Heat Transfer Enhancement in Parallel Flow Double Pipe Heat Exchanger using Aluminum Oxide and Copper Oxide Nanofluids

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Abstract

This study investigates the effects of Copper oxide (CuO) and aluminum oxide (Al_2O_3) nanofluids with different diameter sizes and concentrations dissolved in water on a double-pipe heat exchanger (DPHE) behavior numerically. Thereby evaluating the effect of nanofluid's characteristics on heat transfer coefficient, friction factor, Reynolds number and Nusselt number. This objective was accomplished by numerically investigating (through ANSYS) and determining the effect of volume fraction and diameter of nanoparticles on heat transfer and fluid flow via a DPHE. The results showed that under ideal conditions such as 4 vol% and diameter 25 nm, Al_2O_3 has a better performance by 99.61% than water under 20000 Reynolds number, while CuO performance was 93.52% at the same conditions.

Introduction

Heat exchangers have become increasingly important in recent years due to the growing concern about energy conservation and efficiency (Pordanjani et al., 2019). As industries seek to reduce costs and conserve resources, heat exchangers have become essential in energy management systems. This has led to a surge in the popularity and importance of heat exchangers across various fields. One of the most commonly used types of heat exchangers is the double-pipe heat exchanger. This type of heat exchanger is highly versatile and can be found in a wide range of everyday appliances and utilities. For example, double-pipe heat exchangers are commonly used in refrigerators, air conditioners, and other cooling systems, as well as in industrial processes that require heating or cooling. The growing demand for energy efficiency has only increased the industry's importance and usage of double pipe heat exchangers (Goodarzi et al., 2016; Hashemian et al., 2016; Sheikholeslami & Ganji, 2016; Bahmani et al., 2018).

Heat transfer methods are generally classified into two categories based on the source in which they rely on. These categories are known as passive and active. As the name suggests, the passive techniques primarily rely on internal sources, while active methods require an external form of source in order to aid in the heat transfer process (Sidik et al., 2017). Active techniques include methods such as forced convection, where a fluid is forced to flow over a surface by means of a pump or other mechanical device. This can be an effective way to enhance heat transfer, but it requires significant energy and can be expensive to implement. Passive techniques, on the other hand, rely on internal solutions to enhance heat transfer. For example, changing the chemistry of the fluid involved or altering the shape of pipes or tubes can help to improve heat transfer. This approach is often more cost-effective and sustainable as it does not require external energy sources (Pordanjani et al., 2019).

A double-pipe heat exchanger is a passive means of improving heat transfer, where two pipes or tubes are arranged concentrically, with the fluid to be heated or cooled flowing through the inner pipe, while the outer pipe carries the heat transfer fluid. This configuration is quite effective for heat exchange purposes. This design allows for efficient heat transfer between the two fluids and is commonly used in various industrial and commercial applications. In addition to the use of double-pipe heat exchangers, the usage of nanofluids has also shown promise in enhancing heat transfer rates (Kareem et al., 2015). Nanofluids are a type of heat transfer fluid that consists of a base fluid, such as water, mixed with nanoparticles (Mousavi Ajarostaghi et al., 2022). The small size of these nanoparticles can help increase the fluid's thermal conductivity, resulting in improved heat transfer rates. This has led to increased interest in using nanofluids in heat exchangers and other heat transfer applications.

Previous research has utilized a double-pipe heat exchanger to increase heat transfer rates (Goodarzi et al., 2016; Hashemian et al., 2016; Shakiba & Vahedi, 2016; Sheikholeslami & Ganji, 2016; Sheikholeslami et al., 2016; Templeton et al., 2016; Bahmani et al., 2018). For instance, one study examined the effectiveness of combining heat transfer with various working fluids in a double-pipe heat exchanger and discovered a significant improvement in heat transfer rates when compared to a base fluid without nanoparticles (Goodarzi et al., 2016). In another study, heat transfer properties of a double-pipe heat exchanger were numerically investigated, with simulations of the heat exchanger's thermodynamic, geometrical, and hydraulic attributes (Hashemian et al., 2016).

However, alternative studies have focused on using nanofluids to improve heat transfer rates (Duangthongsuk & Wongwises, 2009; Zamzamian et al., 2011; Mohammed et al., 2013; Maddah et al., 2014; Han et al., 2017; Gnanavel et al., 2020; Jalili et al., 2022; Kavitha et al., 2022; Zheng et al., 2022). These methods involve mixing various nanoparticles with a base fluid, such as water or other fluids, to create a nanofluid. One of the main issues of traditional fluids is that they suffer from poor thermal conductivity, which require a form of improvement that would enhance such properties (Pordanjani et al., 2019; Sajid & Ali, 2019; Jalili et al., 2022). Fluids such as ethylene glycol, water or oil, can be further improved via the addition of nanoparticles, which inherently have a higher thermal conductivity, and therefore would enhance the thermophysical properties of these fluids. This is just one example of heat transfer improvement, in the practical sense, companies often use a combination of techniques in order to improve the heat transfer properties (Pordanjani et al., 2019).

Even though nanoparticles are considered a popular technique, there is still a lot of unknown factors within the technique. Particularly, the relationship between the various properties of nanofluids and their effect on the characteristics associated with heat transfer enhancement. The extent of the usefulness of these factors in a parallel flow double pipe heat exchanger requires further exploration.

Double Pipe Heat Exchangers have some inherent limitations, with most techniques focusing on counter flow rather than parallel flow (Bahmani et al., 2018). Therefore, enhancing parallel flow heat transfer enhancement is necessary to reduce application restrictions.

Therefore, with these constrains, this study aims to numerically investigate the effect of two passive methods in form of nanofluids and heat exchanger shape to see whether the heat transfer properties would be enhanced significantly or would they remain flat. In this research two nanofluids are used, copper oxide and water, as well as aluminium oxide with water. These nanofluids are then combined with a double pipe heat exchanger within a specific range of Reynolds number (fluid flow speed) and a variety of properties are investigated, such as Nusselt number, heat transfer coefficient and friction factor.

This study is structured as follows. Section 1 gives a background introduction to heat transfer concepts and the importance of a variety of literature surrounding double pipe heat exchangers. Section 2 focuses on the materials and methodology of the research and the research process. Section 3 discusses the results of the simulation. Finally, in Section 4, the study is concluded and summarised, with future studies and prospects being analysed.

Theoretical Methodology

In this research, turbulent flow and heat transfer parameters of water/CuO and water/Al_2O_3 nanofluids in a double pipe heat exchanger by using the finite volume method (FVN) have been investigated.

Thermophysical Properties

Table 1 includes the properties related to the thermophysical aspects of the base fluids and the nanoparticles. These properties are ρ (density), Cp (heat capacity), μ (effective dynamic viscosity) and k (effective thermal conductivity) (Abu-Hamdeh et al., 2021; Awais et al., 2021; Sofiah et al., 2021; Mostafizur et al., 2022).

Table 1
Thermophysical properties of nanofluids at a temperature of 350 Kelvin

Properties	*Water*	*Al_2O_3*	*CuO*
ρ (kg/m^3)	973.46	3970	6500
μ (Nm/s)	0.000369	-	-
k (W/mK)	0.6695	40	20
Cp(kg/kgK)	4194	756	535.6

Table 2 depicts the β values for different nanoparticle boundary conditions. It should be noted that concentration is often a general term used to refer to mass fraction, mole fraction and volume fraction. In this instance, only volume fraction is used for measurement. The Nusselt number plays a critical role in convection problems, and its value depends on the Reynolds number and the Prandtl number. Additionally, if the fluid is in the thermal entry region, the Nusselt number varies as a function of the tube length (Abraham et al., 2011).

Table 2
β values for different particles with their boundary conditions at a temperature 350 Kelvin

Particle	***β***	***Concentration***
Al_2O_3	$8.4407(100\phi)^{-1.07304}$	$1\% \leq \phi \leq 4\%$
CuO	$9.881(100\phi)^{-0.9446}$	$1\% \leq \phi \leq 4\%$

The critical Reynolds number is approximately 2300, and fully turbulent conditions occur at Reynolds numbers above 10000. Between a Re of 2300 and 10000, the flow is considered to be in transition. The correlation between Nusselt and Reynolds numbers is calculated using Eq. 1 (Taler & Taler, 2017). The Prandtl number in Eq. 5 is calculated based on Eq. 1. Regarding the type of pipe, it is considered to be a smooth pipe in a fully turbulent flow.

$$C + O_2 \rightarrow CO_2 \quad \Delta_r H^\circ = -394\,\text{kJ mol}^{-1} \tag{1}$$

$$PV = nRT \tag{2}$$

The correlation between the friction factor and the Reynolds number is calculated using Eq. 7 (Taler & Taler, 2017):

$$C + O_2 \rightarrow CO_2 \quad \Delta_r H^\circ = -394\,\text{kJ mol}^{-1} \tag{3}$$

Geometry and Boundary Conditions

Unlike previous studies (Bahmani et al., 2018) that use a 2D simulation method, this numerical simulation is performed using ANSYS, which allows for a 3D rendering and simulation of the process. The dimensions of the pipe are as follows. The internal pipe is 10 mm, represented by the Figures and Equations with R_{in}, and the external pipe diameter is 15 mm, represented in the formula with R_{out}. Figure 1 illustrates a cross-section of the pipe. For parallel flow, the flow of distilled water (H_2O) and nanofluid (CuO or Al_2O_3) with a temperature of 298 K for the cold fluid on the external pipe and 350 K for the internal pipe. The inlet section received a uniform flow, and radiation effects were not taken into account. The outlet section was assumed to be in a fully developed condition, meaning that velocity variations and axial temperature were considered to be zero.

Simulation Process

The process of simulation is illustrated using the data flow diagram in Fig. 2. The first step in the simulation is to sculpt and model the double pipe heat exchanger inside the ANSYS software, and set up the geometry associated with the 3D mesh. The generation of the 3D mesh based on the boundary conditions, which is a double pipe heat exchanger (Noorbakhsh et al., 2020). The double pipe heat exchanger type uses circular inner and outer pipe cross sections.

Later, the boundary conditions are identified, and the 3D mesh is imported. The physical model and the boundary conditions are set in the program. In this process, the simulation is run and executed once the materials and boundary conditions are applied to the geometry. This means parameters such as the inner and outer pipe's temperature, viscosity, particle diameter and concentration are defined here. The simulation results are saved, and if concluded, then the results are compared and presented. However, if the results are not final, the next material and boundary conditions are tested, such as different concentrations (volume fraction), Reynolds Numbers, and nanoparticle size diameter.

Simulation Work

A double pipe heat exchanger was created using the FLUENT (ANSYS18) software in order to numerically simulate the conditions of the added parameters such as the shape dimensions and the nanofluid attributes. This model was developed and implemented in three distinct stages, including pre-processing, solving, and post-processing, using CFD simulation techniques. The fluid flow and heat transfer characteristics of the model were analyzed using this methodology. (Noorbakhsh et al., 2020). Figure 3 illustrates the base mesh for the double pipe heat exchanger that is created in the ANSYS simulation. The meshes are also presented, which show the wireframe of the double pipe heat exchanger mesh from different angles, presented in Fig. 4.

The temperature distribution of the double pipe heat exchanger is done in ANSYS mesh using the Contour plot of the heat-transfer coefficient. Figure 5 illustrates the thermal heat map produced in ANSYS, while Fig. 6 illustrates the Contour plot.

A contour plot is a graphical representation of temperature distribution over a given geometry or domain. ANSYS. Generates the contour plot. These equations take into account the heat generation, conduction, convection, and radiation within the system. The plot shows a two-dimensional representation of the temperature values, with different colours or shading used to indicate different temperature levels.

The contour plot provides a visual representation of how temperature varies across the domain, allowing for easy identification of hot spots and cold spots. Engineers and designers can use the contour plot to evaluate the effectiveness of a thermal management system, identify potential design flaws, and optimise the design for better heat transfer performance.

Numerical Results

The goal is to identify which combination of concentration and particle size for aluminium oxide has the best heat transfer properties. The simulated concentrations are 1%, 2%, 3% and 4% weight compared to the total fluid, and the particle sizes under test are 25 nm, 50 nm and 100 nm. The simulated results measure three heat transfer characteristics of heat transfer coefficient, Nusselt number, and friction factor.

The heat transfer coefficient and Nusselt number provide information about the efficiency of the heat transfer process. A higher heat transfer coefficient and Nusselt number value imply a more efficient heat transfer. If the values are significantly higher than those for a traditional heat exchanger, it suggests that using nanofluids can enhance the heat transfer efficiency of the system. The friction factor represents the resistance to fluid flow through the heat exchanger. A higher value of friction factor implies a greater resistance and pressure drop across the heat exchanger. This information can be used to optimise the heat exchanger's design and balance the heat transfer efficiency with the pumping power required. Having these values for a parallel flow double pipe heat exchanger using nanofluids can provide insight into the system's performance, efficiency, and potential for improvement through the use of nanofluids.

The observations indicate the best results at 25 nm and 4% concentration. The observations indicate that the heat transfer coefficient also has a linear relationship with the Reynolds Number. Upon closer inspection of the Tables, it is clear that the optimal value belongs to 25 nm at 4% concentration. Although the values are very closely related, it is clear that the particle size has a role in the effectiveness of the heat transfer coefficient. A higher Reynolds number also increases the heat transfer coefficient because heat flux is the main multiplier in the heat transfer coefficient formula, and heat flux is affected by particle velocity. Thus, as the Reynolds number increases, the value increases as a consequence.

The results indicated that the best heat transfer coefficient (Fig. 7) and Nusselt number (Fig. 8) values were obtained with a concentration of 4% at 25 nm particle size. The relationship between the heat transfer coefficient and the Nusselt number with respect to the Reynolds number was linear. The heat transfer coefficient and Nusselt number increased as the Reynolds number increased. This suggests that increasing the Reynolds number can enhance heat transfer and convective heat transfer efficiency. The relationship between the nanofluid concentration and heat transfer coefficient was also linear, indicating that the higher the concentration of nanofluid, the higher the heat transfer coefficient. Moreover, all the results obtained for heat transfer coefficient and Nusselt number using the aluminium oxide nanofluid were improved over the control baseline (water). This confirms that using nanofluids can significantly enhance the heat transfer efficiency of the system.

The results suggest that using aluminium oxide nanofluid can enhance the performance of the parallel flow double pipe heat exchanger. The best results were obtained with a concentration of 4% at 25 nm particle size. These findings can be useful for designing and optimising heat exchanger systems that use nanofluids to improve their heat transfer efficiency. The thermophysical properties of water versus the properties of the aluminium oxide nanofluid is what causes the nanofluid to have a better heat transfer coefficient. The velocity of water is 0.189, while with the nanoparticles added to the water, the viscosity is increased to 0.2. With these changes, the mixed fluid will have a higher value of heat transfer coefficient. Consequently, the thermos-physical properties are water has a lower viscosity and density, and thus this affects the equation used to calculate the Nusselt number. Thus, the nanofluid has a better Nusselt number. This is important and closely related to the heat transfer coefficient since the value of the Nusselt number is calculated based on the heat transfer coefficient. Thus, the Nusselt number values follow a similar pattern to the heat transfer coefficient. In this instance, water (the conventional fluid) is the weaker fluid, and the nanofluid aluminium oxide is the superior value. The nanofluid seems to have a better result as the particle size is reduced. This could be attributed to the viscosity affected by the particle size. Based on the equation, the effective viscosity of the nanofluid is calculated using the particle size. Thus, it is only logical to observe a change to the Nusselt number with a change in particle size. However, the change is minor since the viscosity is not a direct value in the Nusselt number equation, but rather it is used to calculate the velocity of the fluid. Thus, as can be seen, the observed gap and distance between the three particles are lower than the observed gap between the particles in the heat transfer coefficient.

The results indicated that the lowest friction factor (illustrated in Fig. 9) was obtained with a concentration of 4% at 25 nm particle size. Although the friction factor values for different concentrations and particle sizes were very close, the friction factor decreased as the Reynolds number increased. This indicates that increasing the Reynolds number can reduce the resistance to fluid flow and minimise the pressure drop across the heat exchanger. An observed phenomenon in the friction factor results is the fact that the incline and slope of the graph are much sharper from 5000 to 10000 than the incline from the 10000 to 20000 Reynolds number. This is because Reynolds numbers of 2300 until 10000 are considered transitional fluid flow, which means they exhibit different properties than when the fluid is perfectly turbulent (Re above 10000) (Peng & Peterson, 1996; Kandlikar et al., 2003; Hishikar et al., 2022). This also makes sense as the velocity of the fluid would only increase with the Reynolds number; thus, the friction factor would be reduced over time.

Discussion

In this section, the results obtained from the highest and lowest nanofluid Nusselt Number and heat transfer coefficient are compared and discussed with the base fluid, water. The reason why the highest and lowest were chosen is to show the range of the values. The comparative analysis is first performed versus water, then versus previous studies.

Nanofluid versus Water

Table 3 and Table 4 depict the results of the heat transfer coefficient and Nusselt Number improvement values over water values. As observed, the Nusselt number for water is much lower than the highest and lowest values for aluminium oxide. This is an indication that the use of nanofluids improves heat transfer greatly upon the use of nanofluids. The reported values showcase that, at minimum, the improvement is 43.88% in terms of heat transfer coefficient, and at most, it is a 99.61% improvement. This indicates a double-value improvement over water as the Reynolds Number Increases. This is continued for the Nusselt number as well, in which Table 4 demonstrates an improvement of 24.44% at a minimum and 48.16% at a maximum.

Table 3
Heat transfer coefficient improvement values

Re	Aluminum Oxide (4% – 25nm)	Copper Oxide (4% – 25nm)	Aluminum Oxide (1% – 25nm)	Copper Oxide (1% – 25nm)
5000	81.84%	71.49%	47.66%	45.59%
10000	98.16%	91.62%	61.08%	58.92%
15000	99.32%	92.88%	61.92%	59.72%
20000	99.61%	93.52%	62.34%	60.13%

Table 4
Nusselt Number improvement values

Re	Aluminum Oxide (4% – 25nm)	Copper Oxide (4% – 25nm)	Aluminum Oxide (1% – 25nm)	Copper Oxide (1% – 25nm)
5000	34.96%	29.93%	25.96%	24.44%
10000	47.11%	39.16%	37.43%	35.87%
15000	47.94%	41.19%	38.13%	36.53%
20000	48.16%	45.97%	38.48%	36.87%

Figure 10 and Fig. 11 are visual representations of a bar chart in Table 3 and Table 4. These figures are bar charts as opposed to line charts since the enhancement is not directly linear, and thus, guaranteed linearity would not be accurate among all values. Thus, for the sake of clarity, a bar chart is used. The values are based on pure enhancement versus water.

When comparing copper oxide with aluminium oxide, the physical properties of the aluminium oxide particles give the nanofluid an advantage. This is mainly because the particles for aluminium oxide have a higher velocity of 0.201 than the 0.196 for copper oxide. Thus, the heat transfer coefficient has improved substantially more when using aluminium oxide than when using copper oxide.

When comparing the concentration, it is clear that a higher concentration yields a better result and a higher level of improvement than copper oxide. The improvement also seems to increase as the Reynolds number is increased, thus it is logical to assume that the heat transfer coefficient is would be further improved as the Reynolds number is further increased. This improvement is also observed for the Nusselt number; however, the values for the improvement are lower than the heat transfer coefficient because the values of water are closer to the Nusselt number of nanofluid than they are for the heat transfer coefficient.

Regarding the friction factor, illustrated Fig. 12 demonstrates that the friction factor values for water are higher than for nanofluid. They both decrease throughout the increased Reynolds Number. However, as the Reynolds Number increases more, the slope of the decrease gets smaller. The friction factor is mostly reported to be dependent on the diameter of the tube, as its shape of it plays a major role in the value of the friction factor. A lower friction factor indicates that the fluid has less friction, thus a higher rate of heat transfer enhancement.

The gap between the friction factor values is larger for the 5000 Reynolds number than for the 10000 Reynolds number due to the transitional nature of the flow. Any fluid flow with Reynolds number 2300 until 10000 is considered transitional in heat transfer enhancement. The higher the Reynolds number, the more turbulent it is; any value above 10000 is considered true turbulent flow. Thus, the thermophysical properties are affected due to the velocity changes and the viscosity shifts that occur at lower Reynolds numbers.

Parallel versus Counter-Flow

One of the main issues in double-pipe heat exchangers is that almost all heat exchangers use a counter-flow regime (Goodarzi et al., 2016; Bahmani et al., 2018). Thus, by comparing the simulation results using aluminium oxide at 4% concentration and 25 nm diameter, and base liquid of water. The results illustrated in Fig. 13 and Fig. 14 are based on the improvement percentage of nanofluid over water in heat transfer coefficient and Nusselt number. The water is tested based on the parallel setting so that the results would be consistent among both comparisons.

The observations indicate that parallel flow performs better between 5000 and 10000 Reynolds numbers, but as the value of Re increases, so does counter-flow effectiveness. This would explain the reasoning behind counter-flow usage, as it is more effective in higher values. The critical Reynolds number is ~ 2300, and fully turbulent conditions occur at a Reynolds number over 10000. Between a Re of 2300 and 10000, the flow is considered to be in transition (Bahmani et al., 2018). Thus, the values observed at 5000 Reynolds number are much lower than 10000 and above.

Correlations and Relationships

One of the main observations that can be concluded from the results is the relationship between the various attributes and heat transfer characteristics. Mainly between the Reynolds number and heat transfer coefficient, and Nusselt number. Both the heat transfer coefficient and Nusselt number increase as the Reynolds number increases.

The calculated Nusselt Number and friction factor are illustrated alongside their simulated results in Fig. 15, Fig. 16 and Fig. 17. In contrast, the proposed value is based on the results obtained by simulating ANSYS. Both values are compared to observe the differences between the actual simulation and the results predicted from the simulation.

Based on the observed results illustrated in Fig. 15, the expected nanofluid obtained from the correlation formula was far superior to the results obtained from the simulation. In this instance, the simulation values and the formula conditions were set at 1% concentration and 25 nm diameter for the nanoparticles. The reason behind the expected results being superior to the simulated results is that the simulation takes into consideration attributes that are not considered when applying the formula. The correlation formula considers an ideal situation when comparing the results. The simulation from ANSYS uses a formula that obtains the Nusselt number based on the calculated heat transfer coefficient. However, this is not the case for the correlation formula. In the correlation formula, the Nusselt number value depends entirely on Reynolds and Prandtl numbers (Pr). This omits several different underlying factors that can have an impact on the value of the Nusselt number.

The observations are quite distinguished and stark when the values are set at 1% concentration. However, when considering the 4% concentration, the shape of the graph is more interconnected, as seen in Fig. 16. In both scenarios, aluminium oxide performs better than copper oxide. However, in one instance, the value of the proposed aluminium oxide reaches very close to the expected copper oxide. Based on this, if the values were to be continued, it is expected that at 25000 Reynolds number, the proposed aluminium would overtake the expected copper oxide. This is mainly due to the visual indication that the proposed aluminium oxide has a steeper incline than the copper oxide, and they would eventually reach. Using a linear trendline, it can be calculated that the proposed aluminium oxide would be at around 101 Nusselt number at 25000 Reynolds number. Using the correlation formula would yield a 98 Nusselt number for the expected copper oxide. This would mean that the higher the Reynolds number at 4% concentration, the better the proposed aluminium oxide.

It is important to note that higher concentrations would change the values significantly, depending on the Reynolds number. However, aluminium oxide is still considered superior to copper oxide when in simulated form. The Nusselt number is a significant dimensionless factor that measures the temperature gradient at the surface where heat transfer takes place through convection. This number holds a critical value in convection problems and is affected by the Reynolds number and the Prandtl number. The friction factor formula depends directly on the Reynolds number, while the ANSYS conditions consider several attributes, such as the length of the pipe, the diameter, the pressure drop, the velocity of the fluid and the density of the nanofluid. Thus, the value of the simulation would more accurately represent the friction factor than the correlation formula that uses mainly Reynolds numbers. However, even based on these observations, the friction factor in the simulation is better than the one calculated using the Re correlation formula. The expected and proposed value for copper oxide is identical to the aluminium oxide values.

Conclusion

This study aimed to conduct numerical experiments using ANSYS to enhance the heat transfer properties of a double-pipe heat exchanger using CuO and Al_2O_3 nanofluids under a parallel flow regime. The points below summaries the main conclusions:

- It found that the fluid flow directly affects the heat transfer properties of the heat exchanger; at high concentrations with low particle diameters, it can dissolve easier within the base fluid achieving better heat transfer characteristics.

- These results indicate that under ideal circumstances of 4% concentration and diameter of 25 nm, Al_2O_3 performs 99.61% better than water under 20000 Reynolds number, while CuO performs 93.52% better than water under the same circumstances.
- The Nusselt number results also have a similar pattern, with a 48.16% improvement for Al_2O_3 and 45.97% for CuO under 20000 Reynolds number; it can note that the higher the Reynolds number, the better the degree of improvement.
- When Reynolds number between 2300 and 10000 is considered to be transitional. This effect is particularly visible for the friction factor since a larger gap was observed for transitional flow than when the flow was considered fully turbulent above 10000; the improvement is greater when the turbulent flow.
- It was observed that at a lower Reynolds number, the parallel flow performed was better; with an increased Reynolds number, the counter flow performed better overall, which means the higher the Reynolds number, the better to use counter-flow.
- Using Al_2O_3 nanofluid with a double pipe heat exchanger can greatly improve the heat transfer rate at higher concentrations, and smaller particle size contributes towards better Nusselt Number and Heat Transfer Coefficient values.
- The relationship between Nusselt Number, Reynolds Number and heat transfer coefficient have shown to be direct and positive, while for friction factor, the opposite is true, since as the Reynolds number increases, the friction factor decreases.

The results obtained in this study can aid future researchers understand the intricacies between different heat transfer attributes. Further studies in this vein can be regarding measuring using lower Reynolds number values (laminar flow) and further enhance the shape of the double pipe heat exchanger, such as using helically coiled double pipes, or the usage of different traditional fluids, such as oil or Ethylene glycol and compare their effectiveness against water as the base fluid.

Symbols

c_p	specific heat capacity	J kg^{-1} K^{-1}
Re	Reynolds number (= $dw\rho/\mu$)	
T	temperature	K
t	time	h

Greek Letters

α	heat transfer coefficient	W m^{-2} K^{-1}
ε_p	particle porosity	

Subscripts

D	distillate

Declarations

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Conflict of Interest. The authors declare that they have no competing interests

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Figures

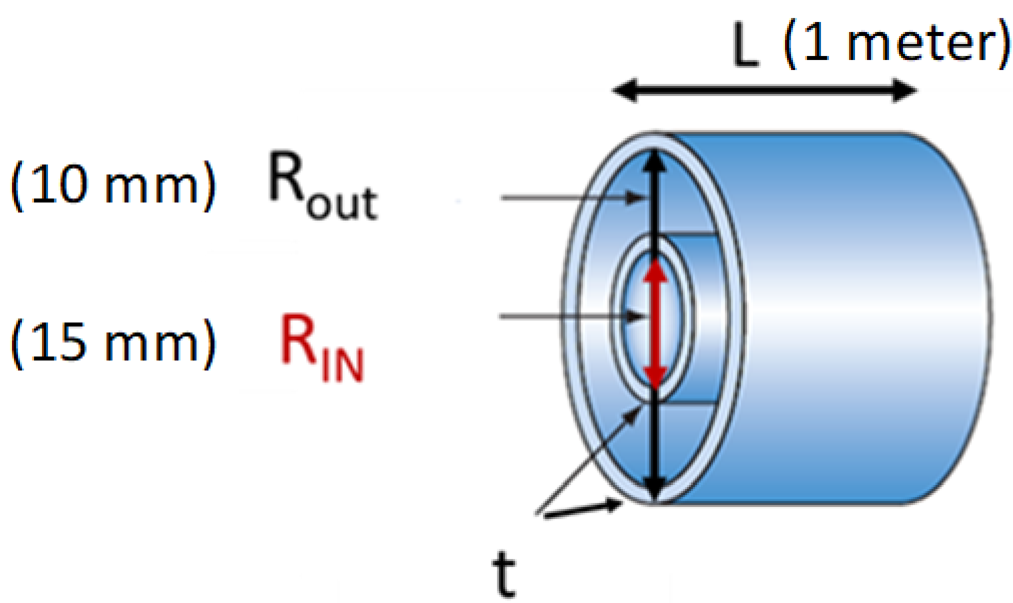

Figure 1

Cross-section of the double-pipe heat exchanger

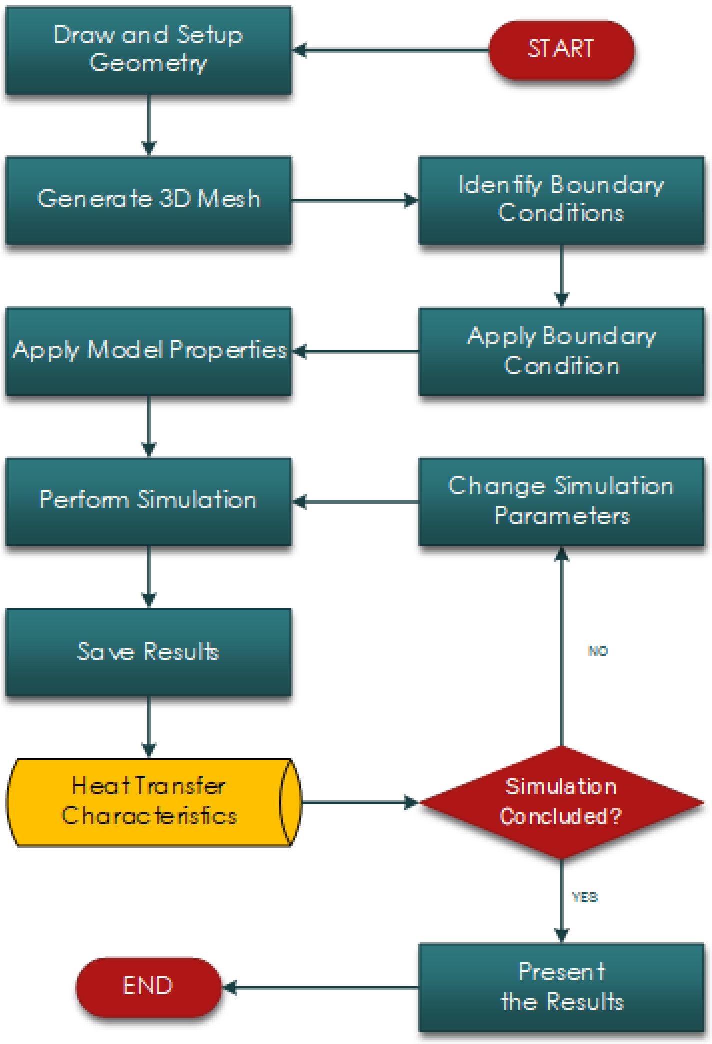

Figure 2

The simulation process diagram

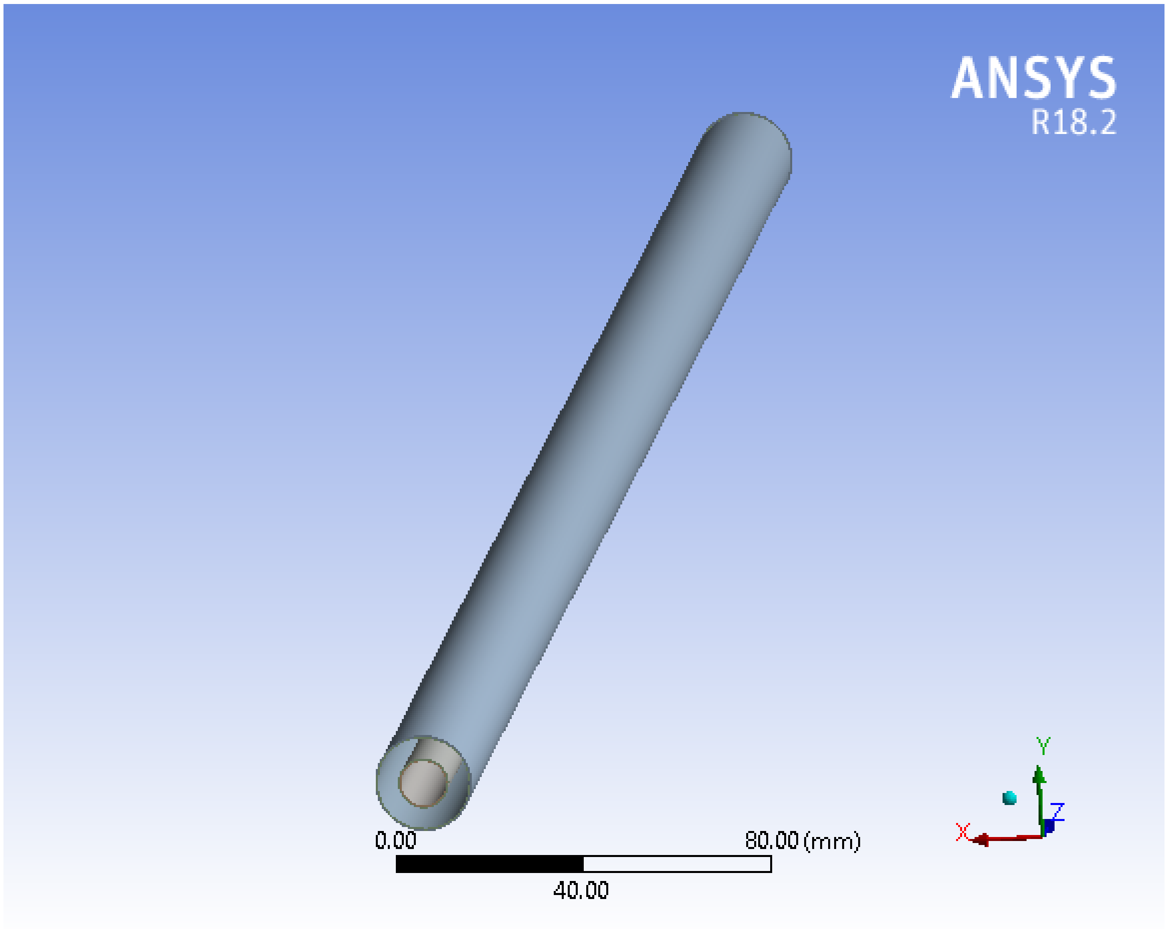

Figure 3

The simulated double pipe mesh in ANSYS.

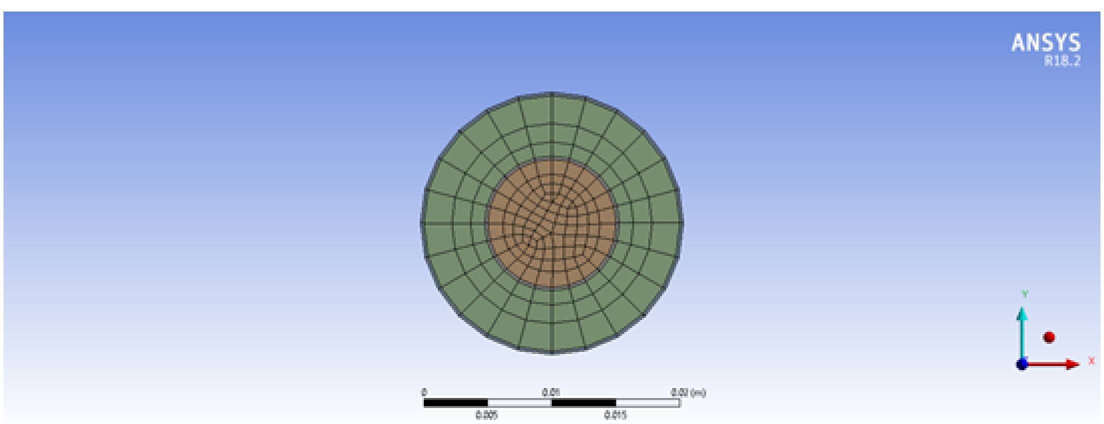

Figure 4

Double pipe mesh wireframe in ANSYS – front view

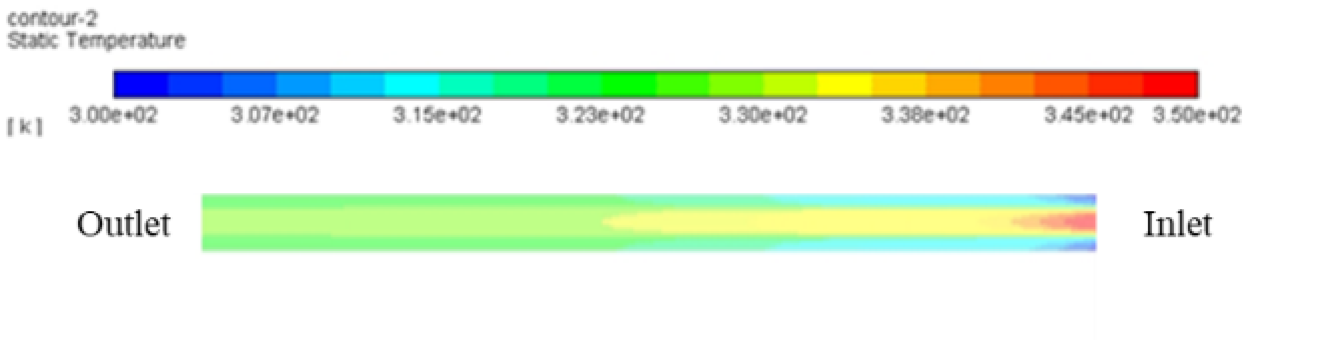

Figure 5

Thermal Heat Map Distribution Contour

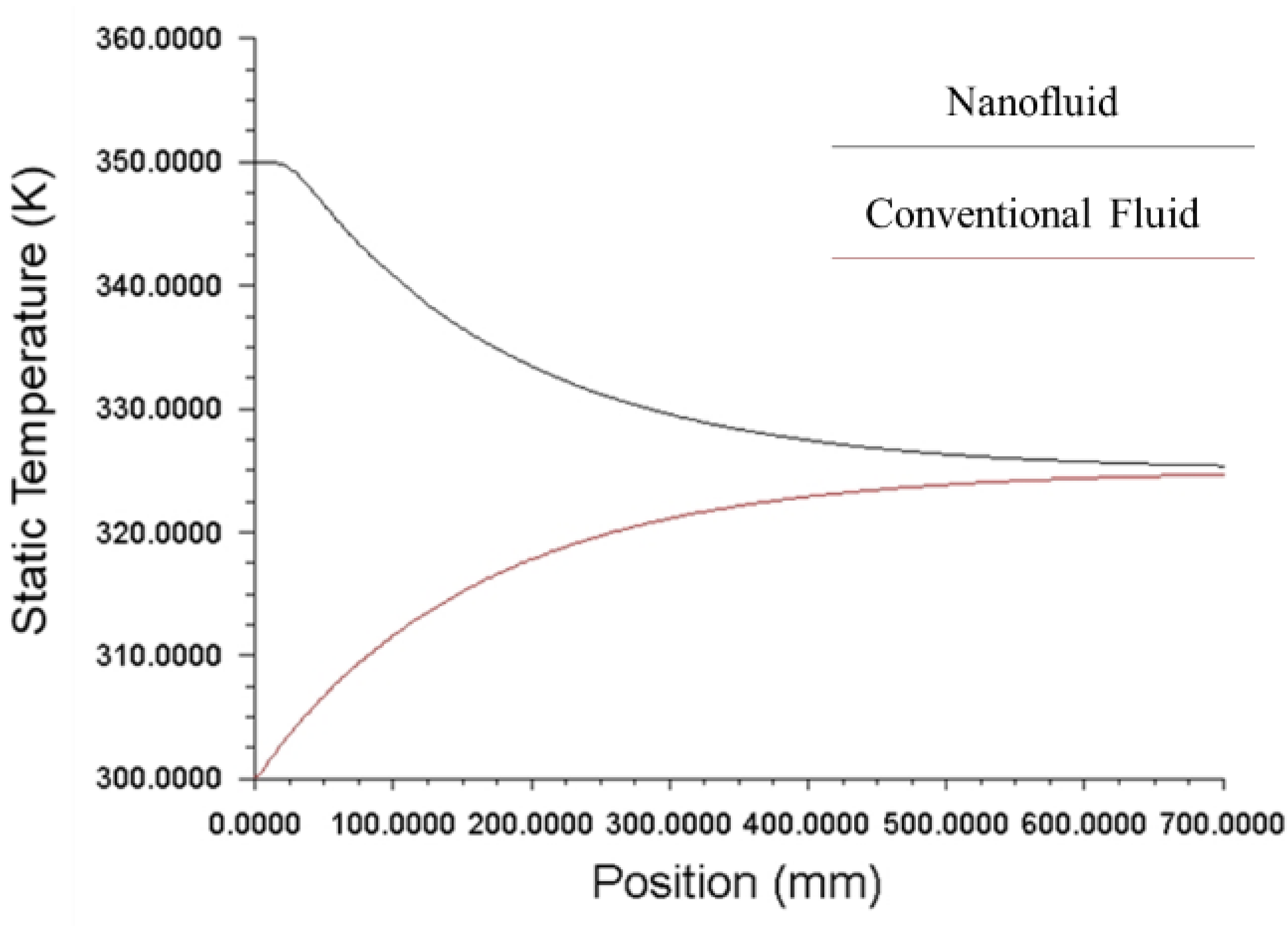

Figure 6

The Contour plot of the temperature was obtained from ANSYS.

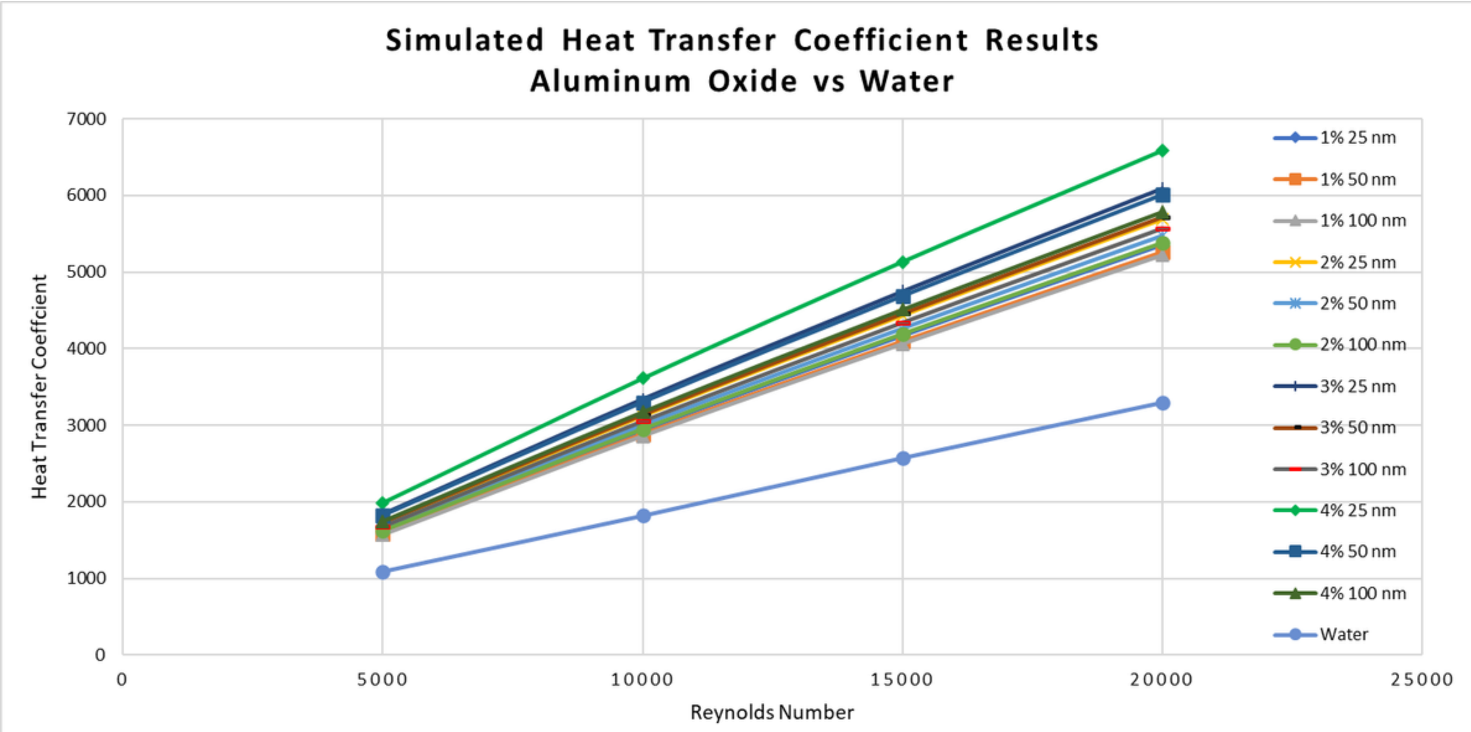

Figure 7

Heat transfer coefficient values for aluminum oxide and water

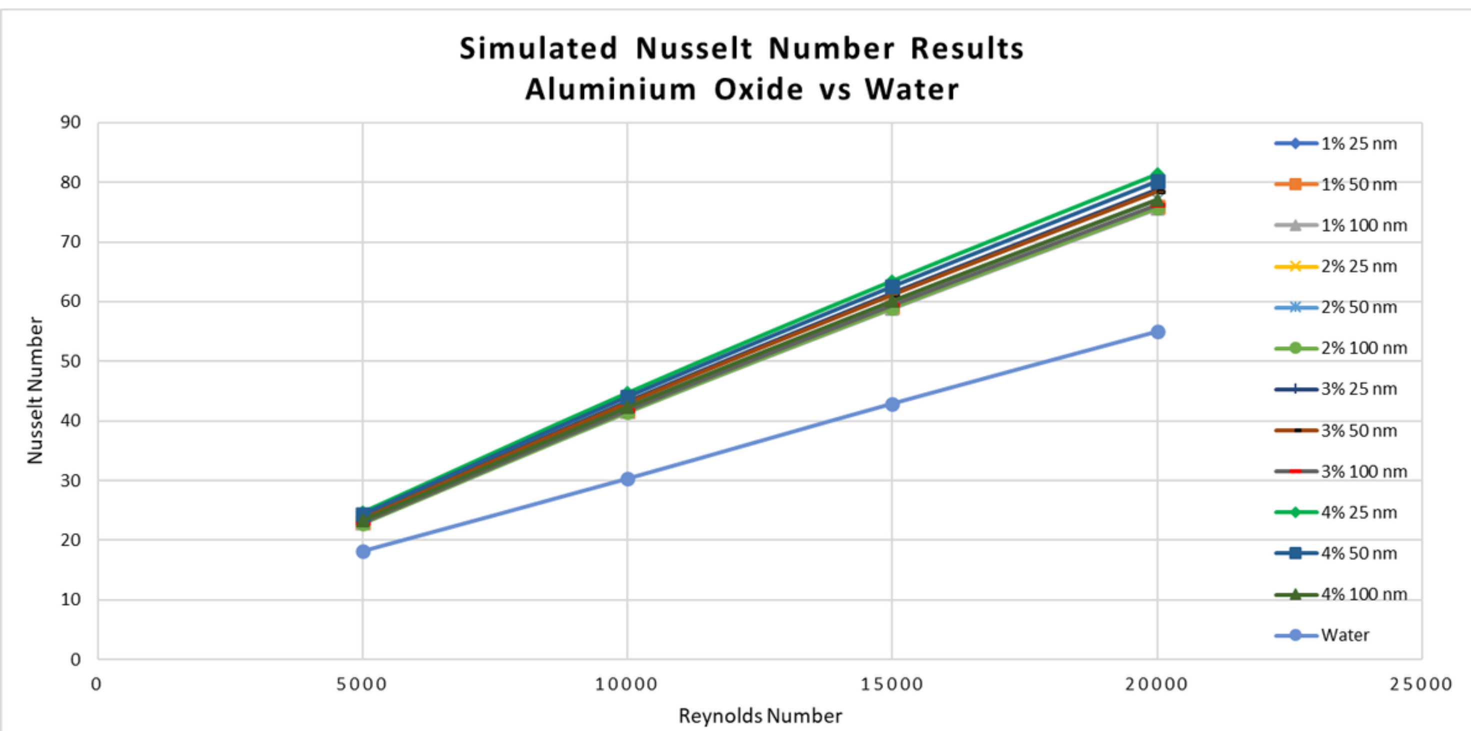

Figure 8

Nusselt number values for aluminum oxide and water

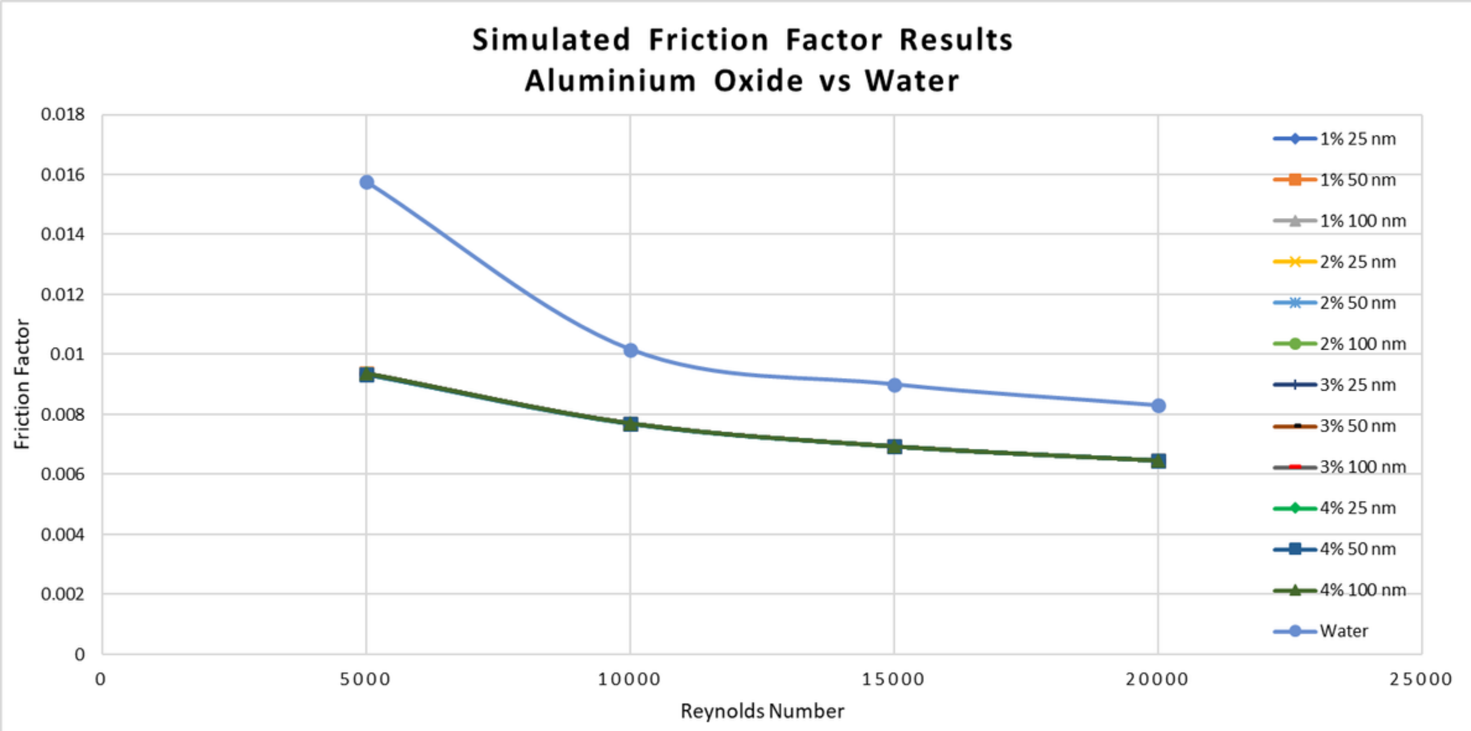

Figure 9

Friction factor values for aluminum oxide and water

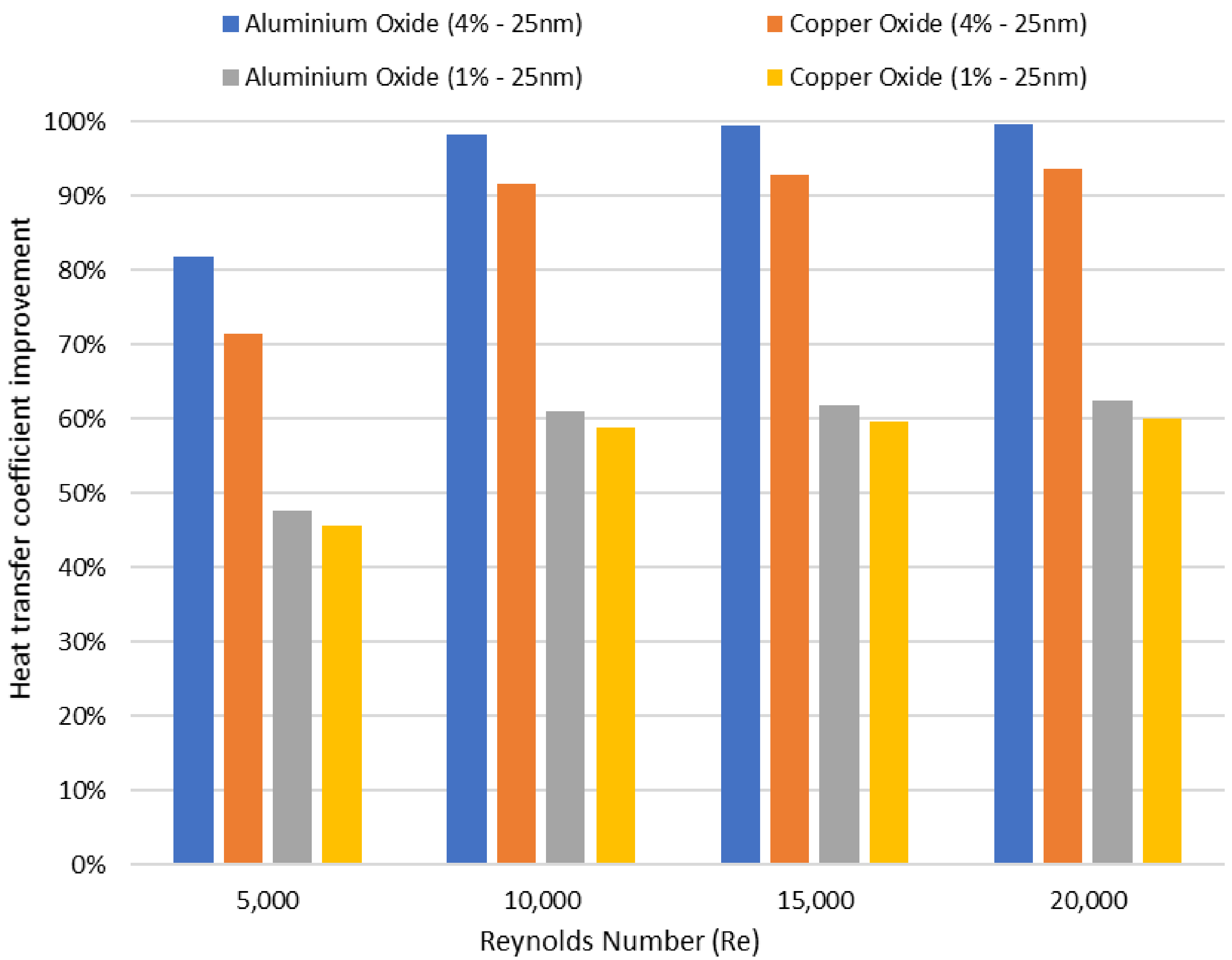

Figure 10

Heat transfer coefficient enhancement of nanofluids versus water

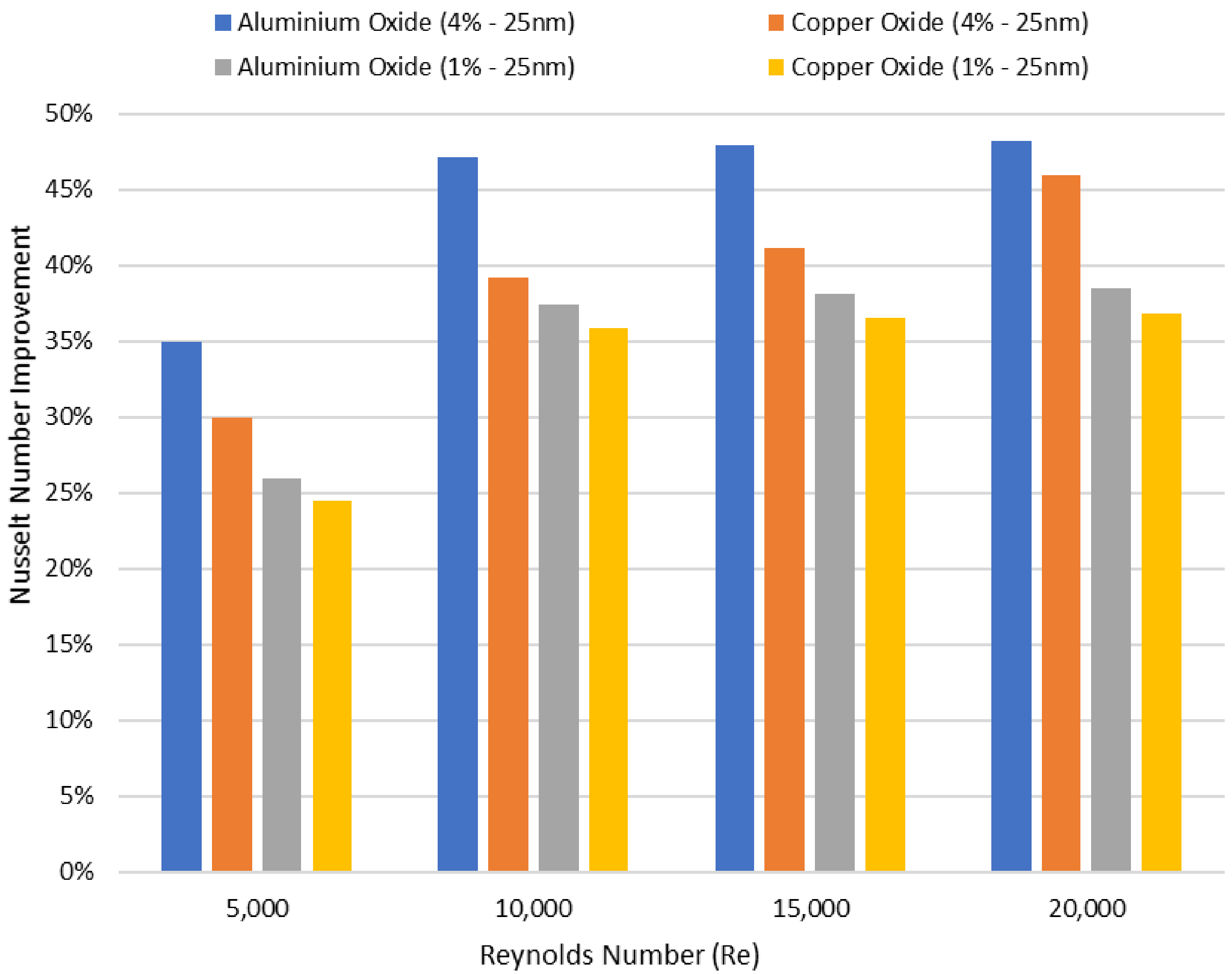

Figure 11

Nusselt Number enhancement of nanofluids versus water

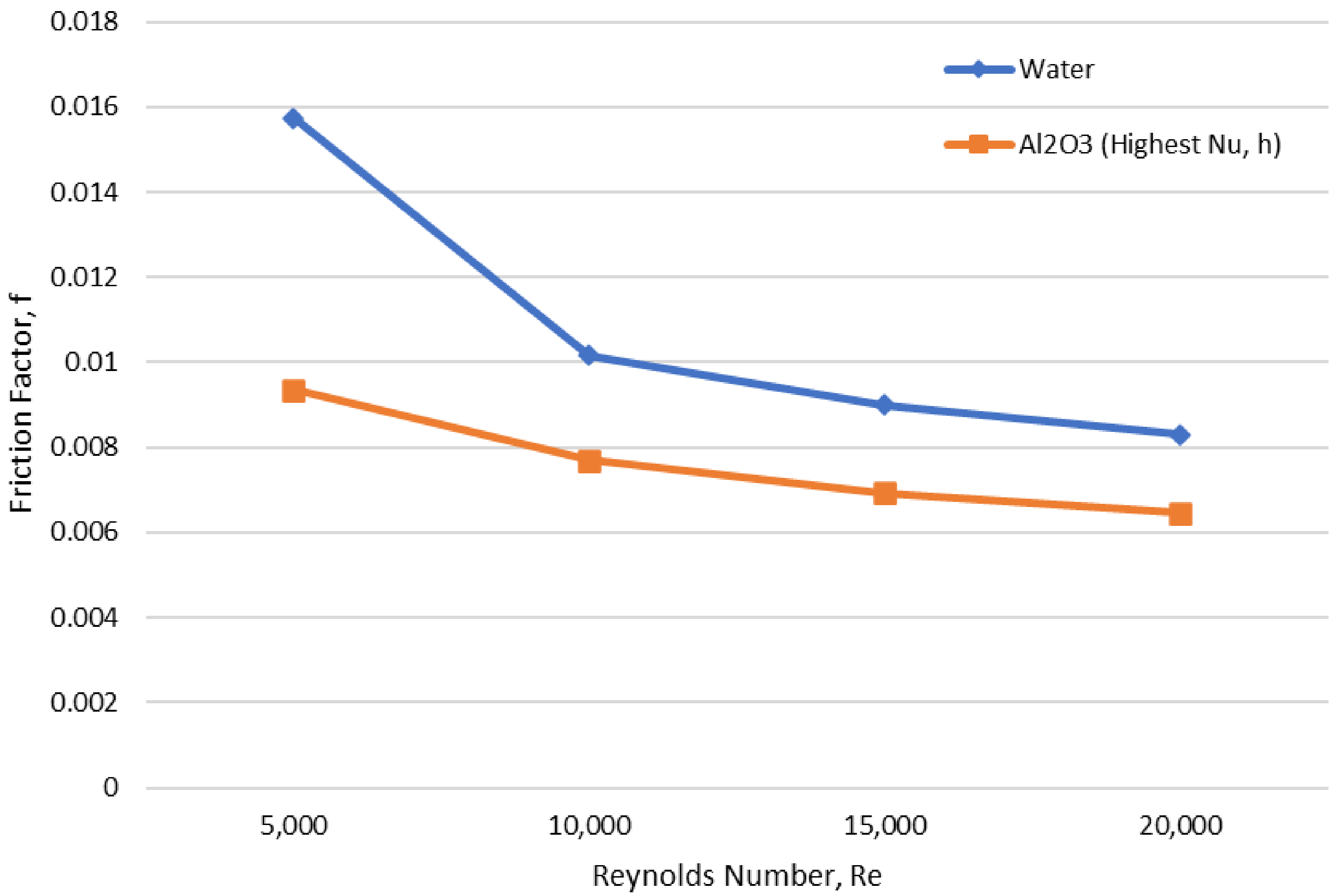

Figure 12

Friction Factor values for Aluminum Oxide Nanofluid Highest Value versus Water

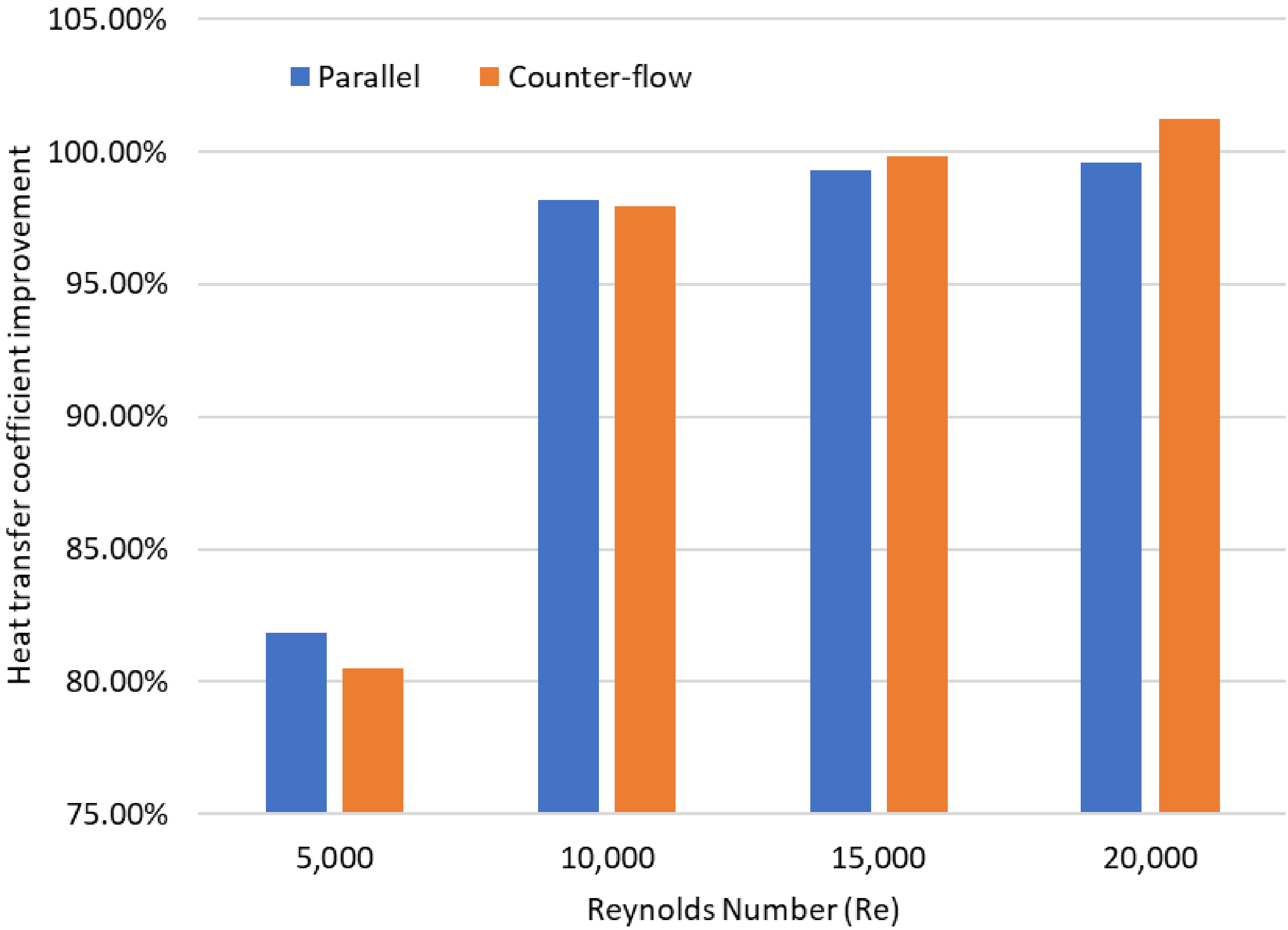

Figure 13

Parallel flow vs Counter flow Heat transfer coefficient improvement percentage

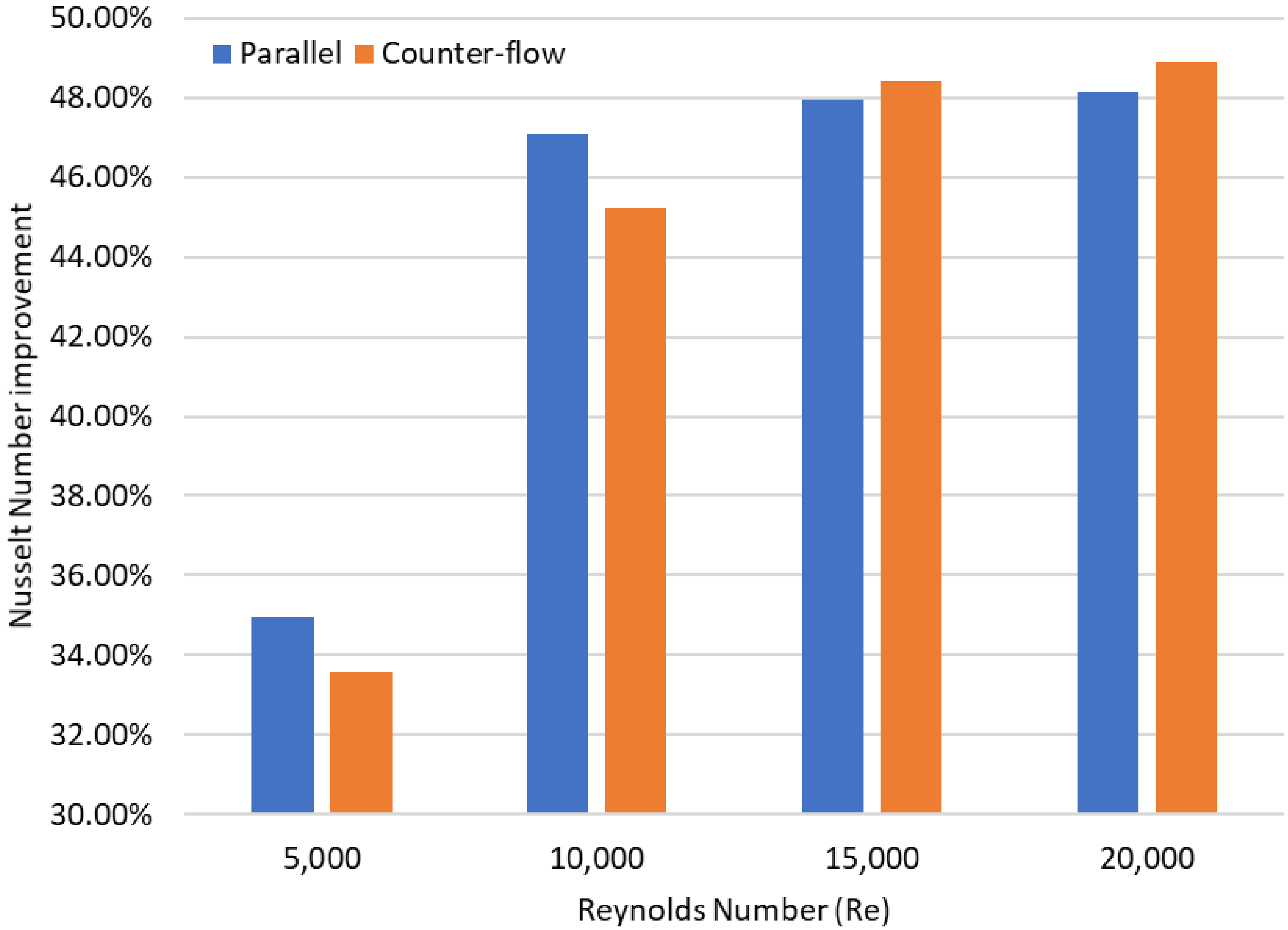

Figure 14

Parallel flow vs Counter flow Nusselt Number improvement percentage

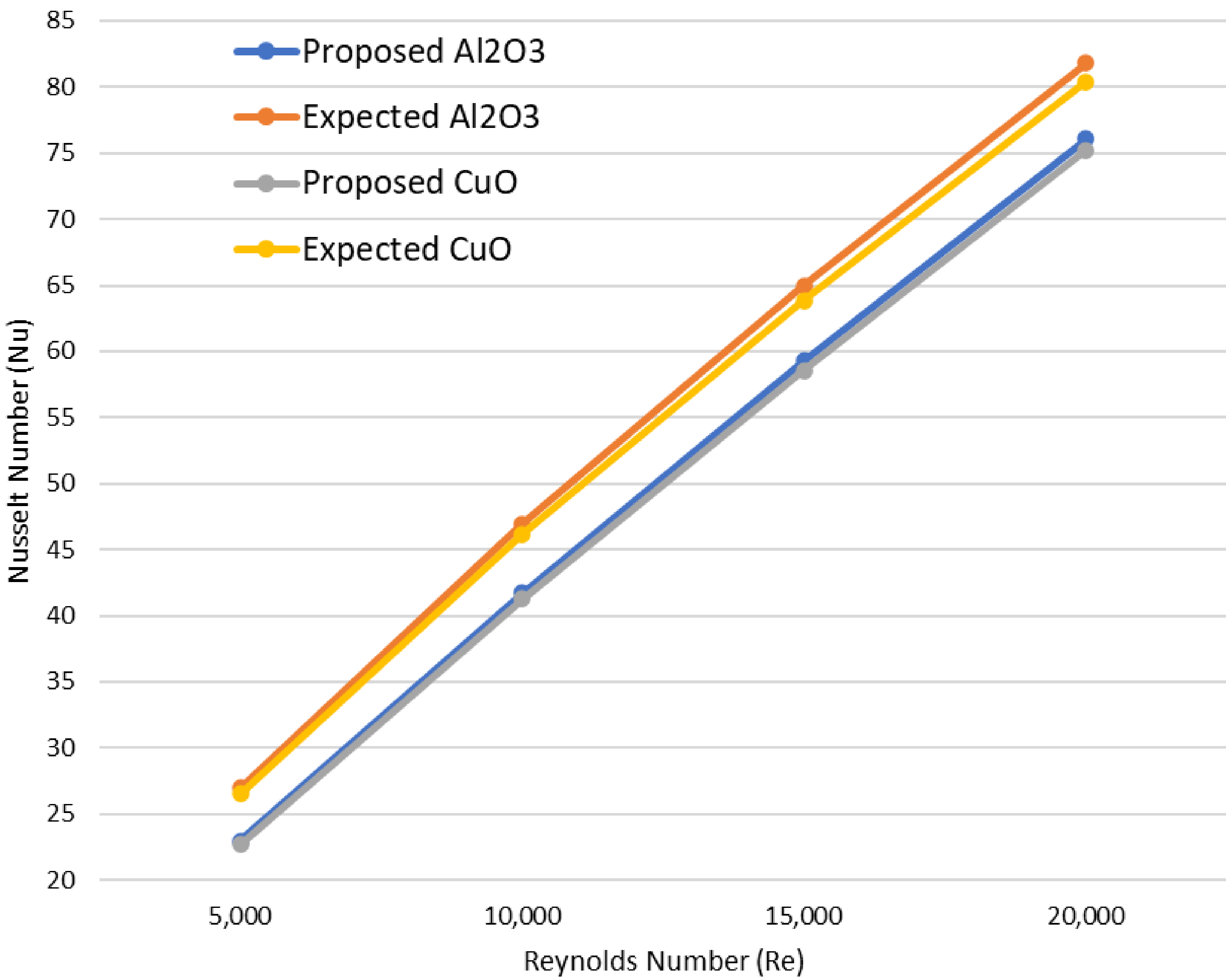

Figure 15

Al_2O_3 and CuO Nusselt number correlation at 1wt% con-centration and 25nm particle size

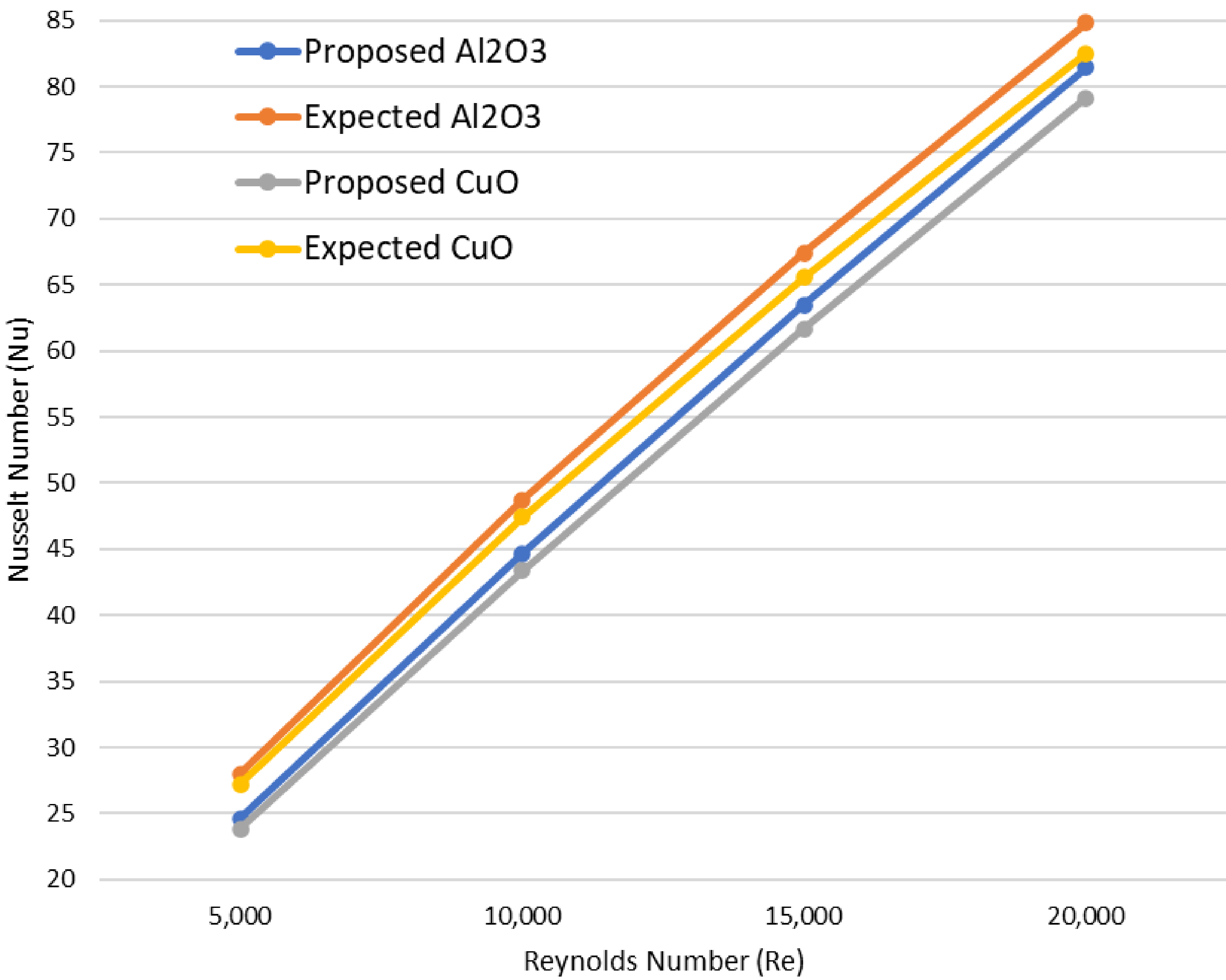

Figure 16

Al_2O_3 and CuO Nusselt number correlation at 4wt% concentration and 25 nm particle size

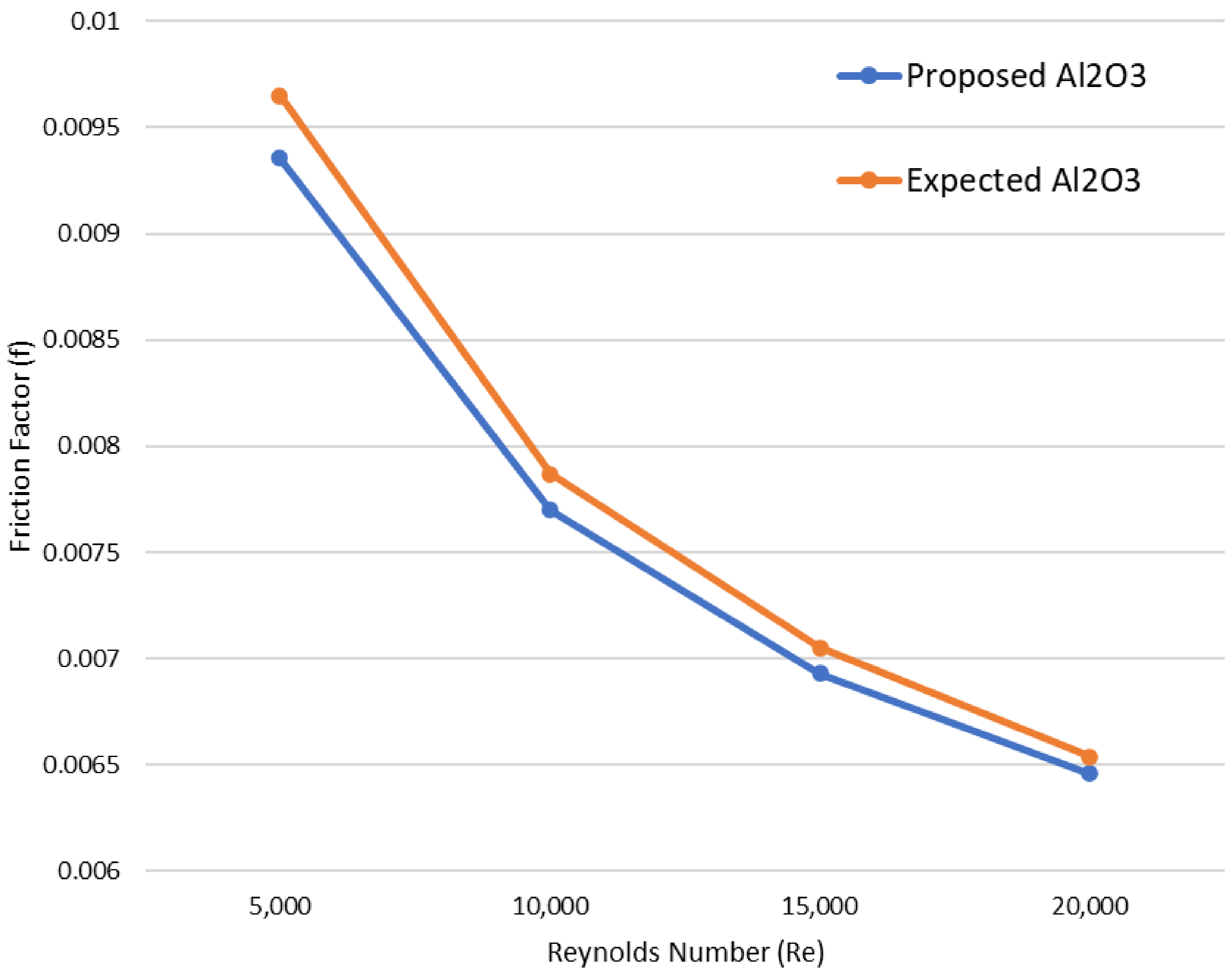

Figure 17

Correlation between proposed and expected nanofluid friction factor for aluminium oxide at 25 nm