Effect of Viscous dissipation on an unsteady MHD free convection flow of nanofluid through porous medium with suction and heat source

[1]D. Vidyanadha Babu, [2]M. Suryanarayana Reddy

[1]Ph.d Schalor, Dept. of mathematics, JNTUA College of engineering, Anantapur-515002.A.P, India
[2]Asst.Professor, Dept. of mathematics, JNTUA College of engineering, Pulivendula-516 390.A.P, India

Abstract: The unsteady MHD flow of a nanofluid past a moving vertical permeable semi infinite flat plate with constant heat source through porous medium in the presence of viscous dissipation is theoretically. We used two types of nanofluids namely Cu-water and Tio2-water are used. The suitable transformations are applied to convert the governing partial differential equations into a set of nonlinear coupled ordinary differential equations.. The transformed equations are then solved analytically by multiple perturbation techninique. The obtained results for the velocity, temperature and concentration are analyzed graphically for several physical parameters. The flow features and heat transfer characteristics for different values of the governing parameters viz. skin friction coefficient, local Nusselt number, and Sherwood parameter are analyzed and discussed in detail.

Keywords: MHD, Free convection, Nanofluid, Heat Transfer, viscous dissipation, Heat source Porous medium, and Suction.

I INTRODUCTION

Over the past decade research in convective heat transfer using suspensions of nanometer-sized solid particles is attracted by many researchers due to its vast and vide applications. The study of heat and mass transfer of nanofluid flow with effects of viscous dissipation has a wide range of applications in chemical industries like that production of polymers and food processing, evaporation, cooling and drying processes, nuclear reactors cooling and also in petroleum industries. The term nanofluid [1-5] carries the metallic particle the heat transfer and diffusion together is an interesting phenomenon with wide application in the field of base fluid with suspension of metallic nanosized particles.Many authors Buongiorno J , M. A.A. Hamad, I. Pop , Khan, W.A., A. Aziz ,Kuznetsov AV, and Nield DA studied the nanofluid flow and heat transfer effects in various geometries and various effects. All the Researches used the Maxwell or Hamilton & crosser model to describe the thermal conductivity of the nano fluid. In these models there is no description about the particle diameter or layer around the particle. Many of the researches carried out so far ignored the natural phenomenon of formation of liquid like layer around nano particle because of the chemical reaction with the solvent. The formation of liquid like layer limits the contact of the metallic nano particle with the boundary. This reduces the effective heat transfer. The idea of using small particles to collect solar energy was first investigated by Hunt [6] in the 1970s. Researchers concluded that with the addition of nanoparticles in the base fluids, heat transfer and the solar collection processes can be improved. Masuda et al. [7] discussed the alteration of thermal conductivity and viscosity by dispersing ultra-fine particles in the liquid. Choi and Eastman [8] were the first to introduce the terminology of nanofluids when they experimentally discovered an effective way of controlling heat transfer rate using nanoparticles. Buongiorno [9] developed the non homogeneous equilibrium mathematical model for convective transport of nanofluids. He concluded that Brownian motion and thermophoretic diffusion of nanoparticles are the most important mechanisms for the abnormal convective heat transfer enhancement. The relevant processes are briefly described in [10–12]. Investigations in the nanofluid flows have received remarkable popularity in research community in last couple of decades primarily due to their variety of applications in power generation, in transportation where nanofluid may be utilized in vehicles as coolant, shock absorber, fuel additives etc., in cooling and heating problems which may involve the use of nanofluids for cooling of microchips in computer processors, in improving performance efficiency of refrigerant/air-conditioners etc. and in biomedical applications in which magnetic nanoparticles may be used in medicine, cancer therapy and tumor analysis. Recently the researchers have proposed the idea of using solar collector based nanofluids for optimal utilization of solar energy radiation [13, 14]. Buongiorno and Hu [15] discussed the heat transfer enhancement via nanoparticles for nuclear reactor application. Huminic and Huminic [16] showed that use of nanofluids in heat exchangers has advantage in the energy efficiencyand it leads to better system performance.

Viscous dissipation play a vital role in Nuclear Physics and in Geographical flows. Many researchers have identified the effect of viscous dissipation and it is characterized by Eckert number. This effect was studied by Kumar[18],in his paper, the effects MHD radiative flow and Viscous Dissipation over a Stretching surface and it has a lot of influence over the engineering. Hence it has been widely investigated by many researchers like V.D. Borisevich and others [19],H. M. Duwairi [20], C.-H. Chen [21]and T. S. Khaleque etc all[22] However, the study of the combined effects of mass transfer and viscous dissipation on MHD flow of a nanofluid past a moving with constant heat source through porous medium has received a little attention.Keeping in view all the above fact we want to study the effect Viscous dissipation on an unsteady MHD free convection flow of nanofluid throus porous medium with suction and heat source.

Hence, the object of the present paper is to analyze the combined effects of viscous dissipation and mass transfer on an unsteady magneto hydrodynamic flow of a nanofluid past a moving vertical permeable semi-infinite flat plate with constant heat source through porous medium. However, the interactions of the unsteady two-dimensional flow of a non-Newtonian fluid over a stretching surface having a prescribed surface temperature in the presence of radiation and suction/injection is considered. The governing boundary layer equations have been transformed to a two-point boundary value problem in similarity variables and the resultant problem is solved numerically using perturbation technique. The effects of various governing parameters on the fluid velocity, temperature, skin-friction and the rate of heat transfer are shown in figures and analyzed in detail**.**

II MATHEMATICAL FORMULATION

Consider the unsteady free convection flow of a nanofluid past a vertical permeable semi-infinite plate in the presence of chemical reaction and thermal diffusion with suction, variable free stream and heat source. The x-axis is taken along surface in flow direction and y-axis is normal to the surface. A uniform external magnetic field B_0 is taken to be acting along the y-axis. Assume that initially at the fluid as well as the plate is at rest and T_w' temperature but for the plate has an move at a constant velocity U_0 and temperature at the plate fluctuates with time harmonically from a constant mean. It is further assumed that the regular fluid and the suspended nano particles are in thermal equilibrium and no slip occurs between them. The governing equations of the flow are given by Tiwari and Das [17] along with the Boussinesq and boundary layer approximations

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

$$\rho_{nf}\left(\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'}\right) = \mu_{nf}\frac{\partial^2 u'}{\partial y'^2} + (\rho\beta)_{nf} g(T' - T'_\infty) - \sigma B_0^2 u' - \frac{u'}{K'} \tag{2}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \alpha_{nf}\frac{\partial^2 T'}{\partial y'^2} - \frac{Q'}{(\rho c_p)_{nf}}(T' - T'_\infty) + \mu_{nf}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D_{nf}\frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

With the initial and boundary conditions are as follows

$$t' < 0, \quad u'(y', t') = 0, \quad T' = T'_\infty \text{and} \quad C' = C'_\infty \quad \text{at } y = 0$$

$t' \geq 0, \quad u'(y',t') = U_0, \; T' = T'_w + (T'_w - T'_\infty) \in e^{iw't'}$ and $C' = C'_w + (C'_w - C'_\infty) \in e^{iw't'}$ at $y = 0$ (5)

$$u'(y',t') = 0, \quad T' = T'_\infty \text{and} \quad C' = C'_\infty \quad \text{at } y = \infty$$

where T' is the local temperature of the nanofluid and Q' is the additional heat source. β_f and β_c are the coefficients of thermal expansion of the fluid and of the solid, ρ_f and ρ_c are the densities of the fluid and of the solid fraction, ρ_{nf}, μ_{nf}, α_{nf}, $(\rho c_p)_{nf}$ and D_{nf} are the density ,viscosity , thermal diffusivity heat capacitance of the nanofluid and the coefficient of mass diffusivity respectively and these are given by [Abu-Nada et al (30)]

$$\rho_{nf} = (1-\varphi)\rho_f + \rho_s, \mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2s}},$$

$$\alpha_{nf} = \frac{K_{nf}}{(\rho c_p)_{nf}}, (\rho c_p)_{nf} = (1-\varphi)(\rho c_p)_f + \varphi(\rho c_p)_s \quad (6)$$

$$(\rho\beta)_{nf} = (1-\varphi)(\rho\beta)_f + \varphi(\rho\beta)_s, K_{nf} = \frac{K_f + 2K_s - 2\varphi(K_f - K_s)}{K_s + 2K_f + 2\varphi(K_f - K_s)}$$

Where φ is volume solid fraction of the nanoparticles and K_{nf} is thermal co nductivity of the nanofluid , K_f and K_s is thermal conductivity of the base fluid and of the solid . σ is electrical conductivity of the fluid and B_0 is the strength of magnetic field applied in the y direction. c_p is the specific heat, K_T is thermal conductivity. Q is the quantity of the heat,T is the temperature ,and β_T coefficient of thermal expansion, β_c coefficient of mass expansion, , K is porous medium permeability coefficient. General thermo-physical properties of the base fluid (water), copper and titanium oxide, and Aluminum oxide are given below.

Material	$\rho(kg/m^3$	$C_p(J/kgK)$	$K(W/mK)$	$\beta X10^{-($	$\sigma(s/m$
Pure Water	997.1	4179	0.613	21	$5.5X10^{-6}$
Copper	8933	385	401	1.67	$5.96X10^{7}$
Al_2O_3	3970	765	40	0.85	3.5x107
TiO_2	4250	686.2	8.9538	0.9	2.38x106

Solving equation (1) we may get,

$$v' = -v_0 \quad (7)$$

where v_0 is the normal velocity at the plate , If $v_0 > 0$ it is suction and if $v_0 < 0$ then it is injection.

Now introducing non dimensional variables as follows.

$$u = \frac{u'}{U_0}, \; y = \frac{U_0 y'}{\nu_f}, t = \frac{U_0^2 t'}{a}, \omega = \frac{\nu_f \omega'}{U_0^2},$$

$$\theta = \frac{T' - T'_\infty}{T'_\omega - T'_\infty}, \; M = \frac{\sigma B_0^2}{\rho_f U_0^2}, S = \frac{V_0}{U_0}, Q = \frac{Q' \nu_f^2}{k_f U_0^2},$$

$$P_r = \frac{\nu_f}{\alpha_f}, G_r = \frac{(\rho\beta)_{nf}\, g\, \nu_f}{\rho_f U_0^2}(T'_\omega - T'_\infty), K = \frac{\rho_f U_0^2 k'}{\nu_f} \quad (8)$$

In view of eq(8), equations (2),(3) and (4) reduces , the dimensionless governing equations together with the appropriate boundary conditions can be written as

$$A\left(\frac{\partial u}{\partial t} - S\frac{\partial u}{\partial y}\right) = D\frac{\partial^2 u}{\partial y^2} + BG_r\,\theta - \left(M + \frac{1}{K}\right) u \quad (9)$$

$$C\left(\frac{\partial\theta}{\partial t}-S\frac{\partial\theta}{\partial y}\right)=\frac{1}{P_r}\left(E\,\frac{\partial^2\theta}{\partial y^2}-Q\theta\right)+CE_c\left(\frac{\partial u}{\partial x}\right)^2 \quad (10)$$

$$\frac{\partial C}{\partial t}-S\frac{\partial C}{\partial y}=S_c\frac{\partial^2 C}{\partial y^2} \quad (11)$$

The dimensionless boundary conditions are

$t' < 0, \quad u = 0, \quad \theta = 0 \text{ and } \quad C = 0 \quad at \ y = 0$

$t' \geq 0, \quad u = 1, \theta = 1+\in e^{iwt}$

$and \ C = 1+\in e^{iwt} \quad at \ y = 0 \quad (12)$

$u = 0, \ \theta = 0 \text{ and } C = 0 \quad at \ y = \infty$

III METHOD OF SOLUTION

Equations (9) to (11) are solved by series method by considering the following solution

$$u(y,t) = u_0(y) + \in \ u_1(y)\, e^{iwt}$$

$$\theta(y,t) = \theta_0(y) + \in \ \theta_1(y)\, e^{iwt}$$

$$C(y,t) = C_0(y) + \in \ C_1(y)\, e^{iwt} \quad (13)$$

Substituting (13) into the equations (9) to (11), equating the harmonic and non-harmonic terms, we obtain

$$D\frac{\partial^2 u_1}{\partial y^2}+AS\frac{\partial u_1}{\partial y}-\left(M+\frac{1}{K}+iAw\right)u_1-BG_r\theta_1 \quad (14)$$

$$D\frac{\partial^2 u_0}{\partial y^2}+AS\frac{\partial u_0}{\partial y}-\left(M+\frac{1}{K}\right)u_0=-BG_r\theta_0 \quad (15)$$

$$E\,\frac{\partial^2\theta_1}{\partial y^2}+CSP_r\frac{\partial\theta_1}{\partial y}-(Q+icP_r w)\theta_1=-2CE_cP_r\frac{\partial u_0}{\partial y}\frac{\partial u_1}{\partial y} \quad (16)$$

$$E\,\frac{\partial^2\theta_0}{\partial y^2}+CSP_r\frac{\partial\theta_0}{\partial y}-Q\theta_0=-CE_cP_r\left(\frac{\partial u_0}{\partial y}\right)^2 \quad (17)$$

$$S_c\frac{\partial^2 C_1}{\partial y^2}+S\frac{\partial C_1}{\partial y}-iwC_1=0 \quad (18)$$

$$S_c\frac{\partial^2 C_0}{\partial y^2}+S\frac{\partial C_0}{\partial y}=0 \quad (19)$$

With boundary conditions

With boundary conditions

$t' < 0, \quad u_0 = 1, u_1 = 0, \quad \theta_0 = 1, \theta_1 = 1$

$and \quad C_0 = 1, C_1 = 1 \quad at \ y = 0$

$t' \geq 0, \quad u_0 = 0, u_1 = 0, \quad \theta_0 = 0, \theta_1 = 0$

(20)

$and \quad C_0 = 0, C_1 = 0 \quad at \ y = 0$

$u_0 = 0, u_1 = 0, \quad \theta_0 = 0, \theta_1 = 0 \quad at \ y = \infty$

The equations (14) to(17) are still coupled second order differential equations. Since Eckert number $E_c = \frac{u_0^2}{(T'_w - T'_\infty)}$ is very small for incompressible fluid flows there fore, $u_0, u_1, \theta_0, \theta_1$ Can be expressed again in the powers of Ec as

$$F(y,t) = F_0(y) + Ec\, F_1(y)\, e^{iwt} + O(\in^2) \quad (21)$$

where F stands for any $u_0, u_1, \theta_0, \theta_1$.

substituting (21) in equations (14) to (19) and equating the coefficient of like powers of Ec, we get a set of second order differential equations which are solved under the corresponding boundary conditions. Hence the solution of $\theta_{00}(y), \theta_{10}(y), u_{00}(y),\ u_{10}(y), \theta_{01}(y), \theta_{11}(y), u_{01}(y), u_{11}(y)$ are known, which are not included for the sake of brevity.

Therefore solution of Eq (14) to (19) is

$$u(y,t) = (B_2\, e^{-m_3 y} + B_1\, e^{-m_1 y} + B_3\, e^{-m_5 y} + B_4\, e^{-m_6 y} + B_5\, e^{-m_7 y}) + (B_6\, e^{-m_4 y} + B_7\, e^{-m_2 y} + B_8\, e^{-m_8 y} + B_9\, e^{-m_9 y} + B_{10}\, e^{-m_{10} y} + B_{11}\, e^{-m_{11} y})\, e^{iwt}$$

$$\theta(y,t) = (B_{10}\, e^{-m_1 y} + B_{11}\, e^{-m_5 y} + B_{12}\, e^{-m_6 y} + B_{13}\, e^{-m_7 y}) + \in (B_{14}\, e^{-m_2 y} + B_{15}\, e^{-m_3 y} + B_{16}\, e^{-m_9 y} + B_{17}\, e^{-m_{10} y} + B_{18}\, e^{-m_{11} y}) e^{iwt}$$

$$C(y,t) = e^{-\frac{S}{S_c} y} + \in\ e^{-m_5 y}\, e^{iwt}$$

The skinfriction cefficient(τ) at the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = (-m_5 A_1 - m_1\, B_1 - m_5\, B_3 - m_6 B_4 - m_7\, B_5) + (-m_4 B_6 - m_2\, B_7 - m_8 B_8 - m_9\, B_9 - m_{10} B_{10} - m_{11} B_{11})\, e^{iwt}$$

The Local Nusselt number (Nu) is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = (-m_1 B_{10} - m_5\, B_{11} - m_6 B_{12} - m_7 B_{13}) + \in (-m_2 B_{14} - m_8\, B_{15} - m_9 B_{16} - m_{10} B_{17} - m_{11} B_{18}) e^{iwt}$$

The Sherewood number(Sh) is given by

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -\frac{S}{S_c} + \in\ e^{iwt}$$

Where $A = 1-\varphi+\varphi\frac{(\rho)_s}{(\rho)_f}$ $\quad B = 1-\varphi+\varphi\frac{(\rho\beta)_s}{(\rho\beta)_f}$

$C = 1-\varphi+\varphi\frac{(\rho C_p)_s}{(\rho C_p)_f}$ $\quad D = \frac{1}{(1-\varphi)^{2s}}$

$E = 1-\varphi+\varphi\frac{(\rho C_p)_s}{(\rho C_p)_f}$

IV RESULTS AND DISCUSSION

The above mentioned numerical scheme is carried out for various values of physical parameters, namely, the Grashoff number(Gr), the magnatic parameter (M), the Prandtl number (Pr), Permiability parameter porous medium(K) Heat source parameter(Q) and the suction/injection parameter (S) to obtain the effects of those parameters on dimensionless velocity, temperature and concentration distributions. The obtained computational results are presented graphically in Figures 1-13..

Fig.1 exhibits the velocity profiles for several values of Grashoff parameter(Gr) . It is seen that the velocity at any point of the cupper water fluid and Titanium oxide increases when Pr=0.71, $\varphi = 0.5$,Q=2,k=2,s=2,M=2and t=1 increase when Grashoff parameter(Gr) increases.Fig.2 exhibits the velocity profiles for several values of magnetic number (M). It is seen that the velocity at any point of the cupper water fluid and Titanium oxide increases when Pr=0.71, $\varphi = 0.5$,Q=2,Gr=2,k=2,s=2and t=1 decreases when magnetic number (M) increases.Fig.3 exhibits the velocity profiles for several values of Permeability parameter number (k). It is seen that the velocity at any point of the cupper water fluid and Titanium oxide when Pr=0.71, $\varphi = 0.5$,Q=2,M=2,s=2Gr=2,s=2and t=1 increases when Permeability parameter number (k).increases.Fig.4 exhibits the velocity profiles for several values of suction parameter number (s). It is seen that the velocity at any point of the cupper water fluid and Titanium oxide when Pr=0.71, $\varphi = 0.5$,Q=2,Gr=2,M=2and t=1 decreases when suction parameter (s).increases.Fig.5 exhibits the velocity profiles for several values of volume solid fraction of the nano particles(φ) . It is seen that the velocity at any point of the cupper water fluid and Titanium oxide when Pr=0.71,$\varphi = 0.5$,Q=2,Gr=2,M=4and t=1 increases when volume solid fraction of the nano particles(φ).increases.Fig.6 exhibits the heat profiles for several values heat source parameter(Q) . It is seen that the temperature at any point of the cupper water fluid and Titanium oxide when Pr=0.71,$\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 decreases when heat source parameter(Q) increases.Fig.7 exhibits the heat profiles for several values suction parameter(s) . It is seen that the temperature at any point of the cupper water fluid and Titanium oxide when Pr=0.71,$\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 decreases when heat source parameter(Q) increases. Fig.8 exhibits the concentration profiles for several values Magnatic Number(M) . It is seen that the concentration at any point of the cupper water fluid and Titanium oxide when Pr=0.71, $\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 decreases when Magnatic Number(M) increases. Fig.9.exhibits the concentration profiles for several values Eckort number (Ec) It is seen that the concentration at any point of the cupper water fluid and Titanium oxide when Pr=0.71, $\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 decreases when Eckort number (Ec) increases.Fig.10 exhibits the concentration profiles for several values Schmidt parameter (Sc) . It is seen that the concentration at any point of the cupper water fluid and Titanium oxide when Pr=0.71,$\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 decreases when Schmidt parameter(Sc) increases.Fig.11 exhibits the effect of skin friction coefficient for several values Prandtl number (Pr). It is seen that the skin friction coefficient at any point of the cupper water fluid and Titanium oxide when $\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 increases when Prandtl number (Pr) increases.Fig.12 exhibits the effect of Nuslet number (Nu). for several values Prandtl number (Pr). It is seen that the Nuslet number (Nu). at any point of the cupper water fluid and Titanium oxide when, $\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 increases when Prandtl number (Pr) increases.Fig.13 exhibits the effect of Sheerwood Number (Sh). for several values Schmidt parameter (Sc). It is seen that the Sheerwood Number (Sh) at any point of the cupper water fluid and Titanium oxide when Pr=0.71, $\varphi = 0.5$,Q=2,Gr=2,M=4,k=2and t=1 decreases when Schmidt parameter (Sc) increases.

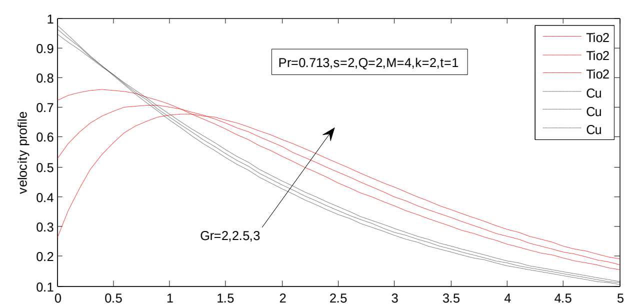

Figure 1Velocity profile of cupper water fluid and Titanium oxide water fluid for different value of Gr

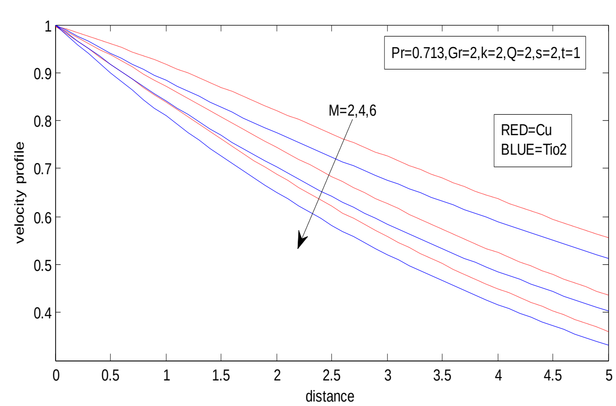

Figure 2Velocity profile of cupper water fluid and Titanium oxide water fluid for different value of M

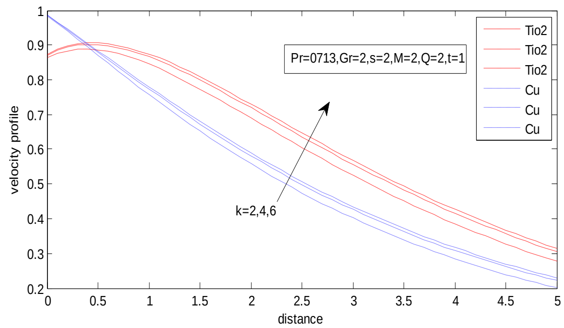

Figure 3Velocity profile of cupper water fluid and Titanium oxide water fluid for different value of k

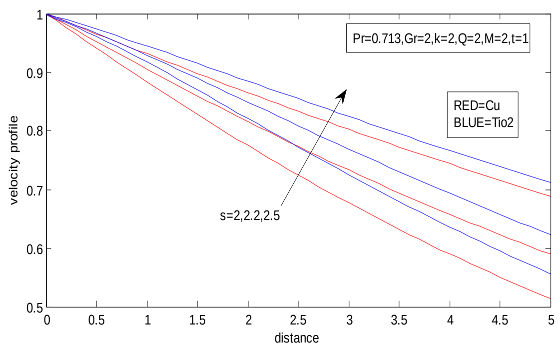

Figure 4Velocity profile of cupper water fluid and Titanium oxide water fluid for different value of suction parameter's'

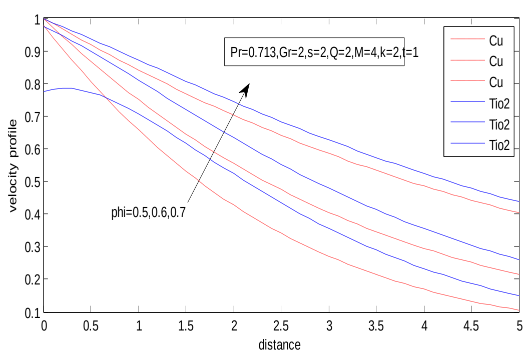

Figure 5Velocity profile of cupper water fluid and Titanium oxide water fluid for different value of phi

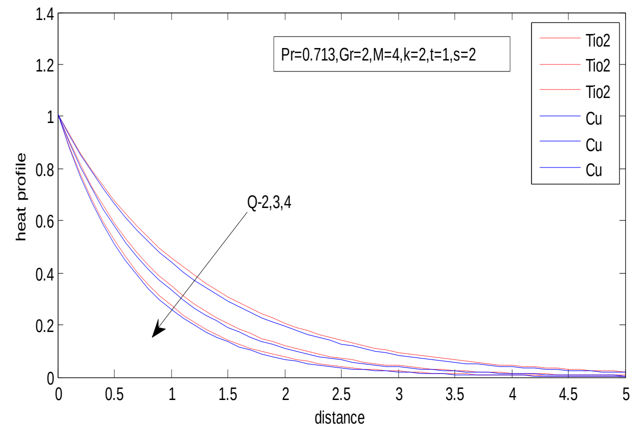

Figure 6 ;Heat profile of cupper water fluid and Titanium oxide water fluid for different value of Q

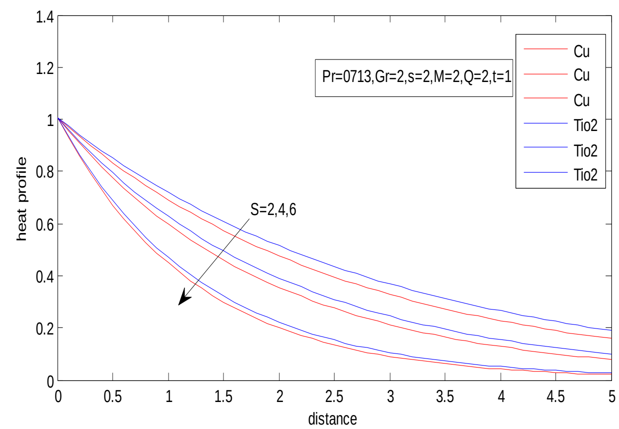

Figure 7:Heat profile of cupper water fluid and Titanium oxide water fluid for different value of s

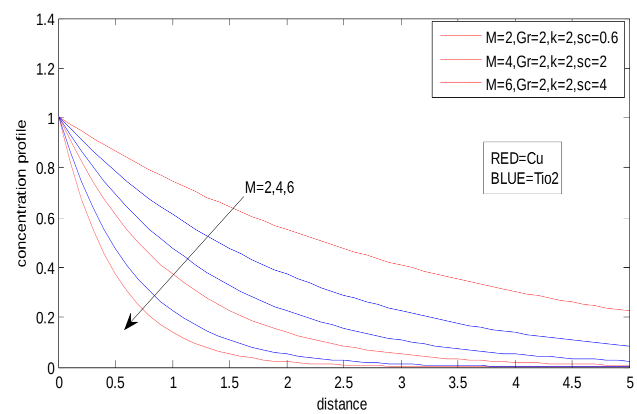

Figure 8Concentration profile of Cu and Tio2 for different values of M

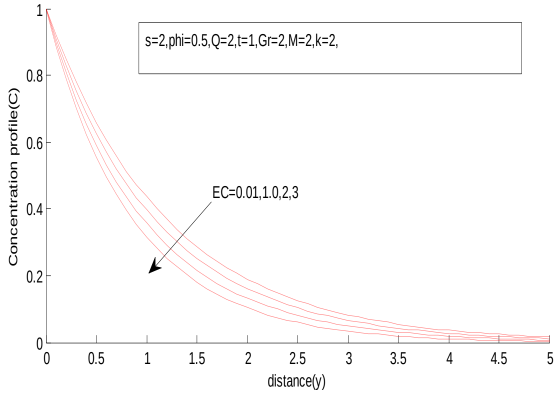

Figure 9 Concentration profile of Cu for different values of Ec

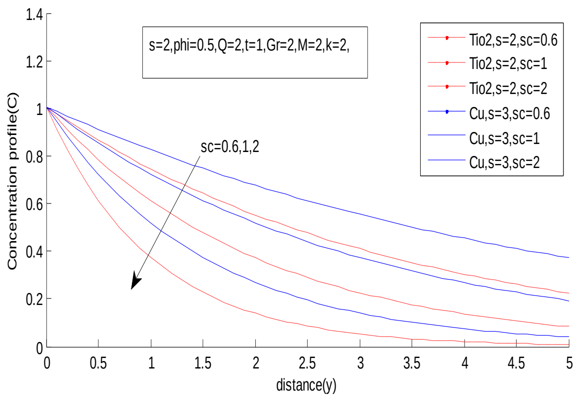

Figure 10:Concentration profile of Cu and Tio2 for different values of sc and s values

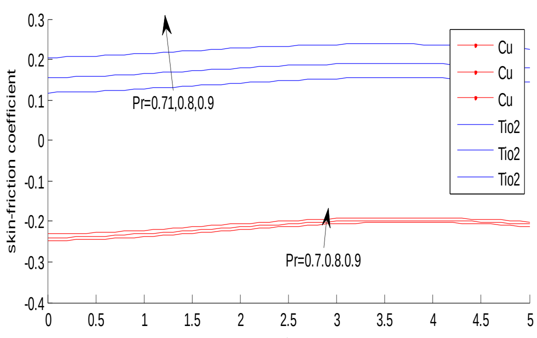

Figure 11:Skinfriction coefficient of Cu and Tio2 for different values of Pr

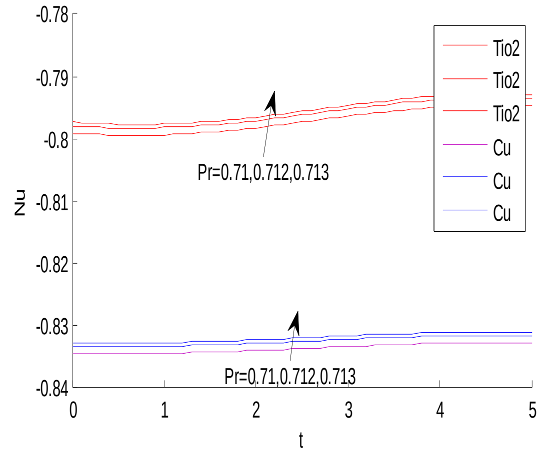

Figure 12Nuslet number of Cu and Tio2for different values of Pr

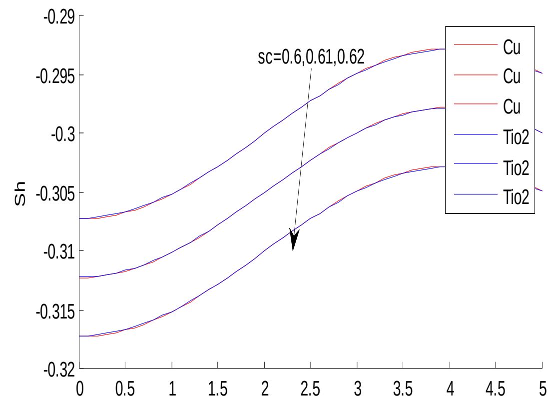

Figure 13: Sherewood number of Cu and Tio2 for different values of sc

V CONCLUSIONS

In this study the effect of viscous dissipation on an unsteady MHD free convection nanofluid through porous medium with suction/injection and heat source was investigated. The resulting governing equations were solved by the regular multiple perturbation technique. From the study, the following remarks can be summarized.

1. Fluid velocity decreases with increasing Magnetic parameter (M) while a reverse effect in the velocity distribution for Grashoff parameter(Gr), Permeability parameter number (k).,suction parameter(s) and volume solid fraction of the nano particles(φ) is observed in both cupper water fluid and Titanium oxide.

2. Fluid temperature decreases with increasing ,suction parameter(s),Magnetic parameter (M) is observed in both cupper water fluid and Titanium oxide.
3. Fluid cocentration decreases with increasing , Magnetic parameter (M) , Schmidt parameter(Sc) and Eckort number (Ec) is observed in both cupper water fluid and Titanium oxide.
4. The skin-friction and local Nuslet number increases with increasing Prandtl number(Pr) while Sherwood number(Sh) decreases in case of both Cupper and Titanium oxide.

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