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Analytical and Numerical Investigation of Mixed Convection Flow and Boundary Layer Control of a Nano Fluid with Heat Generation

Raj Kumar[1], Valmeti Sudheer[2]

[1]M.Tech in Thermal Engineering from CMR Engineering College, JNTU, Hyderabad, Telangana, India

[2]Professor, CMR Engineering College, JNTU, Hyderabad, Telangana, India

Abstract: ***In this project, boundary layer mixed convection fluid flow, heat transfer generation of a Nano fluid over a semi-infinite flat plate of 50*10*2mm with heat generation effects are investigated analytically. The velocity, Nusselt number, Reynolds number, entropy, heat transfer coefficient profiles as well as skin friction and heat transfer rates are determined for different Prandtl number 0.01, 0.1, 1,10, 100 for different Nano fluids. The base fluid water is mixed with Nano particles of Aluminium oxide, Copper Oxide with different volume fractions 0.4 & 0.6 are considered. The properties of the Nano fluids are calculated theoretically. CFD Fluent analysis is done in ANSYS. The boundary condition for CFD analysis is velocity of fluid which is calculated for different Prandtl number and mixed convection values.***

Keywords: Nano particles, Aluminium oxide, Copper Oxide, Ansys

1. Introduction and Literature Survey

In the paper by **M.Chandrasekar, M. S. Kasiviswanathan [1]**, is focused on the numerical solution of steady MHD mixed convection boundary layer flow of a nanofluid over a semi-infinite flat plate with heat generation/absorption and viscous dissipation effects in the presence of suction and injection. In The Paper by **SatyajitMojumder [2];**A lid-driven L-shaped cavity filled with a porous medium is analyzed. The Galerkin weighted residual method is applied to obtain numerical solutions. The effect of the Reynolds number (Re = 1–100), Grashof number (Gr = 10^3–10^5) and Darcy number (Da = 10 ^{5}–10 ^{3}) on the velocity and temperature fields is examined. For the vertical wall, a higher heat transfer rate is observed when a low Grashofnum-ber, higher Darcy number and higher Reynolds number are applied, but the opposite characteristic is found in the horizontal wall. It is evident that heat transfer decreases up to 63% in the horizontal wall when the flow has a high Reynolds number (Re = 100).

Objective of this paper

- Two fluids Aluminium oxide and Copper oxide are mixed with base fluid water with different volume fractions 0.4 & 0.6. The properties of fluid Viscosity, Density, Thermal Conductivity and Specific heat are calculated theoretically.
- The boundary conditions for CFD analysis are velocity of fluid and mixed convection values. The velocities are calculated for different Prandtl numbers 0.01, 0.1, 1, 10 & 100.
- The outputs determined are outlet velocities, Reynolds number, nusselt number, heat transfer coefficient, skin friction coefficient and heat transfer rates.

2. Proposed Nano Fluid Properties and Calculations

The properties of the Aluminium oxide and Copper oxide Nano fluids mixed with base fluid water are calculated for different volume fractions 0.4 & 0.6 of both fluids.

Formulae: (Quoted from Journals)
Density (ρ):
$\rho_{nf} = Ø\rho_s + (1-Ø)\,\rho_w$
Where
ρ_{nf} = Density of Nano fluid
ρ_s = Density of the substance (Al_2O_3 orCuO)
ρ_w = Density of Base fluid (Water)
Ø = Volume fraction of the substances

Specific Heat (C_P):
$C_{P(nf)} = Ø(c_{ps}) + (1-Ø)\, c_{pw}$
Where $C_{P(nf)}$ = Specific Heat of Nano fluid
c_{ps}= Specific Heatof the substance (Al_2O_3 /CuO)
c_{pw}= Specific Heat of Base fluid (Water)

Thermal Conductivity (K):
$$K_{nf} = \frac{Ks+2Kw+2(Ks-Kw)(1+\beta)^3\times\phi}{Ks+2Kw-(Ks-Kw)(1+\beta)^3\times\phi} \times k_w$$
Where K_{nf} = Thermal conductivity of Nano fluid ;
K_S =Thermal conductivity of the substance (Al_2O_3 /CuO)
K_W= Thermal conductivity of Base fluid (Water)
β = Film temperature

Viscocity (μ):
$$\mu_{nf} = Pr * \frac{k_{nf}}{c_{p(nf)}}$$
Where Pr = Prandtl number

Velocity Calculations by Varying Prandtl Number
Velocities are calculated for different Prandtl number, which is used as inlet in the CFD analysis.

$P_r = {c_p \mu}/{k}$

$\mu = {P_r k}/{c_p}$

$v = {\mu}/{\rho}$

$$\frac{Re\, v}{L} = u(velocity)$$

Re = Reynolds number

v= kinematic Viscosity (m/s^2)

L = length of the component (m)

CFD Analysis

CFD analysis is done on the plate by applying velocity of fluid and using mixed convection flow to determine outlet velocities, Reynolds number, entropy, Nusselt number, Heat transfer coefficient, skin friction coefficient and heat transfer rates.

Aluminum Oxide (Al_2O_3) with VF - 0.4
Prandtl Number: 0.01

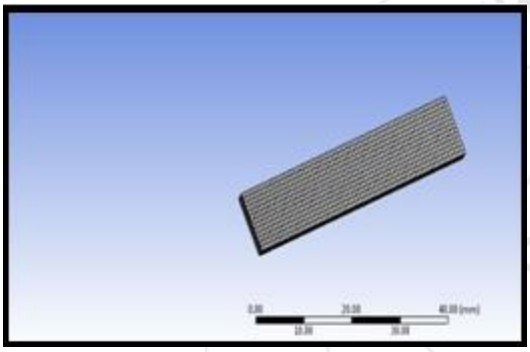

Figure 1: Meshed model

Viscous → edit → k- epslon

Select Viscous Model – Laminar

Boundary conditions → select air inlet → Edit → Enter Inlet Velocity

The velocity values are calculated from the Prandtl number. The mixed convection is considered for the analysis. In wall, select thermal and select Mixed option. Enter heat transfer coefficient of water and free stream temperature.

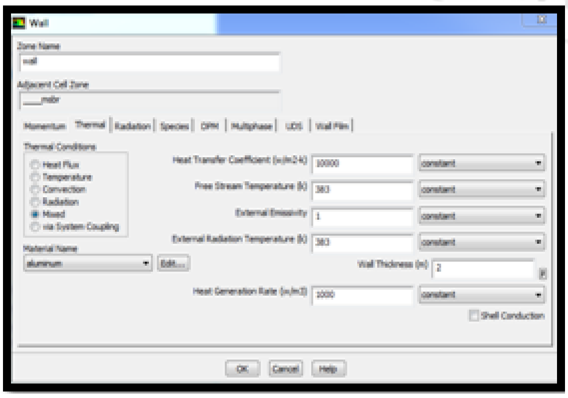

Figure 2: Velocity Inlet for Aluminum oxide with VF 0.4 at Pr = 0.01

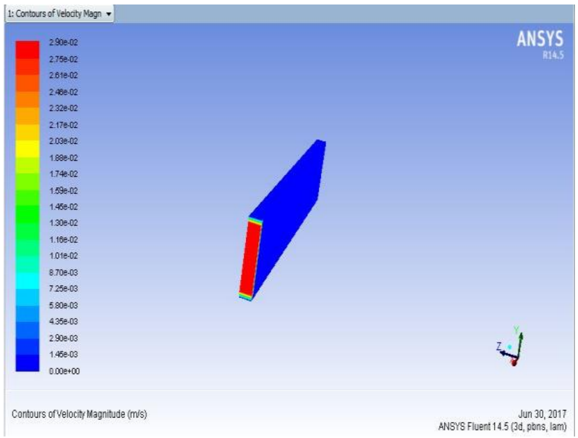

Figure 3: Velocity value for Aluminum oxide with VF 0.4 at Pr = 0.01

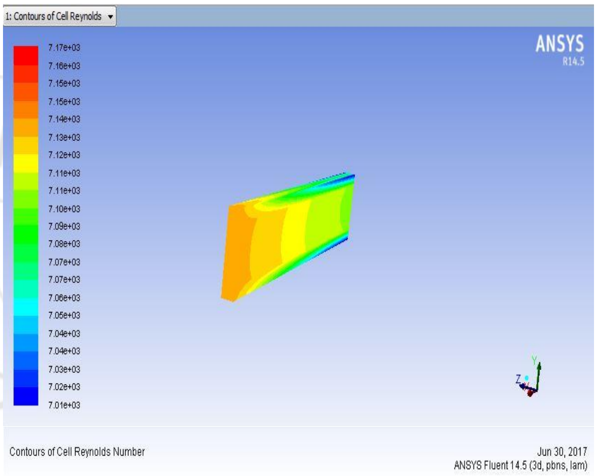

Figure 4: Reynolds number for Aluminum oxide with VF 0.4 at Pr = 0.01

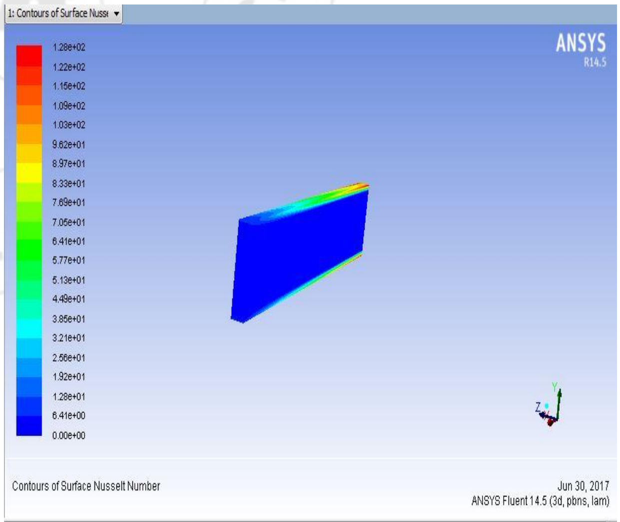

Figure 5: Nusselt number for Aluminum oxide with VF 0.4 at Pr = 0.01

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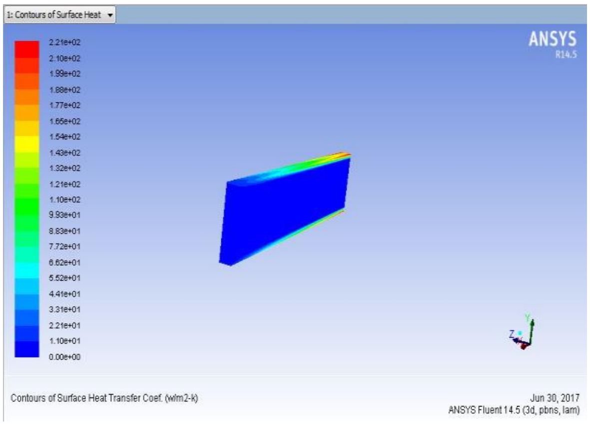


Figure 6: Velocity value for Aluminium oxide with VF 0.4 at Pr = 0.01

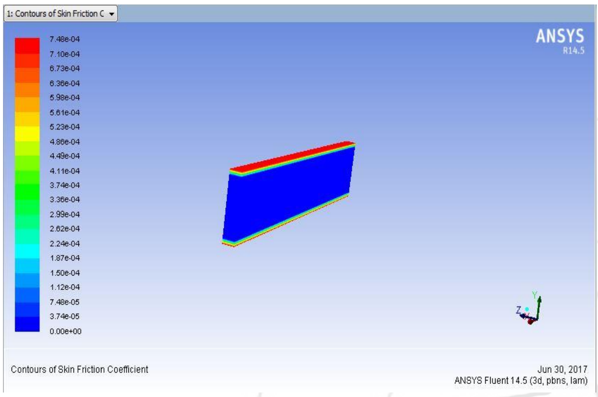
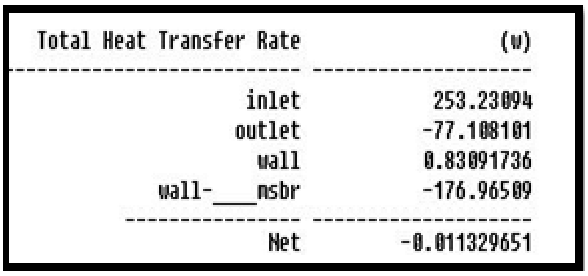


Figure 7: Skin friction coefficient for Aluminum oxide with VF 0.4 at Pr = 0.01



Total Heat Transfer Rate	(w)
inlet	253.23094
outlet	-77.108101
wall	0.83091736
wall-___msbr	-176.96509
Net	-0.011329651

Figure 8: Skin friction coefficient for Aluminum oxide with VF 0.4 at Pr = 0.01

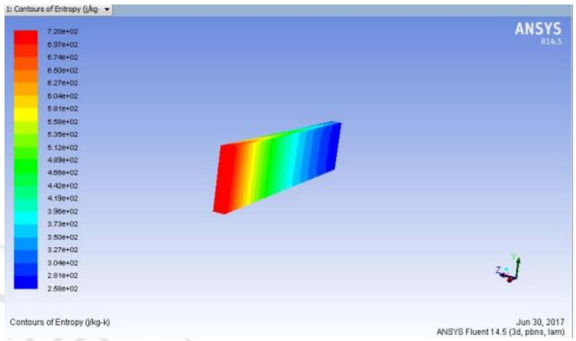


Figure 9: Entropy for Aluminum oxide with VF 0.4 at Pr = 0.01

3. Results & Discussions

Fluid = Al_2O_3 (0.4)

Table 1: Resultant Parameters of the Aluminium oxide Nanofluid @ VF 0.4

	Prandtl Number				
Results	0.01	0.1	1	10	100
Velocity (m/s)	2.90E-02	2.95E-01	2.95E+00	2.95E+01	2.95E+02
Reynolds number	7.17E+03	7.30E+03	7.30E+03	7.30E+03	7.30E+03
Nusselt number	1.28E+02	1.93E+01	7.99E+00	6.87E+00	6.76E+00
Heat Transfer Coefficient (W/m^2-k)	2.21E+02	3.32E+01	1.37E+01	1.18E+01	1.16E+01
Skin friction coefficient	7.48E-04	7.61E-02	7.61E+00	7.61E+02	7.61E+04
Entropy (J/kg-k)	7.20E+02	7.26E+02	7.27E+02	7.27E+02	7.27E+02
Total heat transfer rate (W)	0.011329651	0.08340928	0.078575537	1.857763	8.6138779

Graphs

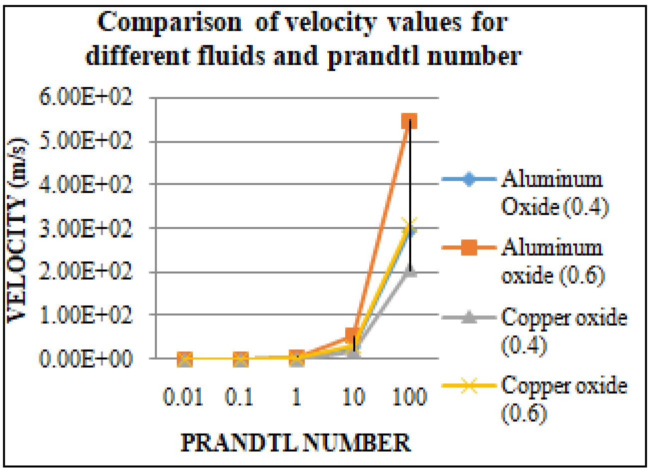


Figure 10: Comparison of velocity values for different fluids and Prandtl number

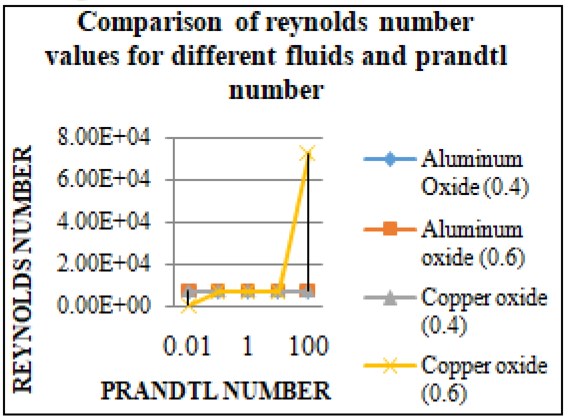


Figure 11: Comparison of Reynolds number for different fluids and Prandtl number

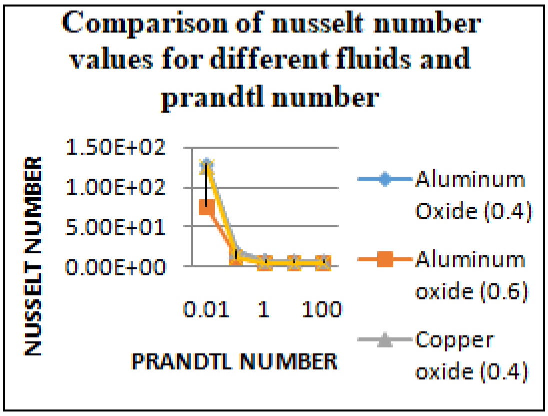


Figure 12: Comparison of Nusselt number for different fluids and Prandtl number

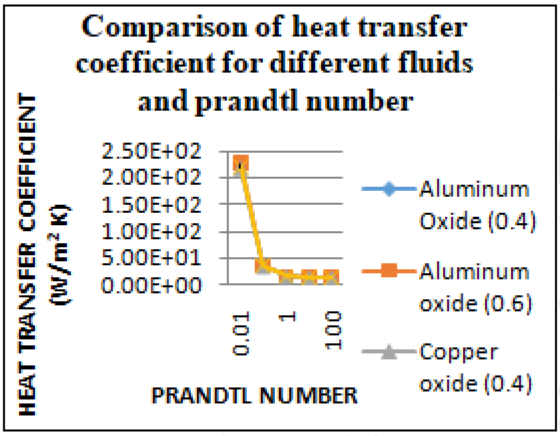


Figure 13: Comparison of Heat Transfer Coefficient for different fluids and Prandtl number

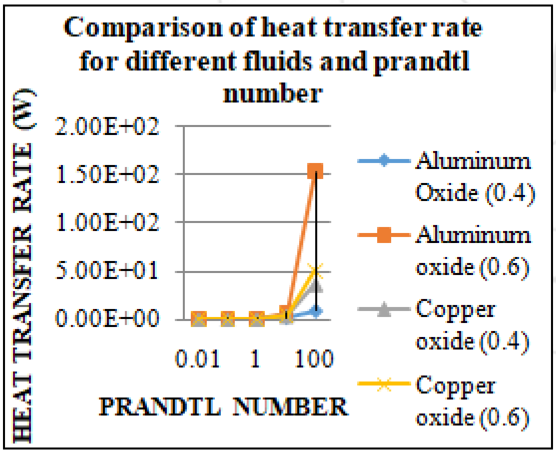


Figure 14: Comparison of Heat Transfer Rate for different fluids and Prandtl number

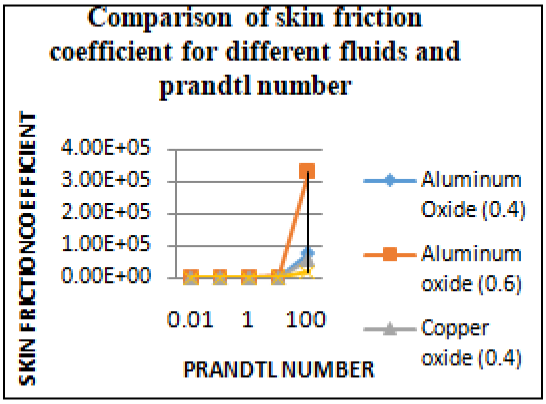


Figure 15: Comparison of Skin Friction Coefficient for different fluids and Prandtl number

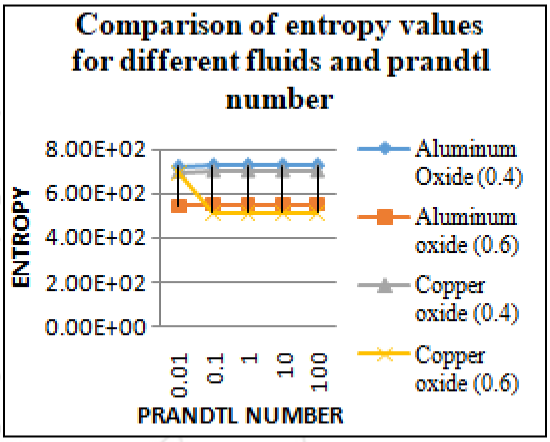


Figure 16: Comparison of Entropy values for different fluids and Prandtl number

4. Conclusion and Future Scope

From the analysis results, it is observed that the heat transfer increases with the values of Prandtl number. Since the higher Prandtl number has very low thermal conductivity, the local Nusselt number increases rapidly. This means that the variation of the heat transfer rate is more sensitive to the larger Prandtl number than the smaller one. Skin friction coefficient is also increasing with increase of Prandtl number. Taking volume fractions and comparing the results between Al_2O_3nano fluid and CuOnano fluid, the velocities are not affected by the change in volume fractions of nano fluids. Reynolds number and Heat Transfer Rate, Nusselt number and Heat Transfer coefficient are increasing with increase of volume fraction. The values are more when Copper oxide is used. The Heat transfer rate is more when Aluminum oxide is used. The entropy values does not effect with the change in Prandtl number. It is increasing with decrease in volume fraction.This work can be extended by performing experimental investigations and validating, considering other nano fluids and volume fractions.

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