Influence of Magnetic Field, Heat Radiation and External Surface Temperature on Nanofluids with Different Base Fluids in Mixed Convective Flows over a Vertical Circular Cylinder

M. Radha Madhavi, Vijaya Nalleboyina, Puvvada Nagesh

Abstract: ***The current study deals with the steady flow of a nanofluid under the influence of magnetic field, heat radiation with prescribed external flow of mixed convective boundary layer flow over a vertical circular cylinder. The radiative heat loss is modelled by Rosseland approximation. Similarity variables are used to remodel the partial differential equations into ordinary differential equations. The remodeled equations are solved numerically by the technique of Runge- Kutta –Fehlberg with shooting. During this study nano particle Alumina(Al_2O_3) with water and kerosene as the base fluids is studied. For Alumina-water and Alumina-kerosene, nanofluid the nanoparticle volume fraction influences on velocity temperature are presented graphically. The impact of pertinent parameters on velocity and temperatures are resolute and details are mentioned through several plots. The coefficient of skin friction and local Nusselt number for different pertinent parameters are discussed and presented graphically.***

Index Terms: Mixed convection, nanofluids, nano particle volume fraction, vertical circular cylinder, magnetic parameter, heat source parameter, radiation parameter.

I. INTRODUCTION

The nanofluids are of colloidal suspensions of nano particles in the base fluids are water, engine oil & ethylene glycol. Nano particle(s) are used in the nanofluids made by metals such as aluminum, titanium, copper and metallic oxides. Thermal conductivity increases on adding nanofluids to ordinary fluids. Characteristics of nanofluids will create a relation between molecular and micro structure. Owing to these remarkable quality's of nanofluids possess generous significance in many heat transfer process like fuel cell, micro-electronics, hybrid power engines, automobile drug delivery and cancer therapy etc. Initially Choi [1] has presented the idea of nanofluid to grow innovative heat transfer fluids along with considerably higher conductivities. The thermal conductivities of different nanofluids shows that the volume fractions of suspended units is the efficient parameter in improving thermal conductivity was measured by Wang and Leon [2]. Hwang et al. [3]. Chamkh and Rashed [4] examined the stable state of allowed convections to flow past a leaky vertical cones implanted in a nanofluids filled with permeable mediums under the unvarying lateral heat with mass flux. It was determined that growth in Lewis quantity increases Sherwood and local Nusselt numbers. The steady varied convection flow on horizontal rounded cylinder by continuous heat flux in porous mediums filled with nanofluid was investigated by Tham et al. [5]. They detected that Brownian motion parameter and buoyancy ratio parameter affects the fluids flow & heat transfer profile(s).

The Unsteady allowed convection movement past a semi infinite perpendicular plate along with continuous heat flux in water centered nanofluid(s) was discovered by Narahari[6]. Five dissimilar kinds of water centered nanofluid containing Cu, Al2O3, Ag, TiO2 & CuO nano particles were taken for the study of the fluid flow property's along with different time & solid volume fractions parameter. It is observed that the average Nusselts number for nanofluid is greater than pure fluids (water). Local skin frictions is greater for pure fluids when matched to the nano fluids. New aspects of homogeneous and heterogeneous reactions with different thickness in nanofluids with carbon nanotube were examined by Taswar hayat et al[7]. They examined homogeneous & heterogeneous responses and internal thermal generations in Darcy-Forchhimer movement of nano fluids along with dissimilar base fluids. Flow generates due to a non-linear expandable surface of different thickness. The properties of nanofluid were examined using CNTs (single, double & multi walled carbon nanotube(s)). Equivalent diffusion constants are considered for all reactant(s) & auto catalyst. Average square remaining residual error was calculated. The best solution was expressions of temperature, velocity & concentration are explored using plots by different values of the physical parameters. Ishek *et al.* [8] examined the effect of injection & force on the stable mixed convections on boundary layer flow along with vertical slight cylinder with a allowed stream velocity & a wall external temperatures proportional to axial distance along with the surface of cylinder. Dinarvend et al. (9) analyzed homotopy analysis methods for varied convective edge layer movement of a nano fliud on vertical rounded cylinder. They examined three dissimilar types of nano-particles, titania (TiO2), alumina (Al2O3) & copper (Cu) along with water as base fluid.

Manuscript published on 30 March 2019.
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For water-copper nanofluid, graphical outcomes were presented to explain the effect of the nano particles volume fraction over the velocitys & temperature field(s) for forced and varied convections, the feature(s) of flow & heat transfer property's are analyzed & conversed for the nanofluids. It was observed that skin frictions coefficient & heat transfer rate at the surface were high for water-copper nanofluids compared to water-alumina & water-titania nano fluids.

II. MATHEMATICAL FORMULATION

Consider the axisymmetric mixed convective boundary layer flow of a nanofluid over a vertical circular cylinder under the influence of external magnetic field, heat source and radiation. The main stream velocity is assumed as U(x), temperature of the ambient nanofluid as T_∞, and the temperature of the cylinder as $T_w(x)$. Using these assumptions and using the proposed model of the Tiwari and Das the governing equations of the boundary layer are

$$\frac{\partial}{\partial x}(ru')+\frac{\partial}{\partial r}(rw')=0 \qquad (1)$$

$$u'\frac{\partial u'}{\partial x}+w'\frac{\partial u'}{\partial r}=U\frac{dU}{dx}+\upsilon_{nf}\left(\frac{\partial^2 u'}{\partial r^2}+\frac{1}{r}\frac{\partial u'}{\partial r}\right) \qquad (2)$$
$$+\frac{\varphi\rho_s\beta_s+(1-\varphi)\rho_f\beta_f}{\rho_{nf}}g(T-T_\infty)-\sigma B^2\frac{u'}{\rho_{nf}}$$

$$u'\frac{\partial T}{\partial x}+w'\frac{\partial T}{\partial r}=\alpha_{nf}\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right) \qquad (3)$$
$$+\frac{1}{r(\rho C_P)_{nf}}\frac{\partial}{\partial r}\left(\frac{r16\sigma^* T_\infty^3}{3k^*}\frac{\partial T}{\partial r}\right)+\frac{Q_0}{(\rho C_p)_{nf}}(T-T_\infty)$$

The corresponding boundary conditions are:

$$u'=w'=0,\ T=T_w(x)=T_\infty\Delta T\left(\frac{x}{l}\right),\ \text{at } r=b\ ,$$

$$u'=U(x)\rightarrow U_\infty\left(\frac{x}{l}\right), T\rightarrow T_\infty,\ \text{at } r\rightarrow\infty \qquad (4)$$

In the above equations, x and rare Cartesian co-ordinates measured in the axial and radial directions, respectively, u' and w' are the velocity components along x and r directions, T is the temperature of a nanofluid, l is characteristic length of the cylinder, b is radius of the cylinder β_s, β_f are thermal expansion coefficients of solid and fluid fraction, g is acceleration due to gravity, ρ_{nf} is density of the nano fluid, ρ_s & ρ_f are the densities of the solid and fluid fractions, σ is electrical conductivity, B is magnetic field strength, σ^* Stefen- boltzman constant, and k^* is absorption coefficient , υ_{nf} is the kinematic viscosity of the nanofluid and α_{nf} is the thermal diffusivity of the nanofluid, which are given by

$$\nu_{nf}=\frac{\mu_f}{(1-\varphi)^{2.5}[(1-\varphi)\rho_f+\varphi\rho_s]} \qquad (5)$$

$$\rho_{nf}=(1-\varphi)\rho_f+\varphi\rho_s \qquad (6)$$

$$\alpha_{nf}=\frac{k_{nf}}{(\rho C_p)_{nf}} \qquad (7)$$

$$(\rho C_p)_{nf}=(1-\varphi)(\rho C_p)_f+\varphi(\rho C_p)_s \qquad (8)$$

$$\frac{k_{nf}}{k_f}=\frac{(k_s-2k_f)-2\varphi(k_f-k_s)}{(k_s+2k_f)+\varphi(k_f-k_s)} \qquad (9)$$

where φ is the nanoparticle volume fraction, k_{nf} is the thermal conductivity of the nanofluid, k_f & k_s are the thermal conductivities of the fluid and of the solid fractions μ_f is dynamic viscosity of the fluid and $(\rho C_p)_{nf}$ is the heat capacity of the nanofluid $(\rho C_p)_f$ is heat capacity of the base fluid. $(\rho C_p)_s$ is heat capacity of solid particle.

III. METHOD OF SOLUTION

The following similarity transformations are introduced to solve the equations (1-3)

$$\psi=\sqrt{\frac{U_\infty\upsilon_f b^2}{l}}xf(\eta)\ ,\qquad T-T_\infty=\Delta T\frac{x}{l}\theta(\eta),$$
$$\eta=\frac{r^2-b^2}{2\upsilon_f l}\sqrt{\frac{U_\infty\upsilon_f l}{b^2}} \qquad (10)$$

The stream function ψ is defined as

$$u'=\left(\frac{1}{r}\frac{\partial\psi}{\partial r}\right), w'=-\left(\frac{1}{r}\frac{\partial\psi}{\partial x}\right) \qquad (11)$$

By using the similarity transformations (10) equations (1-3) are transformed to the following dimensionless non – linear ordinary differential equations.

$$\frac{1}{(1-\varphi)^{2.5}\left[1-\varphi+\varphi\left(\frac{\rho_s}{\rho_f}\right)\right]}[(1+2\gamma\eta)f'''+2\gamma f'']+ff''-f'^2+$$
$$\frac{(1-\varphi)+\varphi\left(\frac{\rho_s}{\rho_f}\right)\left(\frac{\beta_s}{\beta_f}\right)}{(1-\varphi)+\varphi\left(\frac{\rho_s}{\rho_f}\right)}\lambda\theta-Mf'+1=0$$
(12)

$$\frac{1}{Pr}\left[\frac{\left(\frac{k_{nf}}{k_f}\right)}{(1-\varphi)+\varphi\left(\frac{(\rho c_p)_s}{(\rho c_p)_f}\right)}\right]\left(1+\frac{4}{3}Nr\right)[(1+2\eta\gamma)\theta''+2\gamma\theta']+$$
$$f\theta'-\theta f'+\delta\theta=0$$
(13)

Subject to the boundary condition

$$f(0)=0,\ f'(0)=0,\ f'(\infty)=1$$
$$\theta(0)=1, \theta(\infty)=0 \qquad (14)$$

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Where

$$\gamma = \sqrt{\frac{\nu_f l}{U_\infty b^2}} \quad \text{(Curvature parameter)}$$

$$Gr = \frac{g\beta_f \Delta T l^3}{\nu_f^2} \quad \text{(Grashof number)}$$

$$\mathrm{Re} = \frac{U_\infty l}{\nu_f} \quad \text{(Reynolds number)}$$

$$Pr = \frac{k_f}{\mu_f C p_f} \quad \text{(Prandl number)}$$

$$\lambda = \frac{Gr}{\mathrm{Re}^2} \quad \text{(Mixed convection parameter)}$$

$$M = \frac{\sigma_{nf} B^2 l^2}{\rho_{nf} U_\infty} \quad \text{(Magnetic parameter)}$$

$$Nr = \frac{4\sigma^* T_\infty^3}{k_{nf} k^*} \quad \text{(Thermal radiation parameter)}$$

$$\delta = \frac{Q_0 l}{(\rho C_p)_{nf} U_\infty} \quad \text{(Heat source parameter)}$$

The physical quantities of engineering interest in this problem are the skin friction coefficient C_f and local Nusselt number Nu which are defined by

$$C_f = \frac{\tau_w}{\rho_f u_\infty^2} \qquad Nu = \frac{l q_w}{k_f \Delta T} \qquad (15)$$

In the above equations τ_w is the shear stress at the surface of the cylinder and q_w is the surface heat flux of the cylinder and are given by

$$\tau_w = \mu_{nf}\left(\frac{\partial u}{\partial r}\right)_{r=b}, q_w = -k_f\left(\frac{\partial T}{\partial r}\right)_{r=b} \qquad (16)$$

Using equations (15),(16) and (10) we get

$$\sqrt{Re}C_f = \frac{\bar{x}}{(1-\varphi)^{2.5}} f''(0) \quad , \quad \frac{1}{\sqrt{Re}} Nu = -\frac{k_{nf}}{k_f}\bar{x} \quad \theta'(0)$$

(17)

Where $\bar{x} = \frac{x}{l}$

The ordinary differential equations (12) and (13) are highly non-linear and coupled. These equations are solved using method of Runge-Kutta Fehlberg with shooting technique with the boundary conditions (14) and attained numerical solutions.

Table.1: The fluids, nanoparticles and its Thermo physical properties

Thermo Physical Properties	Fluids		Nano Particles
	Water	Kerosene	Al_2O_3
$C_p[Jkg^{-1}K^{-1}]$	4179	2090	765
$\rho[kgm^{-3}]$	997.1	783	3970
$k[Wmk^{-1}]$	0.613	0.145	40
$\beta \times 10^{-6}\ (20^0 C)$	214	990	24

IV. RESULTS AND DISCUSIONS

The effect of Aluminium (Al_2O_3) nanoparticle on convective nano fluid flow is studied. To calculate thermo physical properties of metals the Values of ***table.1*** is considered. The Pandtl number for water is taken as 6.2 and the Pandtl number for kerosene is taken as 23.6. The nanoparticle volume fraction is very less and it is taken between 0 and 0.1. If $\varphi = 0$ the fluid is Called Newtonian fluid. For heated cylinder the mixed convention parameter $\lambda > 0$ the considered as assisting flow, for cooled cylinder $\lambda < 0$ the flow considered as opposing flow and $\lambda = 0$ be similar to forced convection flow ($T_w = T_\infty$). The velocity and temperature profiles of different pertinent parameters in Al_2O_3-water and Al_2O_3-kerosene nano fluids are studied graphically **for $\gamma = 2, \delta = 0.4, M = 10, Nr = 0.05$**. The co efficient of skin friction and nusselt numbers are also discussed graphically. **Fig 1 and Fig 2** illustrates the impact of the dissimilar nanoparticle volume fractions on the velocity and temperature profiles in the forced convection by Al_2O_3-water and Al_2O_3-kerosene nano fluids ($\lambda = 0$). It can be observed that for increased values of nano particle volume fractions velocities decreases. There is no significant change in temperature for increased values of nano particle volume fractions in Al_2O_3-water where as in Al_2O_3-kerosene temperature increases.

Fig.3 and Fig.4 shows the effect of mixed convection parameter λ in Al_2O_3-water and Al_2O_3-kerosene. For increasing values of λ the velocity increases within the region $0 \le \eta \le 3$ and there is no significant change further in Al_2O_3-water where as it decreases within the region $0 \le \eta \le 4$ and there is ignorable change for $\eta \ge 4$ in Al_2O_3-kerosene. The temperature contours decreases and the curve concave upwards in Al_2O_3-water and increases in the mid region significantly between $0 \le \eta \le 4$ in Al_2O_3-kerosene for growing values of λ. **Fig.5 & Fig.6** portraits variation of curvature parameter on velocity and temperature profiles. The increasing values of curvature parameter γ, there no significant change in velocity profiles and temperature profiles decreases gradually in both Al_2O_3-water and Al_2O_3-kerosene.

The effect of Magnetic parameter **(M)** on Al_2O_3-water and Al_2O_3-kerosene nano fluids are discussed in **Fig 7 and Fig 8.**It is clear that, increase in the strength of '**M**' is to diminish velocity in the Al_2O_3-water nano fluid. This decrease can be ascribed to the way that transverse magnetic field gives rise to repelling type of force recognized as Lorentz force. This force tends to slow down the motion of the fluid and consequently velocity depreciates. The velocity increases in $0 \le \eta \le 1.7$ after that it decreases gradually in Al_2O_3-kerosene. The temperature is found to enhance with magnetic field parameter. Consequently there is an expansion in the thickness of the thermal boundary layer in the fluid since the fluid is decelerated, energy is dissipated as heat and this facilitates to increase temperature in the thermal boundary layer. The influence of thermal radiation parameter 'Nr' can be seen in **Fig.9**.

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For increasing values of 'Nr' the temperature decreases in Al_2O_3- Water and the temperature decreases gradually and concave upwards in Al_2O_3-kerosene. In **Fig.10 & 11** the heat source parameter δ and Prandl number 'Pr' both increases as temperature increases.

The skin friction coefficient increases for increasing values of nano particle volume fraction ϕ in both Al_2O_3- water and Al_2O_3-kerosene, the increasing values of the nusselt number decreases as in Al_2O_3- water but increases in opposite direction in Al_2O_3-kerosene as shown in **Fig.12. Fig.13** shows that the skin friction coefficient increases in both Al_2O_3- water and Al_2O_3-kerosene, the nusselt number increases as in Al_2O_3- water but decreases in Al_2O_3-kerosene for increasing values of mixed convection parameter λ. The co efficient of skin friction coefficient and nusselt number increases for increasing values of curvature parameter γ, decreases for increasing values of magnetic parameter **M** in both Al_2O_3- water and Al_2O_3-kerosene as shown in **Fig.14 & 15.**

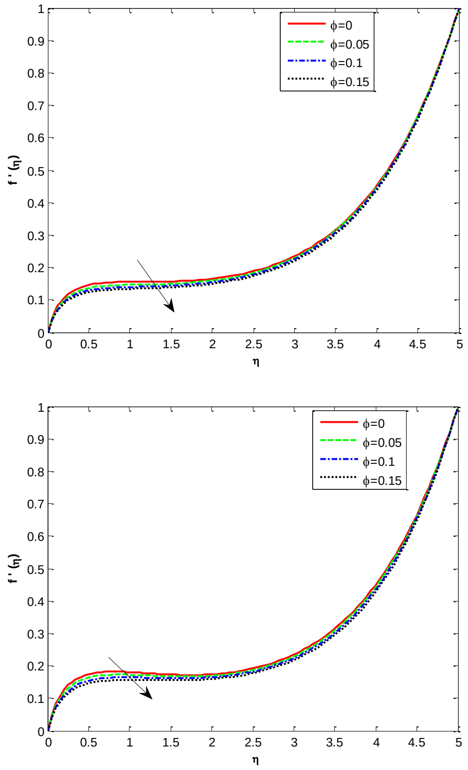

Fig.1: Velocity contours for nano particle volume fractions in Al_2O_3- water, Al_2O_3-kerosene of nano fluid for $M = 10, \delta = 0.4, Nr = 0.1, \lambda = 1, \gamma = 2$

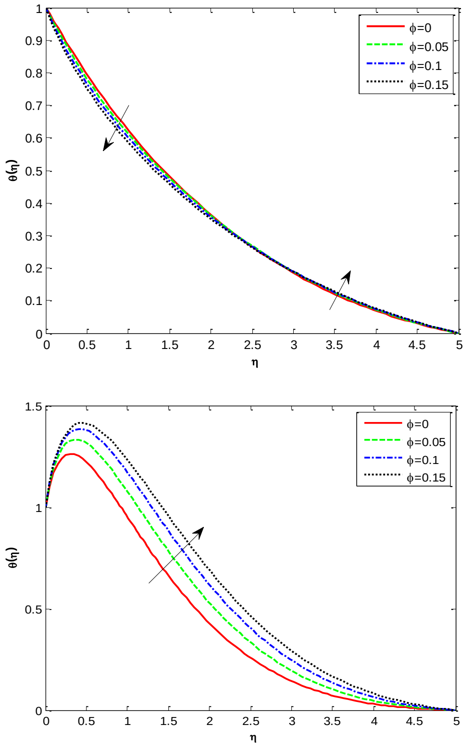

Fig.2: Temperature contours for nano particle volume fractions in Al_2O_3- water, Al_2O_3-kerosene of nano fluid for $M = 10, \delta = 0.4, Nr = 0.1, \lambda = 1, \gamma = 2$

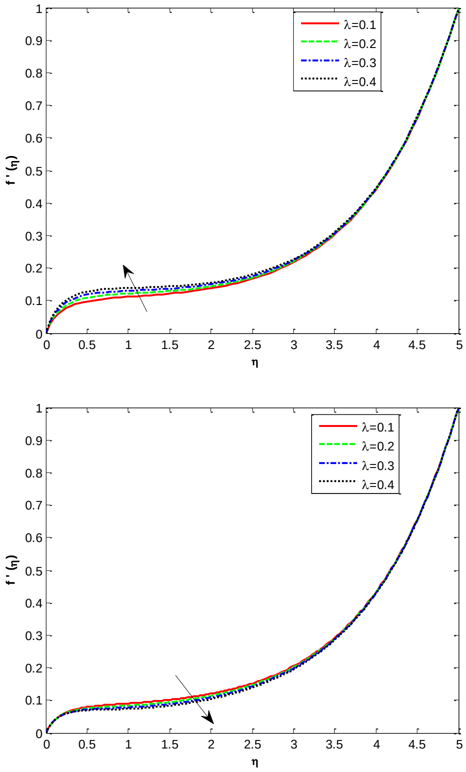

Fig.3: Velocity contours for values of λ in Al_2O_3- water, Al_2O_3-kerosene of nanofluid for $M = 10, \delta = 0.4, Nr = 0.1, \phi = 0.05, \gamma = 2$

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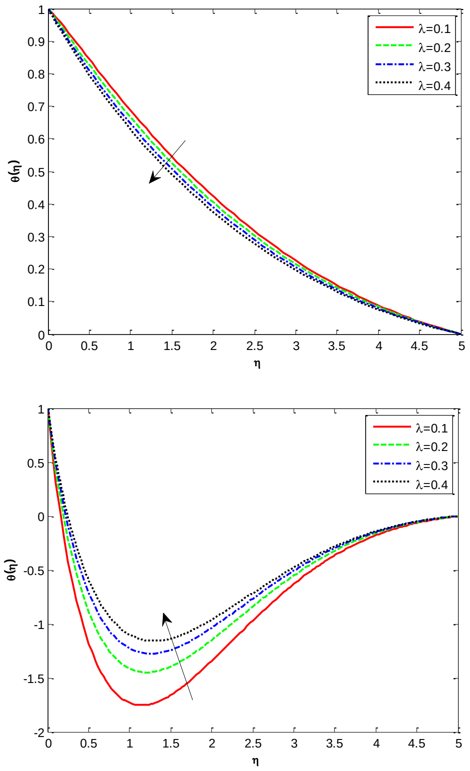

Fig.4: Temperature contours for different values of λ in Al_2O_3- water, Al_2O_3-kerosene of nano fluid for $M = 10, \delta = 0.4, Nr = 0.1, \phi = 0.05, \gamma = 2$

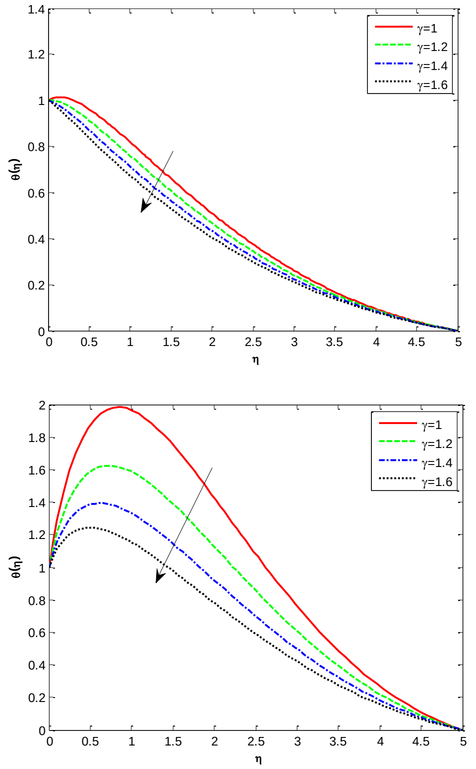

Fig.6: Temperature contours for different values of γ in Al_2O_3- water, Al_2O_3-kerosene of nano fluid for $M = 10, \delta = 0.4, Nr = 0.1, \lambda = 1, \phi = 0.05$

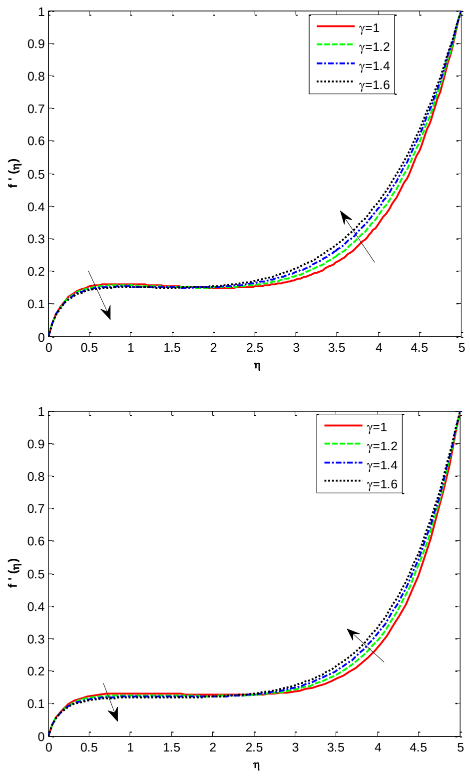

Fig.5: Velocity contours for different values of γ in Al_2O_3-water, Al_2O_3-kerosene of nano fluid for $M = 10, \delta = 0.4, Nr = 0.1, \lambda = 1, \phi = 0.05$

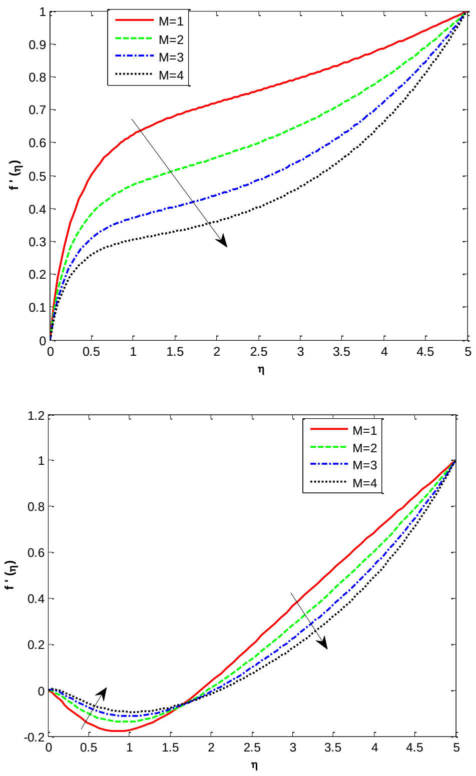

Fig.7: Velocity contours for different values of M in Al_2O_3-water, Alumina-kerosene of Nanofluid for $\phi = 0.05, \delta = 0.4, Nr = 0.1, \lambda = 1, \gamma = 2$

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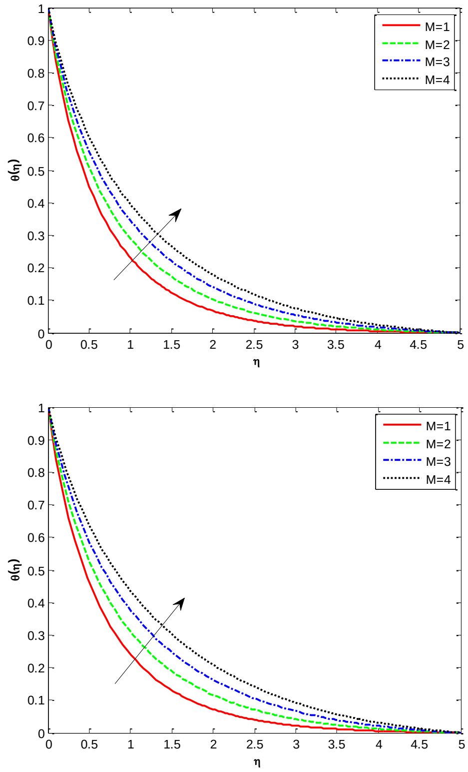

Fig.8: Temperature contours for different values of M in Al_2O_3- water Al_2O_3-kerosene of Nanofluid for $\phi = 0.05, \delta = 0.4, Nr = 0.1, \lambda = 1, \gamma = 2$

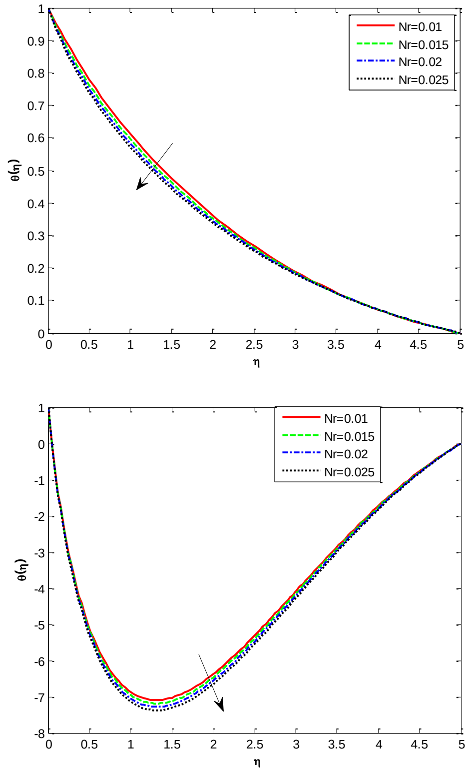

Fig.9: Temperature contours for different values of Nr in Al_2O_3- water, Al_2O_3-kerosene of Nano fluid for $M = 10, \delta = 0.4, \phi = 0.05, \lambda = 1, \gamma = 2$

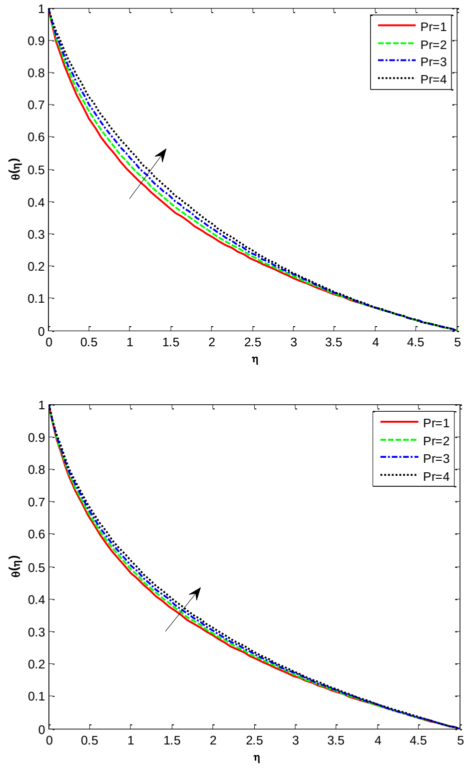

Fig.10: Temperature contours for different values of Pr in Al_2O_3- water, Al_2O_3-kerosene of Nano fluid for $M = 10, \delta = 0.4, Nr = 0.1, \lambda = 1, \gamma = 2, \phi = 0.05$

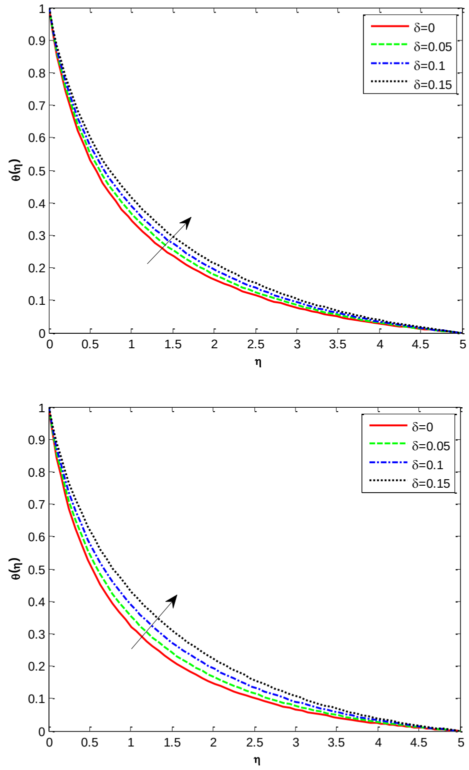

Fig.11: Temperature contours for different values of δ in Al_2O_3- water, Al_2O_3-kerosene

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of Nano fluid for $M = 10, \phi = 0.05, Nr = 0.1, \lambda = 1, \gamma = 2$

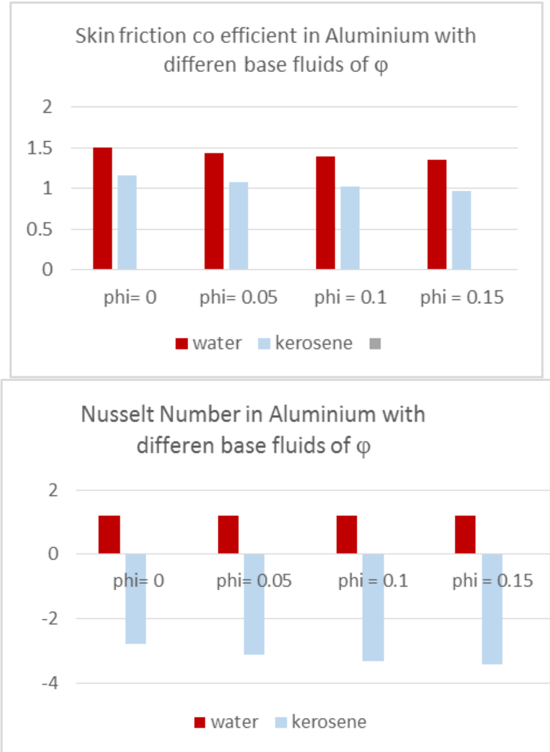

Fig.12: The coefficient of skin friction and local nusselt number meant for different values of ϕ in Al_2O_3-water and Al_2O_3-kerosene nano fluids.

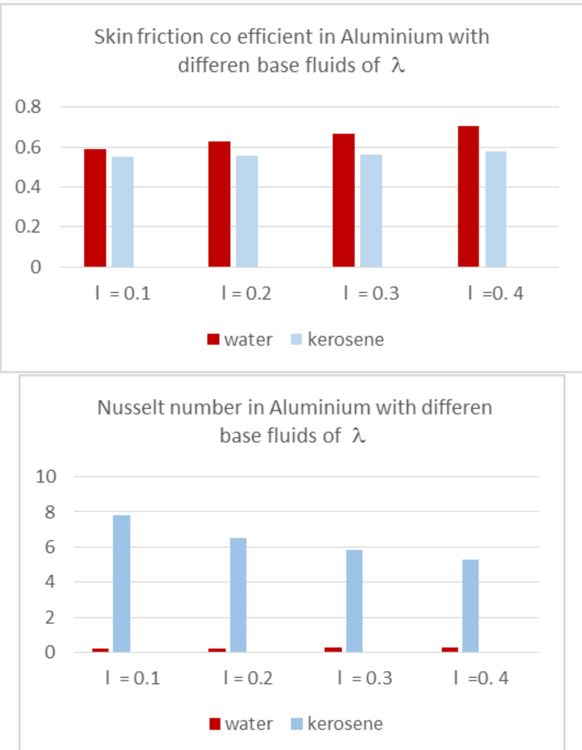

Fig.13: The coefficient of skin friction and local nusselt number meant for different values of λ in Al_2O_3-water and Al_2O_3-kerosene nano fluids.

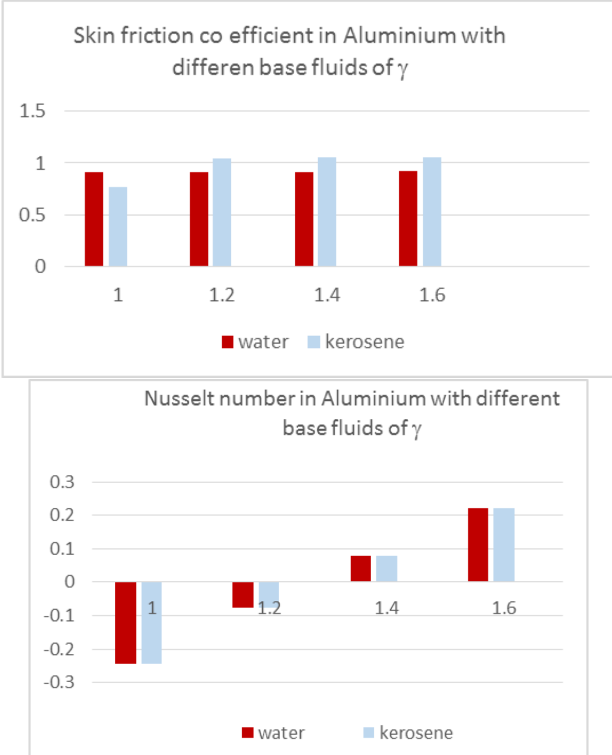

Fig.14: The coefficient of skin friction and local nusselt number meant for different values of γ in Al_2O_3- water and Al_2O_3-kerosene nano fluids.

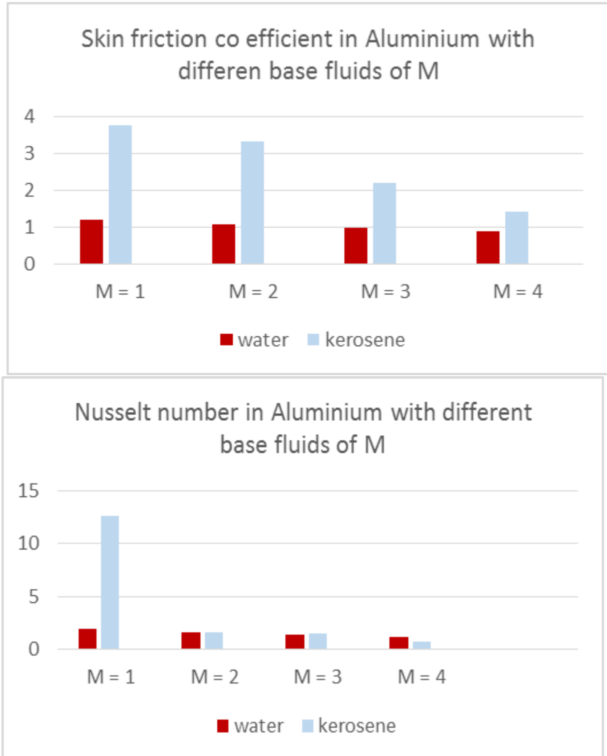

Fig.15: The coefficient of skin friction and local nusselt number meant for different values of M in Al_2O_3- water and Al_2O_3 -kerosene nano fluids.

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V.CONCLUSIONS

1. For expanding estimations of mixed convection parameter the temperature contours decrease in Al_2O_3-water and increase in Al_2O_3-kerosene.
2. For the increasing values of curvature parameter there is no significant change in velocity profiles and temperature profiles decreases gradually in each Al_2O_3-water and Al_2O_3-kerosene.
3. Increase in the strength of '**M'** is to diminish velocity in the Al_2O_3-water nano fluid and the velocity increases in some extent after that it decreases gradually in Al_2O_3-kerosene.

The temperature is found to enhance with magnetic field parameter.

4. The heat source parameter and Prandl number both increases as temperature increases.
5. The skin friction coefficient increases in both Al_2O_3- water and Al_2O_3-kerosene,the nusselt number increases in Al_2O_3- water but decreases in Al_2O_3-kerosene for the increasing values of mixed convection parameter λ.
6. The skin friction coefficient and nusselt number increases as increasing values of curvature parameter γ, decreases for increasing values of Magnetic parameter **M** in both Al_2O_3- water and Al_2O_3-kerosene.

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Blue Eyes Intelligence Engineering
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