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Enhancement of tube in tube heat exchanger by using nanofluids

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Abstract:

This work was carried out to study the effect of copper oxide (CuO) and aluminum oxide (Al_2O_3), when mixed with water as a base fluid on heat transfer enhancement in a tube in tube counter flow heat exchanger under turbulent flow regine. The two types of nanofluids have been taken at different volume concentration ratios (1%, 3% and 5%). The effect of different parameters such as Reynolds number, temperature, type and concertation of nanoparticles on heat exchanger effectiveness, Nusselt number and pressure drop are studied. The (ANSYS FLUENT R-14.5) was applied to solve the governing equations and to evaluate the effectiveness of heat exchanger. The results showed that adding the nanoparticle to water caused by increasing the heat exchanger effectiveness and the coefficient of friction. Both of them were decreased with increasing Reynolds number, but the values of effectiveness and friction coefficient for CuO/water were higher than that of Al_2O_3/water.

Keywords: *double tube heat exchanger, nanofluid, Heat Transfer Coefficient, Friction Factor.*

Introduction

Heat exchangers (HEs) are widely spread in the fields of thermal engineering, and are played a very important role in the engineers' awareness of energy and their desire to find the optimum design not only in terms of economic returns and thermal analysis, but in terms of energy savings returns [1].

The performance of any thermal system, whether it is a heating or cooling system or others, depends on many factors, the most important of which is the heat transfer characteristics' of working fluid. The efficiency of heat transfer depends on the thermal properties of the fluid, such as thermal conductivity, specific heat, viscosity, and thermal expansion coefficient. In order to enhance the process of heat transfer, a variation had been made in the thermal properties of traditional liquids used in many industrial applications, such as water, oils, ethylene glycol, and others. These liquids have a low conductivity when compared to metallic and non-metallic solids like (titanium, aluminum, copper), and (titanium oxide, aluminum oxide, copper oxide) respectively. Therefore, the researchers conducted research activities in the field of heat transfer and found different methods and technologies to improve the thermal properties of the liquids used, and one of the most important of these technologies is the addition of solid particles to these liquids to obtain the so-called nanofluid (NF), and the properties of NF differ according to the ratio of nanoparticle (NP) in the base fluid and the size and type of particles as well as the type of base liquid [2].

Yimin and Qiang [3] carried out a calculation of nanoscale fluids thermal conductivity. They noted that nanoscale liquids consisting of copper-water gave a clear HE enhancement, and that the thermal conductivity is affected by the style, scale and concentration of the NP. They showed that the change in conductivity values of the nanoscale varied from (1.24% to 1.78%) when changing the NP concentration in the base liquid from (2.5% to 7.5%) respectively.

An experimental and theoretical study of a double-tube HE performance using (γ-AL_2O_3) with volume concentrations (0%, 0.5%, 1%, and 2%) mixed with water have been done by Jibory and Al-hilaly [4]. The researchers noticed that the heat transfer enhancement is proportional to the growing in volume cocentration and (*Re*). The highest enhancement in heat rate was got for theoretical and experimental results are (46.63%) and (48.93%) respectively.

Mushtaq et al. [5] studied a parallel and counter, laminar flows in a concentric tube HE using (TiO_2) and (Al_2O_3) NP added to the base liquid experimentally. The NP diameter is 20 nm for both materials. The flow rates of NFs were varied from (0.5 to 2 l/min). Results illustrated that nanofluid including (Al_2O_3) and (TiO_2) NP improved the coefficient of heat transfer by (18.25%) and (15.5%) for Al_2O_3/water and TiO_2/water respectively.

Chavda [6] carried out an experimental work on a double tube HE using CuO/water with different concentrations (0.002%, 0.003% and 0.004%). It was concluded that the overall coefficient of heat transfer increases with an increase in concentration of CuO in water.

Mahrooghi and Moghiman [7] conducted a numerical study of heat transfer through pure liquid and nanoscale liquid consisting of aluminum oxide (Al_2O_3) mixed with water as a base fluid at different volumetric concentrations in a double-tube HE. The results showed that the heat transfer coefficient increases with increasing the volumetric concentration of NP. The improvement rate in total coefficient of heat transfer reached 220% at 3% concentration and at a flow rate of 10 l/min. The pressure drop increased by 3% and 5% at the concentration of 2% and 3%, respectively.

Talib and colleagues [8] used a simplified model of a double tube HE with counter flow and turbulent flow. The heat transfer was studied when adding NP of 20 nm diameter alumina oxides mixed in water as a base liquid. Their results indicated that there is an enhancement in heat rate when using nanoscale fluid by 26%, and this led to an improvement in the effectiveness of the exchanger by 11%.

Padmavathi and Mahanti [9] conducted an experimental and numerical study of turbulent flow of an iron oxide of concentration 0.03% mixed with water, which takes place in the inner tube of a double-tube HE. The researchers concluded that the heat transfer rate at a volume concentration of 0.03% and a flow rate of 8 l/min for the NF consisting iron particles mixed with water was better than that consisting aluminum and copper particles, and the same trend in case of a flow rate 10 l/min.

Hasan et al. [10] carried out a practical work to estimate the thermal performance of nanomaterials in a tube-in-tube HE. Two types of NPs (Al_2O_3 and TiO_3) of diameter 20 nm mixed with non-ionized water were used. Both liquids flow at a constant entry speed. The two types of NPs were used with five different concentrations (0.05, 0.1, 0.15, 0.2 and 0.3%), with different flow rates (0.5, 1, 1.5 and 2 l/min), for parallel and counter flow. They showed from their results that the heat rate increases with increasing the concentration of NP in base liquid. It was found that the highest heat transfer rate was at a concentration of (0.3%), and the rate of improvement in the heat transfer rate was (18.25%) for the liquid containing aluminum oxide, while the heat transfer rate was (15.5%) for the liquid containing titanium oxide particles.

Various types of NPs were used, such as alumina oxide (AL_2O_3), titania oxide (TiO_2), copper oxide (CuO) and zinc oxide (ZnO), which are the most common ones, which were mixed with different types of fluids as a base such as (water, ethylene glycol and oil). The researchers are interested in the concentration of NP and the stability of those particles in the basic fluid because of its major role in enhancing HE. The researchers agreed on the difficulty of maintaining the distribution and stability of the NP in the base liquid for long periods. Most of the researchers used NP with a diameter of 20 nanometers.

In the current study, NPs of aluminum oxide and copper oxide of diameter 40 nm were used with water as a base fluid and volume concentrations (1%, 3%, and 5%) for both types of particles were used to investigate the improvement in performance of the exchanger. The HE of (900 mm) tube's length was used. The inner diameters of inner and outer tubes were (6 and 12 mm) respectively, with wall thickness of (1 mm) for both tubes.

Calculation of Nano-water properties:

The thermal conductivity of nanowater can be estimated by the following equation [11-12]:

$$k_{nf} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\emptyset}{k_p + 2k_{bf} - (k_p - k_{bf})\emptyset} k_{bf} \quad (1)$$

The dynamic viscosity, density, and specific heat of NF are calculated from the equations below [11],[13]:

$$\mu_{nf} = (1 + 2.5 * \emptyset) * \mu_{bf} \quad (2)$$

$$\rho_{nf} = (1 - \emptyset)\rho_{bf} + \emptyset\rho_p \quad (3)$$

$$C_{p_{nf}} = \frac{(1 - \emptyset)C_{p_{bf}} \times \rho_{bf} + \emptyset \times \rho_p \times C_{P_P}}{\rho_{nf}} \quad (4)$$

A sample of of calculated values of the properties mentioned above were tabulated in table (1).

<u>Heat Exchanger Effectiveness</u>:

In the present work, two types of NPs (AL_2O_3) and (CuO) of diameter (40 nm) dispersed in water were used. The nano-water flows through an annular space with constant inlet temperature of (25 ^oC) and flow rate of (0.0233 kg/s). The hot water of (0.8333 kg/s) rate enters the inner tube at constant temperature of (60 ^oC). The actual heat transfer rate from the hot fluid can be computed from [14]:

$$Q_{actual} = \dot{m}Cp(T_{hi} - T_{ho}) \quad (5)$$

Since the HE is perfectly insulated, so the rate of heat from the hot water is equal to that transfer to nano-water, and calculated from [14]:

$$Q_{actual} = \dot{m}Cp(T_{co} - T_{ci}) \quad (6)$$

The coefficient of heat transfer at both inner tube surfaces can be estimated from [14]:

$$Nu = \frac{h \times d}{k} = 0.023\, Re^{0.8} Pr^{0.4} \qquad (6000 \le Re \le 14000) \qquad (7)$$

and the HE effectiveness can be evaluated from [14]:

$$\varepsilon = \frac{Q_{actual}}{Q_{max}} \qquad (8)$$

Where Q_{max} is the max. possible rate of heat for the HE and presented as [14]:

$$Q_{max} = \left(\dot{m}C_p\right)_{min}(T_{hi} - T_{ci}) \qquad (9)$$

Numerical Analysis:

The thermal performance of tube-in-tube counter flow HE was analyzed using the (CFD) software in (ANSYS FLUENT R14.5) has been done. The hot water, cold nano-water, and tube wall domain were divided in to a number of Hexa small size cells as shown in figure (1). The 3-D model consists of (166100) elements with (167169) nodes was chosen in this work.

Governing Equations:

The continuity, momentum, and energy equations for turbulent flow were solved by using (FVM). A turbulent model of (k - ε) is chosen and assumed that the folw is incompressible, steady, turbulent, and the heat loss from the exchanger is negligible**.**

a- Equation of continuity [4]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (10)$$

b- Equations of momentum [4]:

$$\frac{\partial \rho u}{\partial t} + \frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho vu)}{\partial y} + \frac{\partial(\rho wu)}{\partial z} = -\frac{\partial p}{\partial x} + \rho g_x + \mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right] \qquad (11)$$

$$\frac{\partial \rho v}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho vv)}{\partial y} + \frac{\partial(\rho wv)}{\partial z} = -\frac{\partial p}{\partial y} + \rho g_y + \mu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right] \qquad (12)$$

$$\frac{\partial \rho w}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho ww)}{\partial z} = -\frac{\partial p}{\partial z} + \rho g_z + \mu\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right] \qquad (13)$$

c- Equation of energy [4]:

$$\frac{\partial}{\partial x}\left(\rho uh - \frac{\mu}{pr}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial x}\left(\rho vh - \frac{\mu}{pr}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial x}\left(\rho wh - \frac{\mu}{pr}\frac{\partial h}{\partial z}\right) \qquad (14)$$

Friction Factor:

The friction factor can be determined from the following equation [4]:

$$f = \frac{\Delta P}{\left(\frac{L}{d}\right)\left(\frac{\rho V^2}{2}\right)} \qquad (15)$$

Table (1) Thermal and physical properties of nano-water.

Nanofluid	***T*** °C	∅%	***ρ*** (kg/m³)	***Cp*** (J/kg.K)	***μ*** (kg/m.s)	***K*** (W/m.K)
CuO+ Water	60	1%	1033.65	3907.26	0.0004611	0.6786
CuO+ Water	60	3%	1133.98	3430.72	0.0004688	0.7318
CuO+ Water	60	5%	1234.31	3031.64	0.0004748	0.7895
AL_2O_3+ Water	60	1%	1012.45	3992.11	0.0004611	0.6787
AL_2O_3+ Water	60	3%	1070.38	3643.16	0.0004688	0.7322
AL_2O_3+ Water	60	5%	1128.31	3330.05	0.0004748	0.7903

Results and Discussion:

The contours of temperature distribution along the HE for Al_2O_3/water and CuO/water with a volume concentration of (1%) are illustrated in figures (3) and (4), respectively.

Figure (5) shows comparison of the results of present work with experimental results of Dittus-Boelter [15] and Gnielinski [16]. It appears a good agreement. Also, a validation of numerical results with experimental results of Blasius [17] and Petukhov [18] was done to test the validity of the method used in this work and it appears in a good agreement as shown in figure (6).

The variation of (*Nu*) with (*Re*) for different concentration of (Al_2O_3) and (CuO) NPs are illustrated in figures (7) and (8), respectively. It is noted that the values of (*Nu*) increases as the (*Re*) increased for both of NFs and the percentage increase ranged between (40.8%) and (44.8%), compared to pure water.

Figure (9) shows a comparison between Al_2O_3/water and CuO/water with a concentration of (5%). It is observed that the values of (*Nu*) for CuO/water is higher than that of Al_2O_3/water due to that the conductivity value of (CuO) is larger than that of (Al_2O_3).

Figures (10) and (11) showed the effect of changing (*Re*), for both nano-waters with different particles concentration, on the effectiveness of HE. In both cases, it can be seen that as the (*Re*) increases, the effectiveness of HE decreases. This means that the performance of the HE suffers with an increase in the (*Re*). For example, the drop in the effectiveness, when used Al_2O_3 and CuO with (5%) concentration, are (40.8% and 44.8%), respectively, compared to the pure water. The comparison of HE effectiveness of two different nano-waters with (5%) concentration illustrated in figure (12). It can be noted that the values of effectiveness for CuO/water are higher than that for (Al_2O_3). This is due to that (CuO) have a higher conductivity than that for (Al_2O_3).

Figures (13) and (14) show the variation of friction coefficient with the change of (*Re*). In both cases, it can be seen that as the (*Re*) of nano-water increases, the coefficient of friction decreases, for all ratios of concentration. This means that the coefficient of friction is inversely proportional to the (*Re*). Also, it is seen that the friction coefficient is increased as the ratio of particles concentration increases, for fixed mass flow rate. This is due to the action of the particles motion in water. The highest percentage increase in coefficient of friction reached to (68%) for Al_2O_3/water and (87.5%) for CuO/water with particles concentration of (5%), respectively. Figure (15), shows a comparison of friction coefficient vales for both Al_2O_3/water and CuO/water for (5%) concentration.

Conclusions:

The results of the present work revealed the following conclusions:

1- Adding (Al_2O_3) or (CuO) to water caused by enhancing the HE effectiveness, and increasing the coefficient of friction.
2- The HE effectiveness and friction coefficient decreased by increasing (*Re*), and increased by increasing the concentration of particles in water for both types.
3- The values of both of HE effectiveness and friction coefficient for CuO/water are higher than that of Al_2O_3/water.

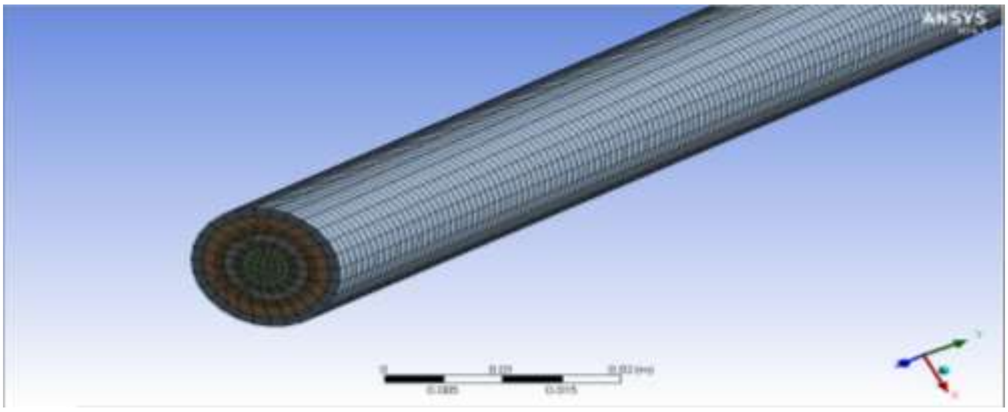

Fig.(1): The Hexa-mesh of present work.

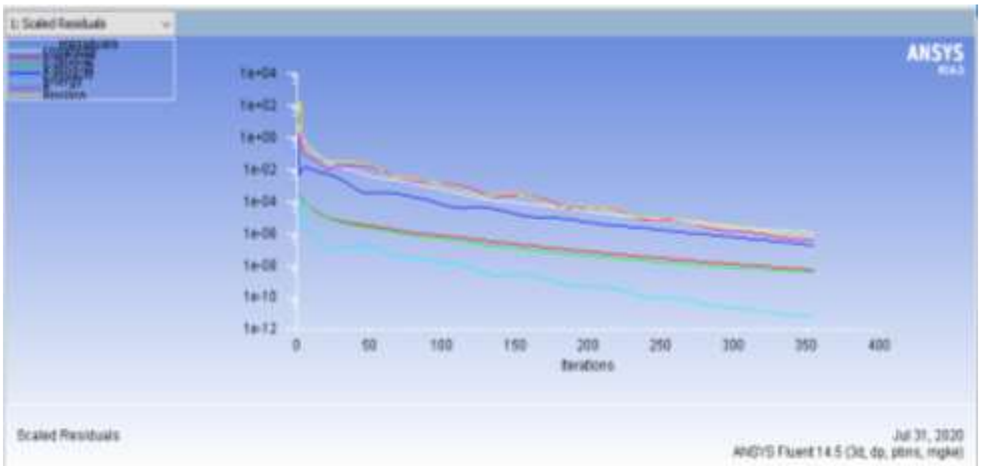

Fig.(2): Scaled Residuals.

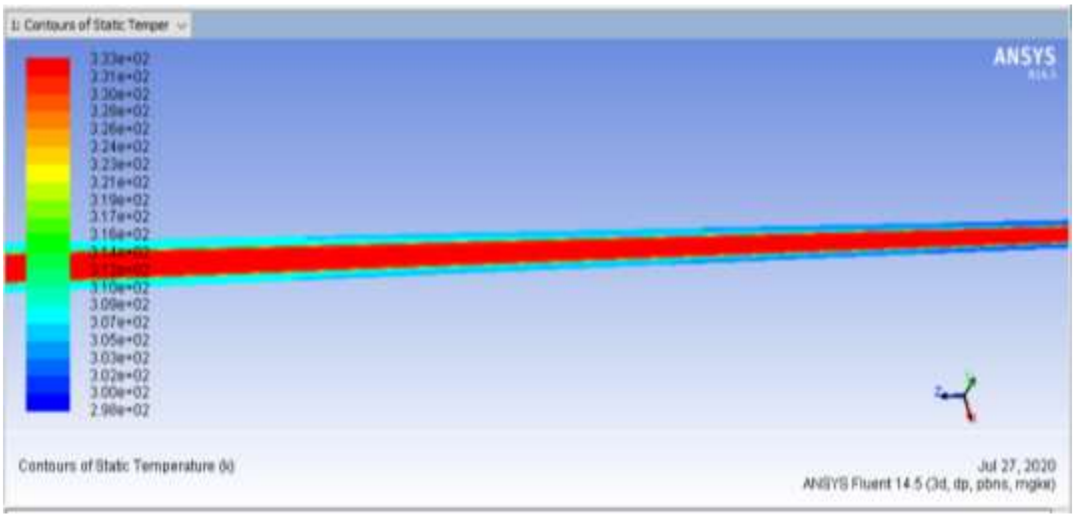

Fig.(3): The temperature contour along the HE for [1% Al_2O_3-water].

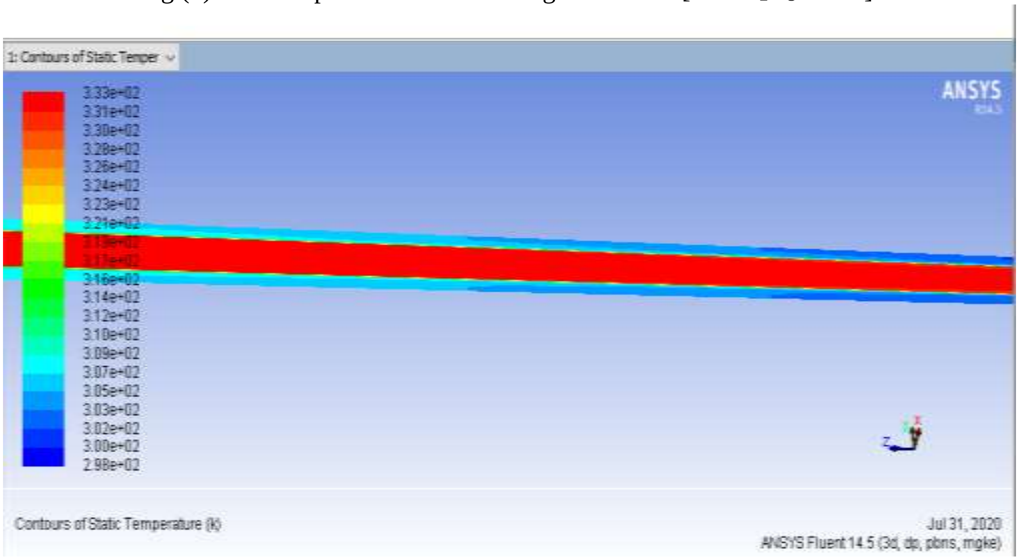

Fig.(4): The temperature contour along the HE for [1% CuO-water].

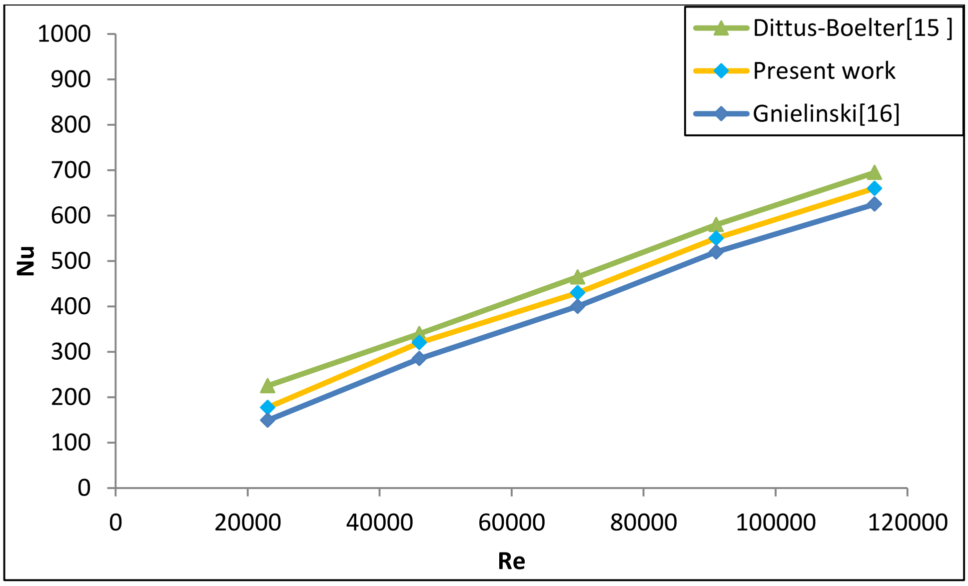

Fig. (5): Comparison of numerical results of the present work with other researchers for pure water.

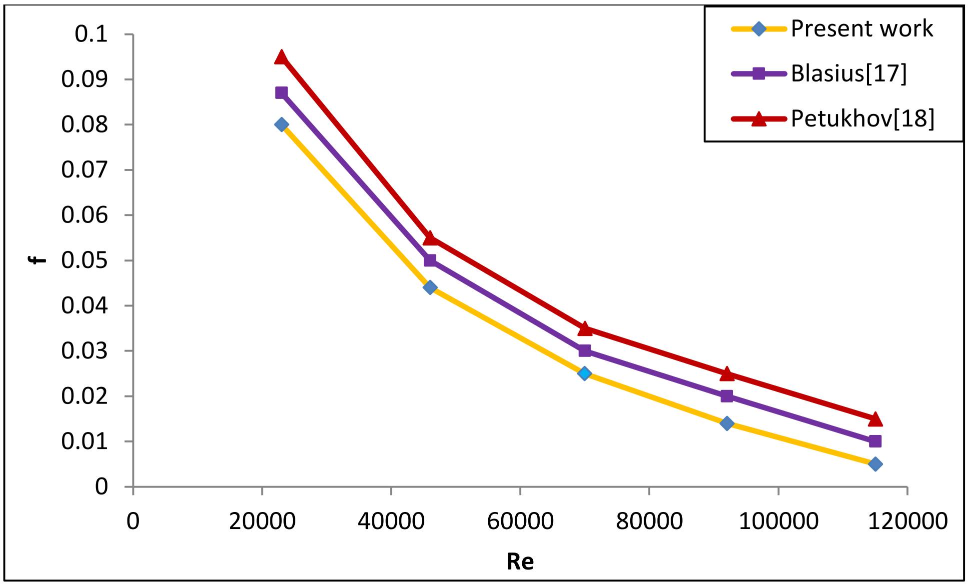

Fig. (6): Comparison of present work results with other researchers for pure water.

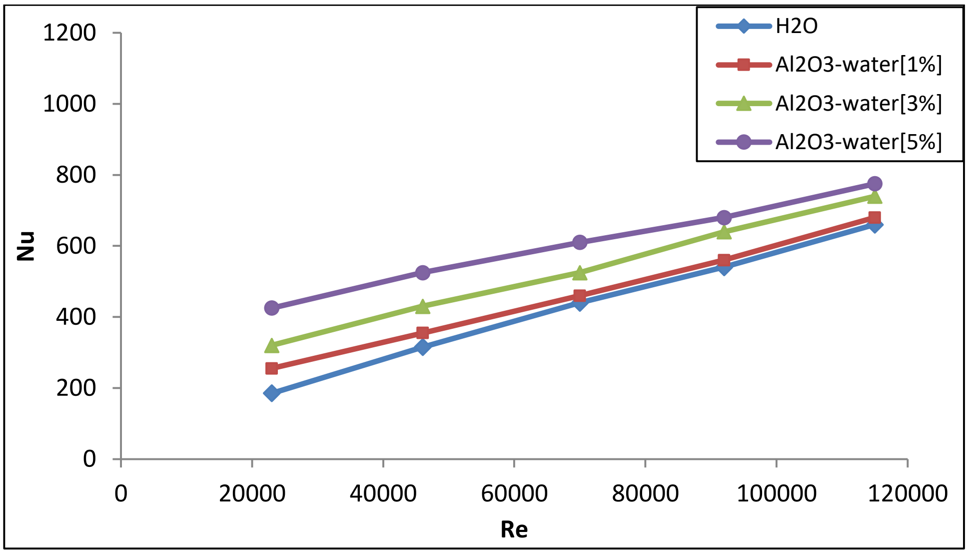

Fig. (7): Nusselt number versus Reynolds number for (pure water) and (Al_2O_3/water) for different concentration ratios.

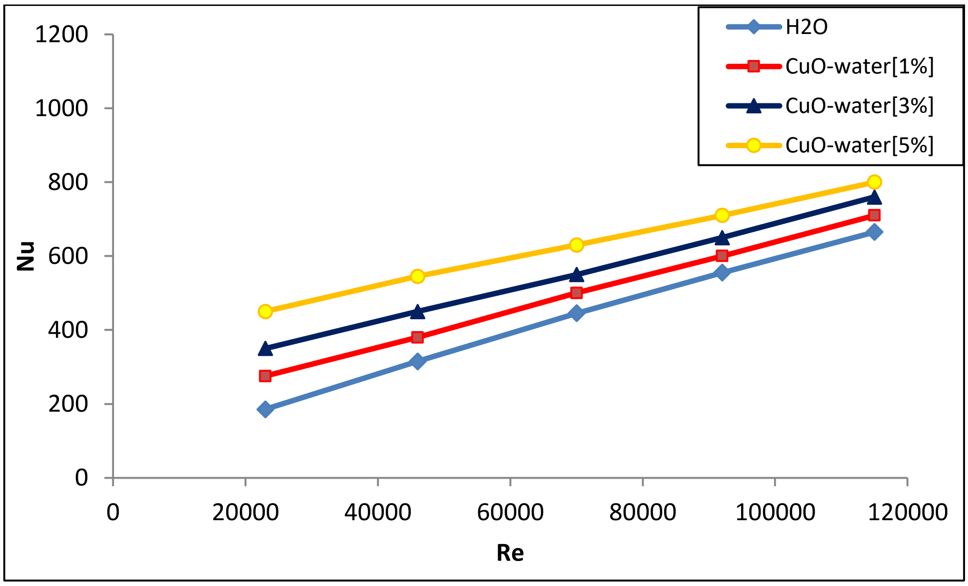

Fig. (8): Nusselt number versus flow Reynolds number for (pure water) and (CuO/water) for different concentration ratios.

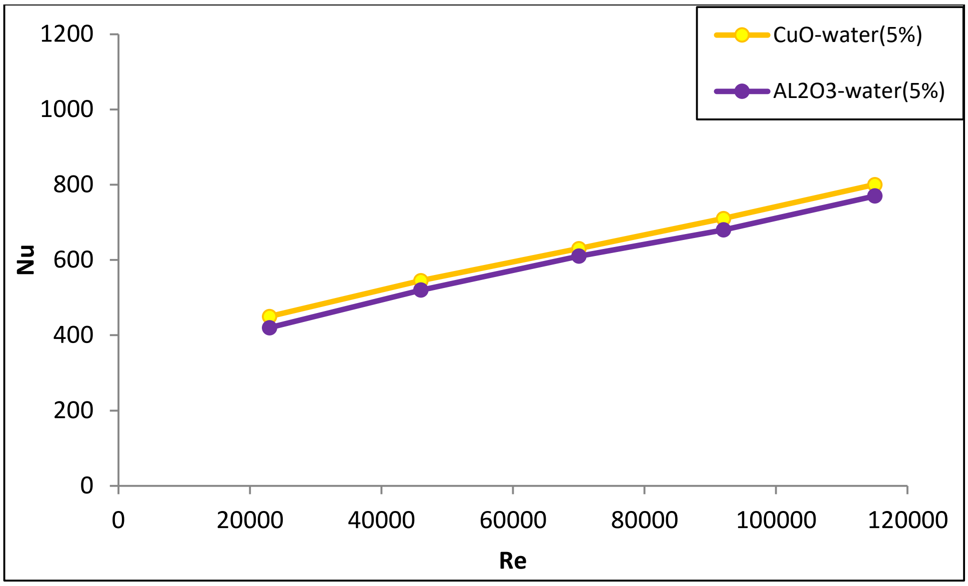

Fig. (9): Nusselt number versus Reynolds number for (Al_2O_3/water) and (CuO/water) at concentration ratio of 5%.

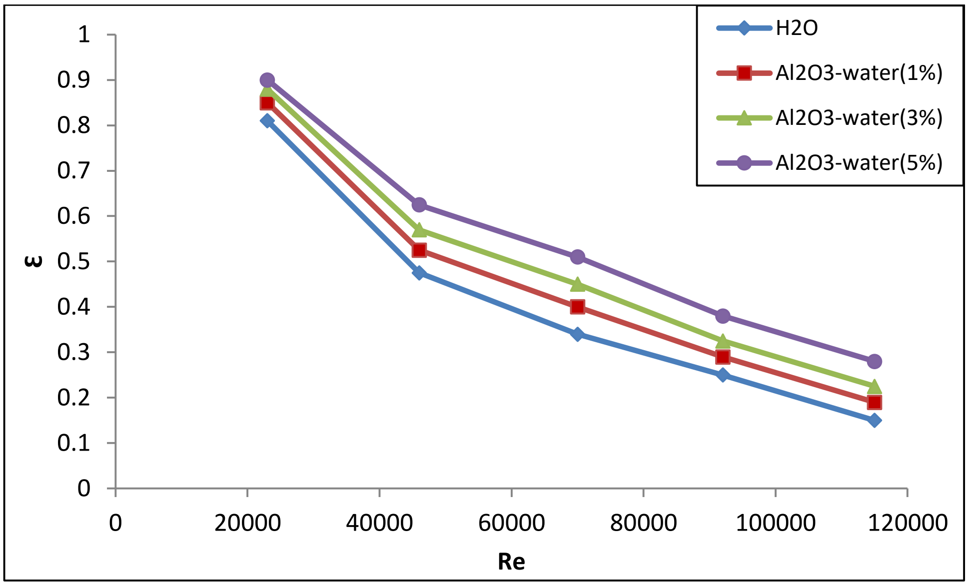

Fig. (10): HE effectiveness versus Reynolds number for (Al_2O_3/water) for different concentration ratios.

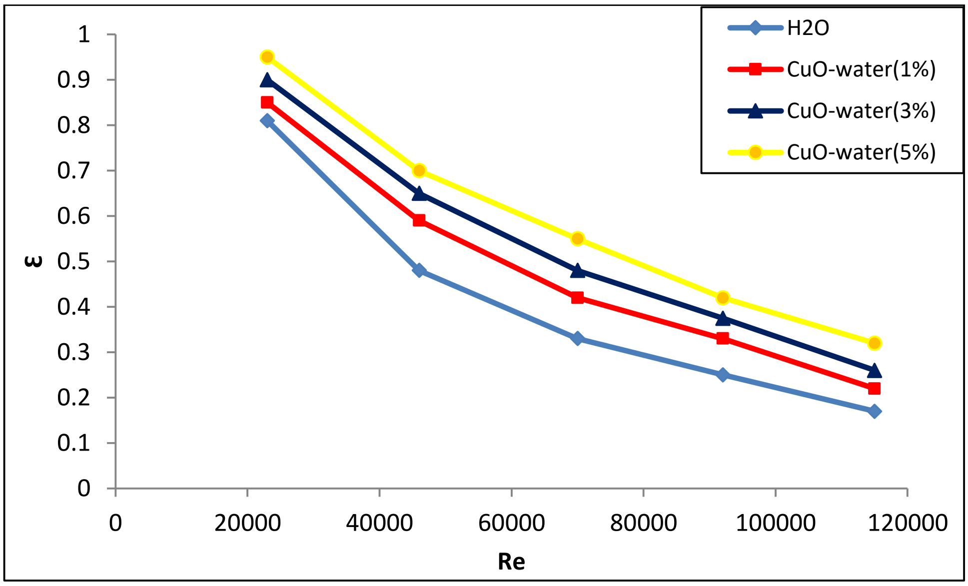

Fig. (11): HE effectiveness versus flow Reynolds number for (CuO/water) for different concentration ratios.

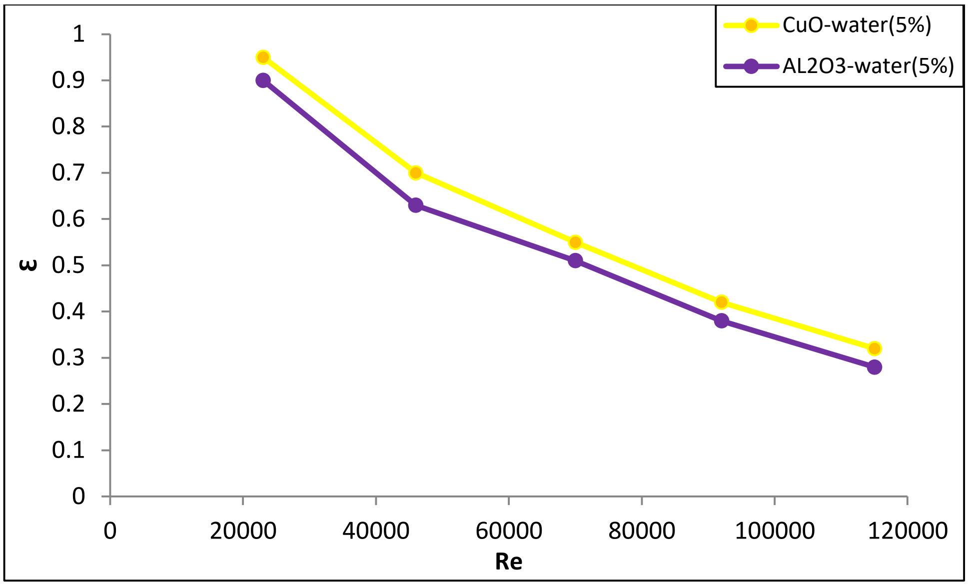

Fig. (12): HE effectiveness versus flow Reynolds number for (Al_2O_3/water) and (CuO/water) at concentration ratio of 5%.

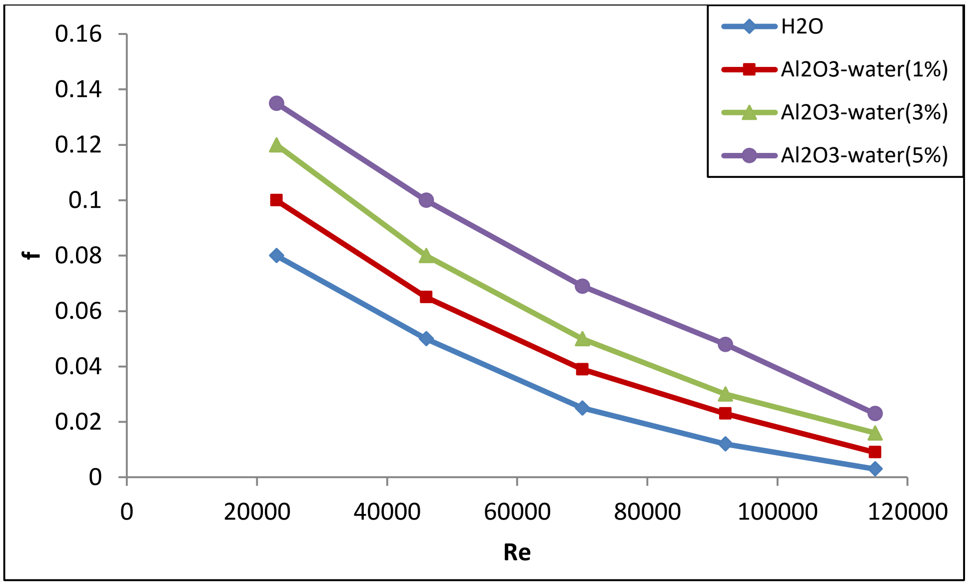

Fig. (13): Friction factor versus Reynolds number for (Al_2O_3/water) for different concentration ratios.

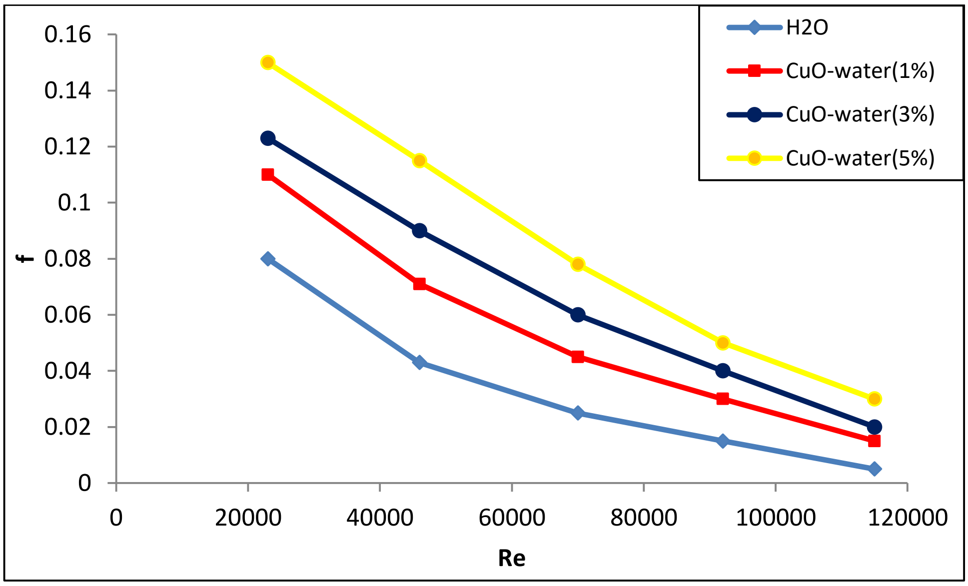

Fig. (14): Friction factor versus Reynolds number for (CuO/water) for different concentration ratios.

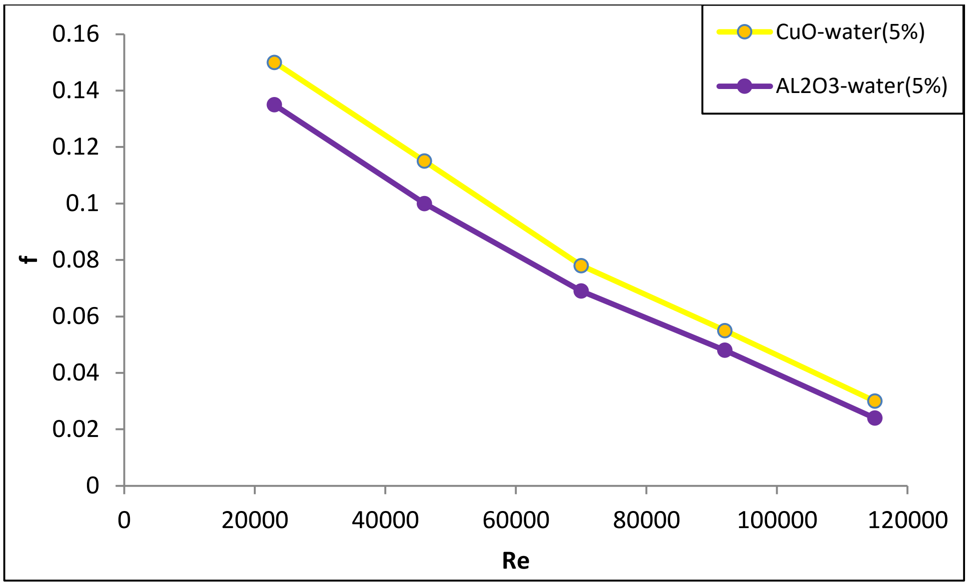

Fig. (15): Friction factor versus Reynolds number for (Al_2O_3/water) and (CuO/water) at concentration ratio of 5%.

NOMENCLATURES

Symbols	Definition	Unit	Symbols	Definition	Unit
A	Area	m^2	Nu	Nusselt number	---
Cp	Specific heat	$J/kg.K$	P	Pressure	N/m^2
d	Diameter	Prandtl m	Pr	number	---
f	Friction factor	---	Q	Heat transfer	W
g	Acceleration due to gravity	m/s^2	Re	Reynolds number	----
h	Convection heat transfer coefficient	$W/m^2.K$	T	Time	s
K	Thermal conductivity	$W/m.K$	T	Temperature	K
L	Length	m	V	Flow velocity	m/s
$\dot{m}$	Mass flow rate	kg/s	u, v, ω	Velocity component	m/s

GREEK LETTERS

$\emptyset$	Volume concentration of N.P.	---
$\boldsymbol{\mu}$	Dynamic viscosity	$kg/m.s$
$\boldsymbol{\rho}$	Density	kg/m^3
$\boldsymbol{\varepsilon}$	Heat exchanger effectiveness	---

Subscripts

Bf	Base fluid
C	Cold
H	Hot
I	Inlet
Nf	Nano-fluid
P	Particle
O	Outlet

Abbreviations

CFD	Computational fluid dynamics	NP	Nano particle
FVM	Finite volume method	*Nu*	Nussult number
HE	Heat exchanger	*Re*	Reynolds number
NF	Nano fluid	3-D	Three dimensions

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