Effect of Al_2O_3 Nanoparticle Concentration on Convective Heat Transfer

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Abstract

This project investigates the effect of Al_2O_3 nanoparticle concentration on the convective heat transfer coefficient (h) using ANSYS Fluent simulations. The study focuses on three concentrations: 0%, 2%, and 4%. Results demonstrate that increasing nanoparticle concentration enhances convective heat transfer. The main emphasis is on the trend of h with nanoparticle concentration rather than absolute values, which depend on flow and geometry conditions.

Introduction

Nanofluids, fluids with suspended nanoparticles, can significantly enhance heat transfer due to higher thermal conductivity. This study aims to simulate laminar flow of water-Al_2O_3 nanofluids at different concentrations to examine the effect on convective heat transfer coefficient (h). ANSYS Fluent is used to perform the simulations, and post-processing allows the calculation of h from wall and bulk temperatures.

Calculation of Convective Heat Transfer Coefficient

The convective heat transfer coefficient (h) is calculated using the following relation:

$$h = \frac{q''}{T_w - T_b} \tag{1}$$

where:

- h = Convective heat transfer coefficient (W/m^2·K)
- q'' = Applied heat flux on the wall surface (W/m^2)

- T_w = Average wall temperature (K)
- T_b = Bulk (mean) fluid temperature (K)

The bulk fluid temperature is obtained as:

$$T_b = \frac{\sum_i m_i T_i}{\sum_i m_i} \tag{2}$$

where:

- T_i = Local temperature of fluid at section i (K)
- m_i = Mass flow rate at section i (kg/s)

Thus, by substituting the measured or simulated values of wall temperature (T_w), bulk temperature (T_b), and known heat flux (q''), the convective heat transfer coefficient can be determined for each nanofluid concentration.

Simulation Setup

- Steady laminar flow in a rectangular channel
- Wall heat flux: 5,000 W/m^2
- Inlet temperature: 300 K
- Nanofluid concentrations: 0%, 2%, 4% Al_2O_3
- Post-processing: $h = \frac{q''}{T_w - T_b}$

Results

Table 1: Convective heat transfer coefficient h for different nanofluid concentrations

Nanofluid Concentration	Average Wall Temp T_w [K]	Bulk Temp T_b [K]	h [W/m^2·K]
0%	307.574	300.012	6615
2%	307.251	300.012	6908
4%	307.074	300.012	7078

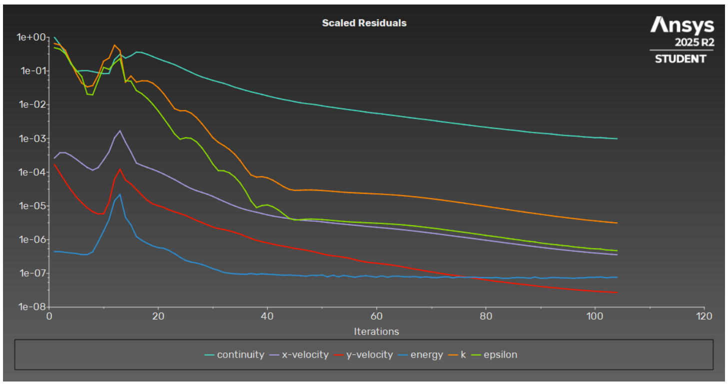

Figure 1: Scaled residuals during Fluent simulation for 0% concentration

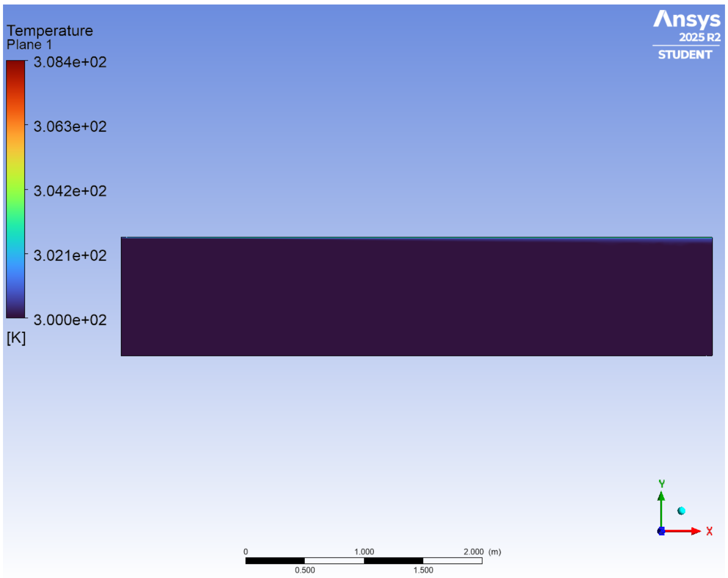

Figure 2: Temperature contour of nanofluid flow

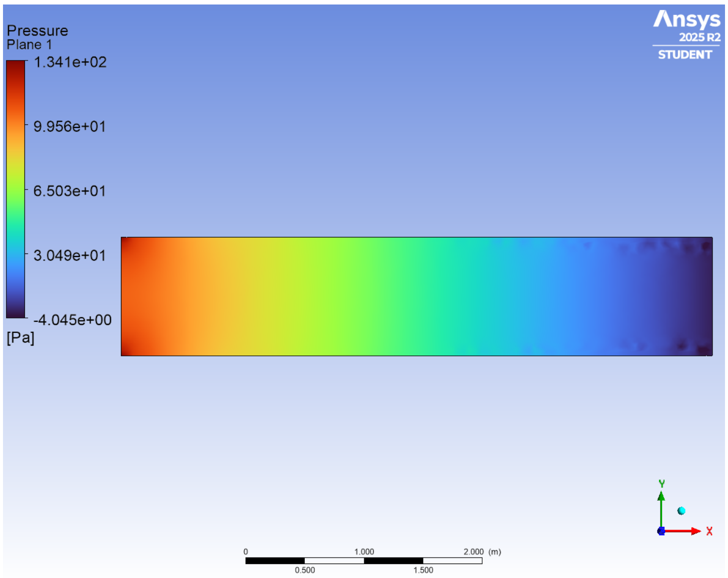

Figure 3: Pressure distribution in the channel

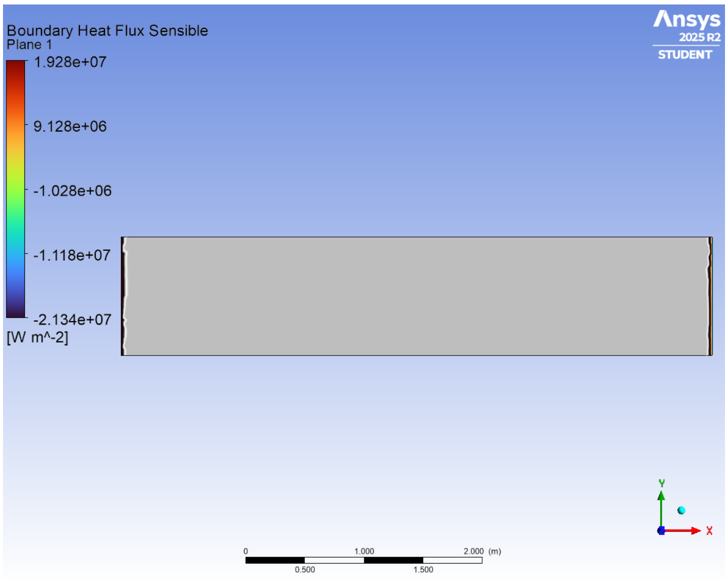

Figure 4: Boundary heat flux (sensible) distribution

Discussion

The results indicate that the convective heat transfer coefficient h increases with Al_2O_3 nanoparticle concentration. This trend is expected because the addition of nanoparticles enhances the effective thermal conductivity of the fluid, allowing heat to transfer more efficiently from the channel wall to the fluid. Although the absolute values of h depend on flow conditions and geometry, the relative increase clearly demonstrates the benefit of using nanofluids. The simulations provide insight into how small changes in nanoparticle concentration can significantly influence heat transfer performance, which is relevant for engineering applications in cooling and thermal management systems.

Conclusion

This study demonstrates that increasing Al_2O_3 nanoparticle concentration leads to a measurable increase in the convective heat transfer coefficient. The results emphasize the importance of nanofluid selection for enhancing thermal performance. While the geometry and flow setup determine the absolute values, the trend observed is robust and consistent with theoretical expectations. The project successfully highlights the relationship between nanoparticle concentration and heat transfer efficiency, providing a clear, interpretable outcome that can be applied to further studies in nanofluid-based cooling and energy systems.