March - April 2020
ISSN: 0193-4120 Page No. 10891 - 10899

Mixed convective flows on Al_2O_3 – Engine oil nano fluid under the influence of thermal radiation & magnetic field over a vertical circular cylinder

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Abstract: The Present study investigates a vertical circular cylinder immersed in mixed convective fluid and the effect of boundary layer flow over of a nano fluid Alumina (Al_2O_3) nano particle with engine oil as the base fluid was studied under the impact of magnetic field, thermal radiation with suggested external flow. The radiative heat loss is modelled by Rosseland estimations. The partial differential equations are modified into ordinary differential equations by using similarity variables. The technique of Runge- Kutta – Fehlberg with shooting is used to solve modified ODE numerically. The influences on velocity and temperature contours for Alumina Engine oil nanofluid the nanoparticle volume fraction are obtainable through plots. The impact of various pertinent parameters on velocity and temperatures Profiles are analyzed through numerous plots. The co-efficient of skin friction &Nusselt number for various relevant parameters are calculated and values are tabulated.

Keywords: *Risk Mixed convection parameter, Magnetic parameter, Nusselt number, Nano particle volume fraction, Prandtl number, Skin friction coefficient and Thermal radiation parameter.*

I. INTRODUCTION

Now a days, the improvement for energy efficiency in heat-transfer fluid(s) are necessary in the process of cooling. The conventional fluids like water, engine oil & ethylene-glycol plays an important part for heat-transfer in industrial process(s) such as power-generation process, cooling and heatingprocess, chemical processes and micro- electronics. The application of solid particle(s) as additional substance is deferred in to the base-fluid is a method for the heat-transfer development since any solid metal(s) have more “thermal conductivity” than a “conventional fluid”. “**N**ano fluid”, is a fluid having “Nano meter” sized particles. These Nano meter sized particles can alter the “transport and thermal” features of the “base fluid” significantly. Nano fluid(s) plays important role in the industry of transportation, atomic reactors, fuel cells, industrial cooling, fuel cells, and hybrid engine(s), cooling electronic component(s), military fields, medical fields and aerospace application(s).

Eventually Choi [1] has developed the idea of nanofluid to grow advanced heat-transfer fluid(s) along with significantly greater conductivities. Thermal conductivities of different nanofluids illustrates the volume fractions of deferred units is the efficient parameter in improving thermal conductivity was measured by Wang and Leon [2]. Hwang et al. [3]. Chamkh and Rashed [4] observed the stable state of allowed convections to flow past a leaky vertical cones implanted in nanofluids packed with permeable mediums under consistent "lateral heat" with mass flux. It is used to determine the growth in Lewis quantity increases Sherwood coefficient and local Nusselt numbers. The steady of various convection flow on horizontal rounded cylinder by continuous heat flux of porous mediums packed with nanofluid was examined by Tham et al. [5]. They noticed that "Brownian motion" parameter and "buoyancy ratio" parameter moves the fluids flow and also heat transfer profile(s).

The Instable allowed convection movement past a semi-infinite perpendicular plate along with continuous heat flux in H2O centered nanofluid(s) was discovered by Narahari[6]. Five dissimilar kinds of water centered nanofluid containing Al2O3, Cu, Ag &TiO2 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 typical "Nusselt number" for nanofluid(s) is greater in pure fluids (H2O). Native skin frictions is greater for pure fluid(s) when matched with the nanofluid.

New features for homogeneous and heterogeneous reaction(s) with different thickness of nanofluids with carbon nanotube were studied by Taswarhayat et al[7]. They detected homogeneous & heterogeneous responses & internal thermal generations in Darcy-Forchhimer movement of nano fluids in dissimilar base fluid(s). Flow causes outstanding to a non-linear expandable surface with different thickness. Properties of nanofluids were studied with CNTs. The best solution was expressions of temperature, velocity & concentration will be explored using plots with numerous values of the physical parameter(s).

Ishek*et al.* [8] examined the effect using 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 the axial distance along with the surface of a cylinder".Dinarvend et al. (9) analyzed "homotopy analysis" methods for various convective edge layer movement of nanofliud on vertical rounded cylinder. They inspected three dissimilar kinds of nano-particles, copper (Cu), titania (TiO2) & alumina (Al2O3) along with H2O as base fluid.

Many researchers worked on "Soret and radiation effects" of unstable flow of a "casson fluid" through different porous vertical channels [12-16]. Some of the researchers worked on MHD heat transfer stream among two moving parallel plate(s) of a dusty viscoelastic fluid, radiation effects, suction or injection on top of a stretching surface, hall currents & non Newtonian fluids [17-24].

Vijaya, N. et al.[25] unfaltering axisymmetric blended convective limit layer stream of a nanofluid over a vertical round chamber affected by warm radiation, heat age and attractive power with recommended outer stream was examined. They utilized two distinct kinds of nano particles like Titania& Copper with water as the base liquid. Radha Madhavi, M. et al. [26] studied the impact of magnetic field, external surface temperature & heat radiation in the diversified convective flow(s) over a vertical circular-cylinder on nanofluids with different base fluids. For Al-water & Al-kerosene, nanofluids the nano-particle(s) volume fraction (φ) influence on velocity and temperature is illustrated graphically. The important impact on relevant parameters on velocity & temperature are determined & details are discussed in several plots.

II. MATHEMATICAL MODELLING

Assume vertical circular cylinder immersed with the axisymmetric mixed convective boundary layer flow of a nano fluid over a under the effect of external magnetic field and thermal-radiation. U(x) is assumed as the main stream velocity, T_∞ is

TEST Engineering & Management

March - April 2020
ISSN: 0193-4120 Page No. 10891 - 10899

the temperature of the ambient nano fluid and the temperature of the cylinder as $T_w(x)$. The proposed model of the principal equations of the boundary layer given by Tiwari and Das are

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

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

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

The resultant boundary conditions are:

$$u'=w'=0,\ T=T_w(x)=T_\infty\Delta T\left(\frac{x}{l}\right),\ \text{at } r=b$$
$$u'=U(x)\to U_\infty\left(\frac{x}{l}\right), T\to T_\infty,\ \text{at } r\to\infty \quad (4)$$

In eq. (1-3) x & r are cartesian co-ordinates in the axial & radial directions correspondingly, the velocity components along x & r directions are u' & w' correspondingly. T is the temperature of a nano fluid, b is considered as radius of the cylinder, l is taken as characteristic length of the cylinder. Which are given by

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

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

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

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

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

Where φ is considered as the nanoparticle volume fraction, k_{nf} is the thermal conductivity of the nano fluid, k_f is the thermal conductivity of the fluid fraction and k_s is the thermal conductivity of the solid fraction. μ_f Is the dynamic viscosity of the fluid fraction and $(\rho C_p)_{nf}$ heat capacity of the nanofluid. $(\rho C_p)_f$ is heat capacity of the base fluid and $(\rho C_p)_s$ is heat capacity of solid particle.

III. NOMENCLATURE

β_s	Thermal expansion coefficients of solid fraction
β_f	Thermal expansion coefficients of fluid fraction
g	Acceleration due to gravity
ρ_{nf}	Density of the nano fluid
ρ_s	Densities of the solid fractions
ρ_f	Densities of the fluid fractions
σ	Electrical conductivity, B is magnetic field strength
σ^*	Stefen- boltzman constant
k^*	Absorption coefficient
υ_{nf}	Kinematic viscosity of the nanofluid
α_{nf}	Thermal diffusivity of the nanofluid
$\gamma=\sqrt{\frac{\nu_f l}{U_\infty b^2}}$	Curvature parameter
$Gr=\frac{g\beta_f\Delta T l^3}{\nu_f^2}$	Grashof number
$\mathrm{Re}=\frac{U_\infty l}{\nu_f}$	Reynolds number
$??? = \frac{??}{?????}$	Prandl number
$\lambda=\frac{Gr}{\mathrm{Re}^2}$	Mixed convection parameter
$M=\frac{\sigma_{nf}B^2 l^2}{\rho_{nf}U_\infty}$	Magnetic parameter
$Nr=\frac{4\sigma^* T_\infty^3}{k_{nf}k^*}$	Thermal radiation parameter

March - April 2020
ISSN: 0193-4120 Page No. 10891 - 10899

IV. SYSTEM OF SOLUTION

To solve the equations (1-3) the similarity transformations are introduced below

$$\psi = x\sqrt{\frac{U_\infty \upsilon_f b^2}{l}}f(\eta)$$

$$T - T_\infty = \frac{x}{l}\Delta T\theta(\eta)$$

$$\eta = \frac{r^2 - b^2}{2\upsilon_f l}\sqrt{\frac{U_\infty \upsilon_f l}{b^2}} \quad (10)$$

The stream function ψ is defined as

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

The equations (1-3) are changed to the subsequent non-dimension non – linear ordinary differential equations by using the similarity transformations in eq.(10) are

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

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

The boundary conditions corresponding to above ODE are

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

The physical quantities are the skin friction coefficient C_f and local Nusselt number Nu which are defined as

$$C_f = \frac{\tau_w}{\rho_f U_\infty^2}\ Nu = \frac{lq_w}{k_f \Delta T} \quad (15)$$

In the equation (15) 'τ_w' is taken as the shear stress on the surface of the cylinder and 'q_w'is taken as the surface heat- flux of the cylinder and are defined as

$$\tau_w = \mu_{nf}\left(\frac{\partial u'}{\partial r}\right)_{r=b}, q_w = -k_f\left(\frac{\partial T}{\partial r}\right)_{r=b} \quad (16)$$

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

$$\sqrt{Re}C_f = \frac{\bar{x}}{(1-\varphi)^{2.5}}f''(0) \quad , \frac{1}{\sqrt{Re}}Nu = -\frac{k_{nf}}{k_f}\bar{x}\theta'(0) \quad (17)$$

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

The ordinary differential equations (12) & (13) are extremely non-linear and coupled. These equations are explained 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
	Engine Oil	Al_2O_3
$C_P[Jkg^{-1}K^{-1}]$	1910	765
$\rho[kgm^{-3}]$	884	3970
$k[Wmk^{-1}]$	0.144	40
$\beta \times 10^{-6}\ (20^0C)$	700	24

V. RESULTS AND DISCUSSIONS

The outcome of Aluminum (Al_2O_3) nanoparticle on convective nano fluid flow with engine oil as base fluid was deliberated. The values of table 1 are considered to analyze "thermo- physical properties" on metals. The "Prandtl number" for engine oil is assumed as 5.2. The "nano-particle volume fraction" is very less and it is taken between 0 and 0.1. If $\varphi = 0$ then the fluid is called as Newtonian fluid. The mixed convention parameter $\lambda > 0$ the flow is considered as supporting flow for heated cylinder and $\lambda < 0$, the flow considered as "opposing flow" for cooled-cylinder and $\lambda = 0$ be similar to obligatory convection flow ($T_w=T_\infty$). The temperature and velocity profiles of different

March - April 2020
ISSN: 0193-4120 Page No. 10891 - 10899

important parameters Al_2O_3-engine oil nano fluids are studied graphically**for**$\boldsymbol{\gamma} = \mathbf{2}, \boldsymbol{\delta} = \mathbf{0.4}, \boldsymbol{M} = \mathbf{10}, \boldsymbol{Nr} = \mathbf{0.05}$. The co-efficient of skin friction & local Nusselt numbers are widely discussed and the values are tabulated.

Fig.1 & Fig.2 illuminates the outcome of the dissimilar nano-particle volume fractions and diverse convection parameter on different velocity profiles in the forced convection by Al_2O_3-engine oil nano fluids. It is observed that for improved values of φ velocities increases in between $0 \leq \eta \leq 1$ and then decreases for $\eta \geq 1$. For increased values of λ the velocities increases between $0 \leq \eta \leq 3.5$ and there no significant change from $\eta \geq 3.5$ onwards.

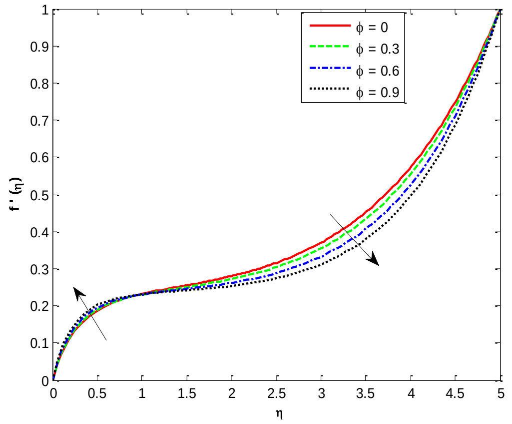

Fig.1: Effect of φ on $f'(\eta)$

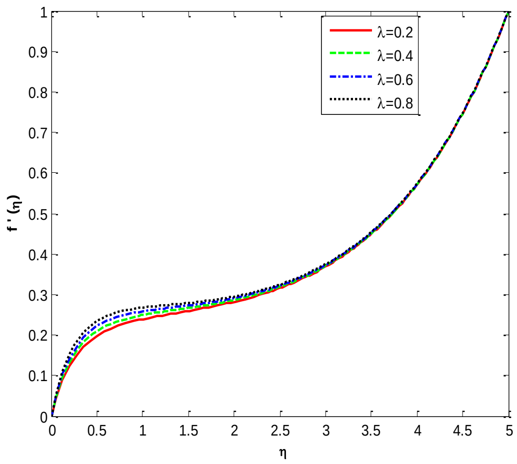

Fig.2: Effect of λ on $f'(\eta)$

Fig.3 and Fig.4 portraits variation of Magnetic parameter **(M)** and curvature parameter **(γ)** on the velocity contours of Al2O3-engine oil nano fluid. It can be observed that growth in the strength of '**M**' is to weaken velocity in Al2O3-engine oil nano fluid. This decrease is recognized to the way that sloping magnetic field gives additional rise to preventing form of force recognized as "Lorentz force". This power tends to careful down the motion of fluid &consequently velocity denigrates. Increasing values in γ increases the velocity & the opposite behavior in velocities can be observe in magnetic and curvature parameters.

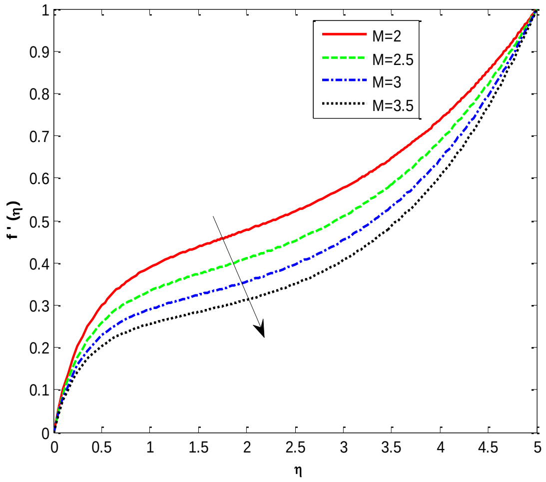

Fig.3: Impact of M on $f'(\eta)$

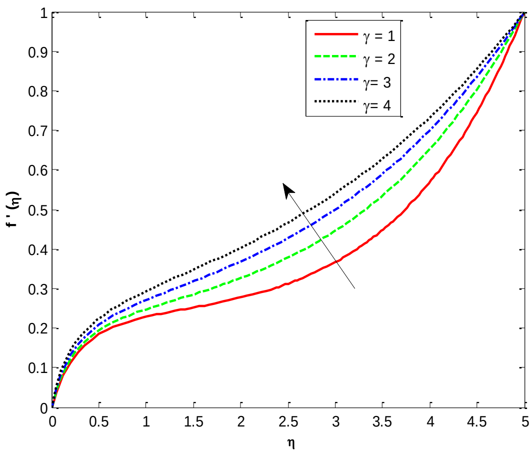

Fig.4: Effect of γ on $f'(\eta)$

Fig.5 demonstrates the impact of the dissimilar "nanoparticle volume fractions" on the different temperature profiles in Al_2O_3- engine oil nano fluid. The parameter φ increases as

March - April 2020
ISSN: 0193-4120 Page No. 10891 - 10899

increasing temperatures. The temperature contours decreases slightly for growing values of λ and it was shown in **Fig.6**

The temperature contours decreases within the region $0 \leq \eta \leq 1.5$ and increases somewhat for $\eta \geq 1.5$ as increasing Curvature parameter in Al_2O_3- engine oil and it can be observed in **Fig.7.**

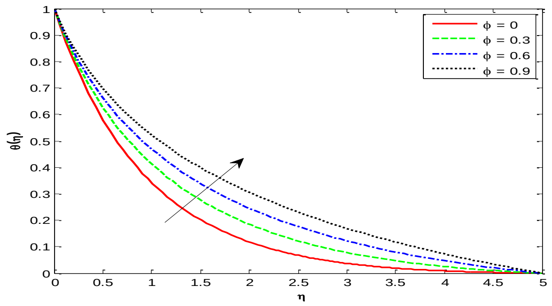

Fig.5: Effect of φ on $\theta(\eta)$

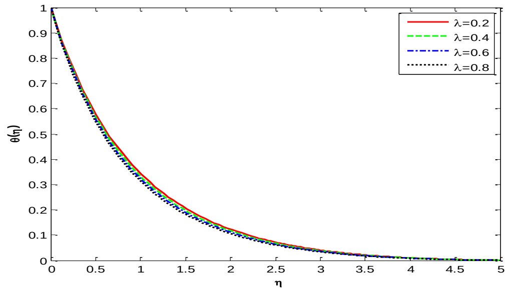

Fig.6: Effect of λ on $\theta(\eta)$

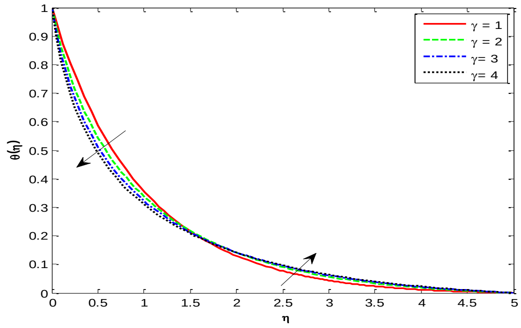

Fig.7: Effect of γ on $\theta(\eta)$

The outcome of Magnetic parameter **(M)**onAl_2O_3- engine oil nano fluid are discussed in **Fig 8.** The temperature is proportionally increasing with magnetic-field parameter. This raises the thickness of thermal boundary layer of fluid since the nano fluid is decreased and energy is dissolute as heat. This initiates the increase in temperature of the thermal boundary layer.

The effect of thermal-radiation parameter ('Nr') is shown in **Figure.9**. For growing values of the temperature 'Nr' increases in Al_2O_3- engine oil. In **Fig.10** the Prandtl number 'Pr' decreases as temperature grows.

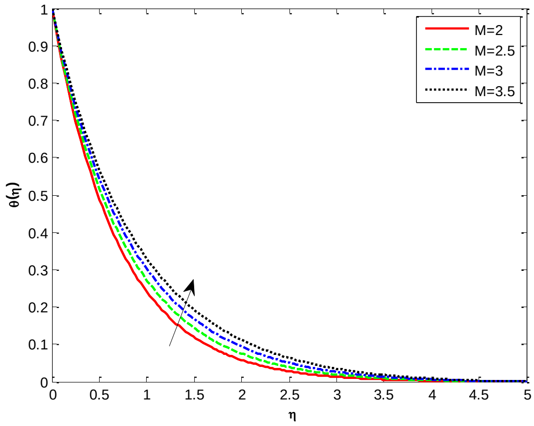

Fig.8: Effect of M on $\theta(\eta)$

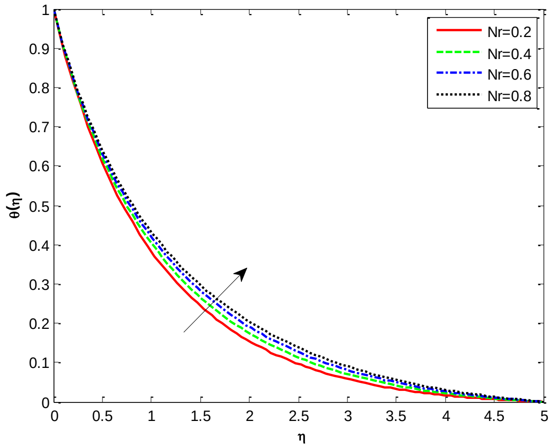

Fig.9: Effect of M on $\theta(\eta)$

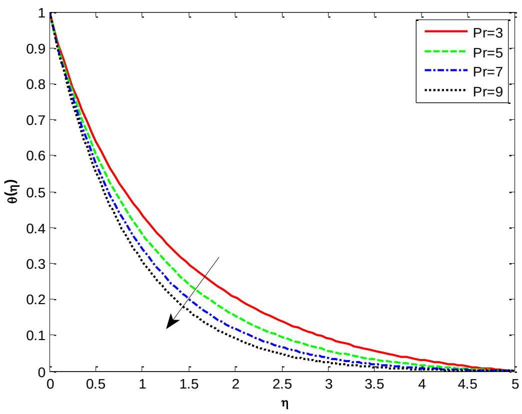

Fig.10: Effect of M on $\theta(\eta)$

Skin friction coefficient raises and Nusselt number comes down for different increasing value(s) of nano particle volume fraction φ. The co efficient of “skin friction” and “Nusselt number” both increases for increasing value(s) of curvature parameter γ and mixed convention parameter(λ) whereas they are decreased for mounting values of magnetic parameter **M.**

There is no noteworthy alteration in the “skin friction coefficient” and the local Nusselt number grows for increasing values for both **Nr & Pr**. The values ofNusselt number & Skin friction coefficient for different pertinent parameter(s) are tabulated in **Table.2.**

Table.2: Nusselt number & Skin friction coefficient values for different pertinent parameter(s)

M	λ	γ	φ	Pr	Nr	$\frac{1}{\bar{x}}(Re)^{\frac{1}{2}}C_f$	$\frac{1}{\bar{x}}(Re)^{-\frac{1}{2}}Nu$
2	0	1	0.05	6.2	0.05	1.190467	1.410291
2.5						1.065721	1.309759
3						0.968473	1.219801
3.5						0.891004	1.138645
	0.2	1	0.05	6.2	0.05	0.91439	1.107123
10	0.4					0.998843	1.146292
	0.6					1.081585	1.182797
	0.8					1.162797	1.217015
10	0	1		6.2	0.05	0.827997	1.06481
		2	0.05			0.972102	1.556492
		3				1.141398	2.021257
		4				1.331492	2.461467
10	0	1	0	6.2	0.05	0.819317	1.077633
			0.3			0.890515	1.005862
			0.6			0.996074	0.937373
			0.9			1.117343	0.863378
10	0	1	0.05	3	0.05	0.827992	0.969504
				5		0.827992	1.029631
				7		0.827997	1.074244
				9		0.827989	1.107835
10	0	1	0.05	6.2	0.2	0.827997	1.035225
					0.4	0.827992	1.0109
					0.6	0.827992	0.99184
					0.8	0.827992	0.976359

VI. CONCLUSIONS

- For expanding estimations of nanoparticle volume fractions the temperature contours increase in Al_2O_3-engine oil.
- The temperature contours decreases within the region $0 \leq \eta \leq 1.5$ and increases somewhat for $\eta \geq 1.5$ as increasing Curvature parameter in Al_2O_3- engine oil.
- The thermal radiation parameter ‘Nr’ increases whenever temperature raises and the

  Prandtl number (‘Pr’) decreases as temperature increases in Al_2O_3- engine oil.
- The co-efficient of skin friction &Nusselt number are increased for increasing values of

curvature parameter γ and mixed convention parameter λ

- There no significant change in the "skin friction coefficient" & the local Nusselt number increases for increasing values of both **Nr & Pr**.

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