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Experimental Investigation on Enhancement of Heat Transfer using γ-Al_2O_3–Water as a Nanofluid in a Finned Tube Heat Exchanger

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ARTICLE INFO	ABSTRACT

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This research discusses the literature on experimental investigations of heat transfer improvement with the help of nanofluids in heat exchangers. The research does show that the performance of the compound is better in terms of heat transfer than the base fluids in the horizontal shell and tube heat exchangers. Nevertheless, the viscosity increases with the nanoparticle concentration, and this influences the friction factor. This study reveals that the application of nanofluids increases the performance of heat exchangers in the cross-flow low integral finned tubes. The experimental studies reveal that there is an enhancement in thermal conductivity and heat transfer coefficients in Al_2O_3/distilled water nanofluid that makes them suitable for improving the heat exchanger efficiency. The experiments were performed at concentrations of γ-Al_2O_3 of 0.0%, 0.1%, and 0.5%, at the temperatures of 45 °C, 55 °C, and 65 °C, and at the γ-Al_2O_3/water flow rates of 2, 4, and 6 LPM. Experiments reveal that finned tubes increase the heat transfer coefficients, which is useful for understanding the performance of heat exchangers under various operating conditions. For instance, the addition of 0.5% Al_2O_3 resulted in an increase of heat transfer rate by 30% and heat transfer coefficient by 22% when the flow rate was 4 LPM and the temperature was 65°C. The Nusselt number also rose by 8% for Al_2O_3 nanofluid compared to distilled water under the same conditions. This research supports that under optimized concentrations of nanofluids, thermal management in heat exchangers is enhanced with the thermal efficiency increasing with the Re to a point of optimum at Re=7000. This work improves heat transfer in finned tube heat exchangers with nanomaterial-water mixtures and presents correlations, recommendations, and directions for further work.

Keywords:
Heat transfer; nano material; finned tube; heat exchanger

1. Introduction

Heat transfer processes are a challenge when heat flow rates are high; thus, heat transfer processes need new technologies to improve efficiency. The conventional heat transfer fluids have lower coefficients of thermal conductivity as compared to metals and oxides. Nanofluids, which are a mixture of conventional fluids and nanotechnology, have been used for enhancing the thermal transport properties. Nanofluids are the suspensions of nanoparticles in the base fluid that can

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improve the heat transfer rate through heat conductivity and convection coefficients. The purpose of this article is to determine the ability of nanomaterial-water solutions in finned tube heat exchangers. The performance of the heat exchangers was evaluated by different operating parameters and experimental results of the studies. The findings revealed that the enhancement of the performance parameters and the nanoparticle volume concentration was higher in the pipes containing nanofluid.

Many works were carried out in the double pipe heat exchanger (DPHE). Bashtani and Esfahani [1] studied a double pipe heat exchanger with simple and corrugated tubes, the ANSYS package, and the turbulent flow and k-ω Stress Transport turbulence model (SST) turbulence model. The observations indicate that an increase in the parameter corrugating results in a greater value of the Nusselt number; hence, the mean Nusselt number is equal to one. It is much higher, 75-fold bigger than this simple heat exchanger. The corrugated heat exchanger also improves the second law of thermodynamics effectiveness and efficiency in the proportions of 1.73 and 1.17, respectively. Ponshanmugakumar and Rajavel [2] proposed a shell and double pipe heat exchanger for improvement of heat transfer operations with the features of both the shell and double pipe heat exchangers. In addition to increasing the area of heat transfer, instead of plain tubes, double pipes were adopted. Three fluids have been used with it, and the results showed that there was fair agreement with the experimental values. The heat exchanger was more efficient as compared to other design formations and was in fact a pre-existing lab-scale shell and tube heat exchanger with an efficiency of ~60%. Hossain *et al.,* [3] resulted in the development of a new type of shell and double pipe heat exchanger that enhanced heat transfer operations. To increase the area of heat transfer, a double pipe was adopted instead of tubes. Three fluids were employed with the assistance of the device, and the results were compared with the experimental outcomes. This design configuration was found to be more efficient (~60% efficiency) as compared to other design configurations and the existing lab-scale shell and tube heat exchangers. Huu-Quan *et al.,* [4] studied the turbulent forced convective heat transfer in double pipe heat exchangers with flat inner pipes with the help of computational fluid dynamics. Lower aspect ratio inner pipes enhance heat transfer, thermal efficiency, and the performance index of the Reynolds number specifically calculated for the flow inside the pipe (Repipe) < 7000. Nonetheless, circular inner pipes are better than flat inner pipes in the case of Repipe > 7000. About 2.9%, 2.7%, and 16.8. The compared heat transfer characteristics revealed an 8% enhancement in the convective heat transfer coefficient, thermal fitness, and performance factor for a flat inner pipe with an aspect ratio of 0.37.

Numerous investigations were also carried out in the double pipe heat exchanger with nanomaterials. Onyiriuka *et al.,* [5] assumed the convective heat flow coefficient of mango bark nanofluids under turbulent conditions in a double pipe heat exchanger. Performance analysis showed that the Nusselt number enhancement factor was 68% at Reynolds number (Re) = 5000 and 45% at Re = 13000, and the heat transfer coefficient was 2 times that of the base fluid. Increased heat transfer rates were also found in some areas; this could be used in the design of heat exchangers. Armstrong *et al.,* [6], conducted on the effect of silver nanoparticles used as a coating material on heat exchangers with copper pipes, and found out that the heat transfer coefficient and mass flow rate were improved by 95% compared to plain copper pipes. This process was observed in countercurrent flow since it provides better heat transfer as compared to the co-current flow.

Sufficient work was done on the finned double pipe heat exchanger (FDPHE). In a study conducted by Hamzah and Nima [7], the impact of incorporating copper foam fins into a double-pipe heat exchanger was examined. The test rig used has two pipes, one of copper and the other of Perspex. For the control of the fluid flow and destruction of the structure of the fluid, the study employed 40 Pores Per Linear Inch (PPI) (copper-made foam fins). The findings indicated that the average convective heat transfer coefficient and Nusselt number augment with the Reynolds number to its optimum when the copper foam fins are inserted and counterflow is in operation. The values of the air temperature difference between the inlet and the exit sections of the double pipe in the case of With Internal Copper Foam (WICF) are 53% larger than that for the case of Without Internal Copper Foam (WOCF) with parallel flow and about 59% with counter flow. Mohsen *et al.,* [8] investigated the heat transfer in double pipe heat exchangers with various fin configurations. The findings of the study demonstrated that the enhancement of surface area affected the heat transfer coefficient in relation to fluid Reynolds numbers. The analysis of the results revealed that rectangular fins provided the highest enhancement of heat transfer rates while circular fins provided the lowest. Comparing pressure loss, circular fins applied the least pressure loss while rectangular fins reflected the biggest enhancement. Sivalakshmi *et al.,* [9] highlighted that twin-pipe heat exchangers with helical fins are more efficient than those with plain inner pipes in average heat transfer rate, heat transfer coefficient, and efficiency. It was also observed that the incorporation of fins improved the heat transfer coefficient with an average rate of 38.45% and a 34% enhancement of heat exchanger efficiency at higher flow rates. Myong *et al.,* [10] investigated generic heat exchangers with oval tubes and round tubes. From the analysis, it was observed that there was improved performance in the oval tube samples than that of the round tube samples but with a slightly higher number of tube rows. Among the tube samples, oval tubes gave the best performance with small-diameter tubes, while large-diameter tubes gave the poorest performance due to a large pressure drop. To the data, correlations were generated out of it.

The study by Gnanavel *et al.,* [11], found that nanofluids enhance discharge velocity, and the best shape is the platelet shape. The study used passive methods to increase heat transfer in a double pipe exchanger using four nanofluids: titanium dioxide, beryllium oxide, zinc oxide, and copper oxide. A circular fin inserts created flow resistance and distributed fluid over the surface. The highest thermal performance factor was 1.86 using TiO_2 nanofluid. Dalkılıç *et al.,* [12] studied the effect of pipe diameter of heat exchangers on flow characteristics, initial cost, operational cost, and total cost. It focused on the fin size, the shape of the fin, and the size of the fin when designing fins and the effect of working fluid types. Mozafarie *et al.,* [13] analyzed the thermal and fluid characteristics of a nanofluid in a circular finned double pipe heat exchanger. To study the effect of nanofluid properties and fin configuration on the friction factor, Nusselt number, and heat transfer characteristics, they employed a three-dimensional CFD model. The analysis showed the enhancement of heat transfer by 36 percent for Newtonian nanofluid and 30 percent for non-Newtonian nanofluid with the help of circular fins. Nevertheless, the volume concentration of Al_2O_3 and Re number increased the Nusselt number (Nu) of the nanofluid. The study also showed that if nanoparticles are added to non-Newtonian fluid without annulus inserts, the performance of the latter could be compromised because of the pressure drop penalty. The new ideas in nano fluids reveal that the heat transfer is better than the conventional heat transfer fluids. Over the recent past, researchers have paid more attention in the higher thermal properties of nanofluids, especially the thermal conductivity and heat transfer coefficient. Elfaghi *et al.,* [14] involved a numerical CFD analysis for forced convection heat transfer of Al_2O_3 nanofluids flowing through a circular pipe with constant heat flow rate. The effects of Reynolds number and particle volume fraction on heat transfer by convective, the Nusselt number and the friction factor of nanofluid are examined. Different volume fractions of Al_2O_3 nanoparticles equal to 0.5 pt, 1.0 pt and 2.0 pt are investigated, the range of Reynolds number is 6000 to 12000. The numerical data reveals that the convective heat of nanofluids is superior to that of base fluid and the enhancement in heat transfer increases with the Reynolds number of the particles and volume fraction.

This study explores the dynamic performance of heat exchangers using nanofluid-water mixtures (concentrations of γ-Al_2O_3–water nanofluid are 0.0%, 0.1%, and 0.5%), focusing on thermal performance, nanoparticle concentration, fluid flow rate, and temperature. The researchers selected gamma alumina (γ-Al_2O_3) as the nanoparticle in nanofluid studies because of its higher surface area, thermal conductivity, and better dispersibility. The present form of gamma alumina is more compatible with the base fluid and provides greater area for heat transfer as compared to alpha alumina. It also has good thermal conductivity and stability and can therefore be used in various heat exchanger conditions. However, such advantages should have been well illustrated in the work. The aim is to develop more efficient and sustainable heat exchanger technologies for various industrial sectors. This study aims to improve heat transfer performance in finned tube heat exchangers using nanofluid-water mixtures under different operating conditions. It evaluates thermal performance, investigates the influence of nanoparticle concentration, fluid flow rate, and temperature on heat transfer enhancement, compares nanofluid-water mixtures with conventional heat transfer fluids, and provides insights into the mechanisms underlying heat transfer enhancement. The research contributes to the development of more efficient and sustainable heat exchanger technologies.

2. Experimental Work

This research sought to establish the heat transfer characteristics of a finned tube heat exchanger when nanomaterial-water mixtures are used. The process of the study included the construction of the apparatus, stating conditions, making experiments, and data analysis. The heat exchanger used for the setup was a double-tube heat exchanger with longitudinal rectangular fins. The independent variables, including fluid temperature, flow rate, and nanomaterial concentration, were used to control and investigate the impact and influence they have on heat transfer enhancement. The objective of the study was to enhance the heat exchange efficiency in industrial uses by adopting the systematic approach.

2.1 Experimental Setup

The test device as shown in the Figure 1, includes two tanks for the cold fluid (filtered water) of 50-liter capacity to which ice is added to maintain the temperature of the cold fluid at around 22 °C and the hot fluid (distilled water or nanofluid Al_2O_3/water) of 6-liter capacity. It has a variable electric heater having a capacity of 2400 watts with a safety thermostat to regulate the temperature of the hot fluid. Two centrifugal pumps, for cold and hot fluids, have an external data storage compartment. Two flow meters with a range of 2-18 LPM, two electronic thermometers for temperature control (one for the cold-water chamber and one for the hot fluid chamber), and two metal valves to control the flow of cold and hot fluids.

The test rig includes a double concentric pipe heat exchanger. The outer tube is made of PVC and is painted with a thermal insulating paint from the outside to avoid heat loss. Measuring 54 mm in diameter and 4 mm in thickness, the cold fluid is the filtered water in this component. The inner tube is made of copper, and its diameter is 26.5 mm, and its thickness is 1 mm. The outer side of the tube has four rectangular fins that are arranged longitudinally with a copper material; the angles between the fins are 90 degrees. Its length is 1 meter, and its height is 5 mm. The total length of the test section is 116 cm and is designed according to the equation [15].

$$L/D \sim 4.4\, Re^{1/6} \qquad (1)$$

The experimental set-up of heat exchanger system has cold fluid temperature of 22 °C and an outer PVC pipe diameter of 54 mm. These parameters are selected according to the possible, application-oriented, and conditions exerting heat transfer effects. It is plausible to have cold fluid temperatures since the room temperature conditions are utilized, making it possible to replicate in other climates without complex cooling. At a constant low temperature of the cold fluid, there exists improved differentiation between temperature and the hot fluids, thereby improving the heat transfer rates. The outer PVC pipe diameter is selected taking into account practical design considerations, such as the inner copper tube and fins. The diameter is large enough to observe heat transfer effects but also permits a realistic and modular configuration that is compatible with standard industry and market sizes. These choices are directed to make the experiment possible, precise, and as close as possible to an industrial environment.

Because the maximum value of Reynolds number in this study is 11,000, the length that is needed to achieve fully developed turbulence is 58 cm, and hence the length of the test rig is 116 cm to ensure that the flow will be developed for all experiments.

16 K-type thermocouples were used; four of them are located at the inlet and outlet of the cold and hot fluids, and four are located inside the copper tube to measure the temperature of the hot fluid. One thermocouple is placed at a distance of 20 cm from the other. There are also four thermocouples in the external tube to measure the temperature of the cold fluid, i.e., filtered water, similar to the thermocouple found to measure the temperature of the hot fluid. At the outer side of the copper tube, there are two thermocouples, and, on the fins, there are two thermocouples. All thermocouples go through calibration in a constant-temperature bath, the maximum error of which is 0.3 °C, which was observed.

Schematic diagram of the experimental arrangement, the side view of the double pipe heat exchanger, along with the position of the thermocouple probes, is depicted in the following Figure 1 and Figure 2.

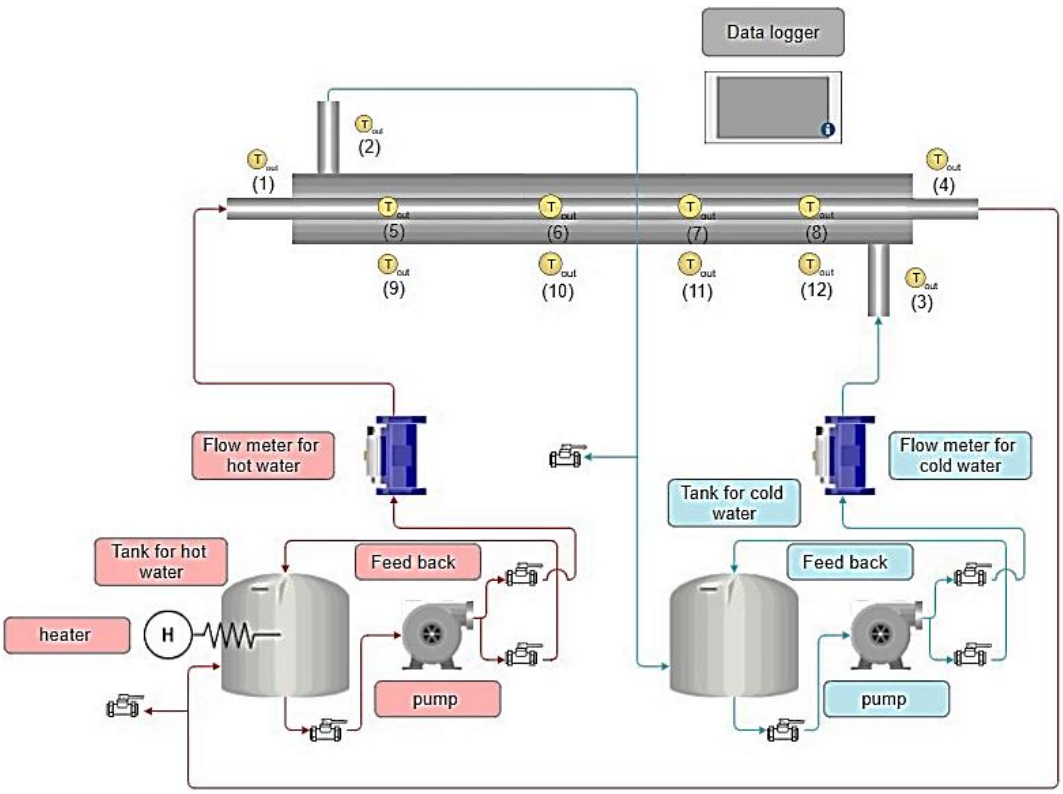


Fig. 1. Schematics Diagram

This research methodology enabled a methodical approach in the analysis of the improvement in heat transfer rate with the help of nanomaterial-water nanofluids in the finned tube heat exchanger system and hence, facilitated the collection of accurate data to be compared with the simulated data.

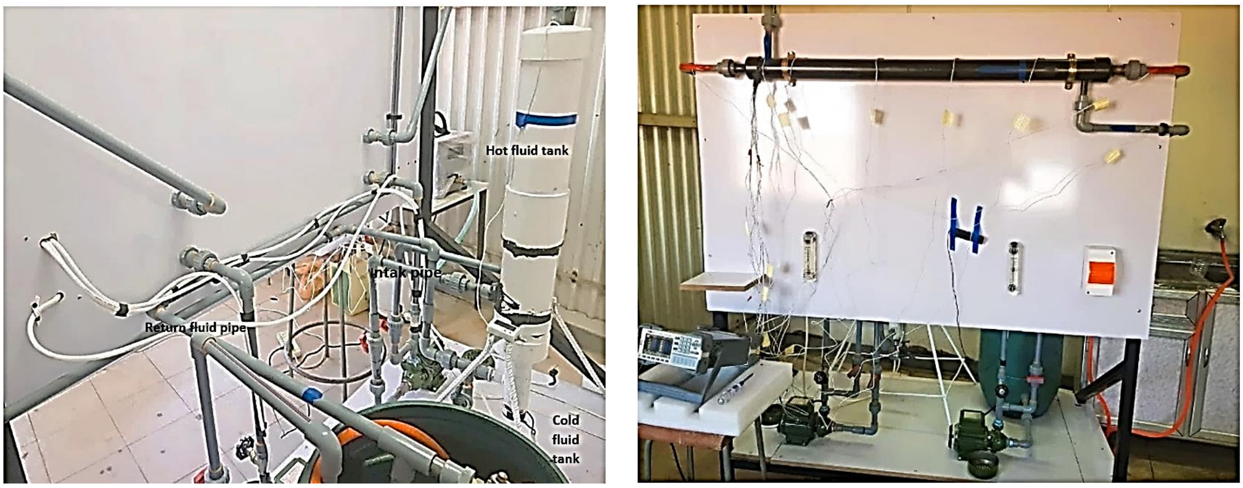


Fig. 2. Photograph of the experimental rig

The nanofluid is prepared by using the formula to determine the weight required to prepare 4 liters of nanofluid (γ-Al_2O_3 / distilled water) for each concentration individually with the help of an electronic balance with four digits according to the following equation [16]:

$$m_{Al_2O_3} = \left(\frac{\varphi}{1-\varphi}\right)\left(\frac{\rho Al_2O_3}{\rho water}\right) m_{water} \quad (2)$$

Next, the alumina powder is dispersed in the distilled water by using a magnetic stirrer for 1 hours and with several cycles of 1500 rpm. The prepared mixture is put in an ultrasonic cleaner device for 4 hours, the maximum power being 720 W.

The weights given to the Al_2O_3 powder are rather in grams or kilograms, while powders, especially dry powders, are normally measured in grams or kilograms. This is attributed to the aspects of density variation, concentration calibration, and comparability in the course of research. The use of density measurements can affect the amount of powders containing nanoparticles, while the use of volume measurements may distort the concentration level. Weight measurements also enable determination of the precise concentration of nanoparticles since the amount of solution is directly related to the mass of the nanoparticles. In addition, weight-based measurements provide the ease of replicability in the sense that another researcher can take the same mass of Al_2O_3, whether the powder is dense or whether the sieving method used is different.

Once the nanofluid is prepared, some amount of it is saved to macroscopically examine its agglomeration. The studies revealed that the fluid did not agglomerate for the period of 24 hours (Figure 3). Specification of γ-Al_2O_3 nanoparticles (purchased from Sky Spring Nanomaterials, Inc., USA) Table 1 shows the properties and particle size of Al_2O_3, and Figure 4 and Figure 5 show SEM test images and XRD test images.

γ-Al_2O_3/distilled water 0.5%   γ-Al_2O_3/distilled water 0.1%

Fig. 3. Samples of prepared nanofluid after 24 h

Table 1
Specification of γ-Al_2O_3 used in this study [17]

Average particle size/nm	Purity	Density/kg m^{-3}	Color	Morphology	Specific area/m^2 g^{-1}	Specific heat/J kg^{-1} K^{-1}	Thermal conductivity /Wm^{-1} K^{-1}
15	>99 %	3970	White	Nearly spherical	120	765	40

The spherical cross section of the nanoparticles was identified at 30,000X magnification using a scanning electron microscope. All the reflections in the XRD pattern can be indexed to the tetragonal phase of Al_2O_3 using JCPDS (Joint Committee on Powder Diffraction Standards).

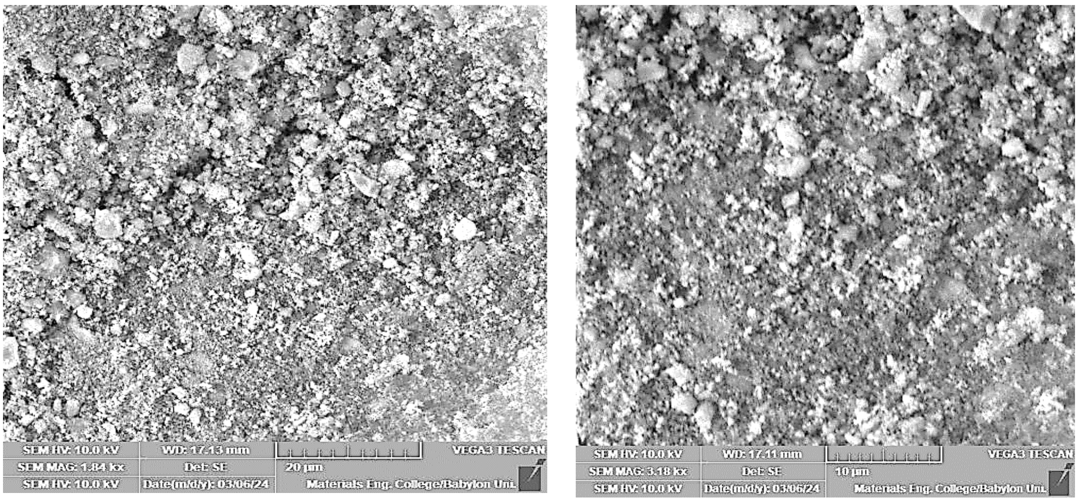


Fig. 4. SEM test images

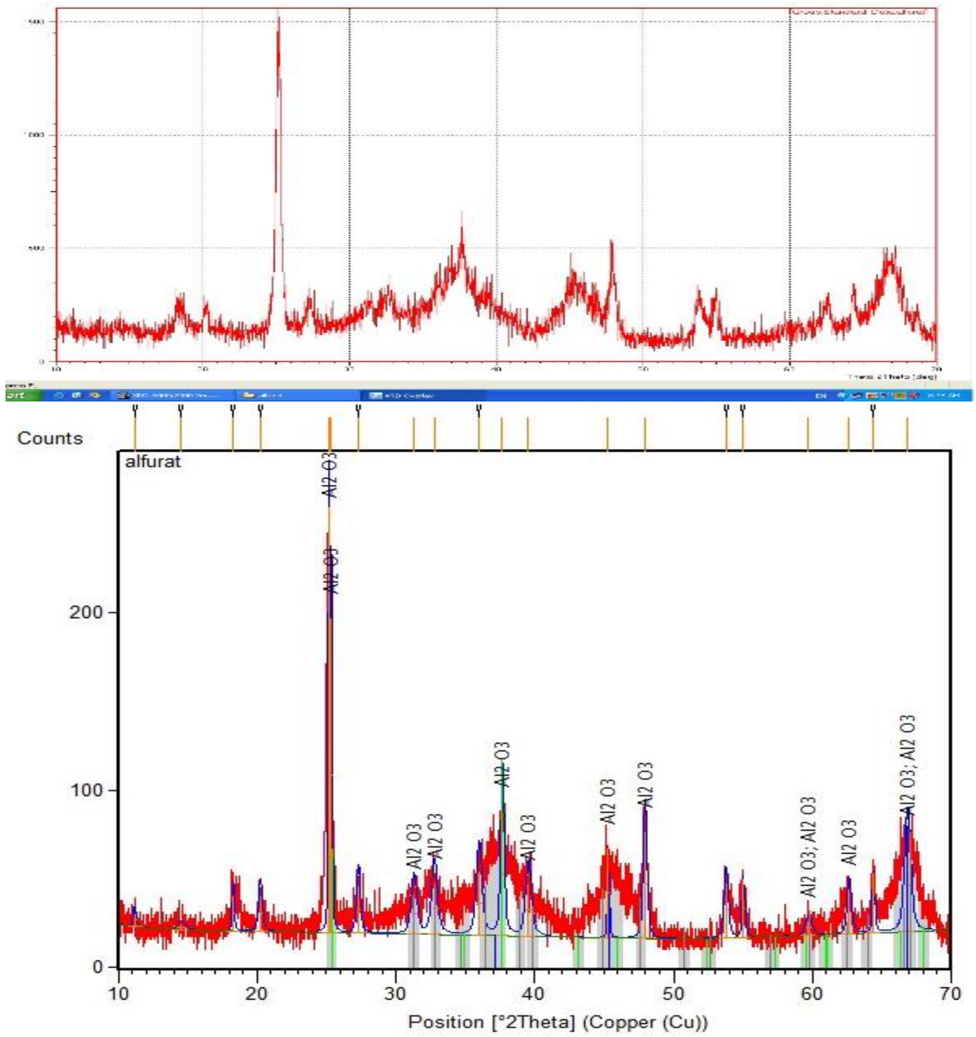


Fig. 5. XRD test images

According to the experimental data, different key parameters and dimensions are defined. These are captured in Figure 6 and Table 2 below.

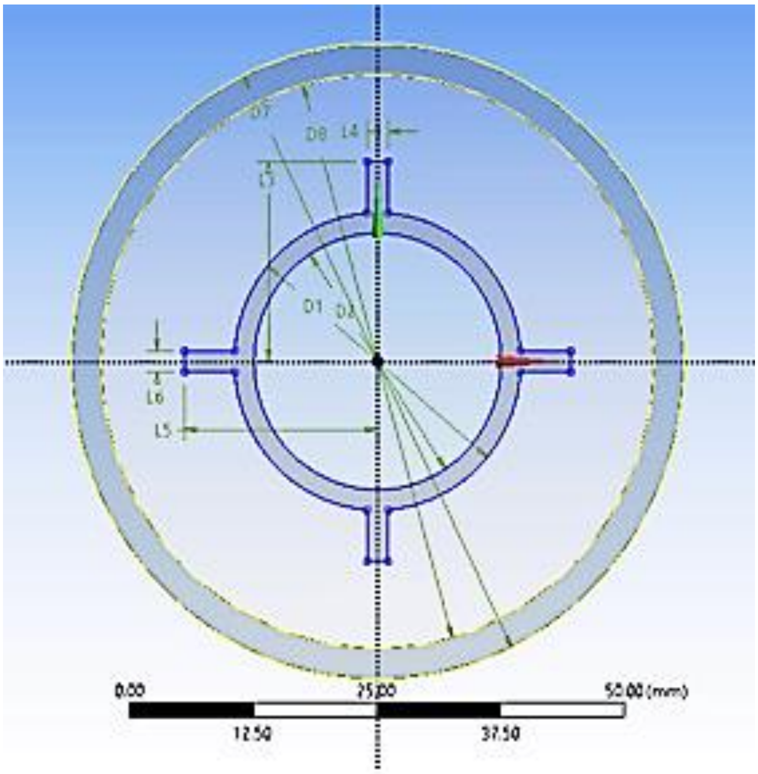


Fig. 6. Key parameters

Table 2
Parameters and dimensions

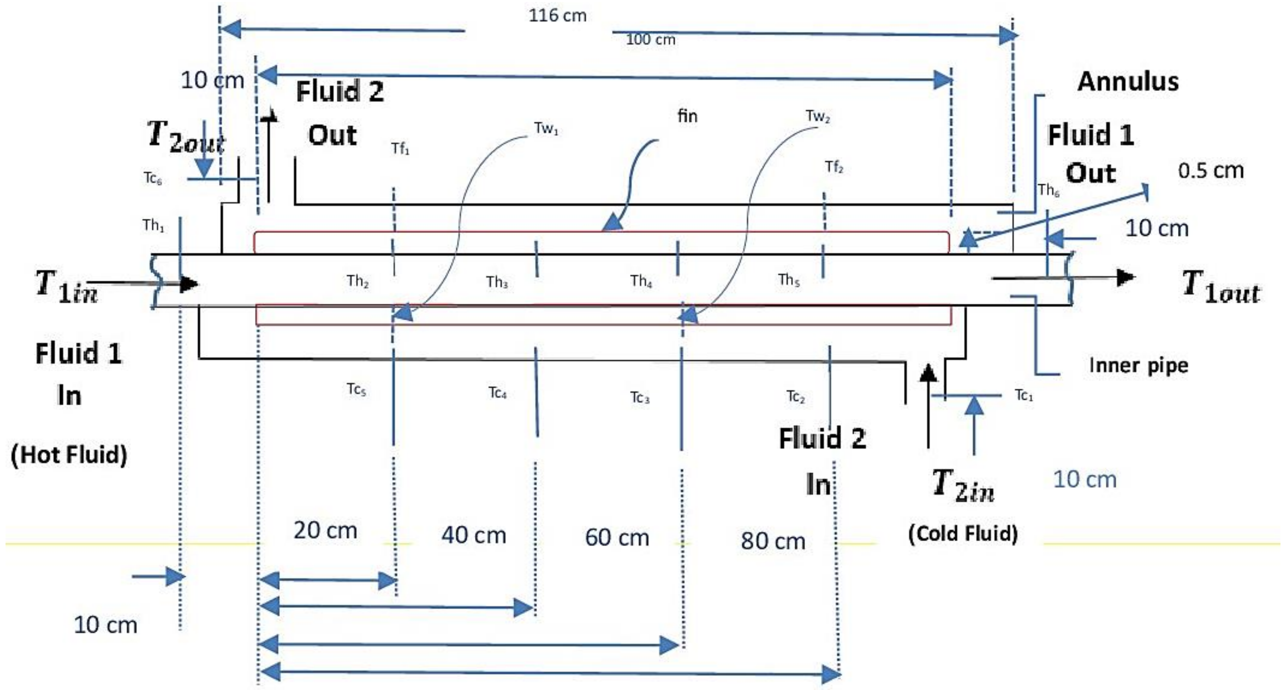
Parameters	Values (mm)
D1, Inner tube (copper), Outer diameter	28.5
D2, Inner tube (copper), Inner diameter	26.5
L3	19.5
L4	5
L5	19.5
L6	2
D7, Outer tube (PVC), Outer diameter	62
D8, Outer tube (PVC), Inner diameter	54
Longitudinal rectangular fins thickness	1
Longitudinal rectangular fins Height	5
Longitudinal rectangular fins Length	1000
Double tube heat exchanger length	1160

The experimental study was carried out employing a double tube heat exchanger, an inner copper tube with longitudinal rectangular fins and an outer PVC tube.

Water at 22 °C and flow rate of 12 LPM was filtered through the outer PVC tube. The inner copper tube served as the hot fluid passage, and three different states of fluids were tested:

i. The water samples to be used should be distilled water with flow rates of 2, 4, and 6 LPM at three different temperatures of 45 °C, 55 °C, and 65 °C.
ii. Nanofluid γ-Al_2O_3/distilled water with volume concentrations of 0.1% and 0.5% and the same temperature and flow rate of the buffer solution as described above.

The double-tube heat exchanger was used in counterflow to obtain the highest levels of heat transfer. Temperatures at different points on the heat exchanger were taken by placing K-type thermocouples at appropriate locations. The thermocouple locations are shown in Figure 7.



Th: temp. of hot fluid, Tc: temp. of cold fluid, Tf: temp. of the fin, Tw: temp. of the wall of the inner pipe
Fig. 7. The location of the embedded

2.2 Calculations

The following calculations were performed using the collected temperature data:

Reynolds number (*Re*):

$$Re = \frac{\rho \, U_m \, d_i}{\mu} \tag{3}$$

Nusselt number (*Nu_{exp}*) [18]:

$$Nu_{\mathrm{D}} = \frac{\left(\frac{f}{8}\right)(Re_D - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}} - 1\right)} \tag{4}$$

Prandtl number (*Pr*):

$$Pr = \frac{\mu \, C_P}{K} \tag{5}$$

Friction factor [19]:

$$f = (0.79 \ln \, Re_{\mathrm{D}} - 1.64)^{-2} \tag{6}$$

Convective heat transfer coefficient (*h*) [15]:

$$h = \frac{Q}{A_s\,(T_{wi} - T_{b})} \tag{7}$$

Overall heat transfer coefficient (*U*) [4]:

$$U = \frac{1}{\frac{1}{h_a} + \frac{1}{K} + \frac{1}{h_w}} \tag{8}$$

Heat transfer rate (*Q*) [9]:

$$Q = \dot{m}_w\, C_{ph}\,(t_{h1} - t_{h2}) = \dot{m}_a\, C_{pc}\,(t_{c2} - t_{c1}) \tag{9}$$

$$Q = U\,A\,\theta_m \tag{10}$$

The Number of transfer units (*NTU*) [1]:

$$\mathrm{NTU} = \frac{UA}{C_{min}} = \frac{Q}{\Delta T_{LM} C_{min}} \tag{11}$$

Where: $C_h = m_h \dot{C}_{P_h}, C_c = m_c \dot{C}_{P_c}$

$C_{\min}$: The minimum value of C_h and C_c

The effectiveness (ε) [1]:

$$\varepsilon = \frac{1 - \exp\,[-NTU(1 - Cr)]}{1 - \mathrm{Cr}\ \exp\,[-NTU(1 - Cr)]} \tag{12}$$

Where: $C_r = \frac{C_{\min}}{C_{\max}}$

Thermal conductivity (k) [20]:

$$k_{nf} = k_{pf}\,(T)(1 + 4.5033\phi) \tag{13}$$

The employed mathematical models were to perform quantitative predictions of micro and macro parameters in heat transfer research of nanofluids, including the friction factor and the Nusselt number. Every model is used for certain experiments, and the selection depends on the type of the flow and properties of nanofluids, like turbulent flow in heat exchangers.

The friction factor for turbulent flow of fluids with variable properties in the pipe is evaluated using the Petukhov (1970) correlation. It is most suitable where the fluids are complex, such as the nanofluids, where the flow resistance or friction loss is a paramount consideration. The use of Petukhov's model is relevant for determining pressure drop and flow resistance in a double pipe heat exchanger with nanofluids, as flow resistance and friction loss are important in this heat exchanger.

The Dittus-Boelter equation, which is suitable for conditions of turbulent flow, is used when evaluated for the Nusselt number, where the properties of fluids are taken as equivalent to water or water-based fluids [18]. This model is useful for assessing the heat transfer efficiency in the system since it uses water and Al_2O_3-based nanofluids.

It has used Gnielinski's correlation for the convective heat transfer coefficient for better refinement in the transitional flow regime between laminar and turbulent flows. This model employs both Prandtl and Reynolds numbers, hence being able to carry out more accurate calculations in a larger flow range. It is applied when the flow regime is uncertain or contains a blend of both types in the nanofluid investigation process.

2.3 Data Analysis

The relationships between the experimental data, such as Reynolds number, Nusselt number, local heat transfer coefficients of water and nanofluid along the axial distance, different flow rates for different temperatures with Nu and heat transfer rate, Reynolds number with friction factor, experimental Nu with Nu correlation, and experimental study results, are defined.

3. Results and Discussion

Nanomaterials in water enhance heat transfer through various processes. High thermal conductivities of nanoparticles increase the thermal conductivity of the mixture, while Brownian motion increases micro-convection and heat transfer rates. Nano-sized particles have larger surface areas, allowing more heat exchange points. This allows for compact and efficient heat exchanger design. Although nanomaterials may be costly, the enhanced heat transfer coefficient reduces overall costs and improves system performance. The concentration of nanomaterials is crucial for enhancing composite properties. Too low or high concentrations may cause issues like increased viscosity and higher pumping power. Stability and uniform distribution of nanoparticles are essential to avoid sedimentation and clogging.

3.1 Temperature Distribution For 2 LPM

This work aims to investigate the application of nanomaterial-water in a finned tube heat exchanger for increasing the heat exchange rate. The analysis also showed that the smaller outlet temperature and the greater decrease in temperature of the nanomaterial-water mixture mean greater heat transfer rates.

The data shows temperature distribution along the x-axis for three different fluids: deionized water, aluminum oxide in deionized water at 0.5% concentration, and aluminum oxide in distilled water at 0.1%, Figure 8.

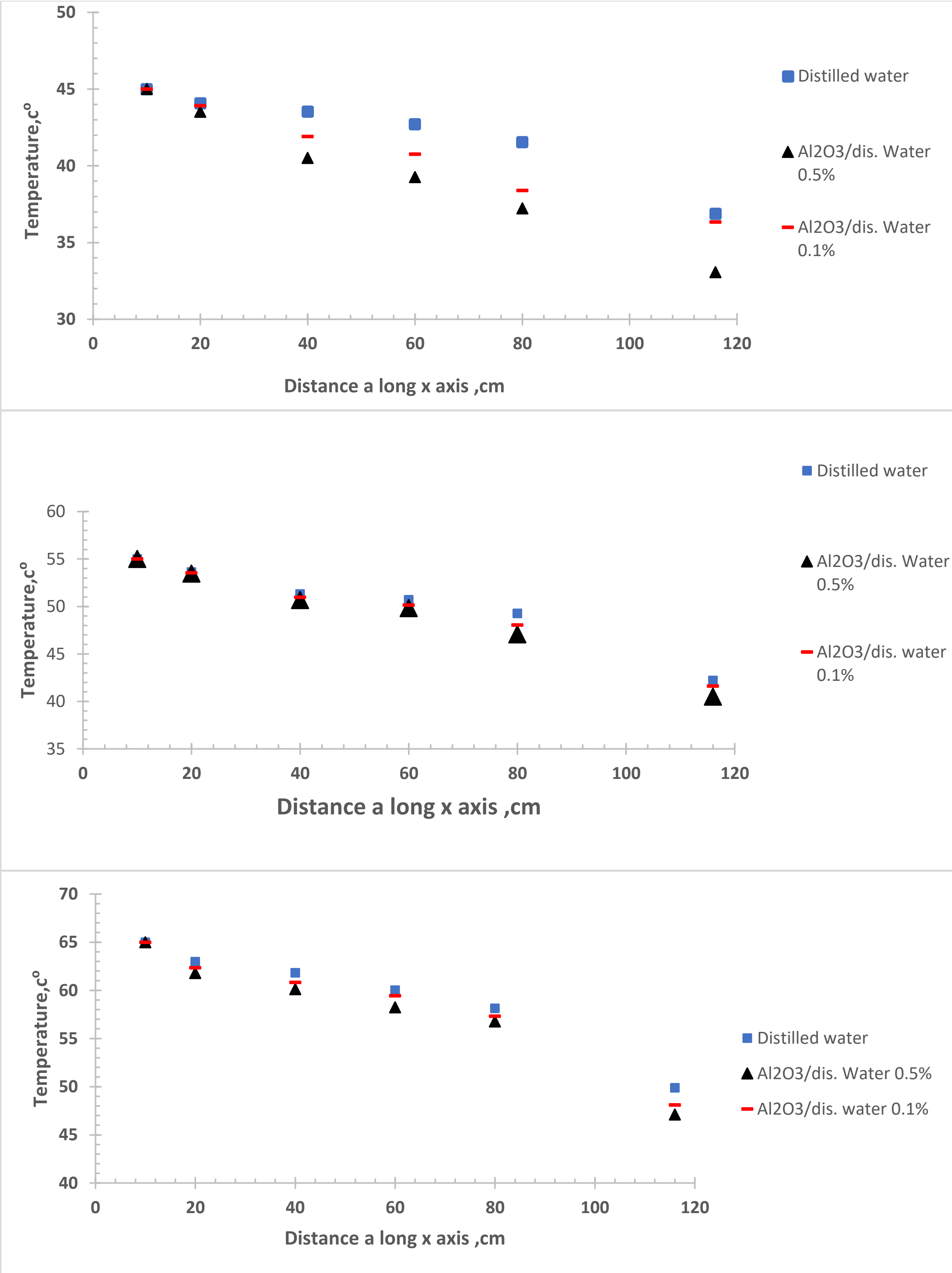


Fig. 8. Temperature distribution along the x-axis, from top to bottom: 45 °C, 55 °C, T=65 °C at 2 LPM

The analysis of the data proves that the addition of Al_2O_3 nanoparticles in distilled water leads to a reduction in the temperature along the x-axis as compared to distilled water. The result revealed that 0.5% Al_2O_3 concentration had the highest reduction in the temperature.

3.2 Temperature Distribution For 4 LPM

The work shows that all examined nanofluids, especially Al_2O_3, possess larger thermal conductivities than water, which improves the heat transfer coefficient and water concentration. When added in water, they enhance the heat transferability of the mixture by a very big margin. This leads to enhancement of convective heat transfer and micro-convection in the fluid as depicted in Figure 9.

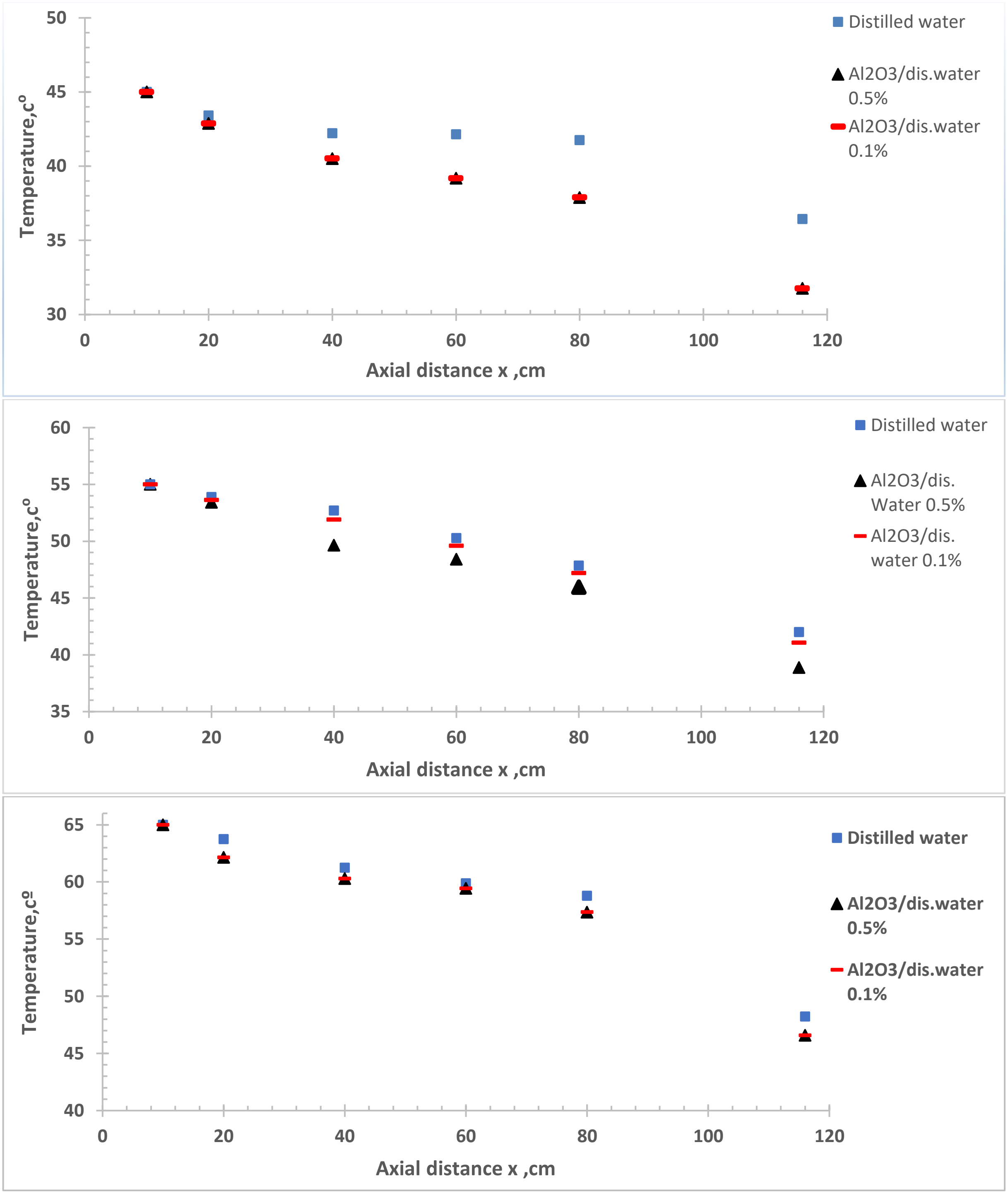
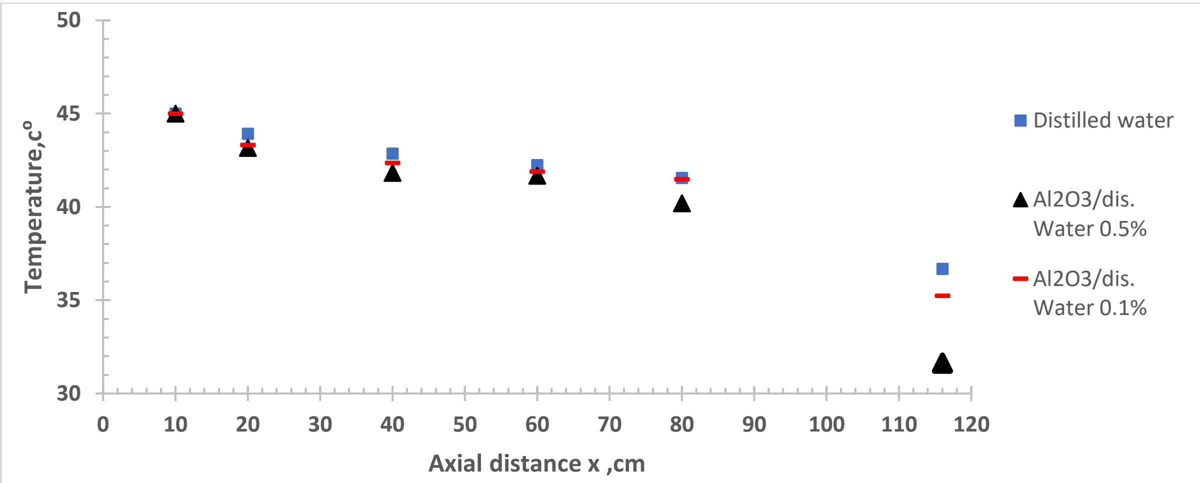


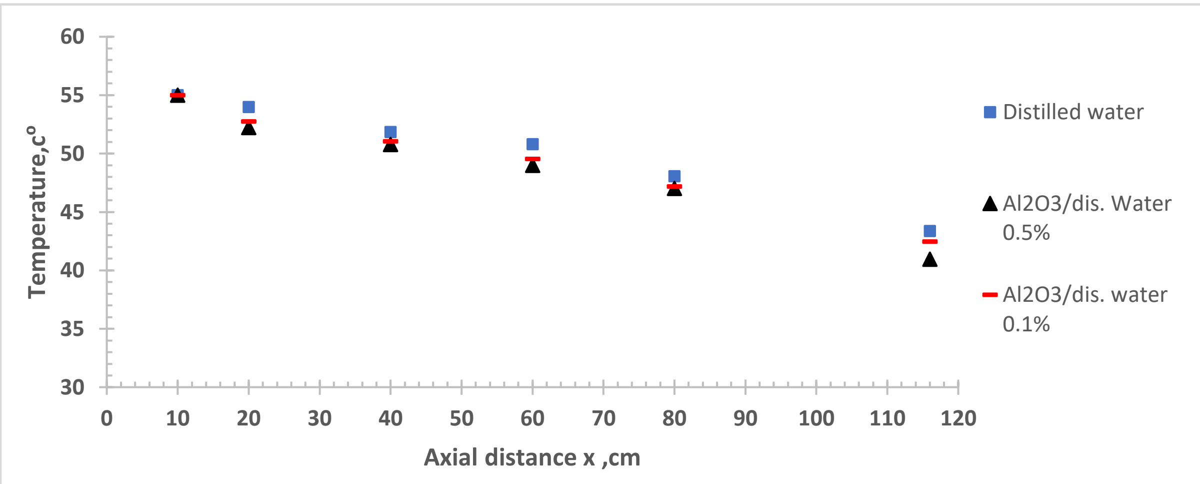
Fig. 9. Temperature distribution along the x-axis, from top to bottom: 45 oC, 55 oC, T=65 oC at 4 LPM

On the figure, one can see the temperature dispersion of distilled water: Al_2O_3/distilled water 0.5% and Al_2O_3/distilled water 0.1% depending on axial distance. Temperature decreases with distance, and with respect to distance, Al_2O_3 influences the temperature pattern whether the initial temperature is high or low. Al_2O_3/distilled water 0.5% has a higher temperature at the axial distance, which shows the effect of the factor on the heat transfer coefficient of the fluid. The increase in the volumetric flow rate leads to an increase in the temperature drop through the heat exchanger, and this is what we notice when comparing the three flow rates.

3.3 Temperature Distribution For 6 LPM

Nanomaterials concentrate in water to determine the ability of heat transferring. High concentrations may enhance the thermal conductivity and convection of the fluids but lead to high viscosity of the fluids and settling of particles. The temperature distribution is found to reduce with axial distance, and distilled water and Al_2O_3 mixtures show better heat transfer rates. As flow rate increases, the initial temperatures reduce. In Figure 10, we find that the increase in flow rate has a clear effect of reducing the temperature more than other flow rates, which confirms that increasing the flow rate is accompanied by a decrease in temperature along the exchanger. In the case of nanofluid, the decrease is greater than that of distilled water, and the largest percentage of decrease is at concentration 0.5% as depicted in Figure 10.





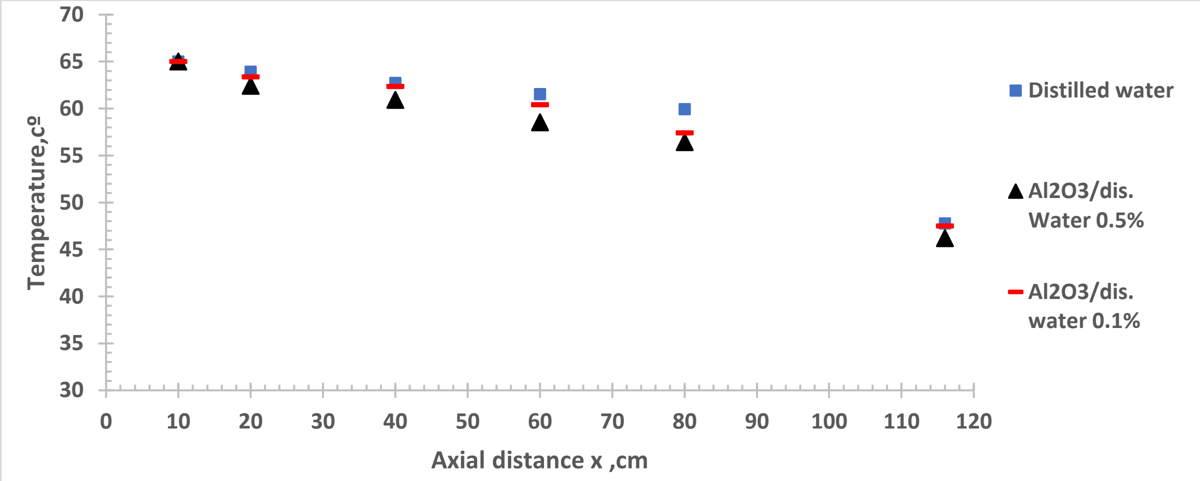


Fig. 10. Temperature distribution along the x-axis, from top to bottom: 45 °C, 55 °C, T=65 °C at 6 LPM

3.4 Heat Transfer Rate Vs. Reynolds Number

The general performance of the heat exchanger can be evaluated based on parameters like the effectiveness (ϵ), number of transfer units (NTU), and the total heat transfer rate. The heat transfer rate and Reynolds number factor are significant when measuring the performance of heat exchangers when using a nanomaterial-water solution.

The heat transfer rate of all three fluids increases with an increase in Reynolds number, as higher Reynolds numbers lead to higher flow rates and convective heat transfer [13]. Distilled water cools the hot wall slower than nanomaterial-water mixtures and loses its effectiveness as Reynolds number rises. The water mixture with 0.5% Al_2O_3/ distilled water has the highest heat transfer rate at all Reynolds numbers. An increase in nanoparticle concentration leads to a decrease in heat transfer rate, making these two nanomaterial mixtures better than distilled water. This suggests that nanoparticles are useful in improving thermal conduction and convection heat transfer as depicted in Figure 11.

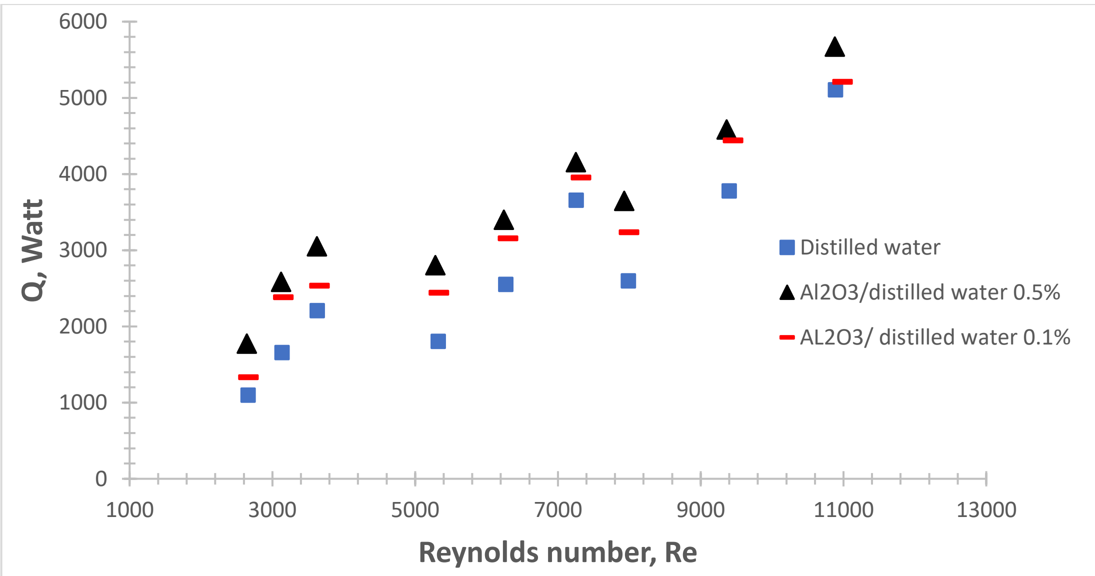


Fig. 11. The heat transfer rate VS Reynolds number

3.5 The Nusselt Number Vs. Reynolds Number

From the findings of the present study, it is clear that 0.5% Al_2O_3/water has higher Nusselt numbers compared to distilled water for all Reynolds numbers. The maximum Nusselt numbers are observed in 0.5% Al_2O_3/water and then distilled water and 0.1% Al_2O_3 mixture. As it can be noted, as the concentration of Al_2O_3 nanoparticles raised, the Nusselt numbers also rose. Comparing the results obtained from both the 0.1% and 0.5% Al_2O_3-water mixtures, it can be concluded that the 0.5% mixture has a better impact on enhancing Nusselt numbers; this is clearly evident in Figure 12 and Figure 13.

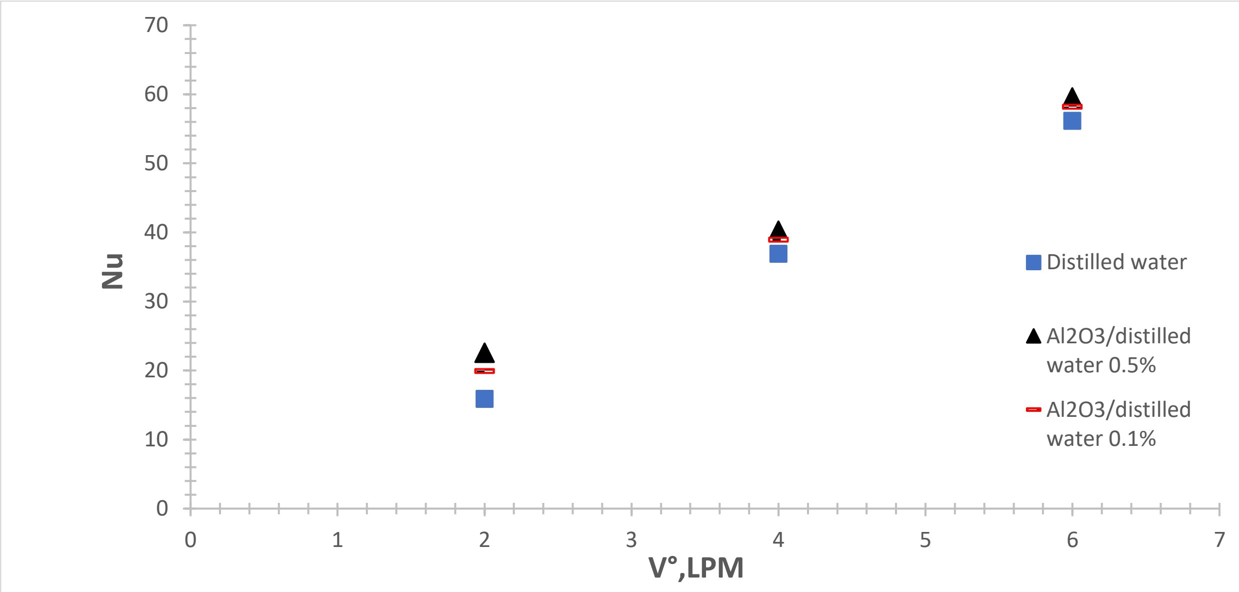


Fig. 12. The experimental Nusselt number VS Reynolds number

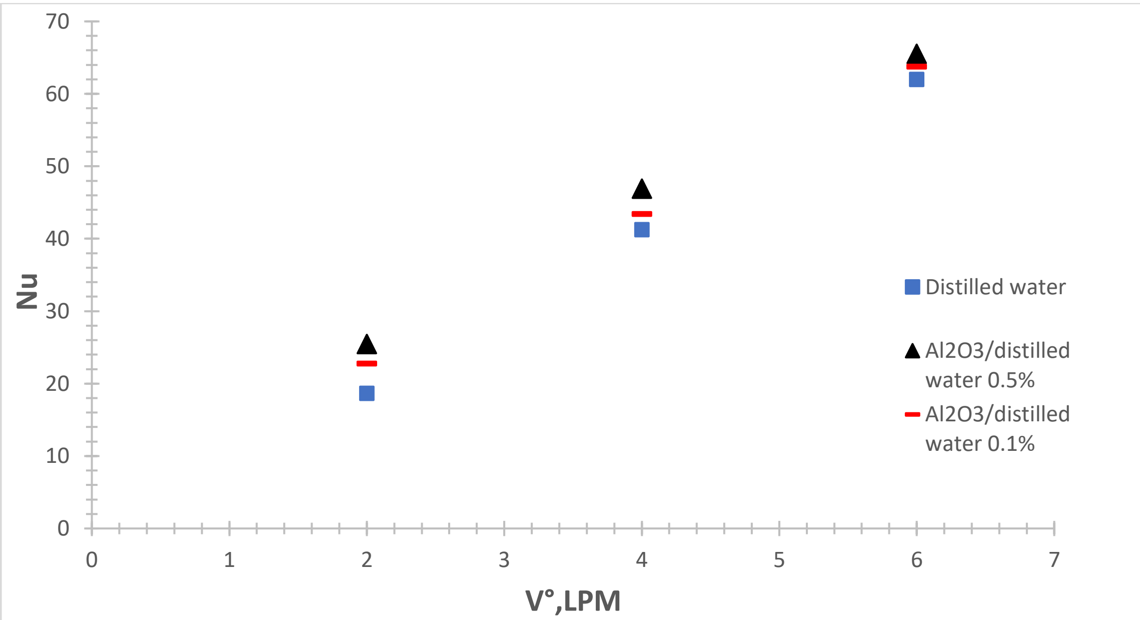


Fig. 13. The experimental and Nu Gnielinski (1976) Nusselt number VS Reynolds number

3.6 The Heat Transfer Coefficient Vs. Reynolds Number

The water mixture is observed to have the highest heat transfer coefficients in all Re numbers of the three fluids investigated. The 0.5% Al_2O_3/dis. water mixture performs better than the 0.1% Al_2O_3/dis. water mixture, which specifies that an increase in the concentration of the nanoparticles improves the heat transfer coefficient as depicted in Figure 14.

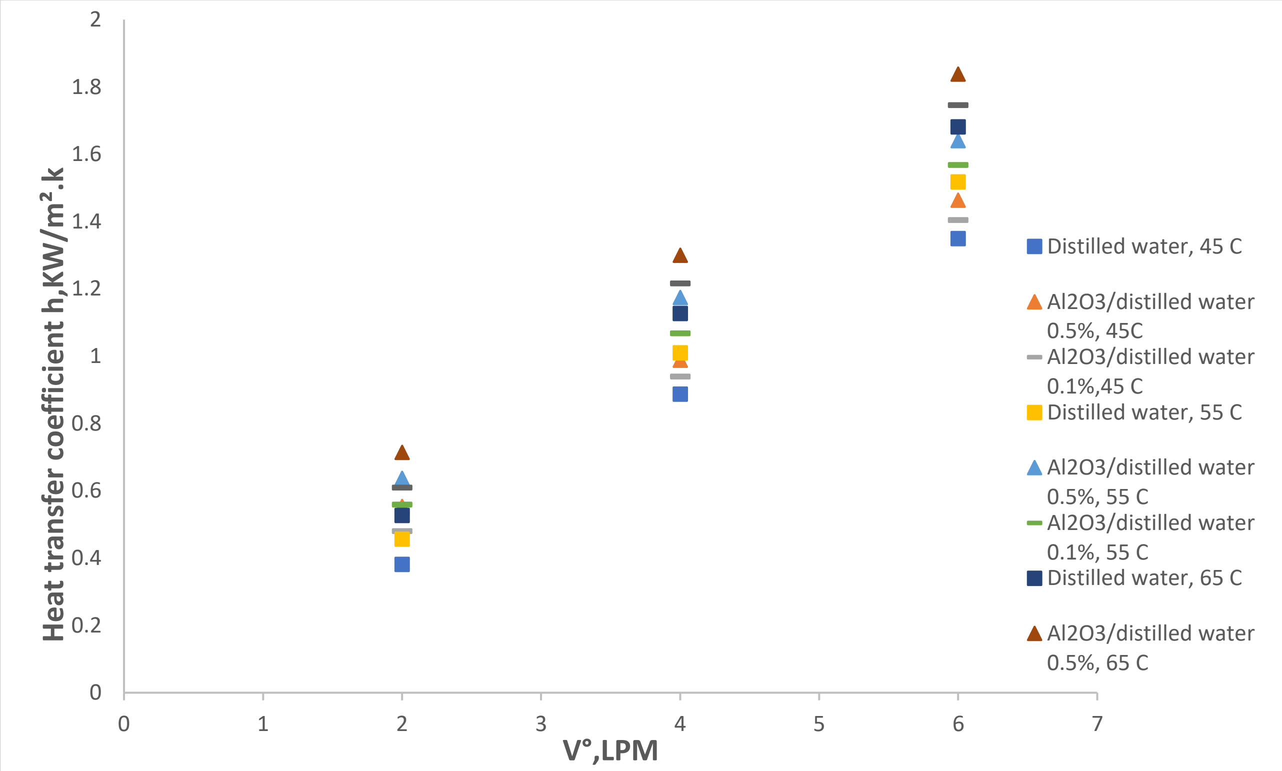


Fig. 14. The heat transfer coefficient VS Reynolds number

3.7 The Number of Transfer Units Vs. Reynolds Number

The Number of Transfer Units (NTU) is a crucial parameter in heat exchanger performance analysis, indicating the efficiency of the heat transfer process between fluids. It is generally higher with the growth of Reynolds number, which depends on the type of fluid used and its characteristics such as viscosity, thermal conductivity, and specific heat. Higher flow rates improve the convective heat transfer coefficient, leading to higher NTU values. As the concentration of nanoparticles increases, the NTU values also increase due to increased convective heat transfer. Enhancing heat exchangers can be achieved through achieving higher NTU values with the help of higher Reynolds numbers. Optimizing for heat exchangers to work in the region of turbulent flow can enhance the heat transfer coefficients.

For distilled water, NTU rises initially with Re and reaches the maximum value at Re = 3100. For Al_2O_3/distilled water 0.5%, NTU mostly remains closer to distilled water but slightly higher in value. The NTU peak is observed at Re equal to 3100, after which the values start to decline. Small oscillations are seen at higher Re, and NTU becomes constant at the end. For Al_2O_3/distilled water 0.5%, NTU values are generally higher than distilled water and the 0.1% Al_2O_3 mixture. When the flow becomes fully turbulent, NTU becomes constant and only slightly increases for distilled water and the 0.5% Al_2O_3 mixture. The concentration of nanoparticles influences the NTU stability at higher

Reynolds numbers. The NTU values of the 0.5% Al_2O_3 mixture are comparatively higher than the base fluid, proving the better thermal characteristics of the nanofluid as depicted in Figure 15.

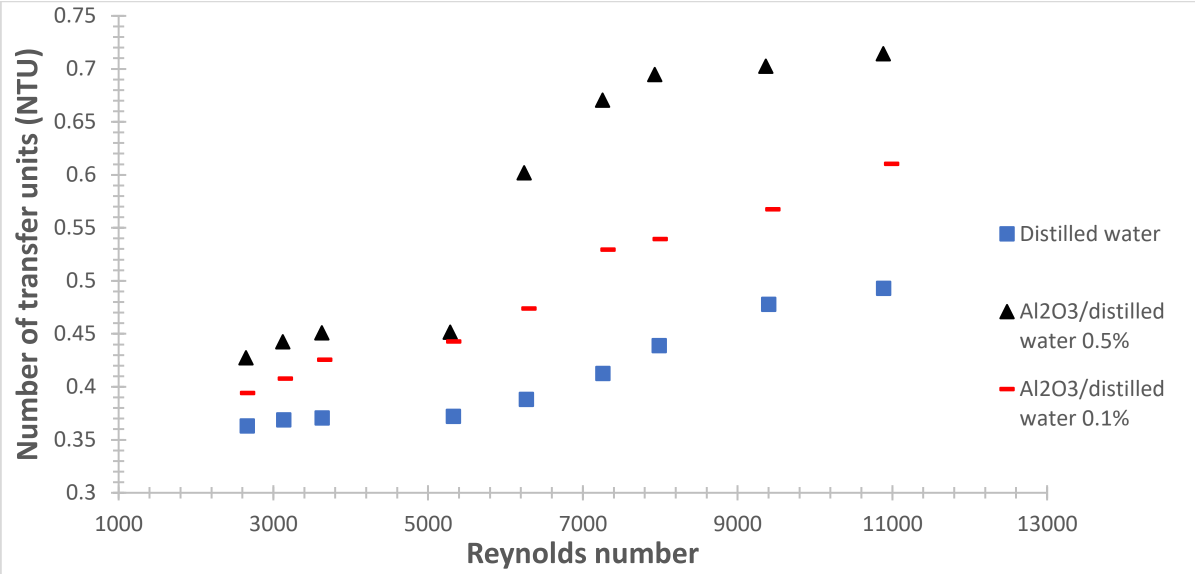


Fig. 15. The number of transfer units VS Reynolds number

3.8 The Effectiveness Vs. Reynolds Number

As a result, it is found out that 0.5% Al_2O_3/water has higher efficiency compared to distilled water for all the Reynolds numbers. From Figure 16, the increase in the effectiveness is more pronounced at higher Reynolds numbers as it should be. According to the results obtained, it can be concluded that the 0.5% Al_2O_3/water is more effective among the three fluids used in the study. Proposes that there is a better performance in terms of heat transfer since the nanoparticles are denser.

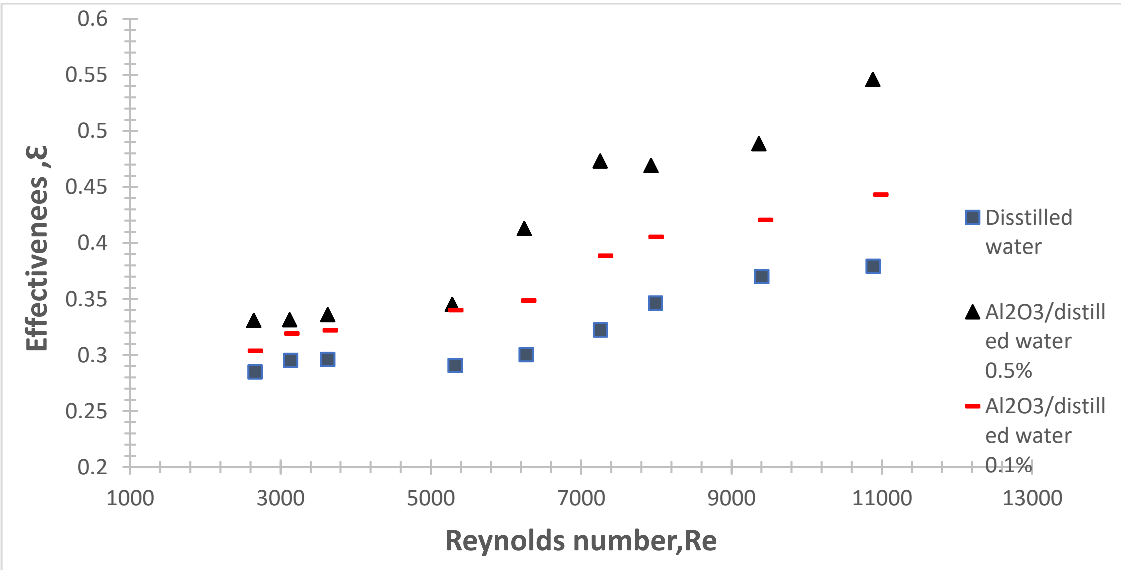


Fig. 16. Effectiveness VS Reynolds number

3.9 The Friction Factor Vs. Reynolds Number

Figure 17 shows the friction factor (F) versus Reynolds number (Re) for three water solutions: distilled water, Al_2O_3 nanofluid/distilled water with a concentration of 0.5%, and Al_2O_3 nanofluid/distilled water with a concentration of 0.1%.

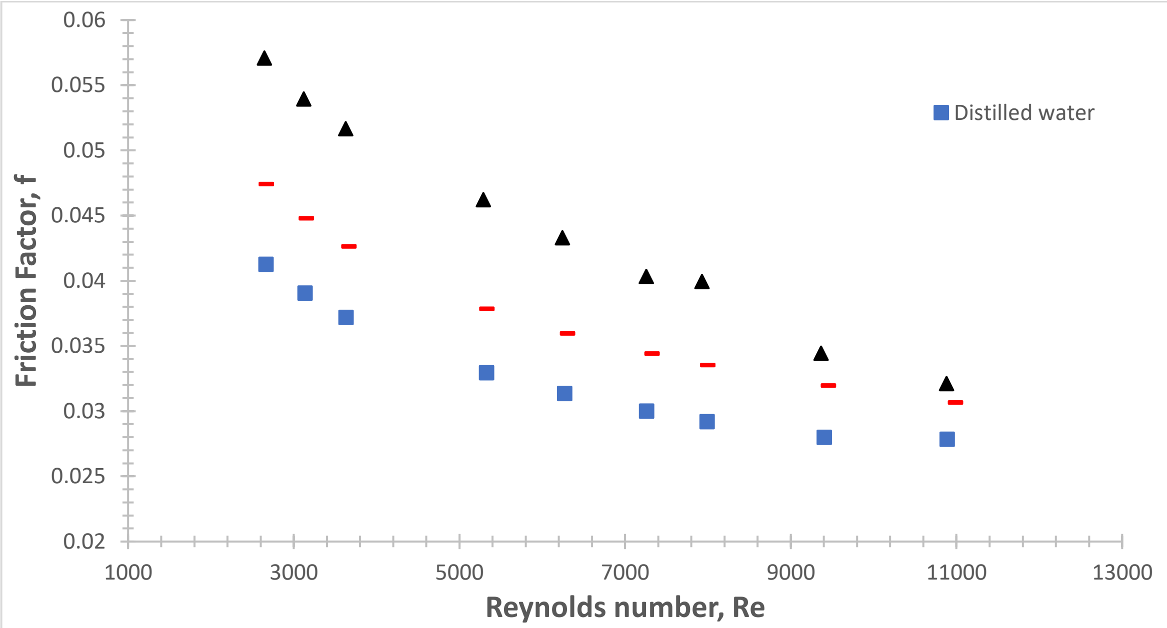


Fig. 17. Friction factor VS Reynolds number

The friction factor decreases with an increasing Reynolds number in all three fluid compositions. Al_2O_3 dispersions have slightly higher friction factors than distilled water at low Reynolds numbers. As Reynolds number increases, all friction factors decrease, and at very high Reynolds numbers, they are almost the same. As Reynolds number increases, friction factor decreases, causing lesser frictional losses. Al_2O_3 dispersions have slightly higher friction factors due to enhanced thermal conductivity, making them more suitable for heat transfer applications. These properties are useful for cooling systems, pipelines, and heat exchanger design, as they influence efficiency and performance.

3.10 The Thermal Conductivity Vs. Temperature

It is possible to note from Figure 18 that the thermal conductivity of the investigated fluids rises with temperature. Alumina particles, when added to water, improve the thermal conductivity of the water, and the thermal conductivity improves with greater concentration of alumina particles in the water.

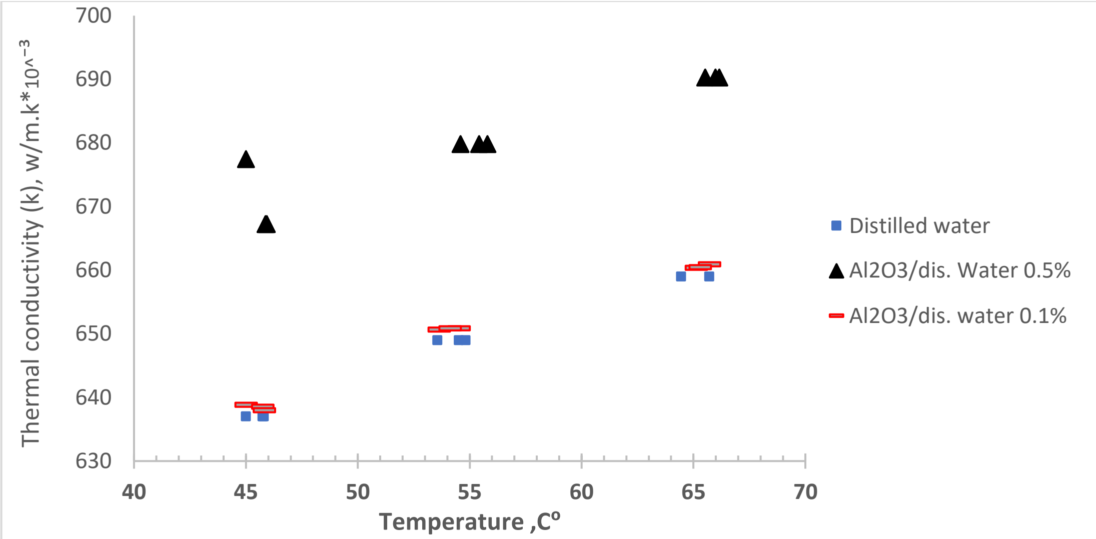


Fig. 18. Variation of thermal conductivity with inlet temperature of hot fluid

The study reveals that water has a moderate thermal conductivity that increases with temperature. However, 0.5% Al_2O_3/distilled water has better thermal conductivity than distilled water and increases with temperature. Higher concentrations of Al_2O_3 improve thermal conductivity, with a noticeable increase in 0.5% Al_2O_3. The study also found that the thermal conductivity of Al_2O_3 dispersed in water increases with temperature, with higher slopes indicating even larger increases than for distilled water. The thermal conductivity of distilled water increases when Al_2O_3 is added, and the enhancements increase with the concentration of Al_2O_3. The study also found that the thermal conductivity of nanofluids is more sensitive to temperature changes than distilled water, making Al_2O_3 dispersions potentially more suitable for heat transfer purposes in industries like electronics cooling, automotive cooling systems, and heat exchangers. These findings are significant for industries where efficient thermal management is critical, such as electronics cooling and automotive cooling systems.

4. Conclusions

The experimental study on the improvement of heat transfer with nanomaterial-water nanofluids in a finned tube heat exchanger has given the fundamental understanding of how nanofluids can help to advance the heat transfer technology. For all three fluids, the heat transfer rate rises with Reynolds number in the initial stages as the heat transfer coefficient increases with the flow velocity. It is observed that all three fluids have high heat transfer rates at high Re greater than 7000, and the nanofluids have better heat transfer rates than distilled water. From the results, the 0.5% Al_2O_3 mixture shows the highest overall performance; hence, it is understood that lower nanoparticle concentration is more beneficial for heat transfer boost. Both Al_2O_3 nanofluids perform better as coolants than distilled water, with the 0.1% concentration exhibiting the highest heat transfer rates. This implies that the nanoparticles increase thermal conductivity and the heat transfer efficiency of the base fluid. The trends also show that the heat transfer efficiency depends on the concentration of nanofluid as a key factor. Through a comprehensive review of relevant literature and empirical studies, several key findings have been elucidated:

i. The experimental study confirms that nanofluids, specifically γ-Al_2O_3-water mixtures, significantly enhance heat transfer performance in finned tube heat exchangers compared to conventional distilled water. This is attributed to the higher thermal conductivity and convective heat transfer coefficients of the nanofluids.

ii. The concentration of nanoparticles plays a critical role in heat transfer enhancement. The study found that a 0.5% concentration of Al_2O_3 in water delivered the best overall performance, indicating that lower concentrations of nanoparticles are more effective in improving heat transfer.
iii. The heat transfer rate for all tested fluids, including distilled water and nanofluid mixtures, increased with the Reynolds number. Higher Reynolds numbers led to increased flow rates and enhanced convective heat transfer, with nanofluids showing superior performance over distilled water.
iv. While increasing nanoparticle concentration generally improves heat transfer, there is an optimal limit. The 0.5% Al_2O_3 concentration provided the highest heat transfer coefficient, but it also resulted in higher viscosity and potential pressure drop issues, indicating the need for balancing concentration with system efficiency.

Based on this study, further research into the improvement of heat transfer performance of nanofluids should consider nanoparticle concentration and size as well as modifying the surface of the particles. It also proposes the research on new nanomaterials and base fluids, the synthesis of enhanced nanofluids, the investigation of the nanofluids' long-term stability and reliability, the comparison of heat exchanger configurations, and the partnership with industry stakeholders to incorporate nanofluids into the existing systems. The above recommendations should facilitate the exploitation of nanofluids to the greatest possible extent across different industries.

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