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Article

Heat Transfer of Al2O3 – Si Nanofluid in a Heat Exchanger

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ABSTRACT

The research in this paper deals with enhancing the heat transfer coefficient and Nusselt number of a nanofluid containing nanoparticles (AL2O3 and Si) with a particle size of 25 nm and a volume fraction of 0.15 percent to 0.25 percent (V/V). It is investigated whether changes in Nusselt number and heat transfer coefficient are dependent on temperature and concentration of nanoparticles in a double pipe heat exchanger, in which the flow goes in both directions through counter-current tubes. An acceptable degree of agreement was found in comparison between experimental data and theoretical data, which were obtained by employing semiempirical equations. Results show that the heat transfer coefficient and Nusselt number can both be increased up to 25% -in that case, an increase of 21% to 25% is observed. This is in addition to what has been observed, which is that the heat transfer coefficient increases with the operating temperature and nanoparticle concentration.

Keywords: Nanofluid, Nanoparticles, Nusselt Number, Nanometre

Introduction

Solid particles have long been known to be useful for enhancing heat transfer, but, especially when using suspended millimetre or micrometre-sized particles, certain problems can occur, such as abrasion, clogging, high pressure drop, and sedimentation. Compared to fluid heat transfer enhancement using suspended large particles, nanoparticle-assisted fluid heat transfer was shown to possess better properties in relation to fluid heat transfer. Because nanoparticles are typically used at extremely low concentrations and at nanometre-sized sizes, this is the case. This sort of design prevents sedimentation of the flow, which could lead to blockage of the channel. To understand the nature of the heat transfer that occurs in nanoparticle suspension, previous studies have been done from the following viewpoints. The previous two researchers used the heat transfer coefficient and fluid flow characteristics of Al2O3 nanoparticles dispersed in water flowing through a liquid cooling system for microprocessors to investigate the phenomenon of heat transfer and fluid flow when these nanoparticles are present in a liquid with a fast-flowing flow condition. When it comes to heat transfer, the results revealed that the nanofluid outperformed the base liquid, and that the nanofluid with a 36 nm particle diameter outperformed the nanofluid with a 47 nm particle diameter. An experimental investigation to see how well TiO2-distilled water nanofluids will flow in a vertical pipe in a heated state and under conditions of constant heat flux boundary conditions. Increasing nanoparticle concentration causes an increase in heat transfer coefficient in both laminar and turbulent flow regimes. However, at a certain Reynolds number and nanoparticle size, heat transfer coefficient was not affected by nanoparticle size. The nanofluids had a lower pressure drop than the base fluid.

Experimental

Experimental Setup

The apparatus includes a test section (heat exchanger), two tanks, two magnetic gear pumps, and a pump that is used to transport nanofluid as the hot fluid and the other that is used to transport cold water. This is a test section made up of a counter-current double pipe heat exchanger with a length of 120 cm. When using this exchanger, the nanofluid flows into the pipe, where it mixes with cold water from the annular space of the pipe. The pipe on the inside is made of a soft steel tube with an inner diameter of 2 mm, outer diameter of 4 mm, and thickness of 6 mm while the pipe on the outside is of steel tubing with an inner diameter of 12 mm, outer diameter of 14 mm, and thickness of 2 mm. The temperature probes, all of which have been tested and approved, are connected to the data logger sets. The pressure readings taken across the test section are accomplished using U-tube manometers mounted on an incline. Stainless steel 15-liter tanks are used for storing nanofluid and water chilled to a temperature less than 18 degrees Celsius. A thermostat is used to keep the fluid temperature steady, and a cooling tank is used to reduce temperature rise. To maintain the temperature of the nanofluid, electric heaters and thermostats are added to the device. The Nusselt number error depends on the magnitude of the temperature and the flow of the cold water and the nanofluid. During the test, the wall temperature of the test section, the mass flow rate, and the inlet and outlet temperatures of the nanofluid and cold water are monitored.

Nanofluid Preparation

To make the nanoparticle used in the experiment, a solution of 99.0% pure aluminium oxide and silicon was prepared in water with an average particle size of 25 nm. The nanofluid was mixed with water that was previously deionized. These nanofluids are known to be stable, which is demonstrated by their resistance to aggregation and aggregation onset over the course of a week; as such, intermediate mixing was not considered to be necessary (Table 1 & 2).

Table 1.Properties of Nano Particles of aluminium oxide

Property	Value
Atomic weight	101.96 g mol^1
Average particle size	50nm
Melting point	2055°C
Purity	99.99%
Density	3.97 g/cm^3
Color	White
Morphology	Spherical

Data Processing

To figure out the overall heat transfer coefficient, convective heat transfer coefficient, and Nusselt number of nanofluids with various particle volume concentrations and Peclet numbers, the new data were used. Hot fluid heat transfer rate in concentric tube heat exchanger: For nanofluid flows in a concentric tube heat exchanger, the heat transfer rate of the hot fluid (AL2O3–Si) in the inner tube can be expressed as follows.

Table 2.Properties of Nano Particles of Silicon

Cutoff diameter (nm)	Particlc diameter (nm)	Surface energy (kJ mol^{-1})	Cohcsive energy (eV/atom)
2.0	2.19	57.97	-3.69
3.0	3.26	37.10	-3.91
4.0	4.27	28.42	-4.00
5.0	5.26	22.74	-4.06
6.0	6.27	18.57	-4.10
7.0	7.28	16.30	-4.13
8.0	8.26	14.12	-4.15
9.0	9.27	12.71	-4.16
10.0	10.27	11.41	-4.18
11.0	11.28	10.35	-4.19
12.0	12.27	9.56	-4.20
Bulk (simulation)			-4.30
Bulk (experiment)			-4.63

[a]Reference [18] (for the cohesive energy at 0 k).

$$Q_{(\text{nano fluid(hot fluid))}=}\, m^{o}_{(\text{nano fluid(hot fluid))}}\, C_{p(\text{nano fluid(hot fluid))}}(T_{out}-T_{in}) \quad (1)$$

Where m^o is the mass flow rate of the nano fluid(hot fluid) and T_{out} and T_{in} are the outlet.

The heat transfer of the cold fluid (water) for the outer tube is

$$Q_{(\text{cold fluid(water))))} =}\, m^{o}_{(\text{cold fluid})}\, C_{p(\text{cold fluid(water))}}(T_{in} - T_{out}) \quad (2)$$

Where m^o is the mass flow rate of the water (cold fluid) and T_{out} and T_{in} are the inlet and outlet temperatures of the water(cold fluid) respectively.

The effective density of nanofluid is

$$\rho_{nf} = (1 - \emptyset_v)\rho_f + \emptyset_v \rho_\rho \quad (3)$$

Subscripts and refer to the base fluid, the nanoparticles, and the nanofluid, respectively. is the nanoparticle volume concentration. is the effective specific heat of the nanofluid which can be calculated from Xuan and Roetzel relation[4]:

$$(\rho C_\rho)_{nf} = (1 - \varphi_v)\left(\rho C_\rho\right)_f + \varphi_v (\rho C)_\rho \quad (4)$$

The heat transfer coefficient of the test fluid, h_i can be calculated as follows[5]:

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{D_i \mathrm{Ln}\left(D_o/D_i\right)}{2k_w} + \frac{D_i}{D_o} + \frac{1}{h_o}, \tag{5}$$

Where D_i and D_o are the inner and outer diameters of tubes respectively, U_i is the overall heat transfer coefficient based on the inside tube area h_i and h_o are the individual convective heat transfer coefficients of the fluids inside and outside the tubes, respectively and K_w is the thermal conductivity of the tube wall U_i is given by

$$Q = U_i A_i \Delta T_{\mathrm{lm}}, \tag{6}$$

Results and Discussion

To ascertain the accuracy of the measurements, the experimental system was first tested with distilled water, after which convective heat transfer of nanofluids was measured. Generally, the heat transfer coefficient is a number that describes how well heat is transferred between two bodies, and is a result of an equation developed by Gnielinski in which *hi* is calculated by using the Gnielinski correlation for turbulent flow through a tube[6]:

$\mathrm{Nu} = 0.012\ (\mathrm{Re}^{0.87} - 280)\ \mathrm{Pr}^{0.4.}$

The Convective Heat Transfer of the Nanofluid

In terms of the Reynolds number, at different volume concentrations, the overall heat transfer coefficient of aluminium oxide nanofluid and water for aluminium oxide nanofluid and water varies as follows. According to the research, the heat transfer coefficient has increased as the Reynolds number and temperature of the nanofluid have increased. Aluminium oxide nanofluid has a greater heat transfer coefficient as concentration increases, but when compared to the base fluid, the heat transfer coefficient of aluminium oxide nanofluid decreases in a fixed Reynolds number. For both aluminium oxide nanofluid and the base fluid, the overall heat transfer coefficient is found to be the highest when the concentration is 0.269 and the Reynolds number is about 27600. When these two fluids are heated to 40 and 60 °C, the overall heat transfer coefficient increases up to 7% and 9.6%. The values of 4.6% and 6.82% apply to water, and these values apply to the temperature ranges of 40 to 60 degrees Celsius (Reynolds number of 27600 and concentration of 0.1). This significant increase in the convective heat transfer coefficient. As the Reynolds number increases, the overall heat transfer coefficient also increases. Increased costs could be attributed to the following possible factors:

- A nanofluid that is infused with suspended nanoparticles that boosts the thermal conductivity of the mixture
- The nanoparticle mobility was responsible for an amorphous process of high energy exchange, which was triggered by the nanoparticles' movement. To verify this, it is demonstrated that compared to base fluid, nanofluid convective heat transfer coefficient increases at the same Reynolds number, and thus, the convective heat transfer coefficient of the nanofluid is higher than that of the base fluid. When increased thermal conductivity is present, it results in an increase in heat transfer efficiency caused by conduction, convection, and the thinness of the thermal boundary layer
- Several mechanisms are at play to increase the thermal conductivity of the nanofluid, with the most prominent ones being the formation of the liquid layer on the surface of the nanoparticles, Brownian motion, classification of particles, the transmission of the phonon's projectiles in the nanoparticles, and the increase of the thermal conductivity of fluids because of the increase in nanoparticles in the pipe wall. An increase in the thermal conductivity can lead to an increase in the heat transfer coefficient in the thermal boundary layer near the tube wall. One of the factors increasing the thermal conductivity of the nanofluid is the temperature, which increases the nanofluid's thermal conductivity and subsequently the heat transfer coefficient and Nusselt number. Experimental findings indicate that nanoparticle effects on thermal conductivity increase with temperature

Conclusion

Much research has been conducted to determine the effects of nanoparticles on different process parameters, such as hydrode-names and thermophysical properties. The research was usually left to a hands-off approach when it came to turbulent nanofluid flow and heat transfer, which often resulted in false conclusions. In this study, the research investigated the heat transfer enhancement of the nanofluid containing aluminium oxide nanoparticles and water when the system was operating under the condition of turbulent flow in a double pipe heat exchanger. 20 nm aluminium oxide nanoparticles (with the concentration ranging from 0.15% to 0.25%) were used to measure heat transfer in a turbulent flow of a nanofluid that contained water at a volume concentration of 0.15-0.25%. The properties of nanofluid are good, and there is a plentiful supply of fluid. Temperature-based heat transfer coefficient (0.21) and Nusselt number (0.25) increase to (0.25) compared to (0.21) of the base fluid, according to the comparison based on fixed Reynolds number. The experimental results showed that the increase in the average heat transfer coefficient in the turbulent flow regime was accompanied by the addition of the nanoparticles to the fluid. It will be necessary to do extensive research to understand the heat transfer characteristics of the nanofluid and to discover the other relations.

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