticle increases the nanofluid temperature, which leads to an increase in rate of heat transfer.
5. The increase in thermal radiation is causes the decrease in temperature of the fluid, this is due to the fact that the effect of radiation decreases the rate of energy transport to the fluid.
6. Spherical shaped nanoparticles helps to increase the fluid temperature compare to cylindrical shaped nano particles.

5.References

[1] Hossain M.A., H.S. Takhar, Radiation effects on mixed convection along a vertical plate with uniform surface temperature, Heat Mass Transfer 31 (1996) 243–248.
[2] Kuznetsov A. V. and D. A. Nield, Natural convective boundary layer flow of a nanofluid past an infinite vertical plate Int. J. Therm. Sci. 49 (2010) 243.
[3] L. Bachok, A. Ishak and I. Pop, Boundary layer flow of a nanofluid over a permeable stretching/shrinking sheet, Int. J. Heat Mass Transf. 55, (2012) 2102.
[4] Hossain M.A., K. Khanafer, K. Vafai, The effect of radiation on free convection flow of fluid with variable viscosity from a porous vertical plate, Int. J. Therm. Sci. 40 (2001) 115–124.
[5] Das K ,Impact of thermal radiation on MHD slip flow over a flat plate with variable fluid properties. Heat Mass Transfer 48 (2012) 767–778.
[6] Mukhopadhyay S, Gorla RSR ,Effects of partial slip on boundary layer flow past a permeable exponential stretching sheet in presence of thermal radiation. Heat Mass Transfer 48 (2012) 1773–1781.
[7] Mehrdad Moosavi, Ahmad Motahari, Abdollah Omrani⇑, Abbas Ali Rostami, Investigation on some thermophysical properties of poly(ethylene glycol)binary mixtures at different temperatures, J. Chem. Thermodynamics 58 (2013) 340–350
[8] Cheng P, Minkowycz WJ, Free convection about a vertical flat plate embedded in a saturated porous medium with applications to heat transfer from a dike. J Geophys Res, 82 (1977) 2040-2044.
[9] Gorla RSR, Tornabene R, Free convection from a vertical plate with nonuniform surface heat flux and embedded in a porous medium.Transp Porous Media J 3 (1988) 95-106.
[10] Gorla RSR, Zinolabedini A, Free convection from a vertical plate with nonuniform surface temperature and embedded in a porous medium.Trans ASME J Energy Resour Technol, 109 (1987) 26-30.
[11] Aziz A, A similarity solution for laminar thermal boundary layer over a flat plate with a convective surface boundary condition. Commun Nonlinear Sci Numer Simul 14 (2009) 1064-1068.
[12] Yao S, Fang T, Zhong Y, Heat transfer of a generalized stretching/shrinking wall problem with convective boundary conditions. Commun Nonlinear Sci Numer Simul 16 (2011) 752-760.
[13] Magyari E, Weidman PD: Heat transfer on a plate beneath an external uniform shear flow. Int J Therm Sci 45 (2006) 110-115.
[14] Hamada M.A.A., I. Pop, A.I. Md Ismail, Magnetic field effects on free convection flow of a nanofluid past a vertical semi-infinite flat plate, Nonlinear Analysis: RealWorld Applications 12 (2011) 1338–1346.
[15]. Tiwari R. K. and M. K. Das, Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids,” International Journal of Heat and Mass Transfer, vol. 50, no. 9-10 (2007) 2002–2018.
[16]. Schlichting H. and K. Gersten, Boundary Layer Theory, 8th edn. Springer Verlag, 2001
[17]. Hamilton R. L. and O. K. Crosser, I & EC Fundamental 1, 187 ,1962.
[18]. Brewster M. Q., Thermal Radiative Transfer and Properties ,Wiley, 1992.