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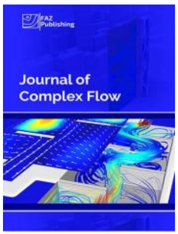

Computational Simulation of Heat Transfer Enhancement in Heat Exchanger using TiO_2 Nanofluid

Muhammad Syahmi Mohammad Hisyammudden[1], Abdulhafid M A Elfaghi[1,*]

[1] Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

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Abstract: Convectional heat transfer is used extensively in many industrial heating and cooling systems. Small solid metal or metal-oxide nanoparticles floating in a base fluid increase heat transfer efficiency in a thermal system. This study used numerical modelling to investigate the transmission of heat of a water-TiO_2 nanofluid forced convection turbulent flow in a circular tube with a uniform and continuous Heat flux on the wall. Different turbulent models are examined in this simulation using Ansys Fluent CFD commercial software. The volume fraction of TiO_2 nanoparticle is of 0.5% with Reynolds number varying from 7000 to 16000. According to modeling results, adding nanoparticles to a base fluid greatly improved convective heat transmission in a pipe, and the heat transfer enhancement improves as the Reynolds number rises. The K-epsilon turbulent model also beats the k-omega turbulent model in terms of accuracy, according to the findings.

Keywords: Heat transfer coefficient, TiO_2 nano fluid, nanoparticles, CFD

1. Introduction

Heat transfer is designed to transfer or transfer thermal energy from one matter to another. When a fluid is utilized to transmit heat, it can be a liquid like water or oil or moving air [1]. A heat exchanger is a device that adds or removes thermal energy to control the temperature of a system. In a conventional heat exchange, heat would be transferred from a hot to a cold medium. The idea of a heat exchanger is the use of pipes or other storage vessels to heat fluid [2]. Nanofluids with at least one of their primary dimensions less than 100 nm are called dilute liquid suspensions of nanoparticles. Nanofluids have increased thermal conductivity, according to the current study, which increases as the volumetric proportion of nano particles increases [3].

Water is commonly used as a heat transfer fluid in heat exchangers, which can cause the heat transfer process to slow down. Nano fluids can be used as heat transfer fluids in water, reducing the pumping power of the heat exchanger while increasing the rate of heat transfer. Nanoparticles in nanofluids can minimize friction in the flow, allowing for more efficient heat transfer. More research is needed to improve the heat transmission of heat exchangers in air conditioners. The objectives of this study is to find out how nanoparticles are affected on heat transfer enhancement in base fluid to compare numerical results obtained with experimental and previous studies and to compare heat transfer enhancement between *k*-epsilon and *k*-omega turbulence models.

The use of fluids for heat transmission at the base like water, air, or ethylene glycol results in forced thermal convection heat transmission in many engineering systems. Thermal conductivity has long been a stumbling block to improving the energy efficiency of heat transfer fluids and the commercial viability of many industrialized companies' products, such as heat exchangers. There is a great effort to boost upper thermal conductivity heat transmission fluids to address this problem. In the past decade, in many industrial applications, nanofluids have been increasingly used for cooling. Compared with particles of a micrometer or millimeter scale in the suspension of nanoparticles, these latest generations of heat transfer fluids require improved suspension stability. The influence and benefits of heat transfer nanofluids or nanoparticles have been extensively studied, in the range $7000 \leq Re \leq 16000$ respectively, the volume proportion of nanoparticles and the number of Reynolds were considered. The experiment was conducted out using a programmed Ansys Fluent and a 0.5 percent by weight volume concentration.

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*Corresponding author: abdulhafid@uthm.edu.my

2. Theoretical Background

2.1 Fundamental of Heat Transfer

In the heat transfer discipline, there are just two factors to consider: temperature and heat fluxes. As the temperature of a substance rises, the thermal instability of its individual components increases [4]. Conduction, one of three heat transfer processes, transports heat from a higher to a lower temperature region. This can happen in solid, liquid, or gaseous media, as well as in direct physical contact between materials [5]. Convection is the most important energy transmission process between a solid surface and a liquid or a gas. Warmer or colder fluid next to the solid surface induces circulation due to density variations arising from the fluid's temperature differences. When a fan is employed to push air over the heat exchanger fins, this is an example of forced convection. Finally, heat moves from a hotter body to a cooler body when the two bodies are separated in space [6].

Changing the viscosity of the fluid, changing its phase from liquid to solid, inducing cavitation, causing the atmosphere to freeze or melt, and significantly changing the fluid density are all possible effects of adding or removing heat from the pipe flow stream. In two-phase flow, temperature is an essential factor in two-step gas-liquid flow. Heat transmission can occur via convection, conduction, or radiation [7]. This chapter summarizes the number and friction factor of the Nusselt proposed correlations for a variety of nanofluid combinations under various operating conditions.

Sir Fourier himself was aware of Biot's paper. In 1804, he somehow ignored the action and tried to come up with the transient heat conduction equation. In general, Fourier switched from bodies that stopped to continuous bodies and went on to idealize how matter behaved macroscopically. Instead of only studying the basic equation first, Fourier made a detailed observation of the behavior of matter macroscopically [8]. Instead of all the points around its region, Fourier suggested that an infinitesimal laminal or element temperature is purely dependent on its upstream and downstream conditions. In the last chapters of his work in 1807, Fourier extended his results, including heat conduction of the cylinder annulus, a sphere and even a cube. Then his manuscript was submitted to the French authorities [9].

Nanofluids, or colloidal nanoscale solutions, contain condensed nano materials [10]. It has shown a wide range of potential applications in a variety of ways. A two-phase system has a few significant drawbacks. Nanofluid stability is one of the most pressing issues, and obtaining the appropriate stability remains a significant difficulty. We will examine recent advances in stable nano fluid production technologies and describe the stability mechanisms in this paper. Nanofluids have gotten a lot of attention in recent years. A wide range of applications is the major driving force behind nano fluid research [11].

Because of the growing demand for high heat flow activities, sophisticated heat transfer methods have advanced significantly. Nanofluids have also been shown to cool welding equipment, and automotive engines Finally, the future direction and problems associated with the usage of nanofluid were discussed [12].

For decades, materials in the nanoscale range have been created. Nano materials and/or nanoparticles are employed in a variety of fields. For most applications, a basic, limited range of particle sizes is required. To make nanoparticles, coatings, dispersions, and composites, scientists use sophisticated synthesis processes. This page discusses the most popular manufacturing processes, such as milling, gas phase, and liquid phase technologies [13].

2.2 Heat Transfer Enhancement by Nanofluids

Based on the cooling load estimation using A laminar convective heat transmission model is used to investigate the efficiency of nanofluid heat transfer in a uniformly heated-wall tank. Furthermore, the heat transfer coefficient of nanofluids increases as the volume percent of nanofluids and the Peclet number increase. CuO-Water nanofluid has a higher heat transfer coefficient when compared to other nanofluids of the same volume fraction. When compared to the basic conventional fluid at a Peclet number of 6500, the heat transmission for 3 percent CuO-Water Nanofluid jumps 1.54 times. The coefficient of heat transfer is lowered by 27.8% when the proportion of nanofluid volume is increased from 0.2 percent to 3%. Al2O3-water nanofluid laminar mixed convection was also measured in a horizontal tube with heating on the upper half of the copper tube's surface. Over a wide range of nanoparticle volume fractions, the two-phase mixture model was used to investigate the nanofluid's hydrodynamic and thermal properties [14].

Three types of nanoparticles (CuO, Al_2O_3, and SiO_2) were introduced to an ethylene glycol and water mixture. They looked examined the impact of different nanoparticles and particle concentrations. The results showed a rise in that the nanofluid concentration is responsible for an increase in the total number of Nusselts. At a Reynolds number of 20000, the Nusselt number rises 1.35 times higher than the base fluid with a 6% CuO content [14]. Finally, the study found that CuO nanofluid had the greatest heat transfer rate at a particular Reynolds number. The mixture model was shown to be the most accurate when the experimental data were compared.

3. Methodology

3.1 Physical Model and Assumption

For the geometric model, Fig. 1 depicts a schematic diagram of a circular heated pipe. For a circular pipe with a length of 2 meters, the diameter is fixed at 5 millimeters. The temperature T_0 = 293 K is assumed for pipe intake profiles with a uniform axial velocity V_0.

The fully established conditions are considered at the pipe exit section, which means that all axial derivatives are zero. Nonslip conditions are enforced on the pipe wall, as well as a consistent temperature of 330 K, with zero turbulent kinetic energy and turbulent kinetic energy dissipation. Furthermore, in the axial plane, the flow and heat fields are symmetrical.

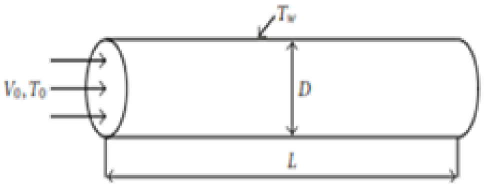

Fig. 1 - Schematic Diagram of Circular Pipe

3.2 Thermophysical Properties of Nanofluids

The density of a nanofluid may be determined numerically using mass equilibrium as follows,

$$\rho_{nf} = (1-\varphi S)\rho_f + \varphi S \rho p \qquad (1)$$

where the centered fluid's and solid nanoparticles' mass densities are ρ_f and ρ_{np}. The following equation may be used to calculate the effective heat capacity under constant nanofluid pressure *(Cp)*$_{nf}$*:*

$$(\rho C_p)_{nf} = (1-\varphi)\rho(C_p)f + \varphi(\rho C_p)_{np} \qquad (2)$$

Effective viscosity equation,

$$\mu_{nf} = \mu_{bf}\frac{1}{(1-\phi)^{2.5}} \qquad (3)$$

where μ_{nf} and μ_{bf} is nanofluid and base fluid's viscosity respectively.

4. Results and Discussion

The circular pipe is 2 meters long and has an inner diameter of 5 mm. A continuous supply of heat is supplied to the pipe's outside surface to conclude the measurement of water and TiO₂ heat transfer properties. The pure water simulation is run first to ensure that the experimental data are valid After that, the nano fluid simulation was running to get distinct results to be compared with water.

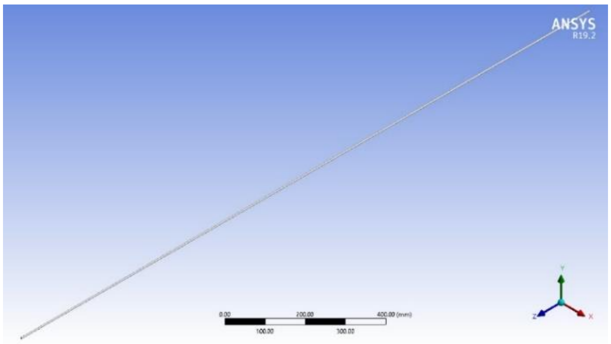

Fig. 2 - Schematic Diagram of Circular Pipe

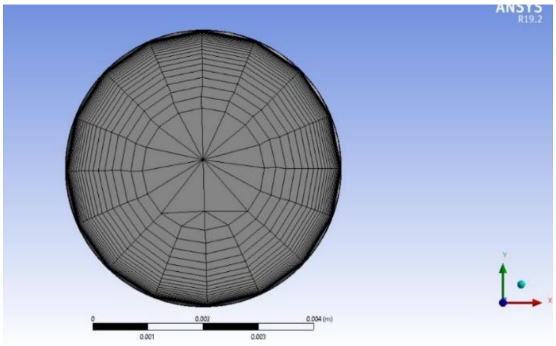

Fig. 3 - Meshing geometry of circular pipe

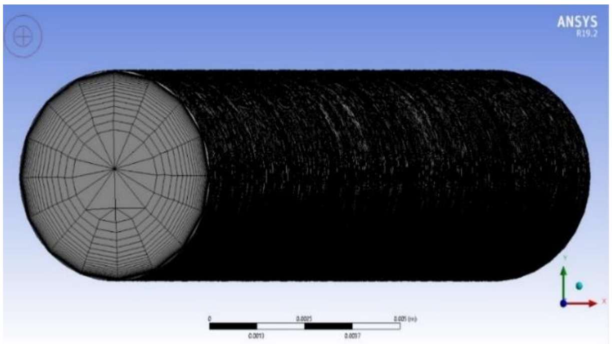

Fig. 4 - Meshing geometry of circular pipe

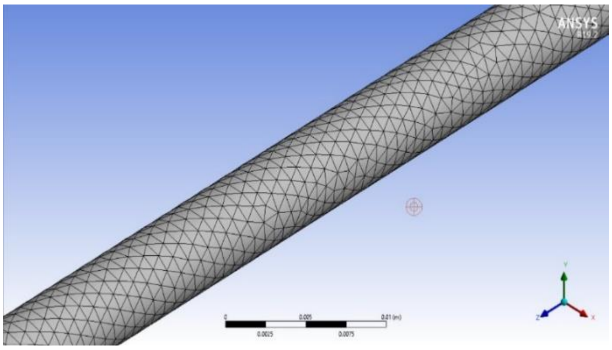

Fig. 5 - Pipe Meshing geometry of circular pipe

4.1 Comparison of Heat Transfer Characteristics

For TiO₂ nanofluids, thermal parameters like coefficient of heat transfer and Nusselt number, as well as flow properties like pressure drop and friction factor, are compared. The k-epsilon and k-omega turbulence models are also compared. Table 1 shows the thermophysical characteristics of TiO₂ nanoparticles, TiO₂ nanofluid, and water.

Table 1 – Thermophysical characteristics of TiO₂ and water

Property	Water	TiO₂	0.5% TiO₂ nanofluid
Density (kg/m3)	998.2	4250	1014.46
Specific heat (J/kg.K)	4182	686.2	4108.77
Thermal conductivity (W/m.K)	0.6	8.9	0.6074
Viscosity (Pa.s)	0.001	-	0.00101

4.2 Heat Transfer Coefficient

The coefficient of heat transmission of TiO_2 nanofluid flow within tube is shown in Figure 6 for various Reynolds numbers. All working fluid heat transfer coefficients have grown as the Reynolds number has increased, and the variation trends are linear. The linear trend of rising heat transfer coefficient for various working fluids flow within tube with Reynolds number is also shown. The present experiment looks at TiO_2-water nano fluid at 0.5% volumetric concentration. Between 7000 and 15,000 was the Reynolds number. It is observed that there is 12.64% difference shown between k-epsilon and k-omega data obtained. This proves that for all working fluids, turbulence increases as the Reynolds numbers of working fluids rises. As turbulence increases, so does the rate of heat transfer. Higher Reynolds numbers result in greater turbulence, which absorbs more heat and has a quicker heat transfer rate. When compared to water, the heat transmission increase can be shown in Figure 7. The data shows an increase of 22.78% heat transfer between water and k-epsilon turbulence model while k-omega turbulence models show and increment of 0.12% heat transfer coefficient when compared to water.

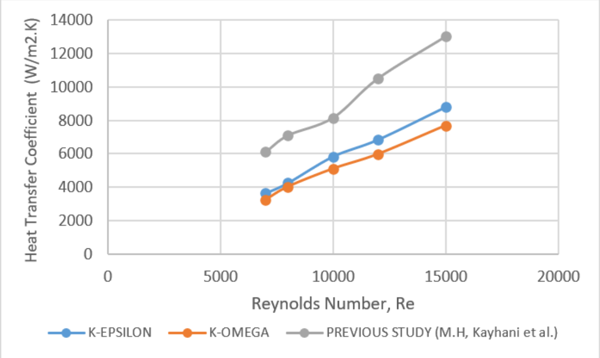

Fig. 6 - Heat transfer coefficient comparison between the prior research and the current simulation

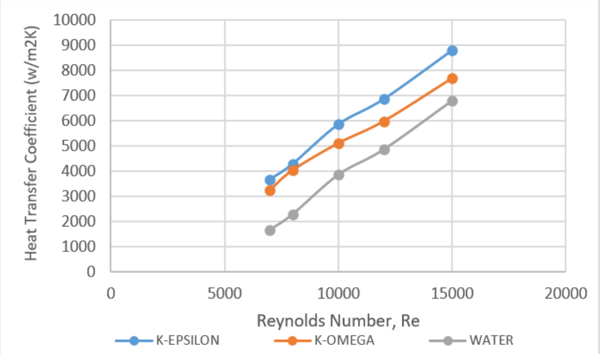

Fig. 7 - The heat transfer coefficients of water and TiO_2 nanofluid were compared.

4.3 Nusselt Number

The Nusselt number for the 0.5 percent volume fraction of TiO_2 nanofluid is greater than that of water because TiO_2 nanofluid has a higher heat transfer coefficient than water. Furthermore, the Nusselt number of TiO_2 nanofluid is superior compared to water due to increased thermophysical properties of nanofluids due to TiO_2 nanoparticle dispersion in water. When solid nanoparticles are added to water, their thermal conductivity improves, and as additional nanoparticles are dispersed, the heat transfer coefficient rises. Therefore, the Nusselt number increases as the volume fraction increases for both k-epsilon and k-omega, much like the earlier study in Figure 8. Based on the comparison conducted between nanofluids and water, referring to the Fig, TiO_2 nano fluids show a significant increase of 13.84% in Nusselt number at 12000 Reynolds Number for k-epsilon turbulence model. In addition, when measured on pure water, Reynolds Number influences the growth in heat transfer coefficient. This shows that mixing nanoparticles into a base fluid increases heat transfer.

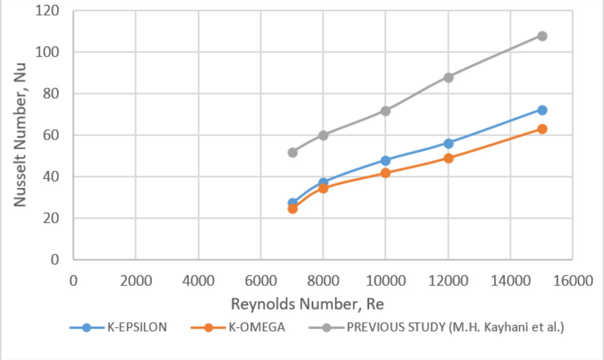

Fig. 8 - Comparison of Nusselt number of previous studies with present simulation

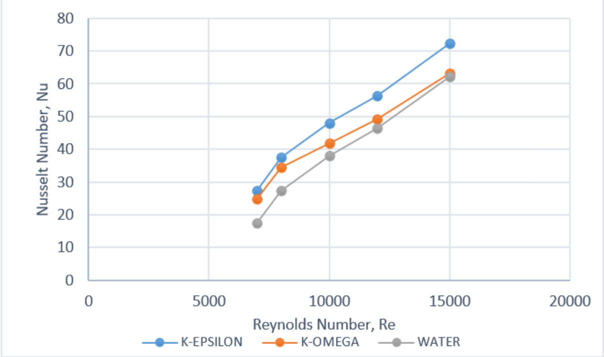

Fig. 9 - Comparison of Nusselt number between water and present simulation

4.4 Pressure Distribution

For all working fluids, the pressure drop increases as the Reynolds number rises because turbulence rises as the Reynolds number rises. For all working fluids, however, the pressure drop variation trend with Reynolds number is not linear. Many research studies in the open literature have established that the variation trend is exponential. Kristiawan et al. [15] found an exponential (non-linear) variation in pressure drop with Reynolds number for various working fluids flowing in a tube, and that pressure drop rises with Reynolds number. Nanofluid has a greater pressure drop than water due to its higher viscosity.

For the obtained results of pressure drop the Darcy Weisbach equation has been considered. Pressure Loss Darcy Weisbach Equation [16].

$$\Delta p = fD\frac{L}{D}(\frac{\rho V^2}{2}) \qquad (4)$$

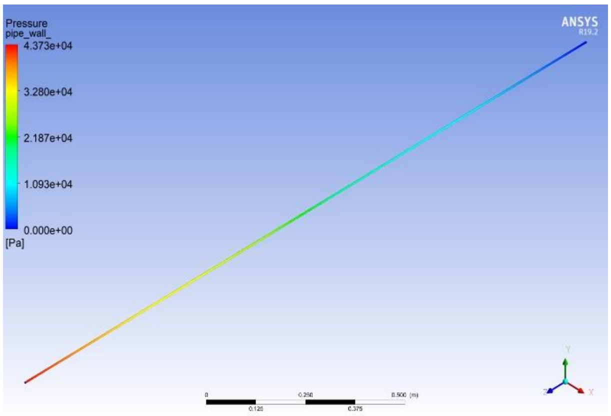

Fig. 10 - Pressure drop distribution of the circular pipe

From the equation above the *Δp* is pressure loss (N/m^3), f is friction factor, L is pipe length (m), *V* is average velocity (m/s) and ρ is fluid density (kg/m^3).

4.5 Friction Factor

The pressure drop and velocity of the working fluid have an impact on the friction factor. As a result, the friction factor variation trend for diverse working fluids is not the same as the pressure drop variation trend. For all working fluids, the Reynolds number range considered depicts the transition from laminar to turbulent domain, resulting in a parabolic friction factor fluctuation pattern with Reynolds number. The friction factor increases as the Reynolds number grows owing to the change in flow from laminar to transition regime below this number and drops as the Reynolds number increases due to the change in flow from transition to turbulent regime above this number. As the Reynolds Number rate increases, the friction factor decreases (see Figure 11).

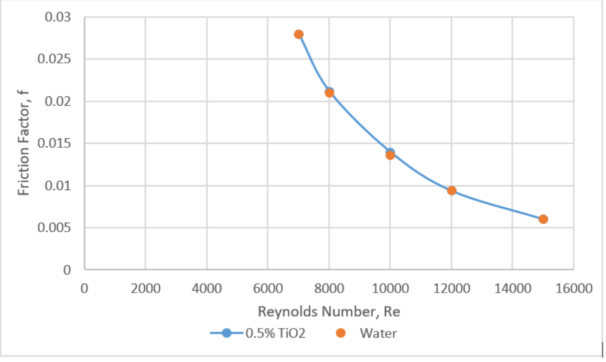

Fig. 11 - Water and TiO₂ nanofluid friction coefficients are compared.

5. Conclusion

In the presence of a constant wall heat flux, several turbulence models were employed to simulate TiO₂-water nanofluids. The turbulent flow domain, which was the focus of this study, is where convective heat transfer happens. According to the findings, adding nanoparticles to the fluid enhanced heat transfer and the system's Nusselt number in turbulent flow. The simulation's results were compared to known convective heat transfer coefficients and nanofluid pressure drop correlations and found to be quite similar therefore, the nanofluid in this investigation exhibited no abnormal heat transfer augmentation and no substantial increase in pressure drop when compared to pure water.

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