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

Raj Kumar¹, Valmeti Sudheer²

¹M.Tech in Thermal Engineering from CMR Engineering College, JNTU, Hyderabad, Telangana, India
²Professor, 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 = 10⁵–10⁷) and Darcy number (Da = 10⁵–10⁻³) on the velocity and temperature fields is examined. For the vertical wall, a higher heat transfer rate is observed when a low Grashofnumber, 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):

\[ \rho_{nf} = \Phi \rho_s + (1-\Phi) \rho_w \]

Where

\[ \rho_{nf} = \text{Density of Nano fluid} \]
\[ \rho_s = \text{Density of the substance (Al}_2\text{O}_3 \text{ or CuO)} \]
\[ \rho_w = \text{Density of Base fluid (Water)} \]

\[ \Phi = \text{Volume fraction of the substances} \]

Specific Heat (\(C_P\)):

\[ C_{P(nf)} = \Phi C_{P_s} + (1-\Phi) C_{P_w} \]

Where

\[ C_{P(nf)} = \text{Specific Heat of Nano fluid} \]
\[ C_{P_s} = \text{Specific Heatof the substance (Al}_2\text{O}_3 / \text{CuO)} \]
\[ C_{P_w} = \text{Specific Heat of Base fluid (Water)} \]

Thermal Conductivity (K):

\[ K_{nf} = K_s + 2K_w + 2(K_s - K_w)(1+\beta) \times \Phi \times K_w \]

Where

\[ K_{nf} = \text{Thermal conductivity of Nano fluid} \]
\[ K_s = \text{Thermal conductivity of the substance (Al}_2\text{O}_3 / \text{CuO)} \]
\[ K_w = \text{Thermal conductivity of Base fluid (Water)} \]
\[ \beta = \text{Film temperature} \]

Viscosity (µ):

\[ \mu_{nf} = \text{Pr} \times \mu_{nf} \]

Where

\[ \mu = \text{Prandtl number} \]

Velocity Calculations by Varying Prandtl Number

Velocities are calculated for different Prandtl number, which is used as inlet in the CFD analysis.

Volume 6 Issue 8, August 2017

www.ijsr.net

Licensed Under Creative Commons Attribution CC BY
\[
\begin{align*}
    p_r &= \frac{c_p \mu}{k} \\
    \mu &= \frac{p_r k}{c_p} \\
    v &= \frac{\mu}{\rho} \\
    \frac{Re}{L} &= u(velocity) \\
    Re &= \text{Reynolds number} \\
    v &= \text{kinematic Viscosity (m/s}^2) \\
    L &= \text{length of the component (m)} \\
\end{align*}
\]

**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\(_2\)O\(_3\)) with VF - 0.4**

Prandtl Number: 0.01

**Figure 1:** Meshed model

Viscous → edit → k- epsilon
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
3. Results & Discussions

Fluid = Al₂O₃ (0.4)

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

<table>
<thead>
<tr>
<th>Prandtl Number</th>
<th>Results</th>
<th>0.01</th>
<th>0.1</th>
<th>1</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (m/s)</td>
<td></td>
<td>2.90E-02</td>
<td>2.95E-01</td>
<td>2.95E+00</td>
<td>2.95E+01</td>
<td>2.95E+02</td>
</tr>
<tr>
<td>Reynolds number</td>
<td></td>
<td>7.17E+03</td>
<td>7.30E+03</td>
<td>7.30E+03</td>
<td>7.30E+03</td>
<td>7.30E+03</td>
</tr>
<tr>
<td>Nusselt number</td>
<td></td>
<td>1.28E+02</td>
<td>1.93E+01</td>
<td>7.99E+00</td>
<td>6.87E+00</td>
<td>6.76E+00</td>
</tr>
<tr>
<td>Heat Transfer Coefficient (W/m²·K)</td>
<td></td>
<td>2.21E+02</td>
<td>3.32E+01</td>
<td>1.37E+01</td>
<td>1.18E+01</td>
<td>1.16E+01</td>
</tr>
<tr>
<td>Skin friction coefficient</td>
<td></td>
<td>7.48E-04</td>
<td>7.61E-02</td>
<td>7.61E+00</td>
<td>7.61E+02</td>
<td>7.61E+04</td>
</tr>
<tr>
<td>Entropy (J/kg·K)</td>
<td></td>
<td>7.20E+02</td>
<td>7.26E+02</td>
<td>7.27E+02</td>
<td>7.27E+02</td>
<td>7.27E+02</td>
</tr>
<tr>
<td>Total heat transfer rate (W)</td>
<td></td>
<td>0.011329651</td>
<td>0.08340928</td>
<td>0.078575537</td>
<td>1.857763</td>
<td>8.6138779</td>
</tr>
</tbody>
</table>

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
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 Al₂O₃ nano 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.

References

International Journal of Mechanical Engineering and Technology


[8] DavoodDomiriGanji, Nanofluid flow and heat transfer between parallel plates considering Brownian motion using DTM.
