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Investigation of Effect of Aluminium Oxide Nanoparticles on the Thermal Properties of Water-Based Fluids in a Double Tube Heat Exchanger

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Abstract: The thermal behavior of aluminium oxide-water nanofluid in a double pipe carbon steel heat exchanger was investigated in the present study. The overall heat transfer coefficient, Nusselt, and heat transfer coefficient of nanofluid were compared with the base fluid. The volume fraction of the nanoparticles was 1%. By adding nanoparticles to the fluid, the thermal properties of the base fluid improved significantly. The hot and cold fluid flow was considered counter-current, and the nanofluid was pumped into the inner tube and once into the outer tube, and the flow rate of each fluid was 0.05 kg/s. The convective heat transfer and the overall heat transfer coefficient enhanced 94% and 253% for the hot fluid flow in the outer tube and 308 % and 144% for the hot fluid flow in the inner tube, respectively. The pressure drop calculations also showed that the pressure drop would not change significantly when using nanofluid.

Keywords: nanofluid; thermal properties; heat exchanger; aluminium oxide.

1. Introduction

Water, oil, and ethylene glycol are conventional heat transfer fluids used in various industries and processes with poor thermal properties. Increasing the thermal conductivity is a key idea for improving the thermal conductivity of conventional fluids. Since solid particles have a higher thermal conductivity than the base fluid, it is expected that suspension of fine particles in the base fluid will improve the thermal conductivity.

Nanofluids are prepared by dispersing nanoparticles into base fluids and nanoparticles are divided into different categories in different studies depending on their morphology, size and chemical properties. Metal oxide, carbon nanomaterials and nanocomposites are used in various industries. Magnetic nanoparticles are another group of nanomaterials made up of magnetic elements such as iron, cobalt, nickel, or oxides. Nanocomposites are materials whose nanoparticles are integrated into their lattice to improve the specific properties of materials [1,2].

One of the simplest and most common methods for the production of metal nanoparticles is the reduction of metal salts. Different types of nanoparticles such as Rh, Os, Pt, Cu Pd, Au, Ag and Ir have been synthesized using this method. Carbon nanomaterials (carbon nanotubes, graphene, activated carbon, etc.) are another group of nanomaterials that due to high electrical and thermal conductivities, tensile strength and flexibility, have received much attention in various studies [3,4].

Conventional synthesis methods are chemical vapor deposition, laser evaporation of carbon nanotubes, sonochemical arc discharge and hydrothermal, each of which has its advantages and disadvantages. Appropriate methods after the synthesis process must purify carbon nanotubes. The choice of nanotube synthesis and purification method is an important parameter that greatly impacts product quality and is based on the type and application required of this material [5]. The thermophysical properties of nanofluids include thermal conductivity, viscosity, density and heat capacity, which depend on the concentration, temperature and nature of the base fluid and nanoparticles, shown in Figure 1.

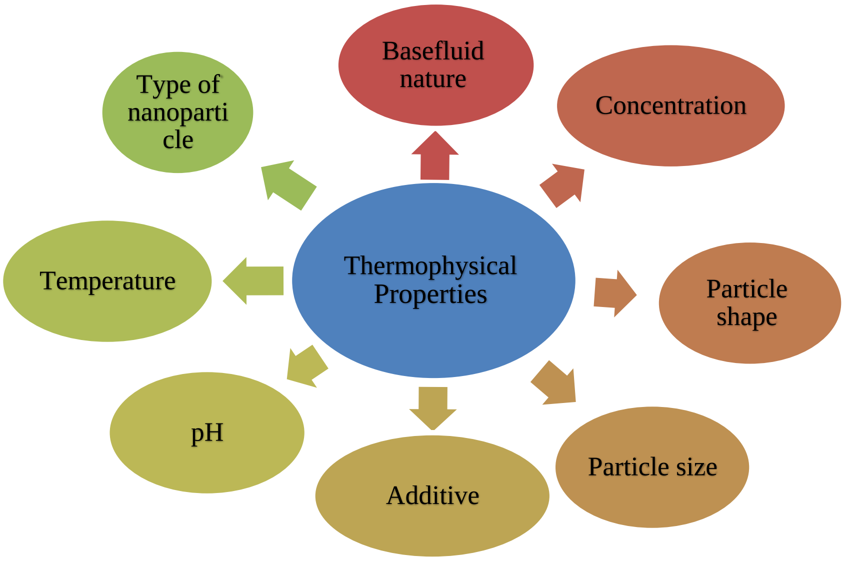

Figure 1. Parameters affecting thermophysical properties [6-9].

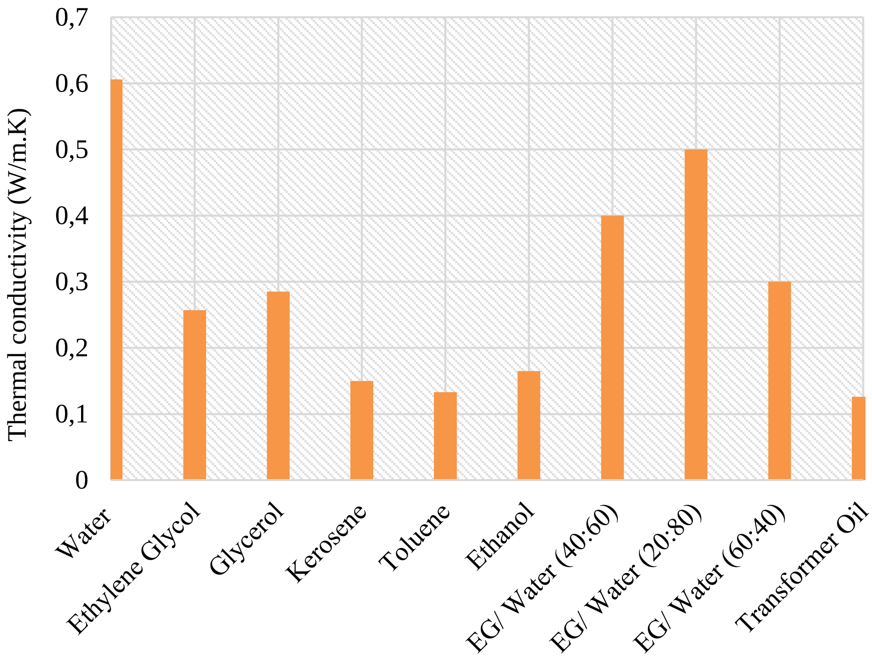

Figure 2. Thermal conductivity of base fluids [10].

The point that should be considered about nanofluids is that the existing models and relationships for nanofluids are limited to the same nanofluid and the same range and can not be generalized. Therefore, in this research, information about nanofluids has been collected.

Many researchers have reported that heat performance increases with nanofluids because nanoparticles are materials with higher thermal properties than base fluids, which, when added to them, increase nanofluids' thermophysical properties except heat capacity. The thermal conductivity of the base fluid is plotted in Figure 2. Figure 3 shows the effect of temperature in changing the thermal conductivity of the base fluids. It is clear from Figure 3 that by increasing the temperature, the thermal conductivity of base fluid increased. As shown in Figure 2, the thermal conductivity of water is higher than other fluids, and therefore the enhancement in thermal conductivity of water is also greater. The temperature has a positive effect on all fluids and, in all cases, increases the thermal conductivity.

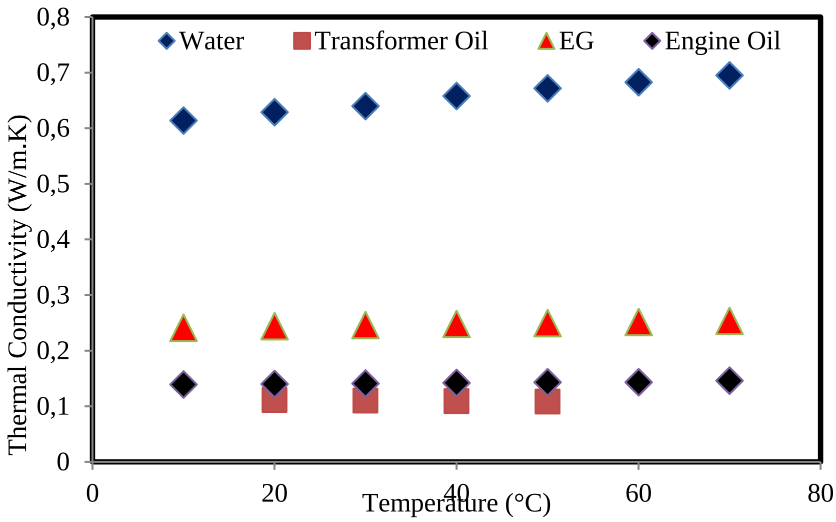

Figure 3. Temperature effect on thermal conductivity of different base fluids [11,12].

Nanoparticles have a higher thermal conductivity than base fluids, which is much higher than base fluids. Figure 4 shows a comparison of the thermal conductivity values of common nanoparticles in various studies.

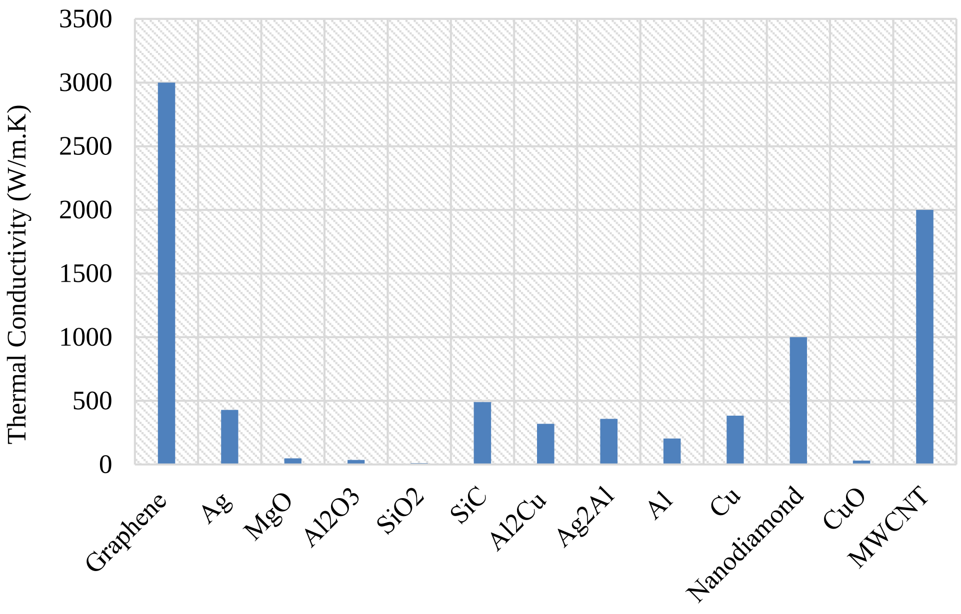

Figure 4. Comparison of thermal conductivity of nanoparticles.

The thermal conductivity coefficient, as compared to other thermophysical properties, has been paid more attention by several researchers. Different empirical relationships and theories have been presented for different nanofluids in different ranges. Influential parameters in thermal conductivity include temperature, concentration, shape size, pH effect in nanofluid, surfactant, ultrasonic fluctuations, particle clustering effect and magnetic field effect. According to a study conducted by Dos *et al.*, the temperature and concentration of nanoparticles have the most effect [13]. Table 1 provides an overview of research on the thermal conductivity of nanofluids.

Table 1. Overview of parameters and nanofluids preparation.

Ref.	Base fluid	Particle	Size (nm)	Preparation method	Enhan. K (%)
[14]	Vegetable oil	Cu–Zn	19,23,25	The samples were sonicated for three hours .Nanofluid was stable for 3 days	130
[15]	Water /EG	Al_2O_3/ CuO	CuO: 29 Al_2O_3: 40	Sonication time was 16 h and nanofluid was prepared by two step method	90 to 95
[16]	DI water, EG	MWCNT	30 to 40	Nanofluid was sonicated for 1 h	90
[17]	EG	Boron nitrid	1	ultrasonic agitation for 200 min	260
[18]	PAO	MWCNTs	-	Ultrasonication and surfactant were used to stabilize	6 to 200
[19]	PAO	MWCNTs	10–15	Ultrasonication and functionalization were used	33 to 160
[20]	Oil	MWCNTs	-	Ultra sonication and dispersant	175
[21]	Oil	MWCNT	25×50,000	-	160
[22]	Water	Al_2Cu	31	-	106
	Water	Ag_2Al	-	-	150 to 210
[23]	EG	Al-Cu	0 to 20	-	125
	Water	Al_2O_3	10	-	100
[24]	Kerosene	Fe_3O_4	6.7	-	300
[25]	Oil	MWCNT	-	-	150
[26]	Water	MWCNT	-	-	150
[27]	Water	MWCNT	-	-	287

Moldoveanu *et al*. studied Al_2O_3-TiO_2 on the water-based fluid in the range of shear rate between 10-1000 (1/s) at ambient temperature and volume fraction between 1-5% and reported all samples showed non-Newtonian behavior. Finally, they presented three experimental models for the viscosity of TiO_2, Al_2O_3, and TiO_2 + Al_2O_3 hybrid at ambient temperature as a function of concentration [28].

Al_2O_3 nanofluid: $\eta_r = \frac{\eta_{nf}}{\eta_f} = 0/6152\varphi^2 - 1/5448\varphi + 2/3792 \; and \; R^2 = 1$ (1)

TiO_2 nanofluid: $\eta_r = \frac{\eta_{nf}}{\eta_f} = 0/2302\varphi^2 - 0/3202\varphi + 1.5056 \; and \; R^2 = 1$ (2)

TiO_2+ Al_2O_3 nanofluid:

$$\eta_r = \frac{\eta_{nf}}{\eta_f} = \frac{0}{3371\varphi^2} - \frac{0}{1011\varphi} + 1.2921 \; and \; R^2 = \quad (3)$$

Sarafraz *et al.*, in their research, investigated the heat transfer coefficient and pressure drop in the heat exchanger by using functionalized carbon nanotube nanoparticles on water base fluid at a concentration between 0.1-0.3 %wt. Their results showed that the heat transfer coefficient increased 56% at a mass fraction of 0.3 and also, the heat exchanger performance using nanofluid showed a 44% improvement in the Reynolds number between 900-10500 [29]. Aghayari *et al*. studied the heat transfer coefficient and Nusselt number in a double-tube heat exchanger using Al_2O_3 nanofluid on a water-based fluid in their research. The volume fraction was between 0.1-0.3 and showed an enhancement in heat transfer coefficient of about 19% and a Nusselt number of 24%. Their results also showed that the heat transfer coefficient increases with increasing temperature and volume fraction of nanoparticles [30]. In a similar study, Walvekar *et al*. examined the heat transfer coefficient of water nanofluid - carbon nanotubes in the weight fraction range of 0.05-0-085 and observed an enhancement of 9 to 67% in the heat transfer coefficient and temperature and weight fraction introduced as parameters that affect on heat transfer coefficient [31]. Chavda investigated the heat transfer coefficient of CuO-water nanofluid in weight fractions of 0.002, 0.003, and 0.004 and prepared nanofluid in a two-steps method and studied the role of weight fraction in increasing the heat transfer coefficient in a double-tube heat exchanger [32]. Peyghambarzadeh *et al*. studied CuO/water and AL_2O_3/water nanofluids in Reynolds between 500-2000 and reported a 49% improvement in volume fraction for 0.1 for AL_2O_3/water and a 27% enhancement in heat transfer coefficient at 0.2 for CuO/water [33]. Yang *et al*. experimentally studied the heat performance of water-graphite nanofluid transfer in a tubular heat exchanger. They reported that the heat transfer coefficient increased with increasing the weight fraction of nanoparticles. However, its value is less than the previous values [34]. In another study, Porgar *et al*. investigated the MWCNTs nanoparticles on transformer oil base fluid in a copper heat exchanger and obtained the thermophysical and thermal properties of the nanofluid as a function of temperature and concentration. They reported that with increasing temperature and concentration, the thermal performance of the nanofluid improved and the average improvement of thermal conductivity of nanofluid and overall heat transfer coefficient was 138% and 37.2% at 45 °C and concentration of 0.8 wt%, respectively [35].

A review also has been done on nanofluids and investigated their important parameters that affect thermal performance. The results have shown in Table 2.

Table 2. Summarized nanofluid heat performance.

Ref.	Basefluid	Particle	Temperature (°C)	Concentration	Remark
[36]	EG/ Water (60/40)	ZnO-MgO hybrid	30–80	0%, 0.0125%,0.025 %, 0.05%, 0.075% and 0.1%	Surfactant: CTAB h improvement: 28.9% sythensize method: co-precipitation & sol–gel
[37]	EG	SiC-MWCNTs	20-50	Up to 0.4 vol.%	K improvement: 32.01 % Nanofluid showed Newtonian behaviour
[38]	Water	Ag- TiO_2	20-45	0.01,0.05,0.1%	Ultrasonication was used to stabilize nanofluid Overal heat transfer coefficient enhanced to 2727.38 W/m^2K Nanofluid thermal conductivity increaesd to 1.84 W/mK
[39]	Water	TiO_2, ZnO and Ag	30-60	0.25%	Flowrate was 1 to 3.5 litre per second Heat transfer enahcement for TiO_2, Ag and ZnO was 32%, 16% and 21% repectively.
[40]	Water	ZnO & Al_2O_3	-	1 to 3%	Thermal performance increased by increasing particle concentration.
[41]	Water	Diamond	20-60	0.125, 0.25, 0.5, 0.75, 1 ,1.25	Thermal conductivity 25% increased Nanofluid was stable for 14 days
[42]	Water	Ni	Up to 60	0.1%, 0.3%, 0.6%	Overall heat transfer enhanced 38.6% Convective heat tranfer enhanced 57.35%
[43]	Water	CNT	30-80	-	Surfactants were SDBS and GA Overall heat transfer coefficient increased 62.62%
[44]	Water	Al_2O_3	34-42	0-5%	Heat transfer improved 75% Pressure drop increased 8%
[45]	EG/ Water	Al_2O_3	-10-70	0.01-0.5	Convective heat tranfer enhanced 22.7% Nanofluid prepared by using twe-step method

Ref.	Basefluid	Particle	Temperature (°C)	Concentration	Remark
[46]	Water	CuO, Al_2O_3, MgO	-	0.5 and 1.167 g/L	Efficiency increased 83% Flowrate was 5, 8, 11, and 14 L/min Pressure drop was 9%
[47]	Water	TiO_2	25-60	0-2	Sample was stable for 30 days Thermal conductivity increased to 0.78 W/m.K
[48]	Water	Al_2O_3-ZnO	25-65	0.33-1.67	Viscosity increased 96.37% Specific heat transfer decreased 30.12% Ultrasonication was 3 h
[49]	Water	TiO_2	20-60	-	Flowrate was 0.1 to 0.5 L/min Thermal conductivity enhanced 12.4%

2. Materials and Methods

The present study was conducted in a manufactured double pipe carbon steel heat exchanger with an inner diameter of 37.5 mm and an outer diameter of 50.8 mm. Thermometers were installed to measure the temperature at certain distances from the heat exchanger. The nanofluid's thermal properties were investigated. The nanofluid consists of aluminium oxide nanoparticles on water-based fluid consisting of a 1% volume fraction of aluminium oxide prepared in two steps and a hot inlet fluid temperature of 80 °C and an inlet nanofluid of 20 °C. Adding nanoparticles to the base fluid increases the adhesion and increases the thermal conductivity, which improves the overall heat transfer coefficient, reduces the boundary layer's thickness, and reduces the surface area required for heat transfer. The Brownian motion of nanoparticles led to higher heat transfer from the wall to the nanofluid. Increasing the volume of nanoparticles intensifies the mechanisms associated with increased heat transfer. Another advantage of using nanofluid is that the flow rate for the nanofluid is lower than the base fluid. Also, the pressure drop will not change much, which means that the nanofluid can transfer the same amount of energy at a lower flow rate that at the same flow rate, the volume of equipment is reduced. The schematic of the experimental setup is presented in Figure 5. This set-up consists of valves, flowmeters, tanks and pressure and temperature indicators.

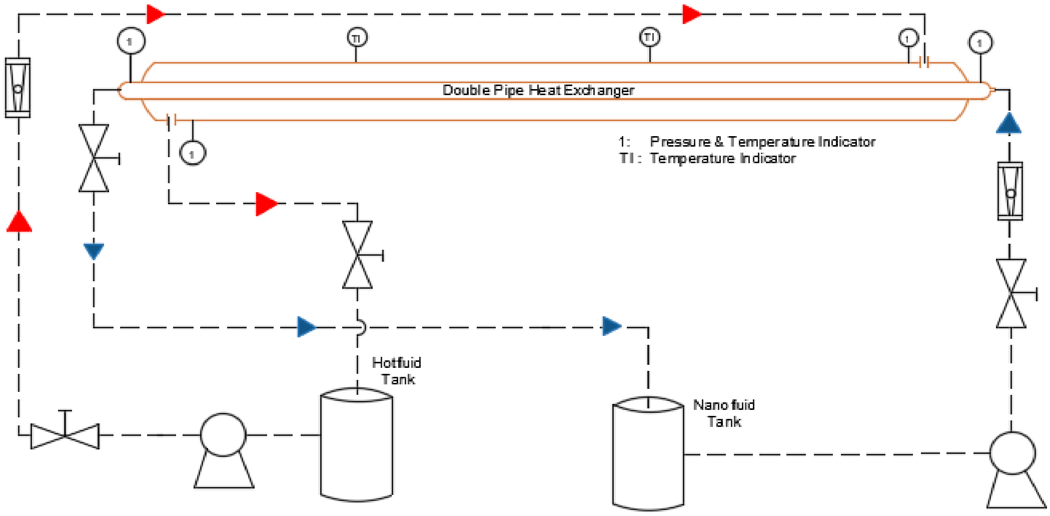

Figure 5. Schematic of set-up section.

3. Results and Discussion

The Nusselt number increases by increasing Reynolds and nanoparticle concentration. The maximum Nusselt number was obtained for the case where the hot fluid flowed in the outer tube, which was 25.44 and the highest percentage was 358%. According to figure 6, the highest overall heat transfer coefficient was 469.9 W/m^2.K for the case where the hot fluid flowed in the outer tube and its increase percentage was 253% and 144% for the hot fluid flow in the inner and outer tube, respectively, and this increase eventually reduced the heat transfer surface and the size of the heat exchanger. Also, by dispersing nanoparticles to the base fluid, the friction coefficient increases, which leads to an increase in the pressure drop, although this enhancement is negligible and does not cause any additional drop over the base fluid.

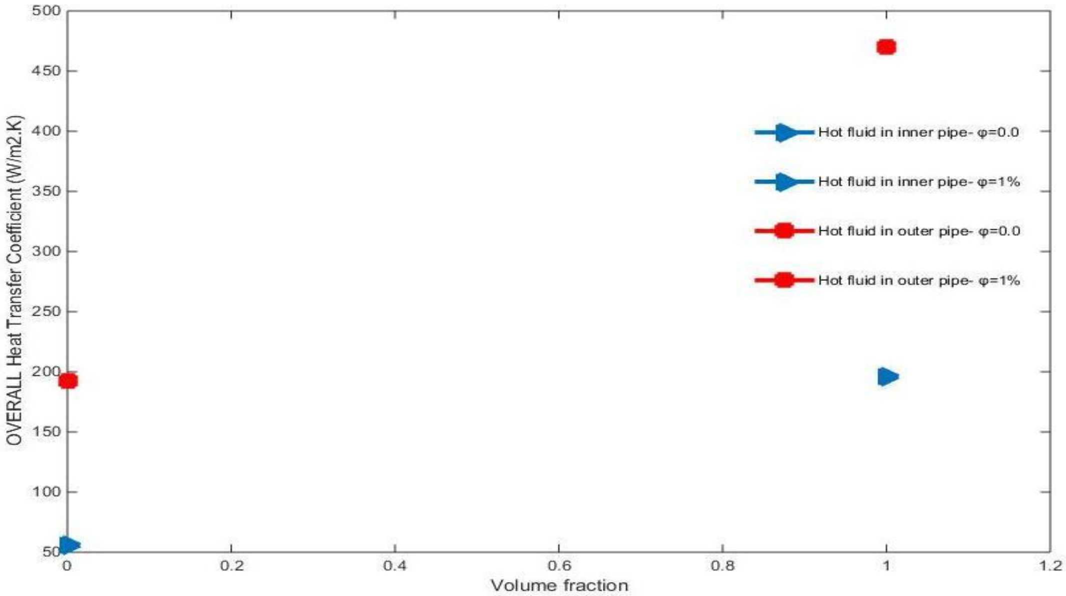

Figure 6. Overall heat transfer coefficient versus concentration.

It is shown in figure 7 that the highest convective heat transfer coefficient is 821.5 W/m^2.C for the case where the hot fluid has flowed in the outer pipe and also improvement in the convective coefficient is 94% and 308% for the hot tube in the inner and outer pipe respectively. The nanofluid heat transfer coefficient is expected to be a function of the thermal conductivity coefficient, nanofluid heat capacity, the flow, nanofluid concentration, dimensions, and the shape of these particles as well as the flow structure.

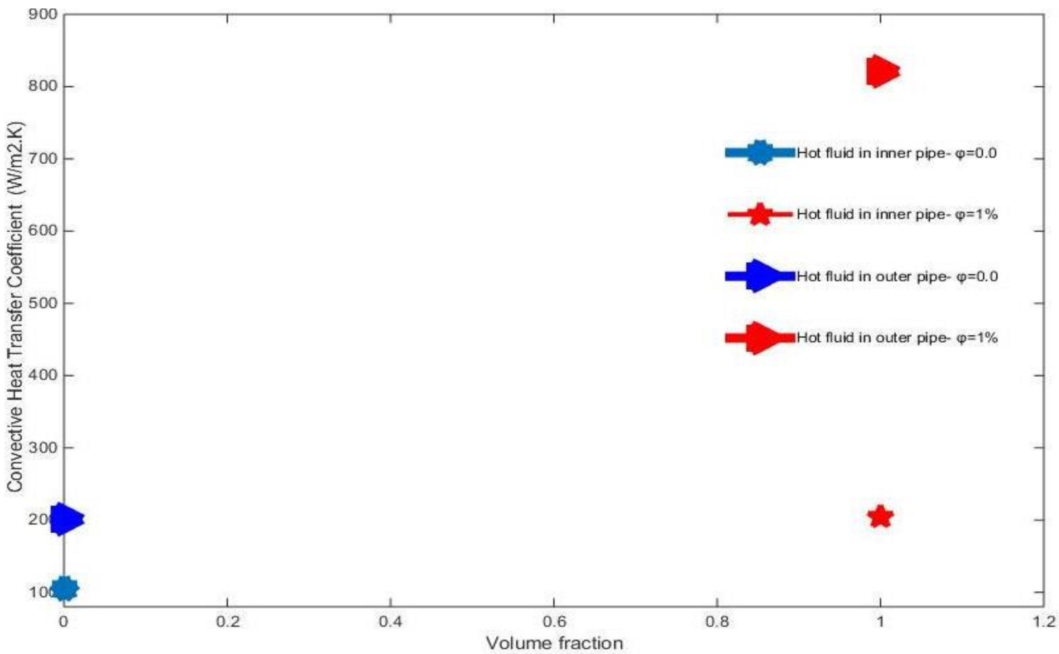

Figure 7. Convective heat transfer coefficient versus volume fraction.

Figure 8 the change in the Nusselt number of nanofluid versus water-based fluid presented at Reynolds number for different volume fractions. As it is shown, the Nusselt number increases with increasing Reynolds number and volume fraction of nanoparticles. Any increase in the concentration of nanoparticles improves thermal conductivity and thus increases the heat transfer coefficient.

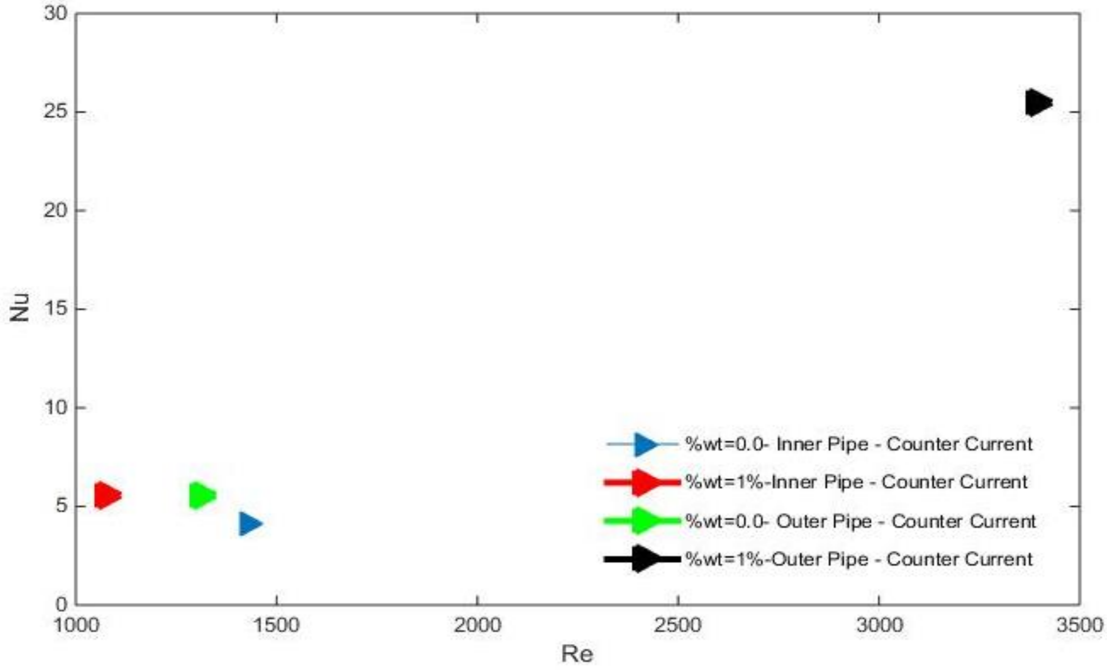

Figure 8. Nu number versus Re number.

4. Conclusions

The results obtained from the study on the heat transfer performance of nanofluids clearly showed that nanoparticles significantly increase heat transfer performance. Nanofluids also have higher heat transfer coefficients than base fluids at the same Reynolds numbers. A number of reports in the literature have shown that the heat transfer performance of nanofluids and the applications of nanofluids to enhance heat transfer are influenced by the thermophysical properties of nanofluids and the size of the particles, the shape of the particles, random motion, and fluid-particle interaction. Therefore, in this study, the heat transfer properties of aluminium oxide-water nanofluid in a heat exchanger and the role of nanoparticles in heat transfer improvement and reduce the heat exchanger size were studied. As a final result, when nanofluid flow into the inner pipe, the heat performance shows good results.

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Conflicts of Interest

The authors declare no conflict of interest.

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