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Effectiveness Enhancement of the Double Tube Heat Exchanger Using ZnO Nanofluid

Hussein Fadhil Kadhim
The State Company for Gas Filling and Services, Ministery of Oil, Al-Qadisiyah
*Corresponding Author E-mail: ihrr1966@gmail.com

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Abstract

In this study, the effect of adding zinc oxide nanoparticles to the reversible effect double tube heat exchanger with a length of 1.5 meters, an outer diameter of 19.0 mm, is made of copper material that is used by Nano water as a cold liquid. Zinc solid nanoparticles with a volume concentration of 3% were used with water as the base liquid. The cold nanoscale water flows into the real tube with a volume of 4 L/min which enters into the heat exchanger at 16°C, where the hot water flows into the separator of the heat exchanger representing a blank volume of 6 L/min. The Reynolds number range and flowrate ranges are 10000 to 20000 and 5 to 15 respectively. The heat exchanger was introduced at a temperature of 65°C. An improvement in the performance of the exchanger was shown in the case of using water with the addition of nanoparticles.

Keywords: Double tube heat exchanger; Nanofluid; overall heat transfer coefficient; effectiveness; ZnO.

1. Introduction

The double tube heat exchanger is the significant device of heat transfer between two different types of fluids. Conducted a study to calculate the heat transfer coefficient of nanoscale fluids consisting of aluminum nanoparticles mixed in transformer oil as a base fluid which was stratified in a double-tube heat exchanger and the nanofluid showed significant improvement in the heat transfer coefficients [1].

[2] were investigated a numerical study of the dynamic and thermal behavior of the nanoscale fluid (AL_2O_3 + Water) consisting of aluminum oxide particles mixed in water as a base, which takes place inside a regularly heated tube under constant laminar flow conditions. It was concluded from this study that the nanoparticles increase the rate of heat transfer relative to the

rate of heat transfer when using the base liquid alone. It was concluded that the improvement in the rate of heat transfer increases with an increase in the volumetric concentration of the particles, and this is accompanied by an increase in stress and shear at the wall.

The measurements of nanofluid properties, three samples of solid nanoparticles have been suspended in water [3]. Thermal conductivity and viscosity have been measured and validated with standard. The recommendation of nanofluid applications in heat exchanger has been conducted by [4].

The different size ratios were used (0.5%, 1% and 5%) of nanoparticles mixed with water as a basis for conducting measurements of thermal conductivity, viscosity, specific temperature and stability of these nanoscale fluids at different temperatures (40-60-80 Celsius), and the results showed that there is an uneven behavior [5]. Naturally at the temperature (80 degrees Celsius), where there was a decrease in the values of the thermal conductivity, he attributed this to the liquefaction of the particles at this temperature, and it was a reason for the decrease in conductivity. The results also showed that there is an increase in specific heat and a decrease in viscosity with increasing temperature and the ratio gave 5% better Thermal behavior of both types and indicated to a researcher that the minimum time for liquid stability is 48 hours. They reviewed the research on the topic of heat transfer to nanofluids, which used nanoparticles of the type (CuO, AL2O3, TiO2, ZnO) mixed in water as a base fluid.

The nanoscale liquids with the highest concentration of nanoparticles that gave the highest heat transfer. The rate of heat transfer is directly proportional to the number of offspring and the number of silt of the liquid [6]. The use of nanoparticles of small size increases the surface area for heat transfer and as a result, the rate of heat transfer increases. The stability of nanoscale liquids and the cost of their production are important factors. If treated, their use in the heat exchanger is the best. There is a pressure drop due to the use of nanoscale fluids, but this phenomenon can be overcome if nanoparticles of small sizes less than (20nm).

The researchers studied research that focused on heat transfer using nanoscale fluids, and studies focused on determining the properties of nanoscale fluids, especially thermal conductivity and viscosity by using larger particle sizes [7-10]. They studied experiments on different nanocomposites with different concentrations and temperatures to calculate the coefficients of heat transfer and friction for nanoscale fluids, and the Reynolds number had an effect on friction and heat transfer. The researcher showed a good agreement between experimental and numerical studies.

The effect of the shape of different nanoparticles (cylindrical, plate and spherical) on the performance parameter of a shell-tube type heat exchanger and used (-AlOOH) particles mixed in the mixture of water and ethyl alcohol as the base liquid and the researcher analyzed the performance of the heat exchanger in terms of the heat transfer rate. And the change of entropy in the nanoscale fluid, and the results showed that there was an increase in both the rate of heat transfer and the thermal performance of the exchanger [11]. The results also showed that the cylindrical particles had the best thermal properties on the rate of heat transfer and the largest change in the energy of entropy. The researcher indicated that the entropy increase was less than 1%. Therefore, this increase in entropy energy can be neglected and thus cylindrical particles are considered to be the best for use in heat exchangers to work with nanoscale fluids.

The experimental and numerical study on the thermal transfer of the nanofluid using AL2O3 for two types of heat exchanger, the first type of the double tube and the other type was the shell and tube. The effect of some important factors such as the volumetric flow rates of the hot and cold nanofluid, the temperature of the nanoscale, and the concentration of particles on the heat performance of the exchanger has been considered. The results showed that the thermal performance of these two types increases by increasing the flow rates of the two fluids and increasing the concentration, as well as the temperature of the nanofluid entering the exchanger. The results also showed that the heat transfer coefficients of the nanoscale fluid in the two exchangers (the first and second) are higher than that of water by (13.2% -21.3%), respectively. Likewise, the thermal performance coefficient of the nanofluid in the shell and tube type heat exchanger was higher than the thermal performance in the double tube increased by 26.2%. [12]

Hussein [13] was studied thermal performance and thermal properties of double pipe heat exchanger under laminar flow by using hybrid nanofluid. It was concluded that the performance of double pipe heat exchanger increases as increase of thermal properties of hybrid nanofluid.

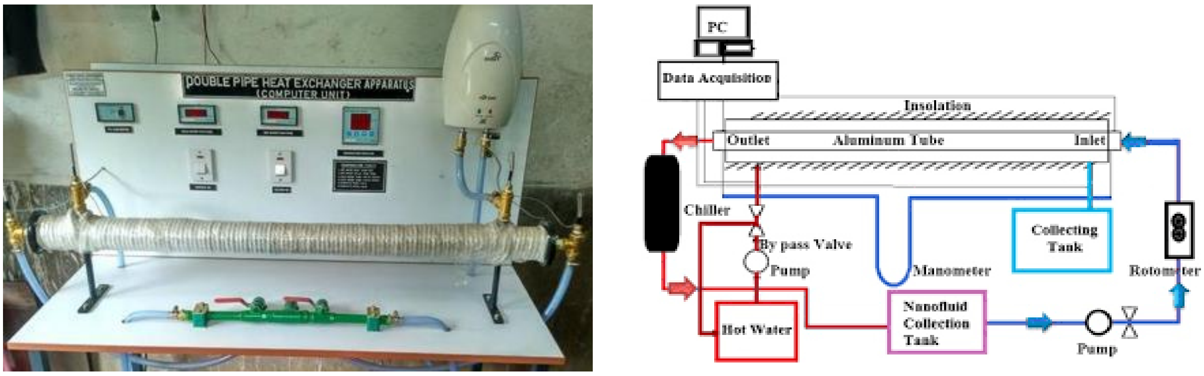
This paper is studied the effect of ZnO solid nanoparticles suspended in water on the double tube heat exchanger. The test rig has been fabricated and nanofluid has been prepared. The friction factor and heat transfer enhancement are measured and compared to pure water. The effectiveness of the double pipe heat exchanger is evaluated by using nanofluid and compared with the results of pure water. The originality of this work is the using of ZnO nanofluid through a double pipe heat exchanger under turbulent flow with volume fractions 3% to enhance effectiveness.

2. Methodology

2.1. Test rig fabrication

The test rig shown in Figure (1), consists of double tube heat exchanger and two plastic tanks with 8 liters, one of them is contained the heat fluid and an electrical coil of 3000 watts, and the other is contained the cold fluid. The cold fluid is used nanofluid flow in the inner tube which will gain the heat from the hot water flowing through the outer tube.

The ZnO solid nanoparticles are suspended in pure water with mechanical mixing to create nanofluid. The ultrasonically device has been applied to break up all agglomerated and ensuring stability of homogenous nanofluid [13].



(a) Image of experimental system.

(b) Schematic of system.

Fig. (1): The experimental system.

2.2. Nanofluid preparation properties

It can be used Eq. (1) to estimate the nanofluid volume concentrations depending on nanoparticles volume (V_p) and water volume (V_f) respectively.

$$\emptyset = \frac{V_p}{V_p+V_f} \tag{1}$$

The of nanofluids is by;

The pH values of nanofluid have been measured using OAKTON device to measure the stability. The pH value before and after tests refers to the stability of nanofluid and the changes of thermophysical properties. ZnO nanopowders suspended in pure water nanofluids undertaken are assumed as a single phase flow, an incompressible, a Newtonian fluid and an isotropic. Thermal properties of ZnO nanofluid have been shown in a Table (1).

Table (1): Thermophysical properties of water and nanoparticles.

	Density (kg/m^3)	Specific heat capacity (kJ/kg.K)	Thermal conductivity (W/m.K)
Water	998	4179	0.6
ZnO	2300	720	7.2

2.3. Calculation of effectiveness

The flow of nanofluid through the double pipe heat exchanger should be under assumptions that the nanofluid is assuming single phase with high stability under the turbulent flow condition. The hot and cold fluid are assumed to be pure water and nanofluid respectively.

$$Q_{actual} = mCp(Thi - Tho) \tag{2}$$

For Counter Flow Arrangement, Logarithmic Mean Difference in temperature.

$$\mathrm{LMTD} = \frac{(\mathrm{Thi}-\mathrm{Tco}) - (\mathrm{Tho} - \mathrm{Tci})}{\ln(\mathrm{Thi}-\mathrm{Tco}) / (\mathrm{Tho} - \mathrm{Tci})} \tag{3}$$

Based on the inner surface area of the inner pipe, the experimental overall heat transfer coefficient.

$$U_i = \frac{Qavg}{Ais{,}ip \times LMTD} \tag{4}$$

Cold Water Flow Rate Heat Capacity

$$C_c = m_C \times Cp_{,c} \tag{5}$$

Flow Rate of Hot Water Heat Capacity

$$C_h = m_h \times Cp_{,h} \tag{6}$$

Flow Rate of Minimum Heat Capacity

C_{min}=Minimum Value out of Cc and Ch

Flow Rate of Maximum Heat Capacity

C_{max}=Maximum Value out of Cc and Ch

Maximum Heat Transfer Possibility

$$Q_{max} = C_{min}(T_{hi} - T_{ci}) \quad (7)$$

heat exchanger is well insulated, so the heat transfer from the hot water is equal to that transfer to cold fluid,

$$Q_{actual} = mCp(Tc_o - Tc_i) \quad (8)$$

The heat transfer coefficient at entire surface of the inner tube can be evaluated by the following equation:

$$Nu = \frac{h \times d}{k} = 0.023\ Re^{0.8} Pr^{0.4} \quad (9)$$

The overall heat transfer coefficient, U_i ,

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{A_i\ \ln D/d}{2\pi kL} + \frac{A_i}{A_o}\frac{1}{h_o} \quad (10)$$

$$\varepsilon = \frac{Q_{acual}}{Q_{max}} \quad (11)$$

$$Q = \left(mC_p\right)_{min}(T_{hi} - T_{ci}) \quad (12)$$

The friction factor along the test rig can be estimated as the following equation [14].

$$f = \frac{2D\ \Delta p}{\rho\ l\ v^2} \quad (13)$$

2.4. Uncertainty analysis

The uncertainties of the experimental tests have been evaluated as systematic errors analysis. The errors were estimated and compared with the maximum errors of parameters and various devices as shown in Table (2).

Table (2) Uncertainty Error.

No.	Parameter	Error %
1	*Re*	0.5
2	*Nu*	0.3
3	*f*	0.01

3. Results and Discussion

Figure (2) shows the effect of the flow direction on the friction factor along test rig. Initially, an experiment was conducted for parallel and counter flow and the results of friction factor and pressure gradient were evaluated. Results of the friction factor of parallel and counter flow were compared and the deviation is not more than 4%. The counter current through the test rig is the flow direction that adopted to perform all experimental tests due to the slightly friction factor generated.

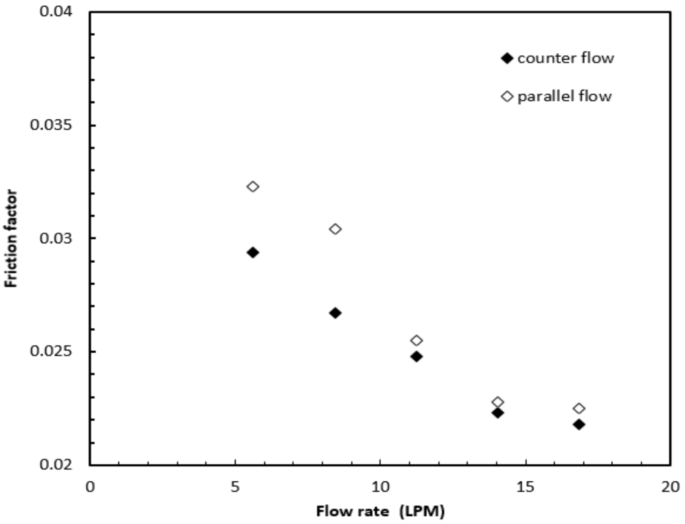


Fig. (2): Comparison of flow direction by friction factor.

Figure (3) indicates the friction factor behavior against Reynolds number when using water and ZnO/Water nanofluid. It can be seen that the friction factor decreases with an increase in Reynolds number but slightly increase with increase of mass concentration. The addition of solid nanoparticles to the base fluids despite the increase in the viscosity of the base fluid, however, the friction factor also increases [4]. The friction factor due to use the nanofluid is compared with the friction factor when using pure water and the deviation is not more than 4% as shown in Figure (3).

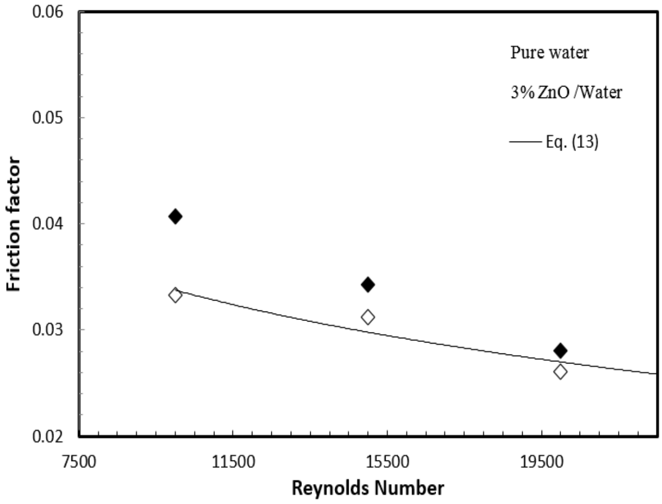


Fig. (3): Friction factor with Reynolds number for pure water and ZnO/Water.

The effect of the nanofluid concentration ratio on the heat transfer coefficient is shown in the Figure (4). It is noted that the convective heat transfer coefficient increases with the increase in the concentration ratio of ZnO nanofluid and flowrate. The maximum deviation between the heat transfer coefficient of the nanofluid and the heat transfer coefficient of the pure water is 21%. The addition of nanoparticles leads to an increase in the value of thermal conductivity and this also leads to an increase in the heat transfer coefficient [14].

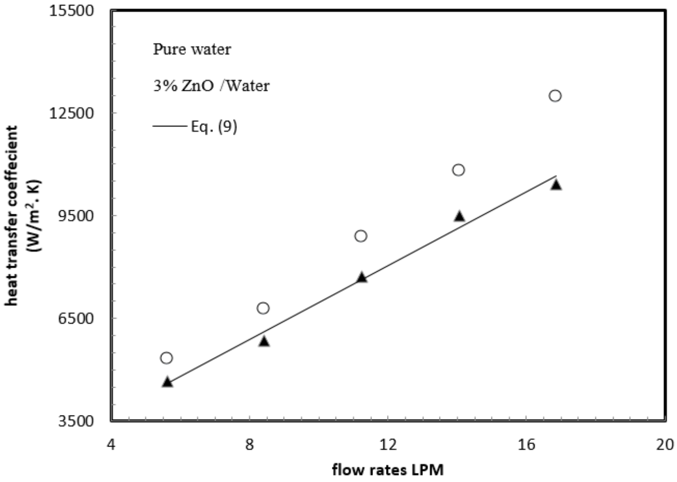


Fig. (4): Heat transfer coefficient with different flowrates for pure water and ZnO/Water.

Nusselt number against Reynolds number is shown in Figure (5). It can be noted that the values of Nusselt number are increased with increase of Reynolds number and nanofluid volume concentration. The behavior of Nusselt number is agreed to results of [4] with the maximum deviation equivalent to 17.5%. The reason for the difference in results between research is due to the difference in the shape of the particle, the diameter and the size of the particle, and the accuracy in Readings and volume heat exchanger [16].

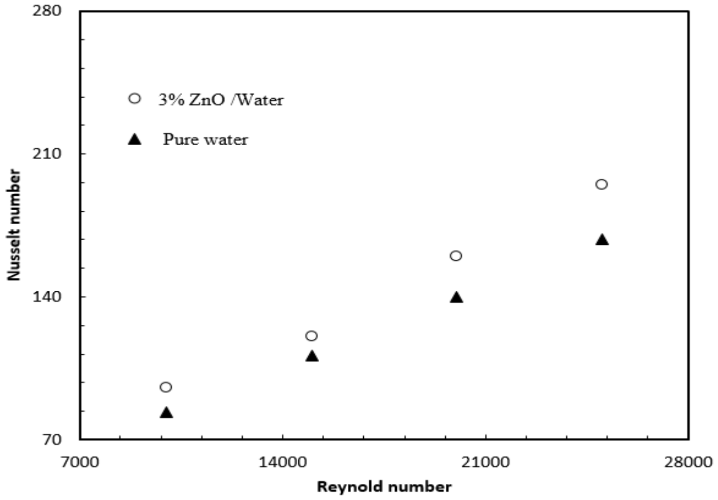


Fig. (5): Nusselt number with Reynolds number for pure water and ZnO/Water.

Figure (6) indicates that temperature distribution along the tube under turbulent flow. It was observed that the temperature increases along the tube length. The minimum temperature values are found by using pure water in the inner tube, while the maximum temperature values are recorded under using 3% ZnO nanofluid.

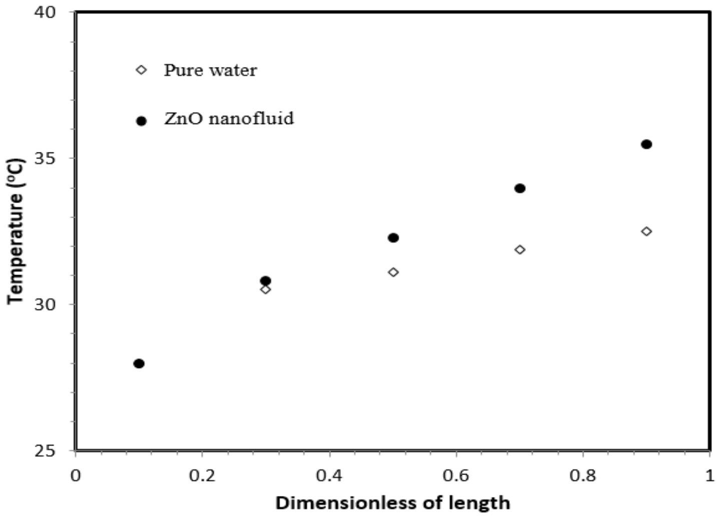


Fig. (6): Temperature measured along the tube.

Figure (7) shows the effectiveness of the system at the different flowrate and nanofluid concentration ratio as it depends on the temperatures entering and exiting the pipes. It was observed that the effectiveness is increased with increase of flowrate and nanofluid concentration ratio. The effectiveness enhancement by 0.3 to 0.67 when flowrate increase from 5 L/min to 15 L/min as compared to pure water. The reason to increase of the NTU and effectiveness values is dependent them on the overall heat transfer coefficient that increasing with increase of nanofluid volume fractions [12].

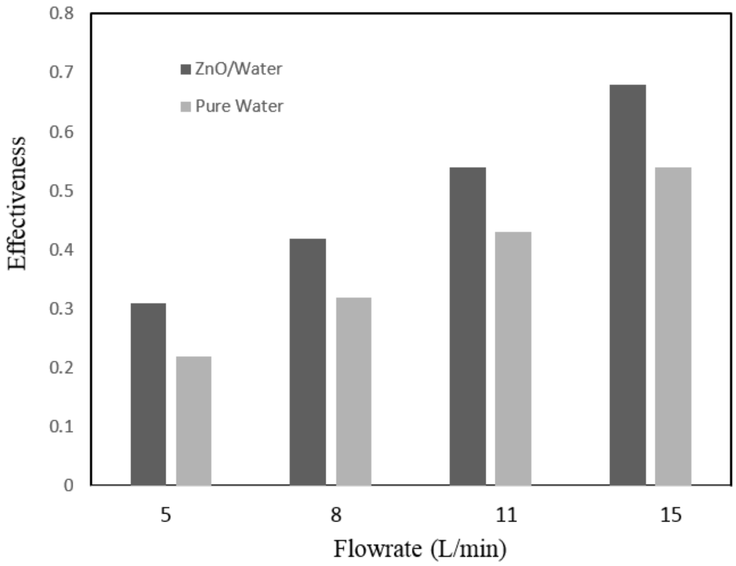


Fig. (7): Effectiveness with different flowrates for pure water and ZnO/Water.

4. Conclusion

This experimental study is included fabrication of double tube heat exchanger and reading temperature at the inlet and outlet by using ZnO/Water nanofluid and the following conclusions are obtained:

1. The friction factor is decreased with increasing flowrate and is slightly increased with increase of nanofluid concentration by 4%.
2. The heat transfer coefficient is increased 21% by using 3% ZnO nanofluid instead of pure water.
3. The maximum percentage enhancement in heat transfer rate when using Nanofluid was 17%.
4. The maximum heat exchanger effectiveness was 0.67 when using ZnO nanofluid.

Nomenclatures

A - *area* [m^2]

C - Specific heat [J/ kg.^{o}C]

D - major diameter [m]

d - minor diameter [m]

f - Friction factor

h - convection heat transfer coefficient [W/m^2.^{o}C]

k - Thermal conductivity [W/m.^{o}C]

Nu - Nusselt Number [$htc\ .D/K_{nf}$]

P - Pressure [N/m^2]

Pr - Prandtle Number [$C.\mu/K_{nf}$]

Re - Renolds Number $[\rho_{nf} D_h\ u\ /\ K_{nf}]$

$m^{\bullet}$ - mass flowrate [kg/s]

u - Velocity [m/s]

μ -Viscosity [N.s /m^2]

ρ - Density [kg/m^3]

ϕ - Volume concentration

Subscripts

f	liquid phases
p	solid particle
nf	nanofluid

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