

# Heat Transfer Performance and Flow Dynamics of Al<sub>2</sub>O<sub>3</sub>/Water Nanofluid in Turbulent Regime

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## ABSTRACT

Rapid heat transfer is one of the major concerns in the growing engineering disciplines. Nanofluid has added a new dimension to rapid heat transfer because of its improved thermophysical properties. In this current investigation, investigation was carried out for 0.1% and 0.2% Al<sub>2</sub>O<sub>3</sub>/Water nanofluid in turbulent flow. Constant heat flux was supplied in the test section tube with the help of nichrome resistance wire which was spirally wound uniformly on the test section tube. The investigation reveals that the heat transfer coefficient and dimensionless Nusselt number enhance for Al<sub>2</sub>O<sub>3</sub>/water nanofluid than water as the working fluid. Heat transfer coefficient also improves with the increase in volume fraction of nanoparticles though the stability of nanofluid decreases. Nusselt number increases by 33.46% for 0.1% Al<sub>2</sub>O<sub>3</sub>/water nanofluid compared to water. Conversely, the Nusselt number increases by 57.01% for 0.2% Al<sub>2</sub>O<sub>3</sub>/water nanofluid compared to water. A higher thermal performance factor was found for a higher volume fraction of nanoparticles. Friction factor and pumping power per unit length also increase with the increase in the volume fraction of nanoparticles. It was concluded that Al<sub>2</sub>O<sub>3</sub>/water nanofluid with a higher volume fraction of nanoparticles gives a higher heat transfer rate for the same pumping power per unit length than water as a working fluid.

Keywords: Nanofluid, Heat Transfer, Al<sub>2</sub>O<sub>3</sub>/water, Thermal Performance Factor.



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## 1 Introduction

Nanofluid is engineered by dispersing nanoparticles of different metals and their oxides in a base fluid for instance water, ethylene glycol, engine oil, etc. which has many potential applications. The recent investigations carried out by different researchers demonstrate that nanofluid seems to be a potential heat transfer fluid (HTF) because of its enhanced thermophysical properties. Brownian motion of nanoparticles contributes to this enhancement of heat transfer. Heat transfer rate can be increased up to 40% using different nanofluids [1]. The heat transfer rate is higher than conventional HTF because of the higher thermal conductivity of nanofluid. The thermal conductivity property of a nanofluid depends on the types of nanoparticles and volume fraction of nanofluid. The thermal conductivity of nanofluid increases with the increase in nanoparticle volume fraction [2].

Chavda *et al.* [3] studied CuO/water nanofluid on different pipes for the investigation of heat transfer characteristics. Their investigation found that friction factor increases if CuO/water nanofluid volume concentration amount increases. The pressure drop of TiO<sub>2</sub>/water nanofluids was explored by Duangthongsuk and Wongwises [4] in turbulent flow. The investigation found a higher pressure drop for the nanofluid than the base fluid. Leong *et al.* [5] experimented with Copper/ethylene-glycol nanofluid in automotive car radiator and observed a higher heat transfer rate. Naraki *et al.* [6] used a CuO/water nanofluid in their investigation of automotive car radiator. Their investigation also found an enhanced heat transfer coefficient. Effective load-carrying capacity and reduced wear were found in the case of nanofluid in automotive lubrication [7]. Some researchers proposed nanofluid as a potential alternative to conventional

transformer oil. Beheshti *et al.* [8] studied MWCNTs nanofluid based on transformer oil and found an increase in convective heat transfer rate. El-Maghlany *et al.* [9] investigated Cu / water nanofluid in a heat exchanger of horizontal double-tube type. Their investigation demonstrates that nanofluid can be a potential HTF for heat transfer enhancement. Hybrid nanofluid is also investigated by different researchers. Momin [10] studied Al<sub>2</sub>O<sub>3</sub>-Cu /H<sub>2</sub>O hybrid nanofluid where the tube was inclined. Al<sub>2</sub>O<sub>3</sub> - MWCNT/water hybrid nanofluid was investigated by Huang *et al.* [11] in a chevron corrugated-plate heat exchanger. They found a heat transfer enhancement in the case of a hybrid nanofluid. Recent studies have highlighted the potential of hybrid nanofluids in enhancing heat transfer efficiency. Gürbüz *et al.* [12] explored the use of CuO-Al<sub>2</sub>O<sub>3</sub>/water hybrid nanofluid in a U-type tubular heat exchanger, demonstrating significant improvements in thermal performance. The study combined numerical simulations and experimental investigations, showing that the hybrid nanofluid outperforms single-component nanofluids. Specifically, they reported a maximum enhancement in the overall heat transfer coefficient of 9.5% and 12% for 0.5% and 1% concentrations, respectively. Zeinali Heris *et al.* [13] conducted an experimental study on the heat transfer performance of a car radiator using CuO/ethylene glycol-water nanofluids. Their research demonstrated a significant enhancement in heat transfer rates compared to using the base fluid alone. The study found that the use of nanofluids led to a substantial increase in the Nusselt number, with enhancements of up to 55% observed in the best-performing nanofluid concentration. The study by Togun *et al.* [14] investigated the heat transfer enhancement in channels with semicircle ribs using

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hybrid  $\text{Al}_2\text{O}_3$ -Cu/water nanofluids. This research addresses the need for improving the thermal efficiency of heating and cooling systems, which is crucial for reducing energy consumption and carbon emissions. The simulation results demonstrated that the presence of ribs significantly enhanced heat transfer in the channel. The Nusselt number increased with higher solid volume fractions of hybrid nanofluids and Reynolds numbers. The study also observed the formation of recirculation zones after and before each rib, which influenced thermal efficiency. A higher number and size of ribs led to a larger improvement in the Nusselt number due to an increase in the number and size of recirculation zones. Wollele *et al.* [15] conducted a numerical analysis to investigate the heat transfer enhancement of  $\text{Al}_2\text{O}_3$ -Cu/water hybrid nanofluid with and without inserts in a circular duct. The study used a circular duct with inserts, a tube length of 3 m, a hydraulic diameter of 0.01 m, and a twist ratio of 125. The results showed that the insertion of twisted tape in the duct led to an additional mixing of fluid, resulting in a temperature increase of around 1% to 1.75% compared to without inserts at a Reynolds number of 20,000. The numerical analysis conducted by Sen and Inam [16] using ANSYS Fluent provides valuable insights into the heat transfer characteristics of the inverted T-shaped enclosure filled with nanofluid. The study demonstrates a significant increase in the average heat transfer coefficient with the rising volume fraction of  $\text{Al}_2\text{O}_3$  nanoparticles in the air. Additionally, the average Nusselt number was found to increase with the Rayleigh number, but it slightly dropped at higher volume fractions of nanoparticles due to increased conductive heat transfer. Mahmud and Rijvi [17], the thermal performance of a car radiator has been investigated using different types of nanofluids, including  $\text{Al}_2\text{O}_3$ , CuO, and  $\text{TiO}_2$  nanofluids, as coolants. The base fluids used are water and a water-ethylene glycol (EG) mixture. The study explores the effect of different nanoparticle volume percentages (1%, 2%, and 3%) on the coolant outlet temperature and heat transfer rate. The study indicates that Water-EG-based nanofluids show better thermal performance compared to water-based nanofluids, with lower coolant outlet temperatures and higher heat transfer rates. This is consistent with the general trend observed in previous studies, where nanofluids have been shown to enhance heat transfer efficiency in various heat exchanger configurations. Alam and Inam [18] investigated the forced convection heat transfer of a water-based nanofluid inside a circular tube with a twisted tape inserter.  $\text{TiO}_2$  particles are used as nanoparticles for the nanofluid mixture. The study examines the effect of parameters such as twist ratio, number of twists, Reynolds number, and volume fractions of nanoparticles on heat transfer characteristics inside the tube with a twisted tape inserter. The results indicate that both the Nusselt number and heat transfer coefficient are higher at the twisted region than at the outlet, highlighting the effectiveness of twisted tape inserts in enhancing heat transfer.

The objective of the present investigation is to carry out an investigation for 0.1% and 0.2%  $\text{Al}_2\text{O}_3$ /Water nanofluid in turbulent flow to observe the characteristics of fluid flow and heat transfer. Despite the extensive research on various types of nanofluids and their applications, there are still areas that need further investigation. Specifically, there is a lack of comprehensive studies on the performance of  $\text{Al}_2\text{O}_3$ /water nanofluid at low volume concentrations (0.1% and 0.2%) in turbulent flow regimes. Most of the existing research focuses on higher volume concentrations or different nanofluids. Additionally, the combined effects of low nanoparticle concentration and turbulent flow on heat transfer characteristics and fluid dynamics have not been thoroughly explored. This investigation aims to fill this gap by providing detailed insights into the behavior of  $\text{Al}_2\text{O}_3$ /water nanofluid at these specific conditions, which can contribute to the optimization and practical application of nanofluids in heat transfer systems.

## 2 Experiment Description

### 2.1 Experiment Setup

The real test section is demonstrated in Fig. 1 with equipment. Fig. 2 illustrates the schematic diagram of the experimental arrangement. The setup involves a test section, and instruments to measure flow rate and temperature. The test portion was a smooth circular copper tube. The inside and outside diameters were 26.6 mm and 30 mm with a length of 900 mm. To supply constant heat flux, the nichrome resistance wire was twisted spirally on the external surface of the test section pipe. The nichrome resistance wire is twisted spirally on the external surface of the test section pipe to provide uniform heating along the length of the tube. This uniform heating ensures that the heat input is evenly distributed, reducing the chances of localized heat losses. Constant voltage (220 V) was supplied by a voltage regulator. The entire test section, especially the heated portion, is wrapped with insulating materials. In this setup, mica sheet material was used between the wire and pipe to provide electrical insulation. To measure the outer surface temperature of the pipe, five thermocouples were equally placed. A U-tube type manometer was placed to determine the pressure drop throughout the tube. Stable pressure readings indicate consistent fluid flow and minimal disruptions in the system. Fluid was circulated by a pump. The flow rate was regulated by a gate valve. Before starting data collection, the system is allowed to run for a sufficient period until the temperature readings at the inlet and outlet thermometers become stable. This indicates that the fluid has reached thermal equilibrium and the flow has achieved a steady state. Data was taken when the temperature of the inlet and outlet thermometer became steady. Data was collected at regular intervals to monitor any potential changes in the system and ensure steady-state conditions were maintained throughout the experiment.

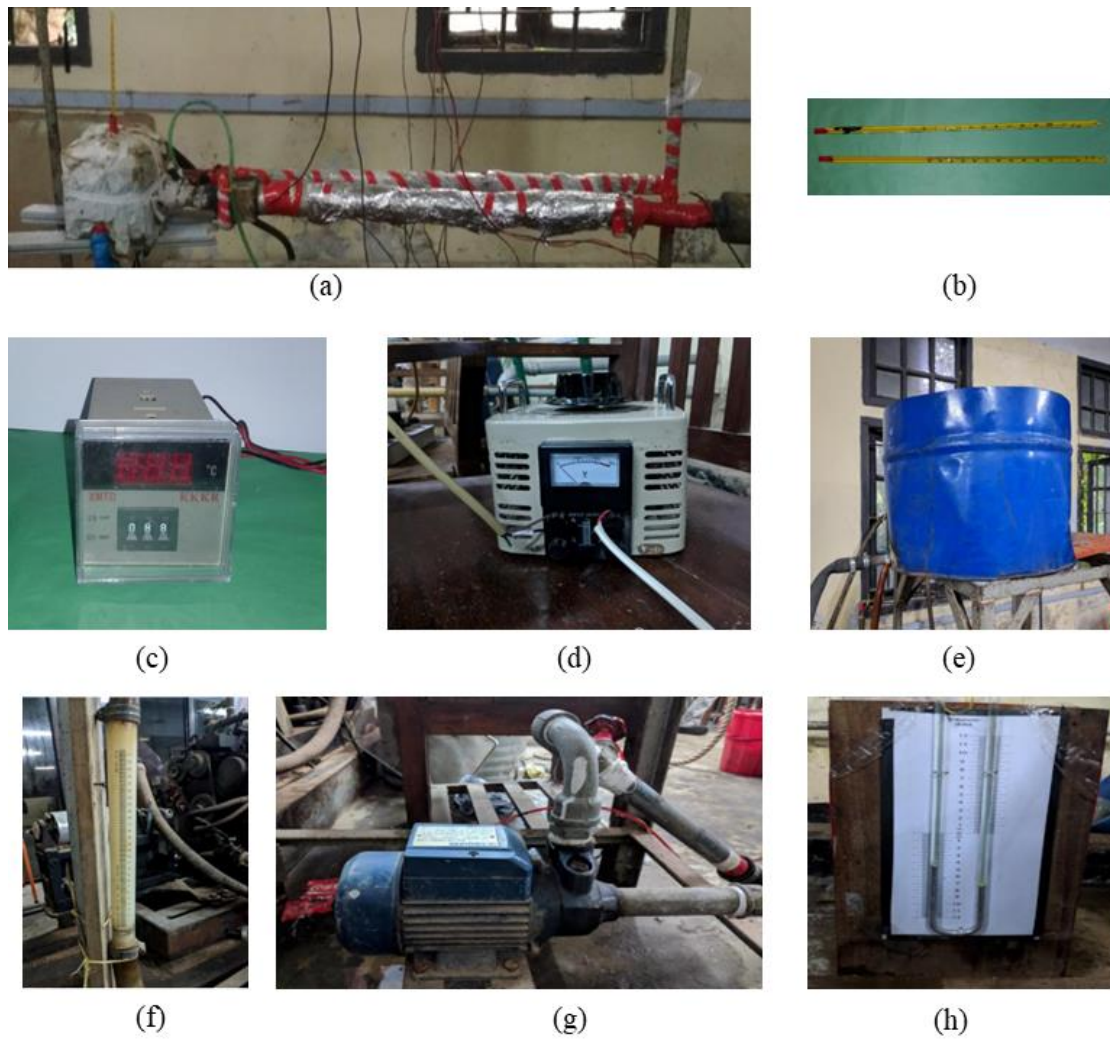


Fig. 1 Experimental setup & equipment

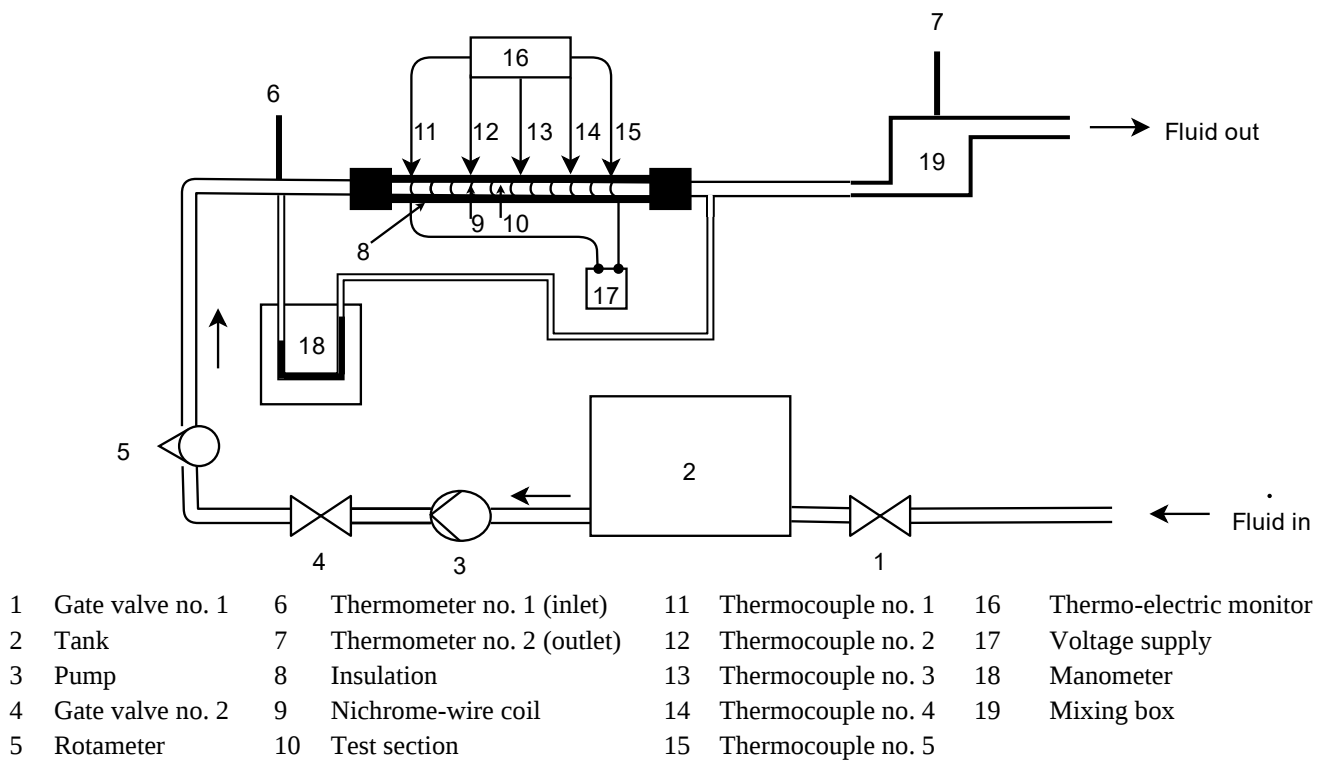


Fig. 2 Experimental setup in schematic diagram

During the experiment, the following assumption were made.

- The flow is steady
- Heat loss by conduction and radiation was neglected.
- Size and shape of nanoparticles were not considered.

The thermophysical properties of water at room temperature are demonstrated in Table 1.

Table 1 Thermophysical properties of water

| Properties                                      | Value   |
|-------------------------------------------------|---------|
| Viscosity [kg/m. s]                             | 0.00087 |
| Density, $\rho$ [kg/m <sup>3</sup> ]            | 996     |
| Thermal conductivity, $k$ [W/m <sup>2</sup> °C] | 0.62    |
| Specific heat, $C_p$ [J/kg. °C]                 | 4179    |

The properties of Al<sub>2</sub>O<sub>3</sub> Nanoparticles are demonstrated in Table 2.

Table 2 Properties of Al<sub>2</sub>O<sub>3</sub> Nanoparticles

| Properties                            | Value |
|---------------------------------------|-------|
| Density, $\rho$ [gm/cm <sup>3</sup> ] | 3.95  |
| Specific heat, $C_p$ [J/kg. °C]       | 773   |

The nanofluid was prepared according to two step model. The volumetric concentration percentage was estimated from the Eq. (3.1)

$$\text{Volume concentration, } \phi = \left[ \frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}} + \frac{W_{bf}}{\rho_{bf}}} \right] \times 100 \quad (1)$$

From Eq. (1), weight of nanoparticles was calculated to prepare desired volume fraction of nanofluid. Nanoparticles of Al<sub>2</sub>O<sub>3</sub> was mixed with water by magnetic stirrer. This process was continued for minimum 9-10 hours at 2400 rpm in a magnetic stirrer. Table 3 shows the required mass of the Al<sub>2</sub>O<sub>3</sub> Nanoparticles to produce required volume concentration.

Table 3 Al<sub>2</sub>O<sub>3</sub> nanoparticles mass

| Volume Concentration (%) | $W_{bf}$ (ml.) | $W_{np}$ (gm) |
|--------------------------|----------------|---------------|
| 0.1                      | 500            | 1.977         |
| 0.2                      | 500            | 3.958         |

## 2.2 Data Reduction

The data was calculated by following equations:

$$\text{Cross sectional area, } A = \pi d_i^2 \quad (2)$$

$$\text{Inner surface area, } A_i = A_s = \pi d_i L \quad (3)$$

$$\text{Supplied heat in the water was computed by, } Q = m C_p (T_o - T_i) \quad (4)$$

$$\text{Bulk temperature, } T_b = \frac{T_o + T_i}{2} \quad (5)$$

$$\text{Outer surface temperature, } T_{wo} = \frac{\text{Thermocouple 1 reading} + \dots + \text{Thermocouple 4 reading}}{5} \quad (6)$$

The one-dimensional radial conduction equation was used to calculate the innermost surface temperature of the tube,

$$T_{wi} = T_{wo} - Q \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi k_{Cu} L} \quad (7)$$

$$\text{Convective heat transfer coefficient, } h = \frac{Q}{A_s(T_{wi} - T_b)} \quad (8)$$

$$\text{Velocity, } U_m = \frac{q}{A_x}, \text{ where, } q \text{ is the flow rate} \quad (9)$$

$$\text{Reynolds Number, } R_e = \frac{\rho U_m d_i}{\mu} \quad (10)$$

$$\text{Prandtl number, } P_r = \frac{\mu C_p}{k} \quad (11)$$

$$\text{Experimental Nusselt number, } Nu_{exp} = \frac{h d_i}{k} \quad (12)$$

Theoretical Nusselt number,

$$Nu_{th} = 0.023 Re_d^{0.8} Pr^{0.4} \text{ (By Dittus and Boelter)} \quad (13)$$

$$\text{Pressure difference, } \Delta p = \Delta h \times \rho \times g \quad (14)$$

$$\text{Theoretical friction factor, } f_{th} = (0.79 \ln Re - 1.64)^{-2} \quad (15)$$

$$\text{Experimental friction co-efficient, } f_{exp} = \frac{\Delta P}{\left(\frac{L}{d_i}\right) \left(\frac{\rho U_m^2}{2}\right)} \quad (16)$$

Viscosity of nano-fluid,

$$\mu_{nf} = \frac{1}{(1-\phi)^{2.5}} \mu_{bf} \text{ (Brinkmen correlation)} \quad (17)$$

$$\text{Density of nano-fluid, } \rho_{nf} = \phi \rho_p + (1 - \phi) \rho_{bf} \quad (18)$$

Specific heat of nanofluid,

$$C_{p_{nf}} = \frac{\phi \rho_{nf} C_{p_{np}} + (1 - \phi) \rho_{bf} C_{p_{bf}}}{\phi \rho_p + (1 - \phi) \rho_{bf}} \quad (19)$$

Thermal conductivity of nanofluid,

$$\mu_{nf} = \mu_{bf} \left( \frac{k_p + 2k_f + 2\phi(k_p - k_f)}{k_p + 2k_f - \phi(k_p - k_f)} \right) \quad (20)$$

$$\text{Pumping power, } P_m = \frac{\Delta P}{m \rho} \quad (21)$$

Performance evaluation criteria (PEC) or Thermal performance factor,

$$\eta = \frac{\frac{Nu_{nf}}{Nu}}{\left(\frac{f_{nf}}{f}\right)^{\frac{1}{3}}} \quad (22)$$

## 3 Results and Discussion

### 3.1 Fluid Flow Characteristics

The variation of friction factor with different Reynolds number is illustrated in Fig. 3. The figure demonstrates that the friction factor reduces with the increase in Reynolds number. Additionally, the increase in volume fraction of nanoparticles causes an increase in friction factor. As the friction factor increases with the increase in volume fraction nanoparticles, rate of heat transfer also rises at the same time.

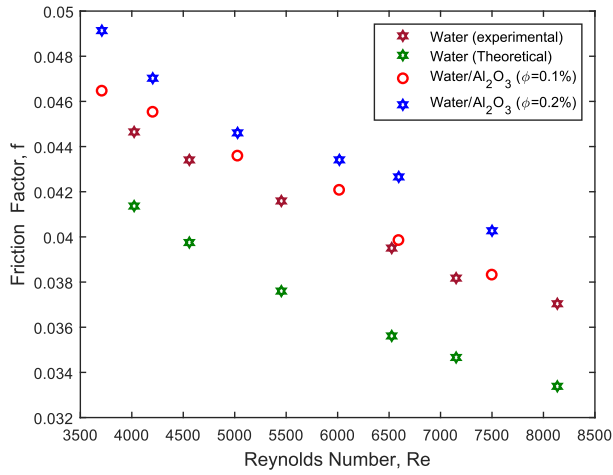


Fig. 3 Interaction between Reynolds number and friction factor variation

Fig. 4 demonstrates the change of pressure drop with the Reynolds number. The figure shows that pressure rises with the increase in Reynolds number. For nanofluid, the pressure drop increases when the volume fraction of nanoparticles increases. In the present study, maximum pressure drop was found for 0.2% volume fraction of water/  $\text{Al}_2\text{O}_3$ . The pressure drop increases with the square of the volumetric flow rate under turbulent flow conditions. Hence, when the Reynolds number rises, pressure drop increases. It is observed that pressure drop increases by a small amount with the addition of nanoparticles.

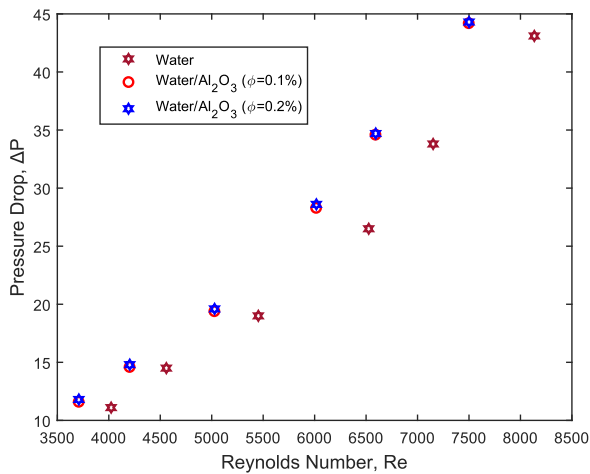


Fig. 4 Variation of pressure drop with Reynolds number

Fig. 5 demonstrates the relation between pumping power required for unit length and Reynolds number for water, 01% water/  $\text{Al}_2\text{O}_3$  and 0.2% water/  $\text{Al}_2\text{O}_3$  as working fluid. Several factors like pump efficiency, pressure difference, fluid density, viscosity, and flow rate are important to the pumping power. Pressure drop intensifies with the increase in Reynolds number. Pressure drop increases when the volume fraction of nanoparticles increases. As pressure drop increases, the pumping power required for unit length also increases. The figure demonstrates that pumping power per unit length of 0.2% water/  $\text{Al}_2\text{O}_3$  is higher than 0.1% water/  $\text{Al}_2\text{O}_3$  and water as working fluid.

### 3.2 Heat Transfer Characteristics

Heat transfer coefficient, dimensionless Nusselt Number, pressure drop, and pumping power per unit length have been demonstrated graphically. The variation of these parameters has been observed. Fig. 6 illustrates the variation of the heat transfer coefficient with Reynolds number. The figure demonstrates that the coefficient of heat transfer increases with the increase in Reynolds number. The heat transfer coefficient significantly increases with the addition of  $\text{Al}_2\text{O}_3$  nanoparticles in the base fluid.

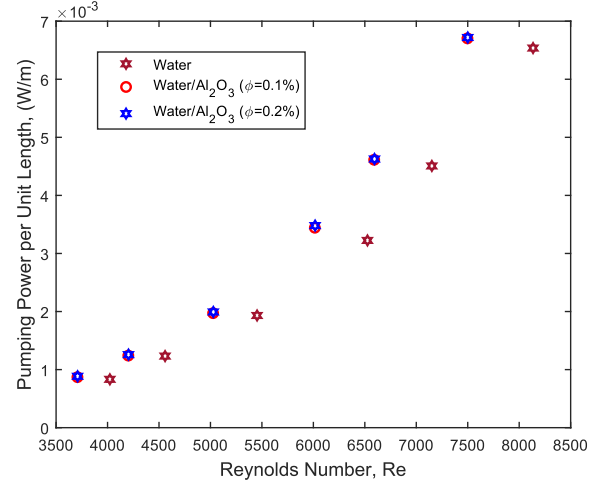


Fig. 5 Variation of pumping power required for unit length with Reynolds number

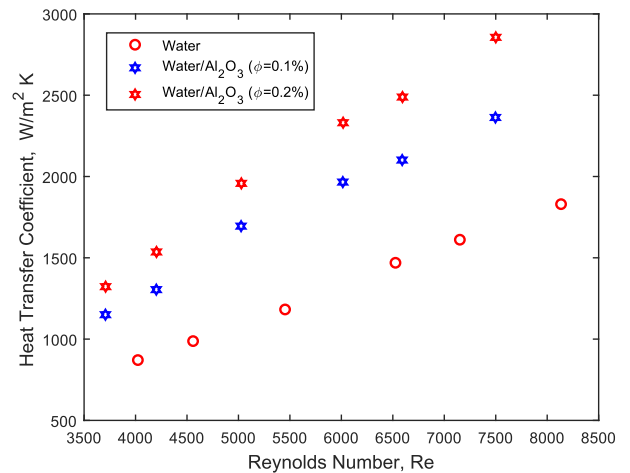


Fig. 6 Variation of heat transfer coefficient with the Reynolds number

In the present study, two concentrations of nanofluid were used which are 0.1% and 0.2%. The heat transfer coefficient increased 29-43% when 0.1% volume concentration of water/  $\text{Al}_2\text{O}_3$  was used. The heat transfer coefficient increases because of the increase in thermal conductivity of the nanofluid than the base fluid. The Brownian motion of the nanoparticles also contributes to the increase in heat transfer coefficient. The thermal conductivity of  $\text{Al}_2\text{O}_3$  nanoparticles is much higher than water.

Fig. 7 illustrates the Nusselt number for different Reynolds numbers. It is observed that the experimental Nusselt Number of water as a working fluid with constant heat flux is higher than the Dittus-Boelter and Gnielinski correlation. Nusselt number increases as the heat transfer coefficient increases with the increase in the volume fraction of  $\text{Al}_2\text{O}_3$  nanoparticles. The Nusselt number for 0.1% volume fraction of water/  $\text{Al}_2\text{O}_3$  increases by about 29-43%. On the other hand, the Nusselt number increases by about 51.8-65.6% for a 0.2% volume fraction of water/  $\text{Al}_2\text{O}_3$ .

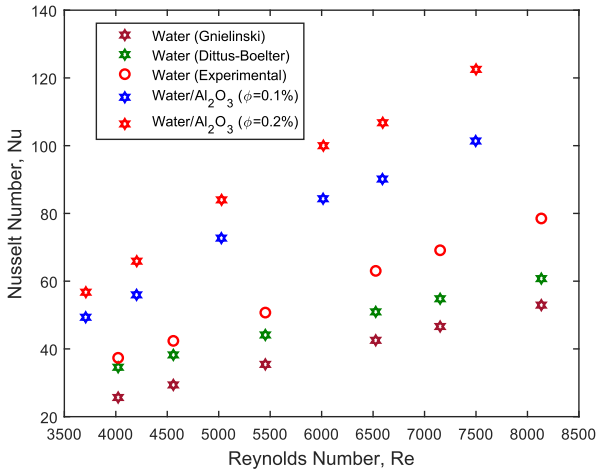


Fig. 7 Variation of dimensionless Nusselt number with the Reynolds number

Fig. 8 illustrates the percentage of error in plain tubes where water was used as a working fluid. The errors between theoretical Nusselt numbers and experimental Nusselt numbers were found to be in the range of 8.04% to 29.2% for water as the working fluid.

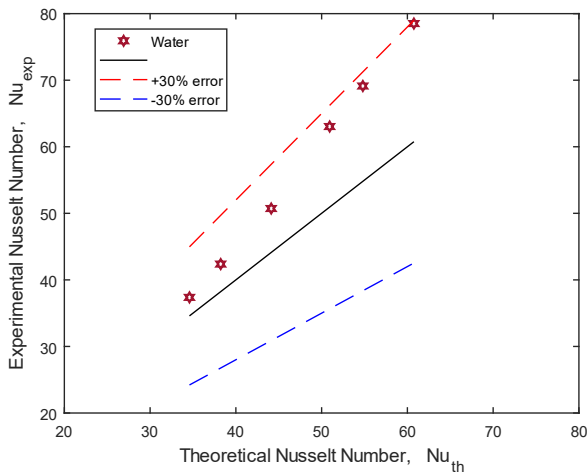


Fig. 8 Variation of experimental Nusselt number with theoretical Nusselt number

Fig. 9 demonstrates the effect of the heat transfer coefficient on pumping power per unit length. The figure also illustrates that higher pumping power per unit length is required for a higher heat transfer coefficient. Nanofluid exhibits a higher heat transfer rate for the same pumping power per unit length than base fluid. The figure illustrates that 0.2% water/  $\text{Al}_2\text{O}_3$  has a higher heat transfer coefficient than 0.1% water/  $\text{Al}_2\text{O}_3$  and water as working fluid for the same pumping power per unit length. Hence,

nanofluid can increase the effectiveness of the cooling system which can save much power.

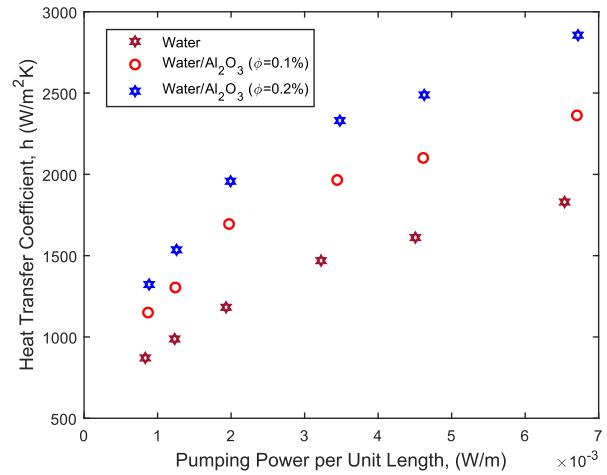


Fig. 9 Variation of heat transfer coefficient with pumping power per unit length

Fig. 10 demonstrates the effect of the Nusselt number on pumping power per unit length. The figure also illustrates that higher pumping power per unit length is required to get a higher Nusselt number. Nanofluid exhibits a higher heat transfer rate for the same pumping power per unit length than base fluid. The figure illustrates that 0.2% water/  $\text{Al}_2\text{O}_3$  has a higher Nusselt number than 0.1% water/  $\text{Al}_2\text{O}_3$  and water as working fluid for the same pumping power per unit length. Hence, nanofluid can save pumping costs.

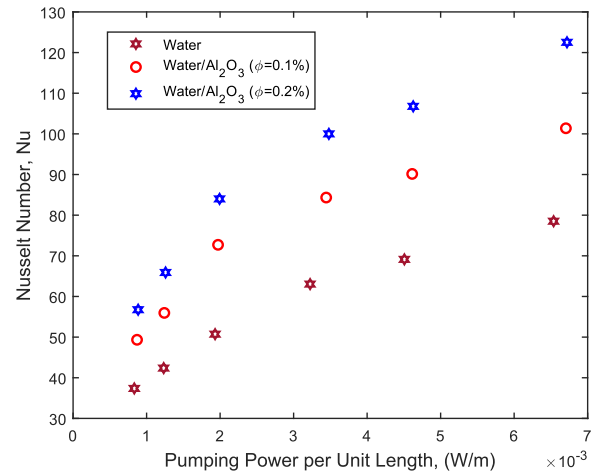


Fig. 10 Variation of dimensionless Nusselt number with pumping power per unit length

The use of nanofluids, such as  $\text{Al}_2\text{O}_3$ /water, for enhanced heat transfer presents a compelling cost-benefit trade-off. On one hand, nanofluids offer significantly improved heat transfer coefficients and Nusselt numbers compared to traditional fluids like water. This enhancement can lead to more efficient heat exchangers and thermal systems, potentially reducing overall energy consumption and operational costs. However, this benefit comes with an increase in pumping power requirements. As the volume fraction of nanoparticles in the nanofluid increases, so does the friction factor and pumping power per unit length. This increase in pumping power translates to higher operational costs due to increased energy consumption. Therefore, while

nanofluids offer enhanced heat transfer performance, the trade-off lies in balancing the benefits of improved heat transfer with the additional pumping power requirements, considering the overall cost-effectiveness of the system. Future research could focus on optimizing nanoparticle concentrations and fluid properties to minimize pumping power requirements while maximizing heat transfer performance, thus improving the cost-benefit ratio of using nanofluids in practical applications.

The thermal conductivity of nanofluid is higher than the base fluid. In the present study, water/ $\text{Al}_2\text{O}_3$  nanofluid shows a higher heat transfer coefficient, Nusselt number, and friction factor. The heat transfer rate increases with the increase in heat transfer coefficient. The present study also shows that the rate of heat also increases with the increase in the nanoparticle's volume fraction. Fig. 11 illustrates that the Nusselt number increases by 33.46% for 0.1%  $\text{Al}_2\text{O}_3$  / water nanofluid compared to water. Conversely, the Nusselt number increases by 57.01% for 0.2%  $\text{Al}_2\text{O}_3$  / water nanofluid compared to water.

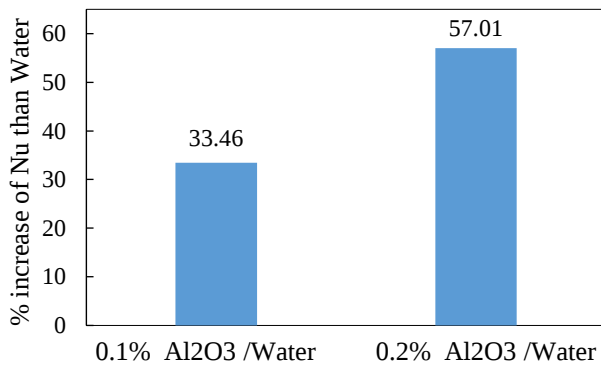


Fig. 11 Percentage increase in Nusselt number

The change of the thermal performance factor with different Reynolds numbers is demonstrated in Fig. 12. The thermal performance factor signifies the enhancement of heat transfer. It is the ratio of the Nusselt number to the friction factor. The figure demonstrates that the thermal performance factor decreases with the increase in Reynolds number. The volume fraction of nanofluid has a great impact on the thermal performance factor. A higher thermal performance factor was found for a higher volume fraction of nanofluid.

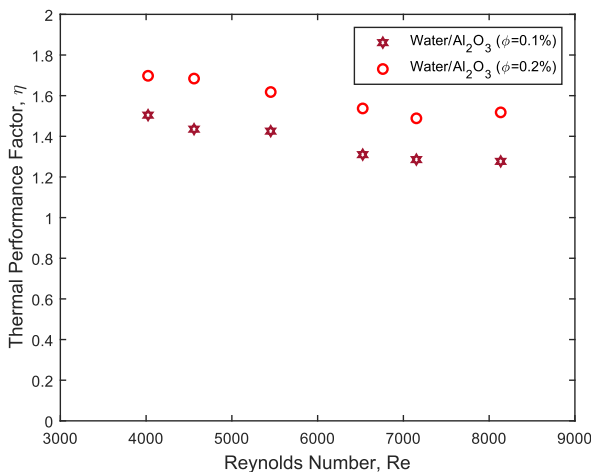


Fig. 12 Thermal performance factor with the change in Reynolds number

Nanofluids, such as  $\text{Al}_2\text{O}_3$ /water, offer significant enhancements in heat transfer performance due to their unique thermophysical properties. However, at higher concentrations, stability becomes a critical issue. The increase in the volume fraction of nanoparticles can lead to particle agglomeration and settling, which can negatively impact the fluid's overall stability. Agglomeration reduces the effective surface area available for heat transfer, diminishing the fluid's ability to enhance heat transfer. Settling can also lead to uneven distribution of nanoparticles within the fluid, further reducing the heat transfer efficiency. To address these stability issues, future research could focus on developing effective stabilization techniques. Surface modification of nanoparticles, such as using surfactants or functionalization, could enhance their dispersion and prevent agglomeration. Additionally, the use of additives or altering the fluid properties to increase the suspension's stability could be explored. Furthermore, investigating the impact of flow conditions and system geometry on nanofluid stability could provide valuable insights for optimizing heat transfer performance in practical applications.

#### 4 Conclusions

Heat transfer and fluid flow characteristics of  $\text{Al}_2\text{O}_3$  / water nanofluid have been analyzed. Augmentation of heat transfer using  $\text{Al}_2\text{O}_3$  / water nanofluid is the main purpose of the present investigation. The findings of this study can be concluded as follows:

- $\text{Al}_2\text{O}_3$ /water nanofluid has higher thermal conductivity than water.  $\text{Al}_2\text{O}_3$ /water gives a higher heat transfer coefficient and Nusselt number than water as the working fluid.
- Heat transfer coefficient also improves with the increase in the volume fraction of nanoparticles. However, the stability of nanofluid decreases if the volume fraction of nanoparticles rises.
- Nusselt number increases by 33.46% for 0.1%  $\text{Al}_2\text{O}_3$  / water nanofluid compared to water as the working fluid.
- Nusselt number increases by 57.01% for 0.2%  $\text{Al}_2\text{O}_3$  / water nanofluid compared to water as the working fluid.
- Friction factor and pumping power for unit length also increase with the increase in Reynolds number. For the same pumping power per unit length, nanofluid demonstrates a higher heat transfer rate than the base fluid.

#### Nomenclature

|        |                              |
|--------|------------------------------|
| $C_p$  | : Specific heat              |
| $K$    | : Thermal conductivity       |
| $Nu$   | : Nusselt number             |
| $T$    | : Temperature                |
| $Re$   | : Reynold number             |
| $W$    | : Weight                     |
| $\phi$ | : Volume concentration       |
| $\mu$  | : Dynamic viscosity          |
| $\rho$ | : Density                    |
| bf     | : Base fluid                 |
| np     | : Nanoparticle               |
| nf     | : Nanofluid                  |
| EG     | : Ethylene glycol            |
| HTF    | : Heat Transfer Fluid        |
| MWCNT  | : Multi-wall carbon nanotube |

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