Mixed Convection Fluid Flow and Heat Transfer Analysis over a Vertical Flat Plate having Slip Boundary Conditions with oxide Nano fluids

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Abstract: *Effects of slip at boundary on velocity, temperature and concentration of nanofluid on the mixed convective boundary layer flow over a flat vertical plate are investigated. The governing partial differential equations are transformed into ordinary differential equations with in Similarity transformation. The nondimensional governing equations are solved numerically by MATLAB bvp4c. The results are presented for different values of governing parameters with concentration of nanofluid and hybrid nanofluid. The obtained results were with compared available results from the literature. The variation in nondimensional velocity and temperature profiles the slip parameter, concentration of nanofluid and mixed convection parameter were studied and presented graphically*.

Keywords: *slip parameter, mixed convection parameter, nano fluid, hybrid nanofluid, concentration of nanofluid, MATLAB bvp4c.*

I. INTRODUCTION

Nanofluids are a new class of fluids engineered by dispersing nano meter-sized materials (nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets) in base fluids. In other words, nanofluids are nanoscale colloidal suspensions containing condensed nanomaterials. They are two-phase systems with one phase (solid phase) in another (liquid phase). Nano fluids have been found to possess enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients compared to those of base fluids like oil or water. It has demonstrated great potential applications in many fields.

In recent years, nanofluids have attracted more and more attention. The main driving force for nanofluids research lies in a wide range of applications. Although some review articles involving the progress of nanofluid investigation were published in the past several years [1-6] most of the reviews are concerned of the experimental and theoretical studies of the thermophysical properties or the convective heat transfer of nanofluids.

The thermal boundary due to heating or cooling of a vertical surfaces Has a large impact on flow and heat transfer characteristics. Convection heat transfer in the fluid flow is great significance from both theoretical and practical point of views because of its large application in many industrial application and other fields.

Blasius [7] first considered steady laminar boundary flow of viscous incompressible fluid over a flat plate. Howath [8] numerically studied various of the Blasius flat –plate flow problem. Combined forced and natural convection over a flat plate has been widely studied from both theoretical and experimental standpoint over the past few decades. The effect of a magnate field on free convection heat transfer on isothermal vertical plate was discussed by Sparrow and Cess [9]. Guptna[10] studied laminar free convection flow of an electrically conducting fluid past a vertical plate with uniform surface heat flux and variable wall temperature in presence of magnetic field. Afzal and Hussain[11] discussed the mixed convection over a horizontal plate. Yao [12] investigated the two dimensional mixed convection along a flat plate. Hossain and Takhar[13] determined the effect of radiation on mixed convection along a vertical plate with uniform free stream velocity and surface temperature. Aydin and Kaya[14] analysed the mixed convection flow of a viscous dissipating fluid about a vertical flat plate.

The non adherence of the fluid to a solid boundary known as velocity slip, is a phenomenon that has been observed under certain circumstances. When fluid in microelectro mechanical system are encountered, the no slip condition at the solid -fluid Interface is abandoned in favour of a slip flow model which represents more accurately the non equilibrium region near the interface. In all of the above mentioned investigations, the no slip condition at the boundary was assumed. Even in literature, the study of the slip flow over a flat plate is not sufficiently available. Martin and Boyd [15] considered the momentum and heat transfer in a laminar boundary layer flow over a flat plate with slip boundary condition. Cao and Baker [16] presented local non-similar solutions to the boundary layer equations for mixed convection boundary layer stagnation point flow on a vertical isothermal plate. Also, velocity slip and thermal jump boundary conditions were considered in their problem. Harris et.al [17] studied the mixed convection boundary layer stagnation point flow on a vertical surface in a porous medium. Aziz[18] studied the boundary layer slip flow over a flat plate with constant heat flux condition at the surface and in this paper the local similarity considered with slip boundary conditions. Rohni et.al [19] investigated a numerical unsteady mixed convection boundary –layer flow near the two dimensional stagnation point permeable surface embedded is fluid saturated porous medium with thermal slip. Anderson [20] investigated the effect of slip boundary condition on the flow of Newtonian fluid due to a stretching sheet. Bhattcharyya [21] investigated effect of slip condition on vertical plate with mixed convection

Now, the objective of the present work is to investigate a numerical solution due to an steady mixed convection boundary layer flow and temperature profile velocity slip and temperature slip boundary condition with water, Al2O3 with different concentration and different oxide nanofluids Al2O3, TiO2, CuO, SiO2 ,at 20^{0}C. The nondimensional equations are solved with matlab code. The velocity and temperature profiles are compared with existing values of literature and presented graphically with conclusions.

II. MATHEMATICAL FORMULATION OF THE PROBLEM:

Let us consider the steady two dimensional laminar mixed convective flow of a viscous incompressible fluid over a vertical plate. Using boundary layer approximation, the equations for the flow and the temperature are written usual notation as :

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty) \qquad (2)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty) \qquad (3)$$

where x and y are axes along and perpendicular to the plate respectively ,u and v are velocity components in x–axis and y –directions respectively , ρ is the density ,μ is the viscosity ,ν is the kinematic viscosity, β is the volumetric coefficient of thermal expansion , g is the acceleration due to gravity, T is the temperature ,T_∞ is the surrounding free stream temperature ,k is the thermal conductivity of the fluid and C_p is the specific heat of the fluid respectively.

The appropriate boundary conditions for the velocity and velocity component with velocity slip and temperature with thermal slip are given by

$$u= L_1\left(\frac{\partial u}{\partial y}\right), v=0\ at\ y=0 \qquad u\rightarrow U_\infty as\ y\rightarrow\infty \qquad (4)$$

and

$$T= T_w+D_1\left({}^{\partial T}\!/_{\partial y}\right)\ at\ y=0; T\rightarrow T_\infty\ as\ y\rightarrow\infty \qquad (5)$$

here $L_1=L(Re_x)^{1/2}$ is the velocity slip factor and $D_1=D(Re_x)^{1/2}$ is the thermal slip factor with L and D being the initial values of velocity and thermal slip factors having same dimensions of length and Re_x being the local Reynolds number and $Re_x=U_\infty x/\nu$, U_∞ is the free stream velocity $T_w= T_\infty+T_0/x$ is the variable temperature of the plate and T_0 is constant that measures the rate of temperature increase along the plate.

The following similarity transformation are introduced to nondimensionalized the governing equatio$\psi= \sqrt{U_\infty\nu x f(x)}, T= T_\infty+(T_w-T_\infty)\theta(\eta)$, and $\eta=y\sqrt{U_\infty/\nu x}$ where ψ is the stream function defined in the usual notation as $u=\partial\psi/\partial y$ and $\nu=-\partial\psi/\partial x$ and η is the similarity variable.

$$f'''+\frac{1}{2}ff''+\lambda\theta=0 \qquad (6)$$

$$\theta''+P_r\left(\frac{1}{2}f\theta'+f'\theta\right)=0 \qquad (7)$$

Where $\lambda= g\beta T_0/U_\infty^2$ is the mixed convection parameter and Pr $=\mu Cp/k$ is the Prandtl number. The boundary conditions (4) and (5) reduce to the following forms

$$f(\eta)=0, f'(\eta)=\xi f''(\eta) at\ \eta=0; f'(\eta)\rightarrow 1\ as\ \eta\rightarrow\infty \qquad (8)$$

$$\theta(\eta)=1+\beta\theta'(\eta)\ at\ \eta=0; \theta(\eta)\rightarrow 0\ \ as\ (\eta)\rightarrow\infty \qquad (9)$$

Where $\delta\ =LU_\infty/\nu$the velocity is slip parameter and $\beta=DU_\infty/\nu$ is the thermal slip parameter.

III. EVALUATION OF THERMO PHYSICAL PROPERTIES OF NANOFLUID

Metal and metallic oxide nanoparticles when dispersed in small quantities in a base liquid such as water, ethylene glycol, etc are observed to possess higher values of thermal conductivity compared to base liquid. Experiments conducted by Choi [22] with Carbon Nano Tubes (CNT) in engine oil at 1.0% volume concentration, obtained thermal conductivity enhancement of 160% of the base liquid value. The determination of thermo-physical properties of metal nanoparticles like Cu and metal oxides such as Al2O3, TiO2, CuO, SiO2, etc in different base fluids and the parameters influencing them is undertaken by **various** investigators The well known theoretical models of Maxwell [23] and Hamilton and Crosser [24] predicted lower values of thermal conductivity compared to experimental observations at higher temperatures. Hence experimental determination of thermal conductivity of various nanofluids is undertaken as the theoretical models are still pursued. It is fairly established that the thermal conductivity and viscosity of nanofluids is influenced by concentration and temperature. The influence of particle size on the properties has not been considered in the development of regression equations by these investigators.

The thermal conductivity and viscosity of various nanofluids are determined experimentally at different particle sizes, temperatures and concentration by many[25- 32] . Experiments for the estimation of nanofluid convective heat transfer coefficients are undertaken with particle size in the range of 20 to 170nm, temperature range of 20-70^{0}C, volume concentration of less than 4.0% with Al2O3, Cu, CuO, SiC,TiO2, ZrO2, etc nanoparticles dispersed in water. The viscosity and thermal conductivity data of metal and their oxide nanoparticles dispersed in water and available in literature is used in the development of regression equations. The nanofluid density and specific heat are determined using the mixture relations given by

A. DENSITY, ρ_{nf}

Applying the principle of mass conservation of the two species in a finite control volume of the nano fluid, the nanofluid density can be obtained from the relation

$$\rho_{nf} = \emptyset\rho_P + (1-\emptyset)\rho_w \qquad (10)$$

where is the volumetric fraction of nano particles in the base fluid.

B. SPECIFIC HEAT, $C_{p_{nf}}$

The thermal conservation of energy of the two species in a finite control volume will yield the overall

$$Cp_{nf} = \frac{(1-\emptyset)(C_p)_w + \emptyset(\rho C_p)_w}{(1-\emptyset)\rho_w + \emptyset\rho_p} \qquad (11$$

The bulk material properties listed in are used in the development of regression equations for density and specific heat. Vajjha and Das [33]considered specific heat ratio to be dependent on concentration and bulk temperature **in** the development of regression equation. Hence equations applicable for metal and their oxide nanoparticles dispersed in water are

$$\rho_{nf} = \rho_w(0.9973 + 0.03479\phi + 0.0000619T_b) \qquad (12)$$

$$Cp_{nf} = Cp_w(1.036 - 0.0298\phi - 0.001037T_b) \qquad (13)$$

with an average deviation of less than 3.7% where ϕ is in percent and T_b in ^{o} C. Nguyen et al. [34] conducted experiments for the determination of viscosity of Al2O3 and CuO nanofluids in water at different concentrations and particle sizes in the ambient temperatures of 22 and 25oC. Experiments revealed the viscosity of Al2O3 with particle sizes of 36 and 47nm and that of CuO with 29nm size predicted close values for volume concentration less than 4%. The dependence of viscosity ratio on concentration and particle diameter by **Sarit et al. [35]** and specific heat ratio on concentration and bulk temperature by **Vajjha and Das [33]** has been considered in the development of regression equations. Based on these observations, it is can be stated that viscosity and thermal conductivity of nanofluids are influenced by volume concentration, temperature and particle size. Hence, the available experimental data in literature for a maximum temperature of $T_{\max} = 70^0$ C and particle size of $d_{\max}$ = 50 nm is used to develop regression equation valid for various metals and their oxide nanoparticles dispersed in water

$$k_{nf} = k_w(0.9808 + 0.0142\phi + 0.003883T_b - 0.00068d_p) \qquad (13)$$

$$\mu_{nf} = \mu_w(0.9042 + 0.1245\phi + 0.0043d_p - 0.0001206T_b) \qquad (14)$$

for $0 \le \emptyset \le 3.7$, $20 \le T_b \le 70$, , $20 \le d_p \le 150$ with a maximum deviation of less than 10% where$\emptyset$ is in percent, *Tb* in ^{0}C and d_p in nm. Yurong He et al. [31] observed the shear viscosity to increase and thermal conductivity to decrease with particle size.

IV. NUMERICAL SOLUTION

The nonlinear coupled differential Eqs.(7) to (8) along with the boundary conditions (9) and (10) from a two point boundary values problem (BVP) and are solved using MATLAV bvp4c code. Bu converting into an initial value problem (IVP).In this method it is necessary to choose a suitable finite value of $\eta \to \infty$, say η_∞ .The following first order system is considered.

$$f = y(1)\,,\ f' = y(2)\ ,\ f''' = y(3)\ ,\theta = y(4),\ \theta' = y(5) \qquad (17)$$

The following set of first order equation are considered with the boundary conditions.

$$y(2), y(3), -\left(\frac{1}{2}\right)y(1)y(2) - \lambda y(4), y(5), -\Pr\left(\frac{1}{2}\right)y(1)\,y(5) + y(2)y(4) \qquad (18)$$

The set of first order differential equations are solved with bvp4c code for different values of concentration of nanofluid, mixed convection parameter, velocity and temperature slip boundary for different nanofluid and compared results of non dimensional velocity and temperature with out and with slip condition.

V. RESULTS AND DISCUSSION: The numerical computations are executed for several values of dimensionless parameter involved in the equations viz. the mixed convection parameter (λ),the velocity slip parameter (δ), the thermal slip parameter (β) and Prandtl number (P_r) for different concentration of nanofluid and different oxide Nanofluid Al203, SiO2, ZnO, CuO. To illustrate the computed results, some figure are plotted and physical explanations are given.

Initially to assure the accuracy of applied numerical method we compared our derived results corresponding to the velocity and shear stress profiles for forced convection for no slip condition at the boundary (i.e for ($\lambda = 0$, $\delta = 0$, $\beta = 0$) with given results of Howarth [2] in Fig .1 and these are found in excellent agreement.

The variation of the dimensional less velocity, shear stress and temperature profiles for different values of the mixed convection parameter λ in with and without slip at the boundary for Al2O3 nanofluid are presented in figs 2 and fig 3. Fig4.0 reports the variation of shear stress for Al2O3 nanofluid for different concentration with mixed convection parameter $\lambda = 0.2, \beta = 0.1, \delta = 0.2$. The slope of the shear stress is increased by concentration of nanofluid.

Figure 5.0& Figure 6.0 represents the velocity profiles and temperature profiles with out mixed convection parameter for different oxide nanofluids variation with nondimensional distance. There is minute variation in velocity profile compare than temperature due to the effect of Prandtl number. The temperature gradient are increases with increasing the value of Prandtl number.

Figure 7.0 represents the variation nondimensional temperature with different values of mixed β, γ, δ for water at the Pr = 4.34 .The slope of temperature profiles are increasing with increasing the mixed convection parameter and slip parameters. Fig 8.0, fig 9.0 and Fig 10 represent the variation of shear stress with nondimensional distance for water and different nanofluids with and without mixed convection parameters and slip parameters. The stress is increases with increasing the Prandtl number and also increases with slip boundary condition

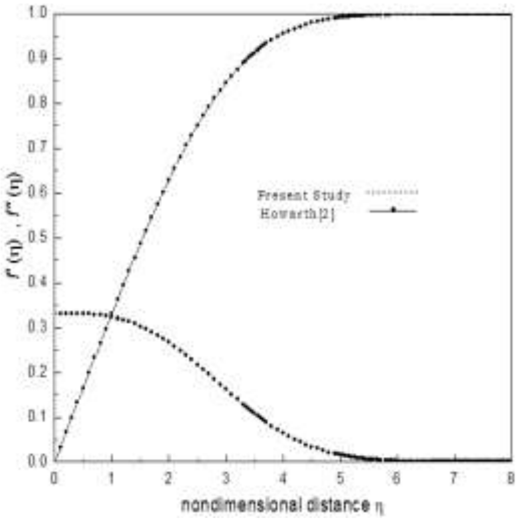

Fig 1.0 Velocity profile $f'(\eta)$ and shear stress profiles $f^{''(\eta)}$ for $\lambda = 0, \delta = 0, \beta = 0$

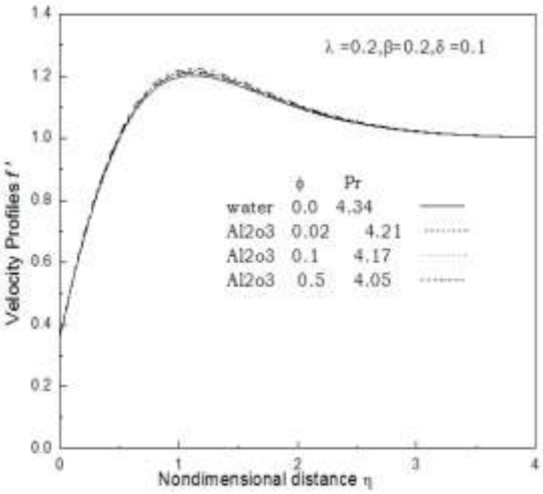

Fig 2.0 variation of velocity profiles with effect of Concentration of nanofluid for $\lambda = 0.2$, $\delta = 0.1$, $\beta = .2$

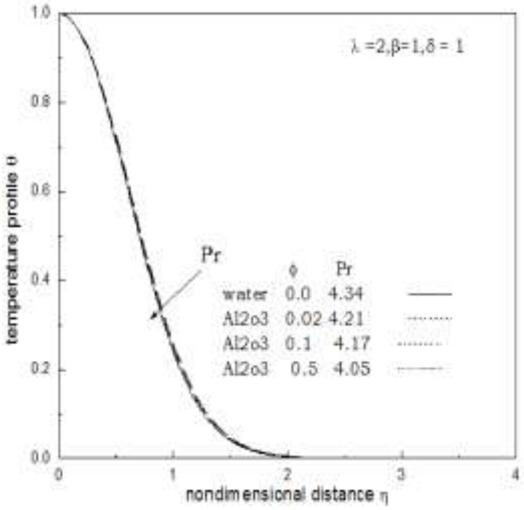

Fig.3.0 Temperature profiles with effect of concentration and mixed convection parameter and slip boundary conditions

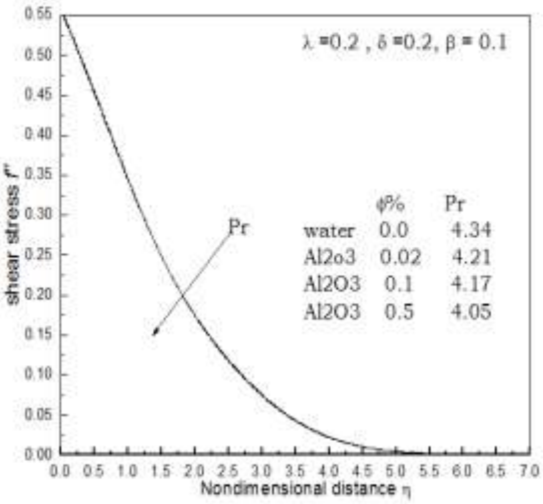

Fig 4.0 shear stress profiles with slip boundary and mixed convection parameter for Al2O3 at different concentration

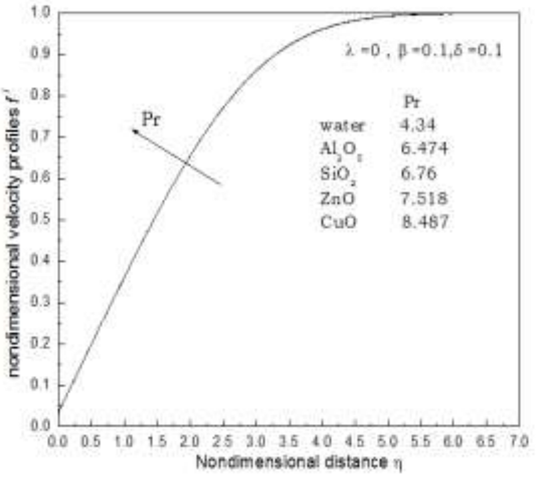

Fig 5.0 variation of velocity profiles without mixed convection parameter with boundary conditions for different nanofluids

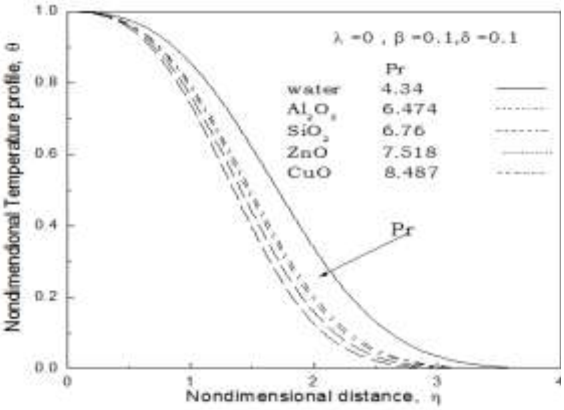

Fig 6.0 variation of nondimensional temperature profiles without mixed convection parameter with slip boundary conditions for different nanofluids

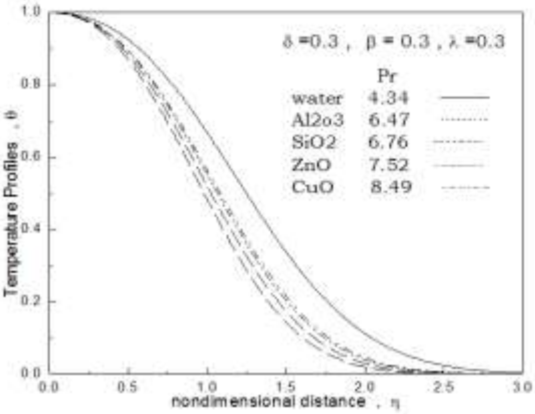

Fig7.0 variation of nondimensional temperature profiles with different nanofluid at with mixed convection parameter

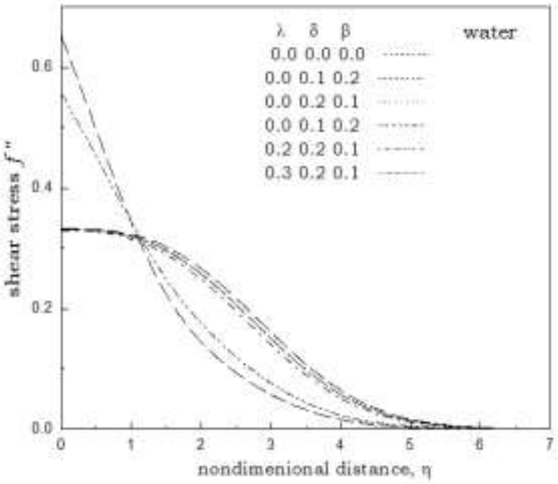

Fig 8.0 variation of shear stress with and without mixed convection parameter for water with different velocity and temperature slip

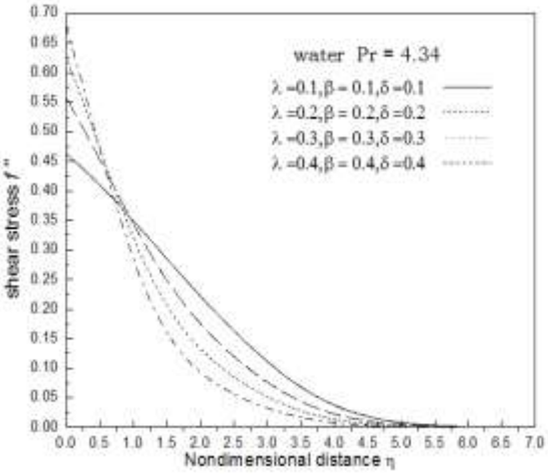

Fig 9.0 variation of shear stress with mixed convection parameter for water at different values of β, δ

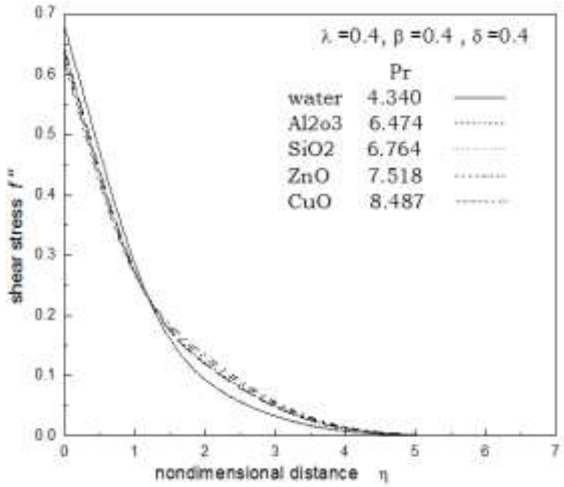

Fig 10.0 variation of shear stress with different nano fluid at $\beta = 0.4, \gamma = 0.4, \delta = 0.4$.

VI. CONCLUSIONS

A numerical study on mixed convection over a vertical flat plate with velocity slip and temperature slip at the boundary with water and different oxide nanofluids is presented. The similarity variable and the self similarity equations corresponding to momentum and energy equations are solved with the help of matlab numerical solution. The parameters such as mixed convection, velocity slip, temperature slip and concentration of nanofluid involved in this study significantly affect the flow and heat transfer. The following conclusions can be noted as a result of the computations.

(i) due to mixed convection parameter the velocity increases and the temperature profile are decreasing

(ii) the velocity shows the increasing and decreasing in its nature before and after a point as the velocity slip increases and the thermal boundary layer thickness becomes thinner for velocity slip.

(iii) the increase in Prandtl number reduces the velocity along the plate as well as the temperature.

(iv) velocity and temperature are found to increase with the increasing thermal slip parameter

(v) The velocity and temperature are found to be increasing with concentration of nanofluid of $Al_2O_3$and the Prandtl of number of oxide nanofluid

REFERENCES

[1] V. Trisaksri and S.Wongwises, “Critical review of heat transfer characteristics of nanofluids,” Renewable and Sustainable Energy Reviews, vol. 11, no. 3, pp. 512–523, 2007.

[2] S. O¨ zerinc¸, S. Kakac¸, and A.G. YazIcIog˘lu, “Enhanced thermal conductivity of nanofluids: a state- of-the-art review,” Microfluidics and Nanofluidics, vol. 8, no. 2, pp. 145–170, 2010.

[3] X.Q.Wang and A.S.Mujumdar, “Heat transfer characteristics of nanofluids: a review,” International Journal of Thermal Sciences, vol. 46, no. 1, pp. 1–19, 2007.

[4] X.Q. Wang and A. S. Mujumdar, “A review on nanofluids— part I: theoretical and numerical investigations,”Brazilian Journal of Chemical Engineering, vol. 25, no. 4, pp. 613–630, 2008.

[5] Y. Li, J. Zhou, S. Tung, E. Schneider, and S. Xi, “A review on development of nanofluid preparation and characterization,” Powder Technology, vol. 196, no. 2,pp. 89–101, 2009.

[6] S.Kakac¸ and A. Pramuanjaroenkij, “Review of convective heat transfer enhancement with nanofluids,” International Journal of Heat and Mass Transfer, vol. 52, no. 13-14, pp. 3187–3196, 2009.

[7] Blasius H. Grenzschichten in Flu¨ssigkeiten mitkleiner Reibung. Z Mathematik Physik;56:1–371908.

[8] Howarth L. On the solution of the laminar boundary layer equations. Proc Roy Soc Lond A 1938;164:547–79.

[9] Sparrow EM, Cess RD. The effect of a magnetic field on free convection heat transfer. Int J Heat Mass Transfer 1961;3: 267–74.

[10] Gupta AS. Laminar free convection flow of an electrically conducting fluid from a vertical plate with uniform surface heat flux and variable wall temperature in the presence of a magnetic field. Z Angew Math Phys 1963;13:324–33.

[11] Afzal N, Hussain T.Mixed convection over a horizontal plate.ASME J Heat Transfer 1984;106:240–1.

[12] Yao LS. Two-dimensional mixed convection along a flat plate. ASME J Heat Transfer 1987;190:440–5.

[13] Hossain MA, Takhar HS. Radiation effects on mixed convection along a vertical plate with uniform surface temperature. Heat Mass Transfer 1996;31:243–8.

[14] Aydin O, Kaya A. Mixed convection of a dissipating fluid about a vertical flat plate. Appl Math Model 2007;31:843–53.

[15] Martin MJ, Boyd ID. Momentum and heat transfer in laminar boundary layer with slip flow.J Thermophys Heat Transfer 2006;20:710–9.

[16] Cao K, Baker J. Slip effects on mixed convective flow and heat transfer from a vertical plate. Int J Heat Mass Transfer 2009;52:3829–41.

[17] Harris SD, Ingham DB, Pop I. Mixed convection boundary-layer flow near the stagnation point on a vertical surface in a porous medium: Brinkman model with slip. Transport Porous Media 2009;77:267–85.

[18] Aziz A. Hydrodynamic and thermal slip flow boundary layers over a flat plate with constant heat flux boundary condition. Commun Nonlinear Sci Numerical Simulation 2010;15:573–80.

[19] Rohni AM, Ahmad S, Pop I, Merkin JH. Unsteady mixed convection boundary-layer flow with suction and temperature slip effects near the stagnation point on a vertical permeable surface embedded in a porous medium. Transp Porous Media 2012;92:1–14.

[20] Andersson HI. Slip flow past a stretching surface. Acta Mech;158:121–5 (2002).

[21] Bhattacharyya ,Swati Mukhopadhayay,Layek, “Similarity solution of mixed convection boundary layer slip flow over a vertical plate”, Ain Shams engineering Journal vol.4,pp 299-305 (2013)

[22] Choi, U. S., “Enhancing Thermal Conductivity of Fluids With Nanoparticles,.. Developments and Applications of Non-Newtonian Flows, D. A. Siginer and H. P. Wang,eds., FED-vol. 231MD-Vol.66, ASME, New York, pp. 99-105, 1995.

[23] Maxwell, J.C., A treatise on electricity and magnetism, Second edition, OxfordUniversity Press, Cambridge, U.K., (1904)

[24] Hamilton, R. L., and Crosser, O. K., ..Thermal Conductivity of Heterogeneous Two Component Systems,.. I & EC Fundamentals, 1, pp. 187-191, 1962

[25] Eastman, J. A., Choi, U. S., Li, S., Yu, W., and Thompson, L. J., ..Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol-Based Nanofluids Containing Copper Nano-particles, .Appl. Phys. Lett., 78, pp. 718-720. 2001

[26] Xie, H.Q., Wang, J.C., Xi, T.G., Liu, Y., Ai, F., Wu, Q.R. Thermal Conductivity enhancement of suspensions containing nanosized alumina particles, J. Appl. Phys., 91, 4568.4572, 2002

[27] Das, S.K., Putra, N., Theisen, P., Roetzel, W., Temperature dependence of thermal conductivity enhancement for nanofluid, Journal of Heat Transfer 125 (2003) 567.574

[28] Murshed, S.M.S., Leong, K.C., Yang, C., Enhanced thermal conductivity of TiO2. water based nanofluids, International Journal of Thermal Sciences 44 (4) (2005) 367.373.

[29] Hong, T.-K., Yang, H. S., Choi, C.J., Study of the enhanced thermal conductivity of Fe nano fluids,Journal of Applied Physics 97 (6) (2005) 1-.4.

[30] Shima, P.D., John Philip, Baldev Raj, Role of micro convection induced by Brownian motion of nanoparticles in the enhanced thermal conductivity of stable nanofluids, Applied physics Letter (2009) 94

[31] Yurong He, Yi Jin, Haisheng Chen, Yulong Ding, Daqiang Cang, Huilin Lu, Heat transfer and flow behaviour of aqueous suspensions of TiO2 nanoparticles (nanofluids) flowing upward through a vertical pipe, International Journal of Heat and Mass Transfer, 50, 2272 - 2281, 2007

[32] Vajjha, R. S. and Debendra K. Das, Specific Heat Measurement of Three Nanofluids a Development of New Correlations, Journal of Heat Transfer 131 (2009) 071601-(1-7) [33].Vajjha, R. S. and Das, Debendra K., Experimental determination of thermal conductivity of three nanofluids and development of new correlations, International Journal of Heat and Mass Transfer 52 (2009) 4675-4682

[33] Nguyen, C. T., Desgranges, F., Roy, G., Galanis, N., Mare, T., Boucher, S., Mintsa, H. Angue, Temperature and particle-size dependent viscosity data for water-based nanofluids . Hystere phenomenon, Int. J. Heat and Fluid Flow 28 (2007) 1492-1506

[34] Sarit, K. D., Putra, N., Theisen, P., Roetzel, W., Temperature dependence of thermal conductivity enhancement for nanofluid, Journal of Heat Transfer 125 (2003) 567-574