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Free and Forced Convective Heat Transfer through a Nanofluid with Two Dimensions past Inclined Vertical Plate

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Abstract

Particularly in this paper discussion is about free and forced convective heat transfer in Cu – water Nano- fluid past permeable flat vertical semi-infinite moving plate due to high conductivity and occurrence in Cu-water Nanofluid with natural or forced convections. In this we consider magnetic field and also heat source. The effect on various parameters such as Reynolds number (Re), solid volume fraction (φ), magnetic parameter (M), inclination angle of the plate (γ), heat source parameter (Q¬h), on linear velocity (U), vertical velocity (V) and temperature (θ) were exhibited in graphs. The profile of every governing parameter is displayed for natural as well as forced convection by considering the Ar>>1 and Ar<<1 respectively. This rate of heat transfer in forced convection is more than counterpart in free convection. Inertial force reducing the heat transfer rate in natural convection but the enhancement of Nu observed in forced convection. The composition of metal particles enhances the heat transfer rate in both convections, which emphasizes the Nano-fluid significance. Lorentz force is enhancing the heat transfer rate slightly. Heat source obviously increase the rate of heat transfer in both convections. The present paper aims to study the convective high temperature transfer of Nanofluids into which we use viscosity proposed with Einstein also with the thermal conductivity proposed by Corcione.

Keywords: *Convection, Heat source, MHD, Runge– kutta–6th order method, Thermal conductivity, Thermal slip, Viscosity.*

I. INTRODUCTION

Nano Technology is emerging due to vast applications in many fields recently. The Nanofluid usage in the convective heat and mass transfer was more significant with many fields like flow boiling, blood flows, environmental studies etc. But the detailed study about Nano particle character in convective heat and mass transfer is still needed. An attempt has been made to overcome this shortcoming for the enthusiastic researchers. The book details in the computational learn with the title "convective heat and mass transfer" include geometries such as inclined plate, stretching sheet and cylinder. These rare models in thermal conductivity proposed by **Graham [1]** and viscosity proposed by **Jang and Choi [2]** are used to describe the particle size in their mathematical forms. The scope of extension or application for real time systems is left to the intellectual researchers or readers. In this paper the discussion is about free and forced convective high temperature transfer through a nanofluid with two dimensions long-ago inclined vertical platter.

In everyday life of mankind, investigations on the ground of heat transfer challenges usage of cool with most of the system. A Nano-particle is suspended in liquid like water, ethylene glycol etc. then the heat transfer enhances enormously. This be substantiate with **Das et al.[3]** here their assessment paper and inside this situation he gave cool system command the extremely small heat transport rate throughout a Nanofluid in addition to heat force method similar to automobile which demand the higher temperature transport rate with Nanofluid. **Kuznetsov and Nield [4]** together be study the traditional way of free convective boundary layer stream with viscous as well as incompressible flowing (Newtonian fluid) long-ago a vertical smooth platter in casing of Nano-fluids. Inside this paper the author use the Nanofluid replica planned with **Buongiorno [5].** Though he discovered seven slip mechanism taken put inside the convective move of Nanofluid but the Brownian diffusion plus the thermophoresis which be mostly significant while turbulent flow effect be missing.

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In recent times **Khan and Aziz [6]** both were study about normal convective stream of a nanofluid above vertical platter through uniform surface heat fluctuation. **Hamad along with Pop [7]** were obtainable inside their latest papers, “the solid volume and the heat source enhancement in heat transfer rate”, this concise survey obviously indicate so as to a definite end concerning the function of nanoparticle enhance the normal convective transportation be yet to be research. This recent paper was presented by **Srikanth et.al [8],** it was intended to explore the magneto hydro dynamic Copper-water nanofluid stream also the heat transport long-ago a vertical infinite permeable inclined oscillate smooth platter in heat resource, suction also radiation. In this paper we discussed about free and forced convections in heat transfer through a Nanofluid with two dimensions past inclined vertical plate.

II. Mathematical Formulation

The main assumptions governing the stream and heat transfer are as follows:

- Consider Cu and water nanofluid flow past a moving semi infinite flat plate.
- The nanofluid flow is assumed in x_1 direction.
- Initially entire system is at rest
- This plate is assumed to be non-electrically conducting, inclined to the base at an angle of γ and moving in the normal direction with the velocity of U_0
- Suppose the standard fluid and suspended Cu particle both are at the thermal equilibrium and no slip occur between them.
- Transverse magnetic field is applied uniformly.
- It is assumed that the magnetic field induced is lesser than magnetic field applied externally.
- By taking surface temperature at a constant value T_w and the ambient temperature as T_∞, where $T_w > T_\infty$
- The fluid is assumed to follow the Bossinesq approximation

The Cartesian co-ordinate system and also the geometry of the plate are shown in the following diagram.

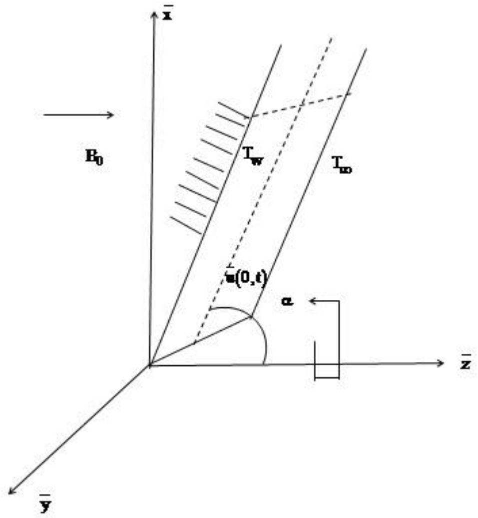

Fig. 1. Schematic Diagram

III. Governing Equations

As per above assumptions, the boundary layer equations leading the flow and temperature are as follows:

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

$$\rho_{nf}\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\left(\rho\beta_T\right)_{nf}\, g\left(T-T_\infty\right)Cos\,\gamma-\sigma B_0^{\,2}u \tag{2}$$

$$\rho_{nf}\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=\mu_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-\frac{Q}{\left(\rho c_p\right)_{nf}}\left(T-T_\infty\right) \tag{4}$$

The boundary conditions for this problem is as follows

$$\begin{aligned}
&u(x,y,t)=0, v(x,y,t)=0, T(x,y,t)=T_\infty, t<0\\
&u(0,y,t)=U_0, v(0,y,t)=U_0, T(o,y,t)=T_w, y>0, t\ge 0\\
&u(x,0,t)=U_0, v(x,0,t)=U_0, T(x,0,t)=T_w, x>0, t\ge 0\\
&u(\infty,y,t)\to 0, v(\infty,y,t)\to 0, T(\infty,y,t)\to T_\infty, t\ge 0\\
&u(x,\infty,t)\to 0, v(x,\infty,t)\to 0, T(x,\infty,t)\to T_\infty, t\ge 0
\end{aligned} \tag{5}$$

Thermo-Physical properties were connected as follows:

$$\rho_{nf}=\left(1-\phi\right)\rho_f+\phi\rho_s, \alpha_{nf}=\frac{k_{nf}}{\left(\rho c_p\right)_{nf}}$$

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

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

$$\mu_r=\frac{\mu_{nf}}{\mu_f}=1+2.5\phi \tag{6}$$

$$\frac{k_{nf}}{k_f}=1+4.4\,\mathrm{Re}^{0.4}\,\mathrm{Pr}^{0.66}\left(\frac{T}{T_{fr}}\right)^{10}\left(\frac{k_p}{k_f}\right)^{0.03}\phi^{0.66} \tag{7}$$

Here we introduce the following non dimensionless parameters as:

$$X=\frac{x}{L}, Y=\frac{y}{L}, t'=t\frac{U_0}{L},\ U=\frac{u}{U_0}, V=\frac{v}{U_0}, \theta=\frac{\mathrm{T}-\mathrm{T}_\infty}{\mathrm{T}_w-\mathrm{T}_\infty} \tag{8}$$

Using equations (6), (7), (8) the equations (2), (3) & (4) will be reducing to:

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$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=\frac{1+2.5\phi}{\left(1-\phi+\phi\left(\frac{\rho_s}{\rho_f}\right)\right)}\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right)+\left(1-\phi+\phi\left(\frac{\beta_s}{\beta_f}\right)\right)\frac{Gr}{R^2}\theta \, Cos\,\gamma-M^2U \tag{9}$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=\frac{1+2.5\phi}{\left(1-\phi+\phi\left(\frac{\rho_s}{\rho_f}\right)\right)}\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right) \tag{10}$$

$$\frac{\partial \theta}{\partial t}+U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1+4.4\,\mathrm{Re}^{0.4}\,\mathrm{Pr}^{0.66}\left(\frac{T}{T_{fr}}\right)^{10}\left(\frac{k_s}{k_f}\right)^{0.03}\phi^{0.66}}{\left(1-\phi+\phi\left(\frac{(\rho c_p)_s}{(\rho c_p)_f}\right)\right)}\frac{1}{\mathrm{Pr}}\frac{1}{\mathrm{Re}}\left(\frac{\partial^2\theta}{\partial X^2}+\frac{\partial^2\theta}{\partial Y^2}\right)-\frac{Q_h}{\left(1-\phi+\phi\left(\frac{(\rho c_p)_s}{(\rho c_p)_f}\right)\right)}\frac{1}{\mathrm{Pr}}\frac{1}{\mathrm{Re}}\theta \tag{11}$$

Here the equivalent boundary condition of equation **(5)** was written in the non dimensional form :

$$U(X,Y,t')=0, V(X,Y,t')=0, T(X,Y,t')=0, t'<0$$
$$U(0,Y,t')=1, V(0,Y,t')=1, \theta(0,Y,t')=1, Y>0, t'\ge 0$$
$$U(X,0,t')=1, V(X,0,t')=1, \theta(X,0,t')=1, X>0, t'\ge 0$$
$$U(\infty,Y,t')\to 0, V(\infty,Y,t')\to 0, \theta(\infty,Y,t')\to 0, t'\ge 0$$
$$U(X,\infty,t')\to 0, V(X,\infty,t')\to 0, \theta(X,\infty,t')\to 0, t'\ge 0 \tag{12}$$

Where the parameters present in the above equations are as follows:

$\mathrm{Pr}=\frac{\nu_f}{\alpha_f}$, (Prandtl Number),

$M^2=\frac{\sigma B_0^{\,2} L}{U_0 \rho_f}$, (Magnetic field parameter),

$\mathrm{Re}=\frac{LU_0}{\nu}$, (Reynolds Number),

$Q_h=\frac{QL^2}{k_{nf}}$, (Heat Source Parameter),

$Gr=\frac{g\beta_{Tf}(T_w-T_\infty)L^3}{\nu_f^{\,2}}$, (Grashoff Number),

$Ar=\frac{Gr}{\mathrm{Re}^2}$, (ArchimedesNumber).

IV. Solution of the Problem

The differential equation from (9) to (11) was coupled and they are nonlinear. These equations were solved subjected to the boundary conditions shown in (12). The domain considered is an infinite rectangular plate; the study is in two dimensions.

For computational purpose the height of the plate is considered to be of 2 units and the width of the plate is to be of 1 unit. To solve this system we used “ND Solve” tool in Mathematica 10.4

The local heat transfer rate is determined by Nusselt number (Nu) in dimensionless form and it was given by, $Nu=-\frac{k_{nf}}{k_f}\theta'(0)$.

V. Results and Discussion

The effect on a range of parameters such as Reynolds number (Re), solid volume fraction (φ), magnetic parameter (M), inclination angle of the plate (γ), heat source parameter (Q_h) on U & V and θ were exhibited in the graphs from Figures 2 to 16. In this profile of every governing parameter is displayed for natural as well as forced convection by considering the Ar>>1 and Ar<<1.

For computation we assumed two cases as Ar = 500 and Ar = 1/500 and the other parameters were taken as constants. The Prandtl Number (Pr) kept as constant and it is 0.7 for water. The vertical velocity (U) and the temperature (θ) were calculated at y=1/2 level and the horizontal velocity (V) is presented at x=1 level.

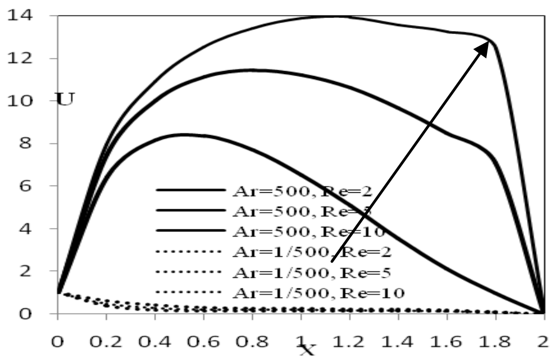

Fig.2. Profile of vertical velocity U with Re

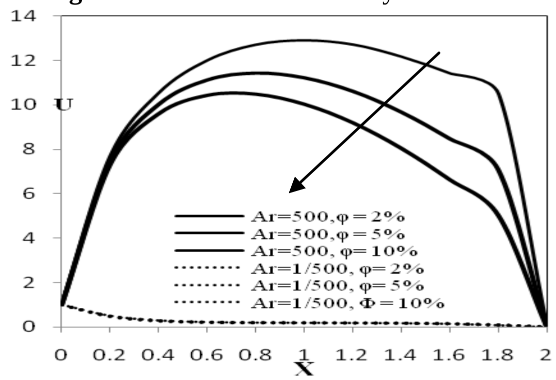

Fig.3 Profile of vertical velocity U with φ

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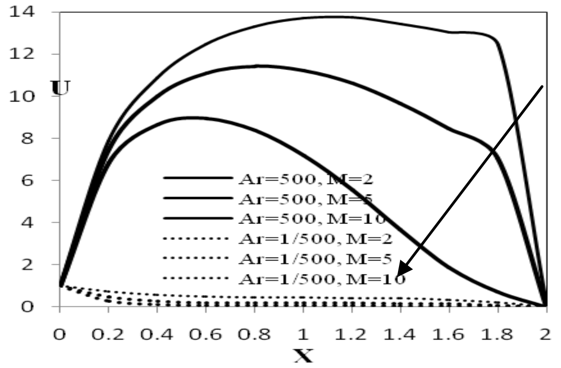

Fig.4 Profile of vertical velocity U with M

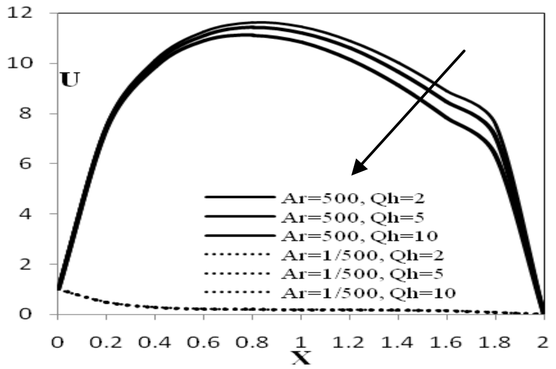

Fig.5 Profile of vertical velocity U with Q_h

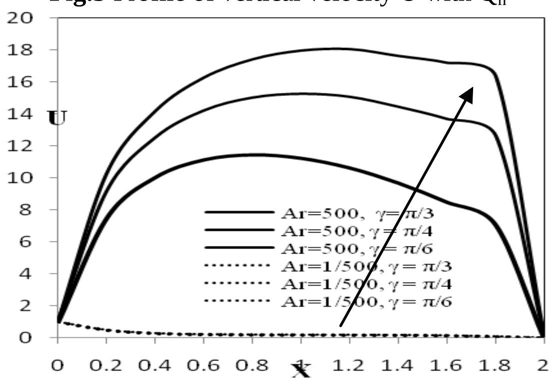

Fig.6 Profile of vertical velocity U with γ

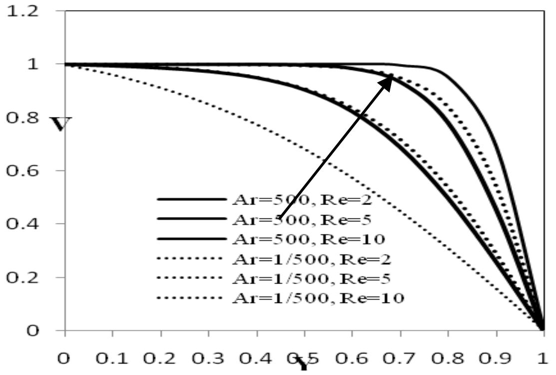

Fig.7. Profile of V with Re

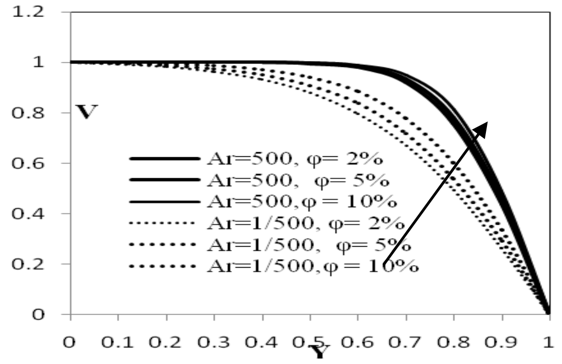

Fig.8. Profile of V with φ

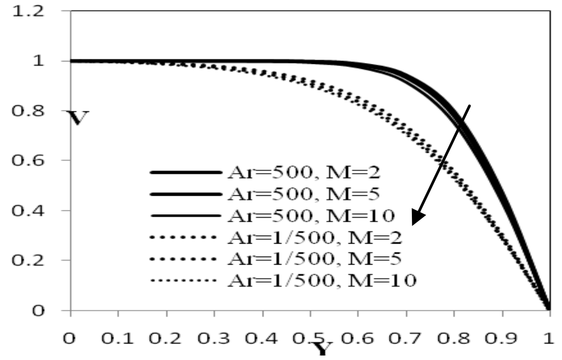

Fig.9. Profile of V with M

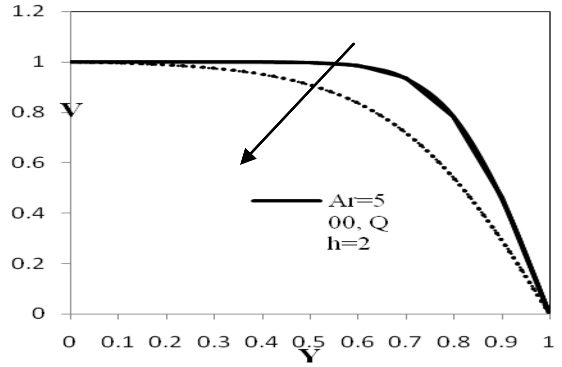

Fig.10. Profile of V with Q_h

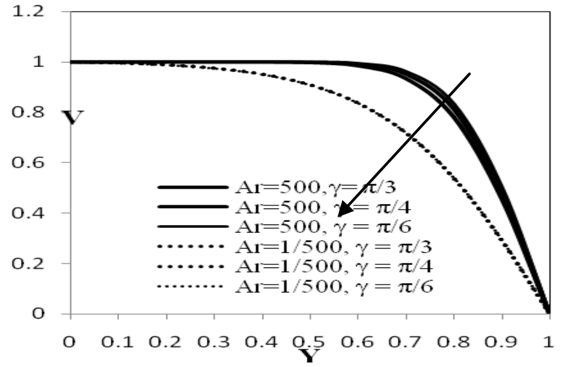

Fig.11. Profile of V with γ

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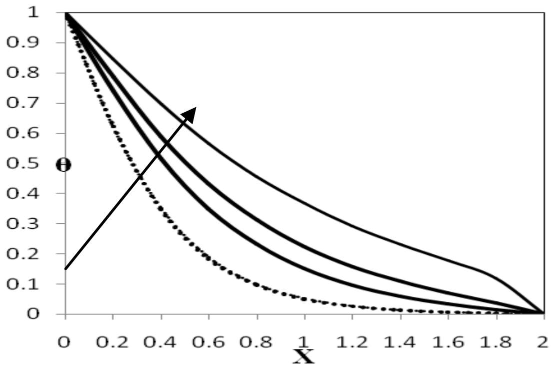

Fig.12. Profile of θ with Re

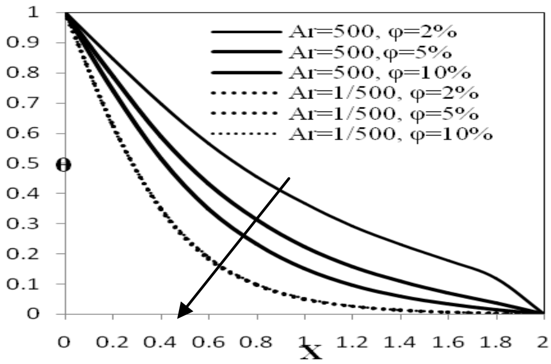

Fig.13. Profile of θ with φ

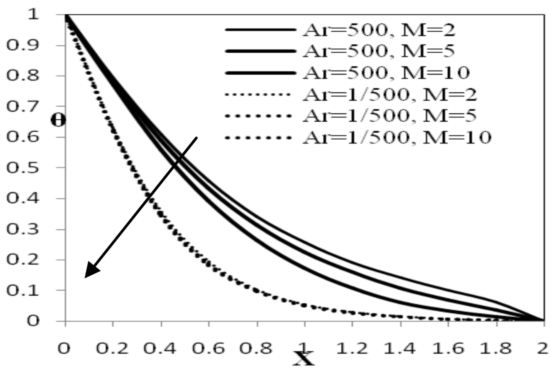

Fig.14. Profile of θ with M

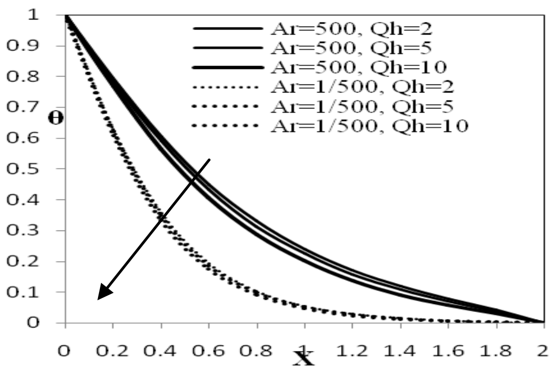

Fig.15. Profile of θ with Q_h

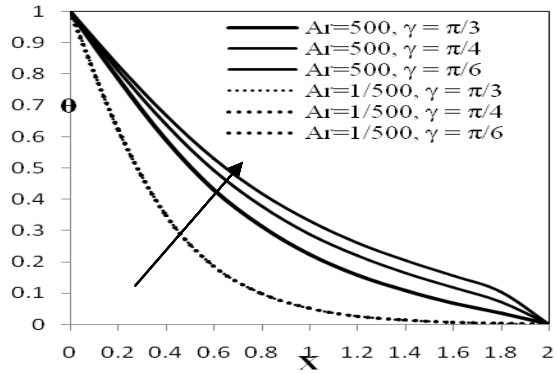

Fig.16. Profile of θ with γ

The vertical velocity (U) profiles are displayed from figures 2-6. The vertical flow is found more in natural convection than in forced convection for all variations. Movement of the plate accelerates the flow more in natural convection. Thus the movement of the boundary regulates the flow in forced convection case. From Fig.2 it is evident that the flow was directly proportional to the inertial force in natural convection and the flow is inversely proportional to the inertial force in forced convection. Fig.3 confirms that the solid volume fraction is always inversely proportional to the flow in both convections. But the flow retards gradually. From Fig.4 Lorentz force dominates the flow in both convections. Heat source is not much significant on flow in both convections, but it showed negative impact when it was increased (Fig.5). It was happened due to the presence of metal particle which is acted as heat absorbers. So the Cu-water Nanofluid will be preferred in heat generating systems. Fig.6 indicates the flow is more when it inclines to the base more for both convections.

The horizontal velocity (V) profiles are displayed from figures 7-11. The horizontal velocity is found more in natural convection than in forced convection for all variations. The flow was found to be more with the base of the plate and retards from the base. From Fig.7 viscous force dominates the inertial force and hence the velocity enhances as Re increases. From Fig. 8 the presence of metal particle enhance the velocity in the Brownian motion of the particle. It was further observed that variation of velocity is significant in forced convection than in natural convection. Fig. 9 exhibits the reduction of velocity with Lorentz force in both the convections. But the variation of M is not clearly significant in both convections. Fig. 10 shows the variation of V with Q_h. The heat source is slightly affecting the velocity V. It is found that the variation of Q_h reduces the velocity. Fig.11 shows the variation of V with γ. The inclination angle is slightly affecting the velocity V in both convections. It was found that the increase of γ reduces velocity.

The temperature (θ) profile is displayed from Fig.12-16. The temperature is significant for variation of different parameters in natural convection and on the other hand the forced convection was not showing significant variation of temperature. Fig.12 shows that temperature increase with increase in inertial force. Fig.13 shows that solid volume fraction is inversely proportional to the temperature in natural convection and directly proportional in forced convection. It may happen due to agglomeration of metal particles. The flow retards with increase in Lorentz force which in turn reduces the temperature

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as given in Fig.14. Interestingly, Fig.15 exhibits increase in heat source decreases the temperature of both convections. This occurs with the presence of Cu Nano-particles in the fluid. The temperature enhancement with reduction in inclination angle in both convections is observed from Fig.16. It shows that the gravitational force affects the flow and the temperature.

Table I- Nusselt Number (Nu) for free convection

Ar=500					
Re	φ	M	Q_h	γ	**Nu**
2	5%	5	5	π/3	**8.4342**
5	5%	5	5	π/3	**7.57042**
10	5%	5	5	π/3	**5.97447**
5	**2%**	5	5	π/3	**3.27403**
5	**5%**	5	5	π/3	**7.57042**
5	**10%**	5	5	π/3	**14.0349**
5	5%	**2**	5	π/3	**7.29409**
5	5%	**5**	5	π/3	**7.57042**
5	5%	**10**	5	π/3	**8.05429**
5	5%	5	**2**	π/3	**7.02208**
5	5%	5	**5**	π/3	**7.57042**
5	5%	5	**10**	π/3	**8.46276**
5	5%	5	5	**π/6**	**5.9171**
5	5%	5	5	**π/4**	**6.52154**
5	5%	5	5	**π/3**	**7.57042**

Table II - Nusselt Number (Nu) for forced convection

Ar=1/500					
Re	φ	M	Q_h	γ	**Nu**
2	5%	5	5	π/3	**11.0598**
5	5%	5	5	π/3	**14.3328**
10	5%	5	5	π/3	**17.5599**
5	**2%**	5	5	π/3	**8.67901**
5	**5%**	5	5	π/3	**14.3328**
5	**10%**	5	5	π/3	**21.5641**
5	5%	**2**	5	π/3	**14.0323**
5	5%	**5**	5	π/3	**14.3328**
5	5%	**10**	5	π/3	**14.626**
5	5%	5	**2**	π/3	**13.7949**
5	5%	5	**5**	π/3	**14.3328**
5	5%	5	**10**	π/3	**15.2047**
5	5%	5	5	**π/6**	**14.3328**
5	5%	5	5	**π/4**	**14.3328**
5	5%	5	5	**π/3**	**14.3328**

Tables 1 & 2 display the Nusselt number values with the base of its plate. Thus the rate of heat transfer with forced convection is more than counterpart of free convection. Inertial force reducing the heat transfer rate in natural convection but the enhancement of Nu observed in forced convection. The composition of metal particles enhances the heat transfer rate in both convections, which emphasizes the Nano-fluid significance. Lorentz force was enhanced the heat transfer rate slightly. Heat source obviously increase the heat transfer rate in both convections. Thus heat transfer rate is more when this plate tends to be horizontal in free convection but no significance observed in forced convections.

VI. CONCLUSION

- Rate of heat transfer is more when plate tends to be horizontal in free convection but no significance observed in forced convections.
- Inclination angle enhances the vertical flow but not significant in horizontal flow.
- The temperature enhancement with reduction in inclination angle in both convections is observed.

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