THE IMPACT OF ALUMINA NANOPARTICLES SUSPENDED IN ETHYLENE GLYCOL ON THE PERFORMANCE EFFICIENCY OF A DOUBLE PIPE HEAT EXCHANGER

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ABSTRACT

The augmentation of the heat transfer in heat exchangers is one of the methods to increase efficiency of the system. The double tube heat exchanger is selected to many suitable techniques of heat transfer enhancement. In this study; the friction factor and heat transfer coefficient of double tube is evaluated experimentally. The Al_2O_3 nanoparticles dispersed in ethylene glycol (EG) with a diameter 50 nm and the weight concentration (0.1%, 0.3%, 0.5%, 0.7%, 1%) has been utilized. Then the effect of parallel current and counter current with different ranges of Reynolds number (10,000 to 30,000) on the friction factor and heat transfer coefficient experimentally examined then selected the best current flow. Thermophysical properties (density, viscosity) are measured and validated with experimental data of the other researches. Result showed that the friction factor decreases with increasing of Reynolds number and increases with increasing of weight concentration but Nusselt number increases with increasing of Reynolds number and concentration of weight. It was concluded that the utilizing of alumina nanoparticles suspended in EG through a double pipe heat exchanger is significant enhancement of heat transfer. The results indicate that the alumina dispersed in EG nanofluid can enhance thermophysical properties of EG to 20%. Likewise, the friction factor is slightly higher than that of pure EG and the nanofluid heat transfer is higher than the pure EG.

Keywords: *Nanofluid; Heat Transfer Coefficient; Friction Factor; Thermophysical Properties.*

1. INTRODUCTION

In recent years, there has been more attention to enhance heat transfer performance by convection of nanofluids. Nano fluid is a nanoparticle that its diameter is in the range of (1-100nm) it is may be solid metallic and non-metalic materials dispersing in a base fluid such as ethylene glycol glycerol, oil and water. There are many applications of thermo fluid system: different types of heat exchanger (heat pipe, car radiator, double pipe Heat exchanger, shell tube heat exchanger). In this present study selected double pipe heat exchanger for the following reasons; this type is widely used in many application, create large heat transfer surface area, small size, easy and good mechanical design easy maintenance. Also it has disadvantages such as; its cost is relatively high, for high thermal load.

Choi et al. (1995) was the first one introduced and used the term nanofluids. It was found difference among bulk materials and nanoparticles due to suspension in liquids. The higher specific surface area of nanoparticles compared to the bulk material is due to the size materials which is 100 nm for nanoparticles and in micrometer for bulk materials. Choi et al. (1995) demonstrated the addition of solid nanoparticles less than 0.01 concentration of volume to liquids improve thermal conductivity of these liquids up to 2 times. Pak and Cho., used two different metallic oxide particles (AL_2O_3, TiO_2) as nanoparticles with (13, 27) nm size diameter respectively in a circular tube. Results showed that Reynolds number and Nesselt number increased with volume concentration of the suspended nanoparticles. The viscosities of the (AL_2O_3-TiO_2) nanoparticles suspended in liquid at a 0.1% volume

fraction are approximately 2 and 3 times as compared to the pure water respectively.

Maddah et al. (2014) studied the effect of mass flow rate, volume fraction of nanoparticles and temperature on the overall heat transfer coefficient. The heat transfer enhancement was about (10 to 20%) when comparison the double pipe H.E with (twisted tape, nanofluid), and (without twisted tape) respectively. The experimental results presented that tetania nanofluid with 0.01% volume concentration and twisted tape has slightly higher pressure drop and friction factor at the same volume concentration when compared to nanofluid without twisted tape. Cao and Ding (2014) were prepared sample AL_2O_3 nanofluid at a different volume concentration with two kinds of commercially available alumina nanoparticles/suspensions and used in double pipe H.E with forced convection. They found the large error between thermal couple and the tube surface were brought by the real inhomogeneity of the heat flux and the interface heat resistance. It was shown that the thermal conductivities of AL_2O_3 nanofluid increases with nanoparticles concentration in a linear fraction at high concentration.

Al- Maghlany et al. (2016) used Cu nanoparticles with size diameter 20 nm and (1-3) % volume fraction suspended in pure water. The test section was a rotation inner tube when its speed was up to 500 r.p.m, adjusted to the value of desired by electrical heater. They found that the Reynolds number for different volume concentration and different rotational speed is the same, and it only depends on the pure water properties of the cold fluid and longitudinal flow velocity during this study when used alumina nanoparticles and water suspension. It was observed that the enhancement effect of viscosity was minimizing at a lower value of the volume concentration. It was shown Reynolds number increases which cause to increase the overall heat transfer coefficient of

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nanofluids (Raghulnath and Surendran). It was 12% of the overall heat transfer enhancement for 2% concentration of volume as compared to pure water. Hussein et al. (2016) were studied the specifications effect of the tube cross sectional area on the heat transfer and pressure drop. Heat transfer enhancement and friction factor evaluated numerically for three horizontal tubes shapes that selected with four volume fractions from 1% to 2.5% TiO2 dispersed in water. Their results had a good agreement with deviation 2% when compared with experimental data available in the literature.

Ibraheem et al. (2020) were studied the alumina nanoparticles suspended in water which used in a straight channel heated by solar radiation. It was measured the nanofluid thermophysical properties to evaluate the thermal characteristics. It was shown that the friction factor decreased as increase in velocity and increased as increase in viscosity. Nusselt number was increased as increase in the flow rate and volume fraction. It was concluded the alumina nanofluid might be slightly increased in friction factor and 54% in heat transfer.

The influence of hybrid nanofluid volume fraction and temperature on viscosity of aluminum oxide and multi-walled carbon nanotubes in a mixture of 20%ethylene-glycol and 80%water was experimentally studied by Afshari et al. (2018). Results showed that the power law index and consistency index were occurred by accurate curve fitting of non-Newtonian behavior of nanofluids samples. It was concluded that the apparent viscosity generally increases with increasing of the nanofluid volume concentration.

An artificial neural network (ANN) method has been investigated by Rostami et al. (2020). It was predicted the thermal conductivity of silica nanoparticles suspended in (50:50) water–ethylene glycol. Results showed that the correlation coefficient for ANN output was 0.993861 for eight neuron numbers.

An algorithm of Zinc Oxide (ZnO)–Silver (Ag) (50%–50%)/Water nanofluid has been proposed to evaluate the best neuron number in the Artificial Neural Network (ANN) by He et al. It had better ability in predicting the nanofluid thermal conductivity with temperature and the nanoparticles volume fraction. It was concluded the maximum absolute value with 0.0095 error and 1.6684e-05 train performance. Soltani et al. (2020) were investigated the experimental analysis to measure the WO3-MWCNTs/Engine Oil thermal conductivity and establishing a new significance. The hybrid nanofluid thermal conductivity was increased by 19.85% compared to the base fluid at $T = 60\,°C$ and $\phi = 0.6\%$. Aghayari et al. (2014) investigated overall heat transfer coefficient of AL_2O_3 nanoparticles experimentally where impacts of Reynolds number, volume fraction, temperature and nanoparticle have been sources.

Aghayari (2014) investigated the Nusselt number and enhancement of heat transfer coefficient of AL_2O_3/water nanofluid 0.1 and 0.3 % concentration of volume and 20 nm size of diameter. Also demonstrated that Nusselt number and heat transfer coefficient increased significantly more than 19% and 24% respectively. In addition, the heat transfer increased with the nanoparticles volume fraction and operating temperature. Sarafraz and Hormozi (2014) studied the carbon nanotube water based nano fluid to enhance the thermal conductivity near up to 56 present, like, CNT Nano fluids that's having higher convective heat transfer coefficient in comparison with water, which is due to longer stability of internal thermal conduction of CNTs. The reason to select alumina nanoparticles suspended in ethylene glycol is to improve the efficiency of the double pipe heat exchanger with reducing the pressure drop.

2. EXPERIMENTAL TEST RIG AND MEASUREMENT

The friction factor and heat transfer coefficient of double tube is evaluated experimentally. The alumina solid nanoparticles dispersed in EG with a diameter 50 nm and the weight concentration (0.1%, 0.3%, 0.5%, 0.7%, 1%) has been utilized in the ranges of Reynolds number (10000 to 30000). Validation of thermophysical properties (density,

viscosity) has been conducted with experimental data of the other researches.

The experimental test rig has been fabricated to measure the outlet, inlet temperature and pressure drop to evaluate friction factor and Nusselt number as shown in Fig. 1. It is included of a tank in cold section for reserving cold fluid, one centrifugal pump, oil manometer tube, water heater, double tube heat exchanger, flow meter, valves, tubes and four digital thermocouple type T. The range of flow meter is between (5-40 LPM) and one valve to control flow rates has been used.

The centrifugal pump (0.5 hp) pumped the cold fluid from the reservoir cold tank to the flow meter then to the inner tube of a heat exchanger at the flow rates (5.6-16.9) LPM. A (10 litters) volume of cold fluids utilized in all experiment's step. Two thermocouples joined at the inner tube outlet and inlet to measure the cold fluid temperature. And two other thermocouples also connected to the outer tube outlet and inlet to measure the hot fluid temperature in the secondary cycle.
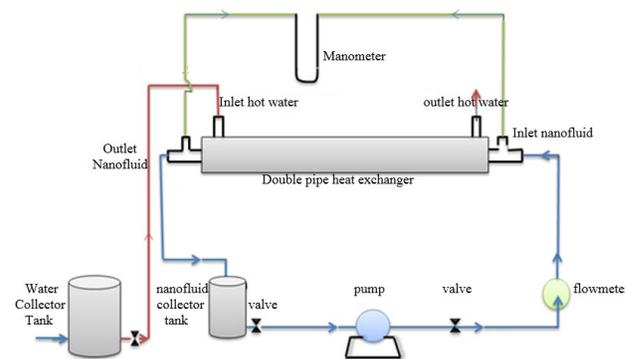

Fig. 1 Setup of experimental test rig.

Thermocouples have been calibrated with glass thermometer and variable temperature baths water which evaluated accuracy was (0.5℃). Two small tubes with 8mm diameters were connected to the oil U-tube manometers to measure the pressure drop. Before running the experiment, the test rig must be cleaned to remove scale or particle inside it after preparing nanofluid and introducing it to the container the temperature of hot water set at (70℃) then running the experiments and set the flow rate of each loop and must be taking enough time to reach the system to the steady state more details about types of instrument used in this study is in Table1.

Table 1 Instruments details used in this study.

Instruments	Number	Type	Accuracy
Thermometer	4	Digital	∓0.5℃
Water pump	1	Centrifugal ,0.5hp	∓1.8
Flow meter	1	Flow-sp, G 1.0	∓0.2 %
Water heater	1	1200watt, 5AMP,	∓0.1% at 20℃ .
PH meter	1	Pen type	∓0.1%
Magnetic stirrer	1	Hand mixer	∓1.1%
Compact scale	1	Digital	

To prepare nanofluid; nanoparticle must be dispersing in a base fluid as a base fluid., Generally, there are methods using in preparation processes these are: - (acid treatment of base fluid, dispersant addition, ultra-

sonication method by using ultrasonic vibration). In this current study 30nm size diameter of alumina solid nanoparticles suspended in EG as a basefluid at a concentration (0.1%, 0.3%, 0.5% 0.7% and 1%) which determined the volume fraction by the Eq. (1) Ramachandran et al.

$$\emptyset = \frac{\frac{m_p}{\rho_p}}{\frac{m_f}{\rho_f} + \frac{m_p}{\rho_p}} \quad (1)$$

The alumina solid nanoparticles and EG properties have been indicated in Table 2.

Table 2 Alumina and EG properties

	Alumina	EG
Density	4000kg/m3	1100kg/m3
thermal conductivity	36 W/m.K	0.23
Viscosity		13.646mPas

For one percentage of concentration mixed 10gram nanoparticle with (10^4 gram pure water) then used hand mixer for stir Nano fluid to be homogeneous mixture for about (20-40) min, then ultranicator used for ultrasonic method for more than 1hr for break up any particle agglomeration.

Viscosity is an important indicator in the evaluation of the thermophysical properties of nanofluids. A commercial Brookfield DV-I prime viscometer (shown in Fig. 2 was used to measure viscosity at different temperatures and rpm. It was used for non-Newtonian and Newtonian liquids for large viscosity range values (1 – 550cP) depending on the spindle.

Fig. 2 viscosity equipment.

The low viscosity fluid is more accurate for this instrument between 1 and 5 cP. Moreover, same shear rate everywhere with this geometry has been allowed and different values of shear rate may be tested by setting a rotation velocity (rpm) range to expect the liquid behavior rheological and viscosity determined as well as controlled of the torque value.

Following that, the cylinder was connected carefully on the viscometer after eight minutes of water bath, the sample is tested to find the lower and upper rpm limits and taking into account their values of torque. When these values were found, the setting of program has been adopting depending to the previous values calculated limit. EG has been utilized for calibration, following which nanofluids has been used to measure viscosity. However, the apparatus of viscometer has been calibrated factory which checked for accuracy.

The pH test is one of important instrument to measure the stability of Nano fluid in this present study; (PH-009, pen-type measurement) as shown in Fig. 4 were used to measure the pH of Nano fluid before and after tests. The scientific instrument to measure the hydrogen-ion activity

in liquid solutions is defined as pH meter which showing its expressed of alkalinity or acidity. It was measured the electrical potential difference between the reference electrode and pH electrode. The electrical potential difference is related to the solution pH or acidity. It is referring to change in thermo physical properties and stability of Nano fluid. The value of PH must keep low for Nano fluids stability (Sarafraz et al. (2016).

Fig. 3 KD2 Pro hot wire meter of thermal conductivity.

Fig. 4. PH measurements with a different volume concentration.

The thermal conductivity of nanofluid is measured with KD2 Pro thermal property analyzer of Decagon Devices, Inc., USA. The KD2 Pro used transient line heat source to measure the liquids and solids thermal properties. It consists of a handheld controller (power control and microcontroller) and two different sensors for measuring the thermal conductivity of liquids and solids. The apparatus meets the standards of both IEEE 442-1981and ASTM D5334. ASTM D5334 is the standard test method for determination of thermal conductivity of soft rock and soil by thermal needle probe procedure, whereas guided by IEEE 442-1981 for measurements of soil thermal resistivity.

For the present sample the KS-1 sensor is used to evaluate the thermal conductivity as illustrated in Fig. 3. The sensor is calibrated by evaluating the glycerin thermal conductivity. The measured value at room temperature is 0.280 W/mK for glycerin, which is in agreed with values in literature of 0.285 W/mK within ± 2.5% accuracy.

3. DATA PROCESSING

Heat transfer can be estimated for hot loop or (water section) by the following equation (Reddy, V. V. Rao):

$$Q_{hot} = m_w \, cp_w \, (T_{in,w} - T_{out,w}) \quad (2)$$

Heat transfer for cold side or (nanofluid section) is as following equation:
$$Q_{cold,nf} = m_{nf} \, cp_{nf} \, (T_{in,nf} - T_{out,nf}) \quad (3)$$

where Q_{hot} and $Q_{cold,nf}$ are the rate of heat transfer to hot water and cold nanofluid, respectively.

And the average heat transfer rate can be defined as the following equation:

$$Q_{avg} = \frac{Q_{hot,w} + Q_{cold,nf}}{2} \qquad (4)$$

Q_{avg} : −mean average rate of heat transfer

The coefficient of heat transfer equation is utilized:

$$U_{nf} = \frac{Q_{avg}}{T_W - T_{b,nf}} \qquad (5)$$

Then can be calculated the Nusselt number respectively through the Eq.(9):

$$Nu = \frac{U_{nf} \, D_i}{k_{nf}} \qquad (6)$$

The outer surface area of Inner tube can be estimated as:

$$A_o = \pi \cdot D_o \cdot L \qquad (7)$$

The inner area of inner tube can be calculated as:

$$A_i = \pi \cdot D_i \cdot L \qquad (8)$$

The Mean Temperature Logarithmic Difference (LMTD) can be evaluated as:

$$LMTD = [(T_{hi}-T_{ci}) - (T_{ho}-T_{co})]/\ln[(T_{hi}-T_{ci})/(T_{ho}-T_{co})] \qquad (9)$$

4. RESULTS AND DISCUSSION

First experiment runs with pure water in both section in parallel current and counter current then compared between the overall heat transfer coefficient for each current which estimated by the Eq. (7), and friction factor for counter and parallel current as the following equation Hussein et al. (2013).

$$f = \frac{2D \, \Delta p}{\rho \, l \, v^2} \qquad (10)$$

As shown in Fig. 5 that the friction factor of counter current is lower than that of parallel current, but the overall heat transfer coefficient is higher therefore selected counter current in this study to enhance performance efficiency.

The viscosity experimental data has been shown in Fig. 6 with a concentration (1- 4%) then compared with the value of viscosity before and after test with viscosity of pure water and viscosity from the Eq. (7), as see the viscosity increases with increasing the volume fraction.

$$\mu_{nf} = \mu_{bf} \left(1 + \frac{5}{2} * \emptyset\right) \qquad (11)$$

Fig. 7, illustrates the friction factor changing with the volume fraction. The friction factor is slightly increased with volume fraction of nanofluid due to increase of nanofluid viscosity but decreases with increasing of Reynolds number. Furthermore, the friction factor of nanofluid is increased as compared to Blasuis Eq. (12) that illustrated as a solid black line.

$$f = 0.316 \, Re^{0.25} \qquad (12)$$

In the current experimental study, the volume concentration 0.1%,0.3%,0.5%,0.7% and 1% and flow rate are (5.6, 8.4 ,11.2, 14 ,16.9) L/min with cold and hot fluid inlet temperature are (300, 343) K respectively.

Fig. 8 shows the heat transfer coefficient at different concentration and Reynolds number as fluid flow rate using. It was noted that the heat transfer increases with increasing volume fraction as well as with increasing fluids velocity or Reynolds number.
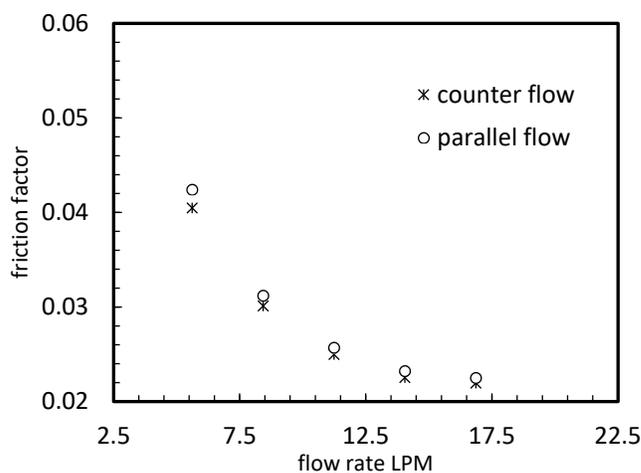
(a)   friction factor at different flow rates.
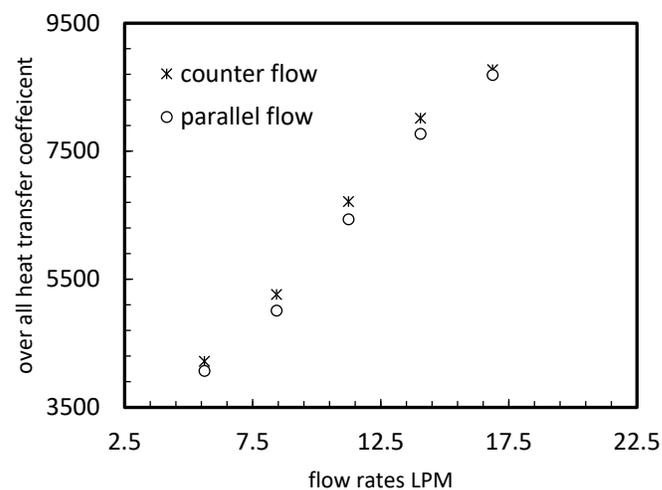
(b)   overall heat transfer coefficient at different flow rates.

Fig. 5 comparison between friction factor and heat transfer coefficient of parallel and counter current at different flow rates.
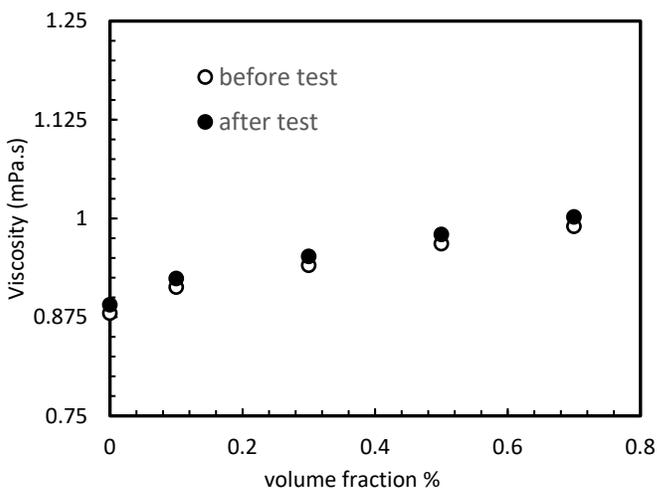

Fig. 6 experimental viscosity data with different volume fraction.
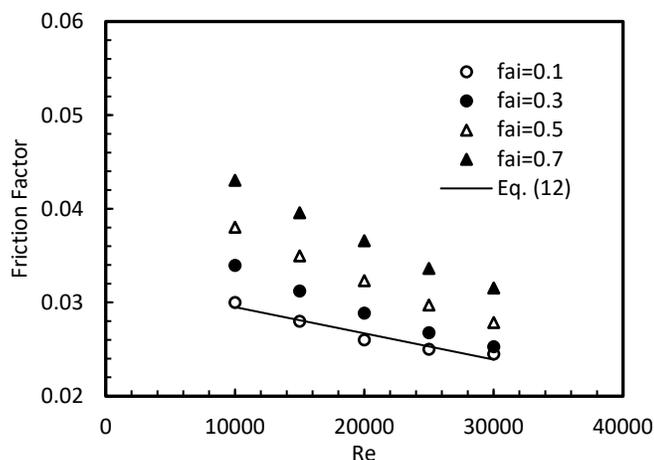
Fig. 7 effect of nanofluid volume fraction on friction factor at different Reynolds number.

(a) Nusselt number at 1% volume fraction.#

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(b)   friction factor at 1% volume fraction.

Fig. 9 validation of experimental data with Reynolds number.
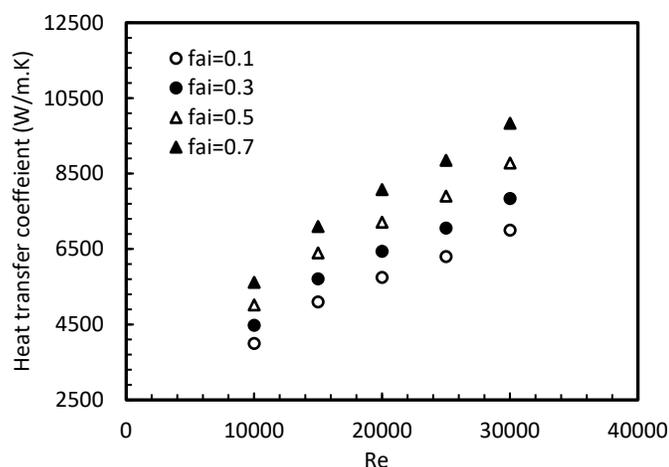

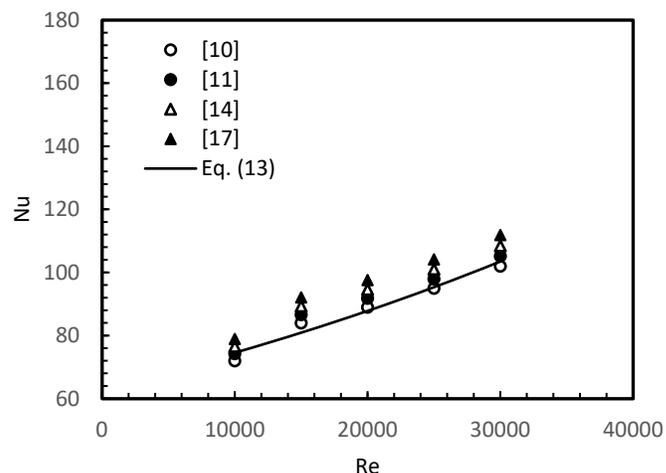**Fig. 8** experimentally overall heat transfer coefficient at different flow rates.

Fig. 9 illustrates the experimental data validation with increasing of Reynolds number. Fig. 9a showed that Nusselt number with Dittus Boilter Eq. (13) and data of researchers (Aghayari et al. (2014), Aghayari (2014), Sarafraz et al. (2016), Ramachandran et al. (2018), Hussein (2017)). It was observed that the Nusselt number behaviors was agreed with data available with deviation not more than 4%.

$$Nu = 0.023 \, Re^{0.8} Pr^{0.4} \text{\#46,\#}}$$
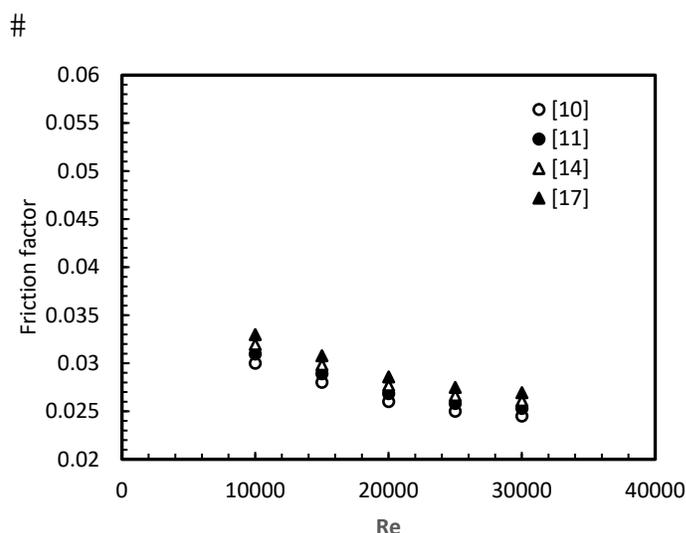
Likewise, Fig. 9b indicated that friction factor validation with data of researchers (Aghayari et al. (2014), Aghayari (2014), Sarafraz et al. (2016), Ramachandran et al. (2018), Hussein (2017)). It can be seen that the friction factor behaviors were agreed with data available with deviation not more than 3%.

The mixing solid nanoparticles with EG as a base fluid increases the Efficiency and heat transfer power with reducing the production and operational costs Therefore, it is reducing the pumping power with increasing of efficiency. It can be noted the increase of efficiency and heat transfer will decrease the destructive impacts of energy on the environment.

The significant reason to enhance and producing higher heat transfer coefficient is collision between the nanoparticle and heating surface. This means that adding nanoparticles to the base fluid increases thermal conductivity and changes the fluid flow structurhv1#

5.   CONCLUSION

This experimental study was performed to find the influence of Al₂O₃/EG nanofluid on performance of a double tube heat exchanger. It is indicated significant potential for convective heat transfer as a cooling system. Conclusions are summarized as following:

- AL$_2$O$_3$ nanoparticle suspended in EG can improve liquid thermal properties a bout more than 20%.
- Alumina solid nanoparticles suspended in EG nanofluid is better than pure EG for heat transfer.
- Friction factor is decreased but Nusselt number is increased as flow rate of fluid increases.
- Both friction factor and Nusselt number are increased as nanofluid volume concentration increased.

ACKNOWLEDGEMENTS

NOMENCLATURE

c_p	specific heat (J/kg·K)

h	heat transfer coefficient (W/m^2.K)
k	thermal conductivity (W/m·K)
q''	heat flux (W/m^2)
T	temperature (K)
u	interfacial velocity (m/s)
m	mass
μ	dynamic viscosity
T	temperature
ρ	density (kg/m^3)
f	friction factor
Re	Reynolds number
Nu	Nusselt number
Pr	Prandtle number
in	inlet
out	outlet
t	time
∀	volume.
LPM	liter per minute
EG	ethylene glycol
fai(ϕ)	volume concentration

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