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ENHANCEMENT OF HEAT TRANSFER PERFORMANCE OF FLAT VERTICAL TUBE USING SIO_2/WATER NANOFLUIDS

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ABSTRAK

Penelitian ini bertujuan untuk mengevaluasi peningkatan karakteristik perpindahan panas radiator melalui penggunaan nanofluid silikon dioksida (SiO_2). Penelitian dilakukan secara eksperimental menggunakan sistem sirkulasi tertutup yang terdiri atas tangki reservoir, pemanas listrik, pompa sirkulasi, radiator, dan kipas pendingin. Pengaruh variasi konsentrasi nanofluid dan bilangan Reynolds terhadap koefisien perpindahan panas dianalisis pada suhu operasi 60 °C dan 70 °C. Hasil eksperimen menunjukkan bahwa penggunaan nanofluid SiO_2 mampu meningkatkan koefisien perpindahan panas rata-rata sebesar 15% pada suhu 60 °C dan 18% pada suhu 70 °C dibandingkan dengan fluida dasar. Peningkatan perpindahan panas maksimum masing-masing sebesar 21% dan 24% diperoleh pada konsentrasi nanofluid 0,2% dan bilangan Reynolds 3200. Peningkatan performa termal ini terutama disebabkan oleh bertambahnya konduktivitas termal efektif fluida akibat dispersi partikel nano SiO_2, yang mempercepat transfer energi panas dari dinding radiator ke fluida kerja.

Kata kunci: Nanofluid, perpindahan panas, suhu, radiator

ABSTRACT

This study aims to evaluate the enhancement of heat transfer characteristics of a radiator using silicon dioxide (SiO_2) nanofluid. The investigation was conducted experimentally using a closed-loop circulation system consisting of a reservoir tank, an electric heater, a circulation pump, a radiator, and a cooling fan. The effects of nanofluid concentration and Reynolds number on the heat transfer coefficient were analyzed at operating temperatures of 60 °C and 70 °C. The experimental results indicate that the use of SiO_2 nanofluid increases the average heat transfer coefficient by 15% at 60 °C and 18% at 70 °C compared to the base fluid. The maximum heat transfer enhancements of 21% and 24% were achieved at a nanofluid concentration of 0.2% and a Reynolds number of 3200, respectively. This improvement in thermal performance is primarily attributed to the increased *effective thermal conductivity of the working fluid due to the dispersion of SiO_2 nanoparticles, which accelerates heat energy transfer from the radiator wall to the fluid.*

Keywords: *Nanofluid, heat transfer, temperature, radiator*

1. INTRODUCTION

As the demand for vehicles increases, the automotive industry continues its efforts to develop engines with high efficiency, economic viability, and low fuel consumption [1], [2]. Vehicles themselves can make tasks faster and simpler. Various methods to enhance the efficiency of vehicle engines have been widely explored, such as optimizing engine design, reducing engine weight, and minimizing the heat effects generated by vehicles [1]. Reducing heat transfer in vehicles can lead to a decrease in energy consumption, and it is possible to enhance system performance [3]. One effort to reduce engine heat is by improving the performance of the radiator [4]. In recent years, numerous studies have focused on enhancing radiator efficiency. Among these, the addition of solid particles in sizes ranging from millimeters to micrometers to the coolant has been investigated as a method to improve the radiator's heat transfer rate [5].

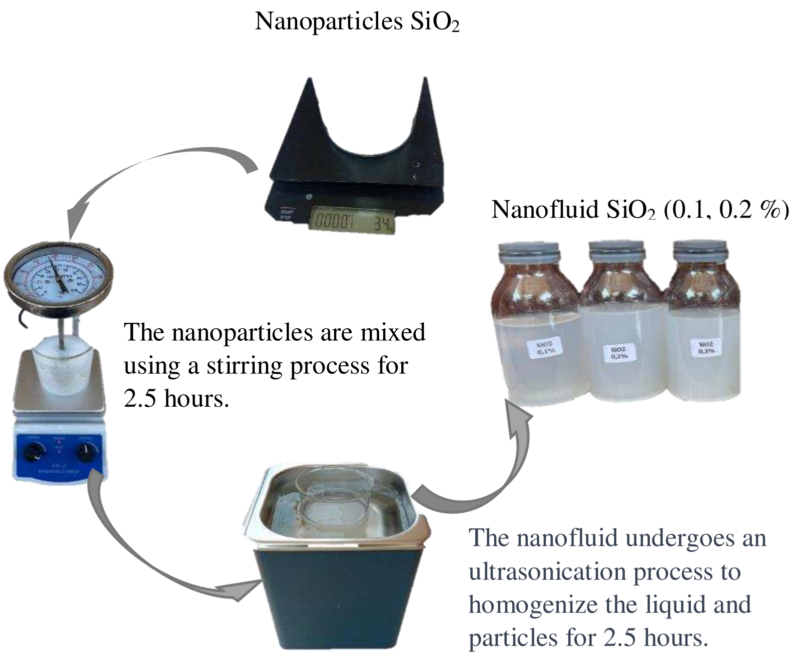
Approximately a decade ago, with the rapid development of nanotechnology, particles in sizes ranging from millimeters to micrometers were replaced by nanometer-sized particles (usually between 1 nm and 100 nm) [6]. Nanometer-sized particles in a fluid, known as "nanofluid," present an intriguing solution that not only enhances heat conductivity but also offers long-term stability and low-pressure drop characteristics [4]. The use of nanofluids can increase heat transfer rates [7]. Silicon dioxide (SiO2) is one of the promising materials for enhancing heat transfer because of its excellent physical stability. Additionally, SiO2 particles are cost-effective and commercially available.

Research on enhancing heat transfer for various industrial applications by adding solid nano-particles to fluids has been a significant topic in the past decade [8]. Nano SiO2 particles suspended in conventional fluids are widely used in various heat exchanger configurations, including circular tubes [9], [10], double tubes [11], [12], shell and tube arrangements [13], [14]. Several serious issues arise with the use of such fluids. For instance, low stability, clogging, and pipe pressure drop are observed in the equipment [6]. Numerous factors influence the heat transfer rate with nanofluid particles, such as particle volume fraction, particle material, base fluid, particle size, particle shape, temperature effects, and the research methodology followed [15]. This study aims to provide clear insights into heat transfer and radiator efficiency with the use of SiO2 nanoparticles as a nanofluid.

2. RESEARCH METHODS

This research was conducted using an experimental method with the aim of analyzing the addition of solid silicon dioxide (SiO2) particles into a base fluid, which is water, in the heat transfer process using fluid flow within a radiator pipe.

2.1 Preparation of Nanofluid



Nanoparticles SiO_2

Nanofluid SiO_2 (0.1, 0.2 %)

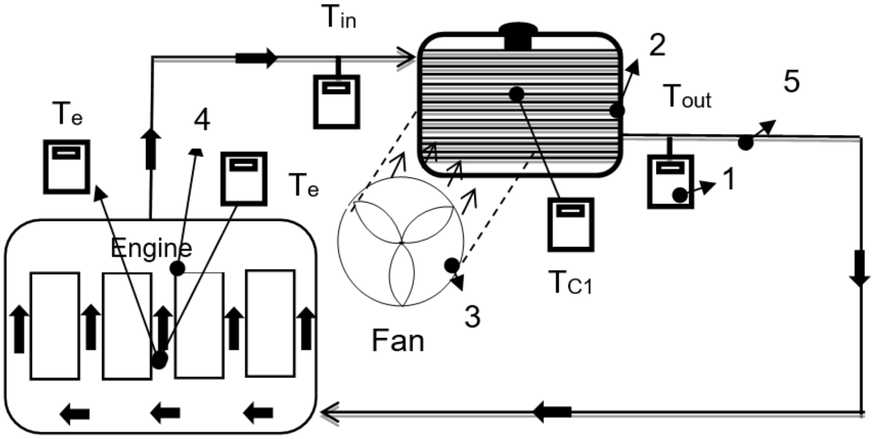
The nanoparticles are mixed using a stirring process for 2.5 hours.

The nanofluid undergoes an ultrasonication process to homogenize the liquid and particles for 2.5 hours.

Figure 1. SiO_2 Nanofluid manufacturing process

2.2 Experimental work

The experimental testing apparatus utilized in this research is depicted in Figure 1. The estimated quantity of nanoparticles required is provided in equation (1). Controlled variations in temperature conditions, specifically at 60, 70, and 80 °C, were applied to the SiO2-water nanofluid, with a baseline temperature of 23 °C for the base fluid. Dependent variables included the outlet temperatures of the nanofluid and the cold fluid (Tout.nf and Tout.cold), as well as the pipe wall temperature (Twall). The main components consist of a car radiator, radiator fan, heater, and circulating water pump. Fluid flow rate observations were facilitated using a rotameter instrument, fan speed was measured with a digital anemometer, and a data logger system recorded temperature values.



1. Thermometer, 2. Radiator, 3. Fan, 4. Engine, 5. Pipe

Figure 2. Schematic of the research apparatus used.

The quantity of nanoparticles required for the known volumetric concentration percentage is estimated using equation (1):

$$\text{Volume Concentration, } (\varphi) = \left[\frac{\left(\frac{W_p}{\rho_p}\right)}{\left(\frac{W_p}{\rho_p} + \frac{W_{bf}}{\rho_{bf}}\right)} \right] \times 100 \qquad (1)$$

The density for different concentrations is calculated using mathematical models (refer to equations 2 and 3) provided by Pak and Cho [6]. The viscosity is determined based on Wang, X.'s [7] model. The calculation results are presented in Table 2.

Table 1. Thermophysical Properties of SiO2 Nanoparticles

Material	Nano silicon dioxide
Appreance	White fluffy powder
Purity	99%
Average grain size	20 nm
BET	145-160 m^2/g
Density	2220 kg/m^3
Specific heat	511,6 J/kg.K

Table 2. Properties table of nanofluid using experimental method

Properti	Volume Concentration of Nanoparticles % (φ)			
	0^a	0.1	0.2	0.3
Density, $\boldsymbol{\rho}$ (kg/m^3)	994	996.226	998.452	1002.9
Specific Heat (Cp) (J/kg ^oK)	4185.5	4173.62	4161.81	4150.03

[a] Water

2.3 Characteristics of the thermophysical properties of SiO_2 nanoparticle

The thermophysical properties of nanofluid, such as density, specific heat capacity, and viscosity, can be evaluated as follows (2-7). These properties depend on the characteristics of nanoparticles, nanoparticle concentration, and the properties of the base fluid.

Density

Density is the mass density of a fluid, and the higher the density value, the greater the mass density of nanoparticles in the base fluid. This can enhance the thermal conductivity of a fluid. The density of nanofluid can be calculated using the equation proposed by Pak and Cho [6], which is:

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_b \qquad (2)$$

where:
ρ_{nf} = Density of the nanofluid (kg/m^3)
ρ_p = Density of the nanoparticles (kg/m^3)
ρ_b = Density of the base fluid (kg/m^3)
φ = Volume fraction of particles

Viscosity

Viscosity is a measure of a fluid's resistance to flow, and the higher the viscosity, the greater the resistance to heat transfer within a fluid. The viscosity of nanofluid can be calculated using the equation proposed by Wang, X. [7], which is:

$$\mu_{nf} = \mu_b(1 + 7.3\,\varphi + 123\,\varphi^2) \qquad (3)$$

where:
μ_{nf} = Viscosity of the nanofluid (kg/m.s)
μ_b = Viscosity of the base fluid (kg/m.s)

Specific Heat

Specific heat capacity can be determined using the following equation [8]

$$Cp_{nf} = \frac{(1-\varphi)Cp_b\rho_b+\varphi(\rho_p Cp_p)}{\rho_{nf}} \qquad (4)$$

where:
Cp_{nf} = Specific heat of the nanofluid (J/kg.^{o}C)
Cp_b = Specific heat of the base fluid (J/kg.^{o}C)
Cp_p = Specific heat of the nanoparticles (J/kg.^{o}C)

The modified equation includes the effect of a liquid nanoplayer on the surface of nanoparticle. This equation is given as

$$k_{nf} = \left[\frac{k_p + 2k_{bf} + 2(k_p - k_{bf})(1+\beta)^3\,\varphi}{k_p + 2k_{bf} + 2(k_p - k_{bf})(1+\beta)^3\,\varphi}\right]k_{bf}$$

β= ratio of a nanolayer thickness

2.4 Heat Transfer Calculation

The following procedure is used to obtain the heat transfer coefficient and Nusselt number. According to Newton's Law of Cooling:

$$Q_{nf} = h_{in}A_{in}\Delta T = h_{in}A_{in}\,(T_{b,nf} - T_w) \qquad (5)$$

Where A_{in} is the inside surface area of the tube, h_{in} is the inside heat transfer coefficient, and $T_{b,\,nf}$ is the bulk fluid temperature assumed as the average temperature between the fluid inlet and outlet.

$$T_{b,nf} = \frac{T_{nf,in}+T_{nf,out}}{2} \qquad (6)$$

where $T_{nf,in}$ and $T_{nf,out}$ are the respective inlet and outlet temperatures.

$$T_w = \frac{T_1+T_2+\cdots+T_4}{4} \qquad (7)$$

where, Tw is the average temperature of the tube wall surface and T_1 until T_4 indicating temperature differences at various positions on the radiator tube wall.

The heat transfer rate of the nanofluid can be calculated:

$$Q_{nf} = \dot{m}_{nf}C_{p,nf}\Delta T = \dot{m}_{nf}C_{p,nf}\,(T_{nf,in} - T_{nf,out}) \qquad (8)$$

where $\dot{m}_{nf}$ is mass flow rate, $C_{p,nf}$ is specific heat of the nanofluid

Diameter flat tube radiator:

$$Dh = \frac{4\,x\,[\left(\frac{\pi}{4}\right)d^2 + (D-d)xd]}{\pi x d + 2x(D-d)}$$

D dan d = major diameter dan minor diameter

Reynolds Number

$$Re = \frac{\rho_{nf}\ x\ v\ x\ D_h}{\mu_{nf}}$$

heat transfer coefficient (h)

$$h_{exp} = \frac{m_{nf}\ x\ c_{p(nf)}\ x\ (T_{in} - T_{out})}{A_s\ x\ ((T_b - T_w)}$$

The bulk mean temperature (T_b) of nanofluids is given by

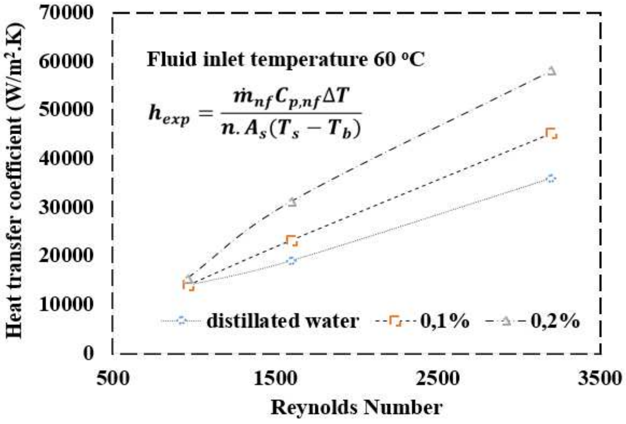
$$T_b = \frac{T_{in} + T_{out}}{2}$$

The Nusselt number is calculated by using equation:

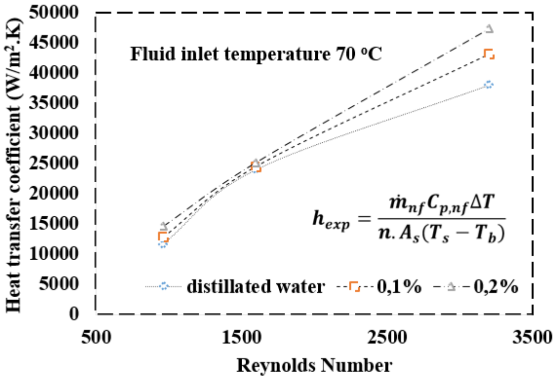
$$N_u = \frac{h_{exp}\ x\ D_h}{k}$$

3. RESULT AND DISCUSSION

Heat transfer coefficient



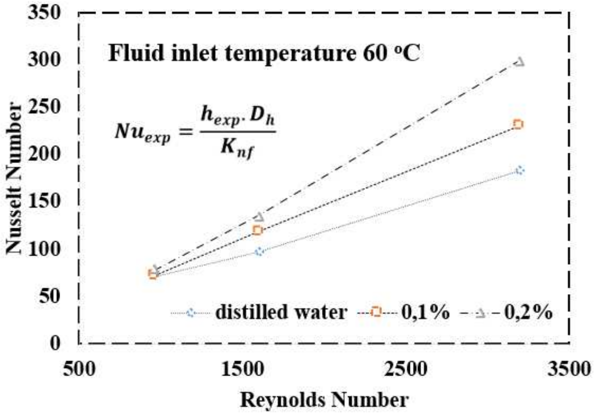
(a)



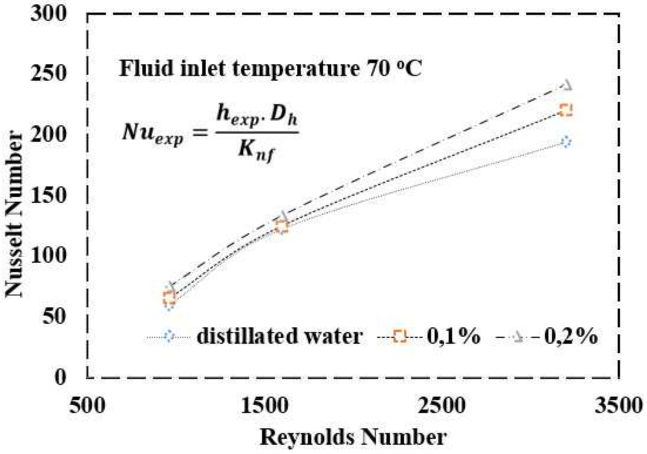
(b)

Figure 3. Variation of Heat transfer coefficient with Reynolds number at different fluid inlet (a) 60 °C and (b) te70 °C.

The heat transfer performance of the nanofluid is illustrated in Figures 3 and 4, explaining the values of the heat transfer coefficient and Reynolds number of the nanofluid at temperatures of 60 and 70°C. It can be observed that the experimental data for the SiO2 nanofluid aligns closely with the trends presented by Dittus and Boelter [48] and the base fluid. Reynolds number is influenced by the increased heat transfer coefficient and Nusselt number. There is a 15% increase in the average heat transfer coefficient at a temperature of 60°C. The maximum heat transfer enhancement occurs at a concentration of 0.2%, with a 21% increase at a Reynolds number of 3200 at a temperature of 60°C. Reynolds number is influenced by the increased heat transfer coefficient and Nusselt number. At a temperature of 70°C, there is an 18% increase in the average heat transfer coefficient. The maximum heat transfer enhancement occurs at a concentration of 0.2%, with a 24% increase at a Reynolds number of 3200. Inlet temperature affects the value of the heat transfer coefficient and Nusselt number. Higher inlet temperatures increase the heat transfer coefficient. However, all concentrations are higher than the base fluid within the pattern. Heat transfer enhancement is observed, and this enhancement increases by 2% with an increase in inlet temperature up to 70°C for a constant Reynolds number and particle concentration. Increases in temperature, volume concentration, and Reynolds number contribute to enhanced heat transfer and Nusselt number. This is due to a decrease in viscosity at higher temperatures. The higher the thermal properties, the better the heat transfer coefficient. The heat transfer rate for the nanofluid is greater than that of the base fluid because the thermal conductivity of the copper oxide nanofluid is higher than that of the base fluid. However, thermal conductivity is not the sole reason for the heat transfer enhancement, and there may be other factors contributing to the increased heat transfer. At higher temperatures, nanoparticles are more uniformly distributed due to Brownian motion, leading to increased heat transfer.



(a)



(b)

Figure 4. Variation of Nusselt number with Reynolds number at different fluid inlet (a) 60 °C and (b) 70 °C

SiO2/water nanofluid with varying concentrations of 0.1% and 0.2% nanoparticles in the base fluid was used in this study. The variations of Nusselt number with Reynolds number and particle concentration are shown in Figure 4 (a), (b) at temperatures of 60 and 70 °C. Nusselt numbers for the nanofluid with different concentrations of SiO2 nanoparticles are higher than those for the base fluid and increase with increasing nanoparticle concentration and Reynolds number of the nanofluid. The enhancement in Nusselt number compared to the base fluid at a temperature of 60 °C is 16% at a Reynolds number of 3200. Nusselt number is estimated by considering the influence of adding nanoparticles to the base fluid at different concentrations. This is evident from the fact that Nusselt number, Reynolds number, and Prandtl number are functions of various thermophysical properties that change significantly with nanoparticle concentration. The average increase in Nusselt number compared to the base fluid at a temperature of 70 °C is 9%, with an average Reynolds number of 1919. The maximum enhancement is approximately 24% for a nanofluid concentration of 0.2% at a Reynolds number of 3200 at a fluid inlet temperature of 70°C. Nusselt numbers for both the nanofluid and the base fluid also increase with an increase in fluid inlet temperature, as shown in Figure 3, as the inlet temperature rises from 60°C to 70°C.

4. CONCLUSION

The heat transfer performance of SiO_2 nanofluid using a mixed nanoparticle composition with water has been investigated for volume concentrations of 0.1% and 0.2% and operating temperatures of 60 and 70°C. The heat transfer coefficient of SiO_2 nanofluid increases with an increase in the composition ratio of both nanoparticles and temperature. There is a 15% average increase in the heat transfer coefficient at a temperature of 60°C. The maximum heat transfer enhancement occurs at a concentration of 0.2%, with a 21% increase at a Reynolds number of 3200 at a temperature of 60°C. At a temperature of 70°C, there is an 18% increase in the average heat transfer coefficient. The maximum heat transfer enhancement occurs at a concentration of 0.2%, with a 24% increase at a Reynolds number of 3200. The Nusselt number increases compared to the base fluid by 16% at a Reynolds number of 3200 at a temperature of 60°C. The average increase in Nusselt number compared to the base fluid at a temperature of 70°C is 9%, with an average Reynolds number of 1919. The maximum enhancement is approximately 24% for a nanofluid concentration of 0.2% at a Reynolds number of 3200 at a fluid inlet temperature of 70°C.

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