CFD Letters

Journal homepage:
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ISSN: 2180-1363

Efficiency Improvement of Double Pipe Heat Exchanger by using TiO_2/water Nanofluid

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ARTICLE INFO

Article history:
Received 17 May 2023
Received in revised form 20 June 2023
Accepted 15 July 2023
Available online 5 December 2023

Keywords:
Double pipe heat exchanger; Nanofluid; Effectiveness; NTU

ABSTRACT

Heat exchangers are commonly utilized to transfer heat between two fluids in a number of industries. However, parameters such as fluid flow velocity, temperature difference, and thermal conductivity limit their efficiency. Researchers have investigated the use of nanofluids - fluids containing nanoparticles that boost thermal characteristics - to improve the performance of heat exchangers. The use of nanofluids can improve the efficiency of double-pipe heat exchangers. However, research on the influence of TiO_2/water nanofluid on the performance of double-pipe heat exchangers is insufficient. The purpose of this research is to investigate the impact of TiO_2/water nanofluid on the efficiency of a double-pipe copper counter-flow heat exchanger. A double-pipe copper counter-flow heat exchanger using cold (room temperature) and hot (70°C) water as working fluids was used in an experimental investigation. They created nanofluids by adding varying concentrations (0.1%, 0.3%, and 0.5%) of TiO_2 nanoparticles to water and measuring their heat conductivity and viscosity. They then calculated the overall heat transfer coefficient and efficacy by measuring the input and outlet temperatures as well as the flow rates of both fluids. It was discovered that adding TiO_2 nanoparticles to water enhanced its heat conductivity and viscosity substantially. The overall heat transfer coefficient increased up to 0.3% but declined at 0.5% nanoparticle concentration. At a nanoparticle concentration of 0.3%, the maximum effectiveness was attained, with a corresponding increase in efficiency of up to 23%. The scientists found that using TiO_2/water nanofluid to improve the efficiency of double-pipe heat exchangers is a viable option.

1. Introduction

A heat exchanger is a mechanical device that allows heat to be transferred from one fluid to another at different temperatures to prevent them from combining. A bigger heat exchanger can be used to lessen this disparity but doing so will increase both the size and expense of the system. When developing tools, it is crucial to consider both orientations [1].

The use of nanofluids can increase a fluid's thermal conductivity. Choi [2] from the Argonne National Laboratory in the United States first used the term "nanofluid" to describe fluids containing nanoparticles (with a diameter of less than 50 nm) (diameter less than 50 nm). Nanoparticles

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https://doi.org/10.37934/cfdl.16.1.4354

suspended in different base fluids can change how that fluid flows and how it transfers heat. Basefluid components are H_2O, EG, and Engine Oil. The fluid's ability to transport heat depends on how well the nanoparticles are dispersed throughout it. Using an ultrasonic mixer or ultrasonic homogenizer to combine the nanofluid with the regular fluid results in a homogenous suspension. The frequency range of operation for the ultrasonic mixer is 20 to 40 KHz. The usefulness of the nanofluid is determined by the concentration and particle size of the fluid. With a larger surface area and less pressure drop over the test section, nanoparticles of a finer grade will remain uniformly suspended. The heat transfer rate was calculated using several factors, including the Nusselt number, the Peclet number, and the Reynolds number. The Nusselt and Peclet numbers of a nanofluid are inversely proportional to the heat transfer coefficient and rate of the fluid.

Several authors [3, 4] worked together to formulate a relation that describes the nanofluid's effective thermal conductivity for a specific boundary condition. Boundary layer phenomena and Brownian motion of the particles play an important role in accelerating the rate of heat transfer. As the nanofluid's concentration in volume grows, the resultant Nusselt number rises dramatically. A heat exchanger's performance depends on more than just its technical specifications; it also must consider the size of the room set aside for it and the price tag of its production. Because of the heat exchangers, engineers became concerned with energy and looked for best designs that would maximize thermal analyses and economic rewards.

Changing the physical-thermodynamic parameters of the fluids being used is necessary to enhance the heat transfer process [5]. The thermal conductivity of common liquids is lower than that of non-metallic solids like copper oxide and alumina, or even metals like copper and aluminum. So, it's important to figure out how to improve the fluids' characteristics by incorporating solid particles into them.

The gap of this study is the lack of research on the effect of TiO_2/water nanofluid on the performance of double-pipe heat exchangers. The significant of this study is that it provides experimental evidence that adding TiO_2 nanoparticles to water can significantly improve its thermal conductivity and viscosity, leading to an increase in efficiency by up to 23% in a double-pipe copper counter-flow heat exchanger. This finding has practical implications for industries that use heat exchangers, as it suggests that using nanofluids can be an effective way to improve their performance and energy efficiency.

The current state of development allows nanoparticles that are easily dispersed and suspended in the liquid. The improved thermal characteristics of the new fluids were accompanied by the absence of deposits that may clog the channels passing through them [6-8]. What kind of nanofluid is used, how much of it is used, and what kind of heat exchanger it is [9-11]. Based on the results of the performed investigations, nanofluids are a potentially useful possibility for increasing heat transfer efficiency [12-14].

2. Methodology

2.1 Experimental Procedure

The apparatus for testing is demonstrated in Figure 1. It consists of two 6-liter plastic basins connected by double-tube heat exchangers, one of which is heated to 65°C by a 3000-watt electrical coil before water enters into the primary heat exchanger (which has two concentric tubes). The diameters are 15 mm on the inside and 25 mm on the outside. The second reservoir was used to collect the water from the secondary exchanger. In this region, the nanoparticles were kept at a constant temperature of 20 degrees Celsius by being cooled in an airtight plastic container filled with a frozen surface. The water was kept in motion by an electric mixer submerged in the water.

Fig. 1. The test rig of the experimental study

A type k thermocouple measures the temperature of the entering cold water, whereas a type j thermocouple measures the temperature of the arriving hot water. Two thermocouples (type k) measure the input and output temperatures of the heat exchanger. Volumetric flow meter with rotameter (Z-3002). Copper pipes that have been insulated. Heater water storage. One of those pumps circulates hot water. Controls for the heater, the hot water pump, the cold water pump, the cold water tank, the cold water pump, and the plastic piping connect the various components.

The total amount of solid nanoparticles that will be distributed by water that has been filtered to nanoparticle size at a weight concentration ratio of (0.1%, 0.3% and 0.5%) for three different volumes of water (2, 4 and 6 litters) has been determined using the following equations:

$$\emptyset = \left(\frac{mp}{mp+mf}\right) \times 100 \qquad (1)$$

The nanoparticles were mixed with clean water in two steps using a two-step process (and for the two types of particles) which are summarized as follows:

The TiO_2 nanoparticles determined in Eq. (1) above are added to 2, 4, and 6 liters of pure water, with the exact weights evaluated by electronic weighing as shown in Figure 2.

Fig. 2. Electronic balance

The produced nanoparticles were mixed with 2 liters of clean water in an electric mixer that was left running for 30-40 minutes, until the mixture was totally homogenous. Since the mixer could only hold one liter, this procedure required four separate phases to complete. To ensure that the nanoparticles are uniformly dispersed in the mixture. Ultrasonic equipment (Ultrasonic) has been applied to help their dispersion as can be seen in Figure 3, the ultrasound device and the mixer were in use for a total of (40-45) minutes.

Fig. 3. The mechanical stirrer and ultrasound machine

After the nanofluid was prepared and a homogenous fluid was obtained, it was poured into the test device's Nano scale water reservoir, where an electric mixer was built to mix the water constantly. Throughout the duration of the test to ensure the suspension and spread of the nanoparticles. Thermal properties of TiO2 nanoparticle and water at 25°C is indicated in Table 1.

Table 1
Thermal properties of TiO_2 nanoparticle and water at 25°C

Material	ρ kg/m^3	K w/m.k	Cp J/kg.k	µ Pa.s	T °C
Np (TiO2)	4175	8.4	692	-	25
Pure water	998.2	0.6	4180	0.001	25

2.2 Experimental test

Once the testing equipment was ready to go and the nanofluid in its reservoir, the following procedures were conducted:

Throughout the experiment, make sure the electric mixer in the nanofluid tank is on to ensure that the nanoparticles are being uniformly dispersed throughout the liquid. Activating the electric coil to raise the temperature of the second basin's water to 65 degrees Celsius. A thermostat with the proper settings may do this. Within the tubes of a heat exchanger, nanoscale water temperatures and flow rates must be accounted for mathematically. The flow of hot water was regulated by pyloric valves at a rate of 4 liters per minute, while the flow of nanofluid was regulated at 2, 4, and 6 liters per minute. Two flow meters were installed in the tester to measure and find flow rates. Monitoring temperature gauges at the exchanger's input and outflow Monitoring the degree of stability and taking temperature readings for both hot and cold fluids every 10 minutes. The temperature difference between the hot and cold water flows can be calculated as [15]:

$$\dot{m}h = \frac{Q}{60} \times \rho \tag{2}$$
$$\dot{m}c = \frac{Q}{60} \times \rho \tag{3}$$

Hot and cold-water heat transfers can be evaluated as:

$$Qh = mh \times Cp, h(Thi - Tho) \tag{4}$$
$$Qc = mC \times Cp, c(Tco - Tci) \tag{5}$$

Average heat transfer can be evaluated as:

$$Qavg = \frac{Qh + Qc}{2} \tag{6}$$

Inner Pipe surface area [16]

$$Ai = \pi \times di \ \times L \tag{7}$$

The Logarithmic Mean Temperature Difference (LMTD) for a counter flow configuration is calculated as [17]:

$$\text{LMTD} = \frac{(\text{Thi}-\text{Tc0}) - (\text{Th0} - \text{Tci})}{\ln\,(\text{Thi}-\text{Tc0})/(\text{Th0} - \text{Tci})} \tag{8}$$

Heat transfer coefficient is calculated based on the area of the inner pipe's wall.

$$\text{Ui} = \frac{\text{Qavg}}{\text{Ai} \times \text{LMTD}} \tag{9}$$

Cold and hot water flow rate heat capacity can be evaluated as:

$$Cc = m_c \times Cp_c \tag{10}$$
$$C_h = m_h \times Cp_h \tag{11}$$

Flow rates for the lowest and highest possible heat capacities Cmin is Lowest Possible Value Between Cc and Ch:

C_{max}=Maximum Value out of C_c and C_h

Maximum heat transfer possibility can be evaluated as:

$$Qmax = Cmin\ (Thi - Tci) \tag{12}$$

Effectiveness of the heat exchanger can be evaluated as:

$$\in = \frac{\mathrm{Qavg}}{\mathrm{Qma}} \tag{13}$$

2.3 Uncertainty analysis

Analysing and measuring the uncertainties in a measurement or calculation is known as uncertainty analysis. The overall uncertainty of measurement or calculation can be evaluated by first determining and describing all the sources of uncertainty that potentially affect the result, then estimating the magnitudes of these uncertainties, and then combining these estimates. Uncertainty analysis aims to quantify how precise and trustworthy a result is, as well as point out for improvement as following:

$$w_A = \left\{\left(\frac{\partial A}{\partial d} w_d\right)^2 + \left(\frac{\partial A}{\partial L} w_L\right)^2\right\}^{1/2} \tag{14}$$

$$\frac{w_A}{A}\% = \pm\left(\frac{w_A}{A}\right) \times 100 \tag{15}$$

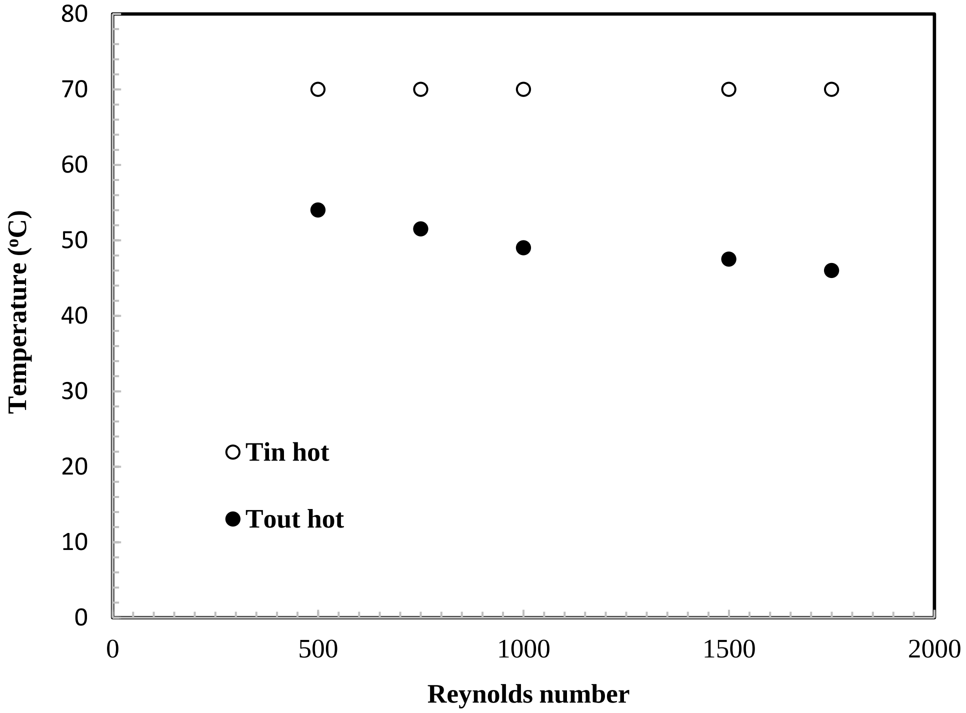
$$\frac{w_{Tin}}{Tin}\% = \pm\left(\frac{w_{Tin}}{Tin}\right) \times 100 \tag{16}$$

$$\frac{w_{\Delta P}}{\Delta P} = \left\{\left(\frac{w_{\Delta P}}{\Delta P}\right)^2\right\}^{1/2} \times 100 \tag{17}$$

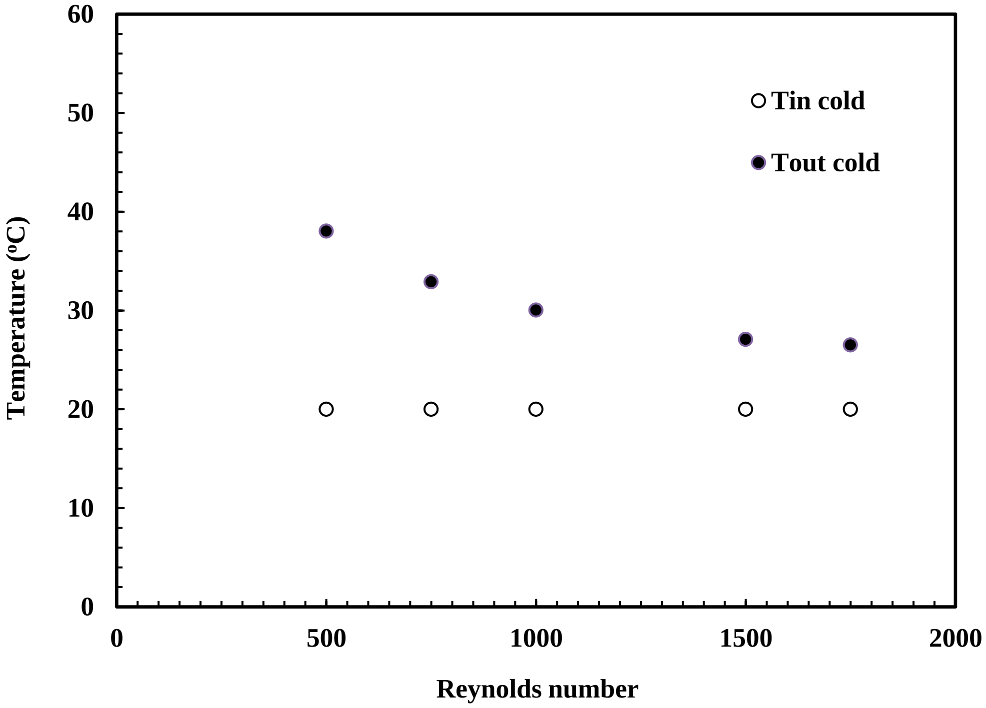
$$\frac{w_{\dot{m}}}{\dot{m}}\% = \pm\left\{\left(\frac{w_\rho}{\rho}\right)^2 + \left(\frac{w_{\dot{v}}}{\dot{v}}\right)^2\right\}^{1/2} \times 100 \tag{18}$$

3. Results and Discussion:

Figure 4 shows the temperature as a function of Reynolds number for nanofluids flowing through inner tube at three different concentrations (0.1, 0.3, and 0.5). The information presented here is the result of tests performed on a double-pipe heat exchanger. Low Reynolds numbers (Re=500) result in considerable temperature differences between the entering and exiting fluids. Cold fluids see less of a temperature drop between their entry and departure locations as the Reynolds number increases. It explains why high-mass heating leads the Reynolds number to rise proportionally with the increase in the flow accelerator [18].



(a) Hot water temperature



(b) cold water temperature

Fig. 4. Temperature gradient against Reynolds number

Figure 5 depicts Nusselt numbers against Reynolds number when the volume concentration is varied from 0.1 to 0.5%. It explains why both the Nusselt and Reynolds numbers tend to increase together. The increasing fluid velocity is the result of a breakdown in the boundary layer on the tube wall, which allows for more efficient heat transfer [19]. Additionally, the increasing in the nanofluid concentrations is led to increase Nusselt number due to the increasing of heat transfer coefficient.

The increase in the heat transfer coefficient of the nanofluids is due to the enhanced thermophysical properties of the nanofluids compared to the base fluid and the effects of Brownian motion [20].

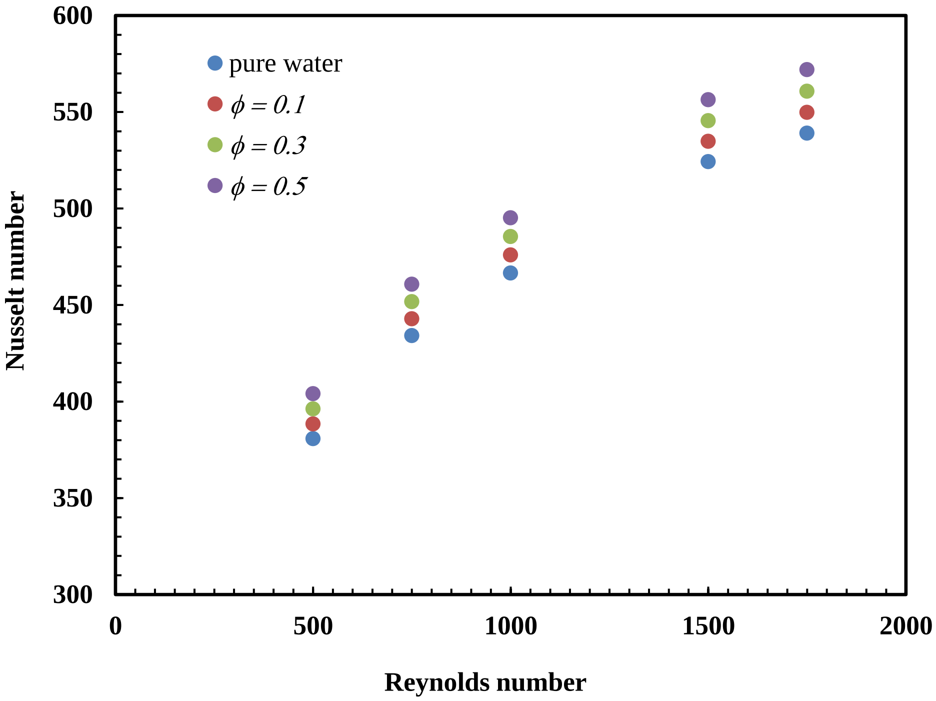


Fig. 5. Shows the Nusselt-Reynolds correlation as volume concentration increases

Different volume concentrations (0.1, 0.2, and 0.3) are depicted in Figure 6 to illustrate the relationship between the Reynolds number and the heat transfer coefficient. The enhanced thermal conductivity of nanofluids causes the heat transfer coefficient to increase as the concentration of the fluid does. As the concentration in each volume rises, so do its thermal and physical characteristics.

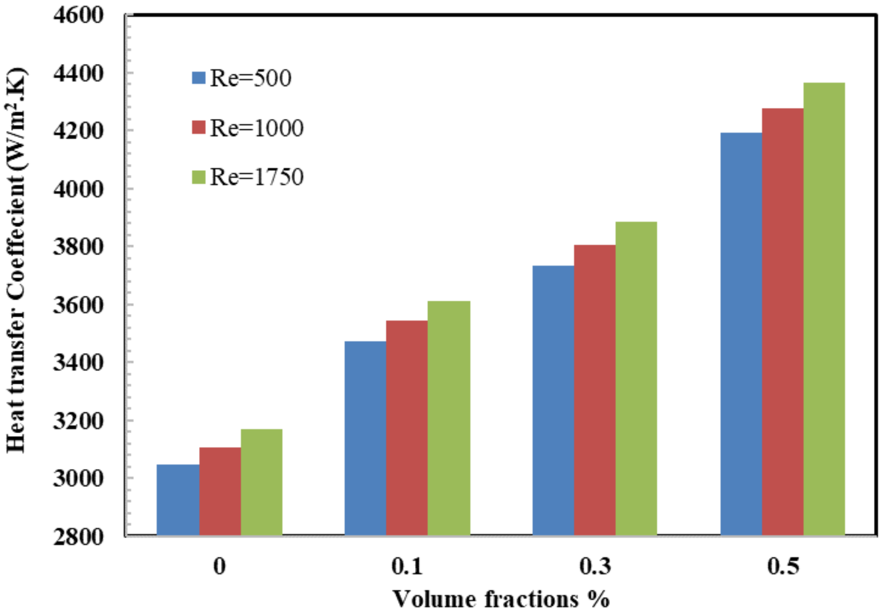


Fig. 6. Heat transfer coefficient and nanofluid volume fractions at different Reynolds numbers

Using three different concentrations of volume (=0.1, 0.2, and 0.3), Figure 7 illustrates the relationship between the Reynolds number and the friction factor. At low Reynolds numbers, a significant friction factor was found (500). When the Reynolds number is raised, the friction factor of nanofluids is reduced. It explains why increased shear stress leads to a faster flow and hence a higher Reynolds number [21].

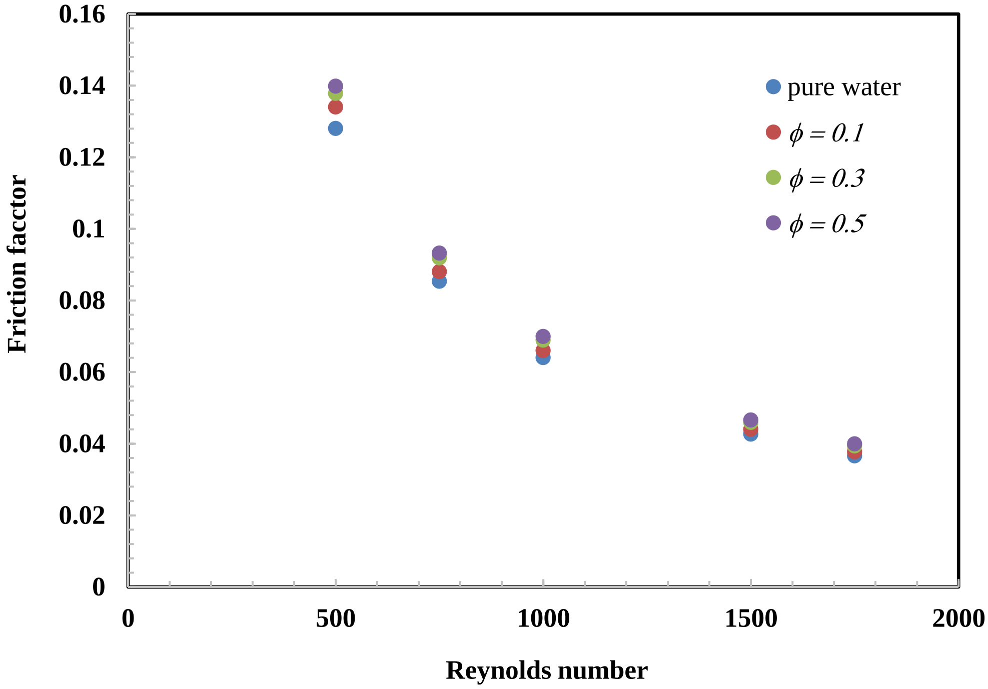


Fig. 7. Friction factor and Reynolds number with different volume concentration

Figure 8 indicates that the number of heat transfer units (NTU) varies with the Reynolds number and nanofluid concentration. The optimum NTU is recorded when Reynolds number is 500 and a nanofluid concentration is 0.5%. It can be seen that the NTU is increasing as increase in the volume concentration of nanofluid from 0.1 to 0.5. This increase of NTU is due to the effect of the decrease in the specific heat at constant pressure, increase of the thermal conductivity and the decrease of the vicious force [21].

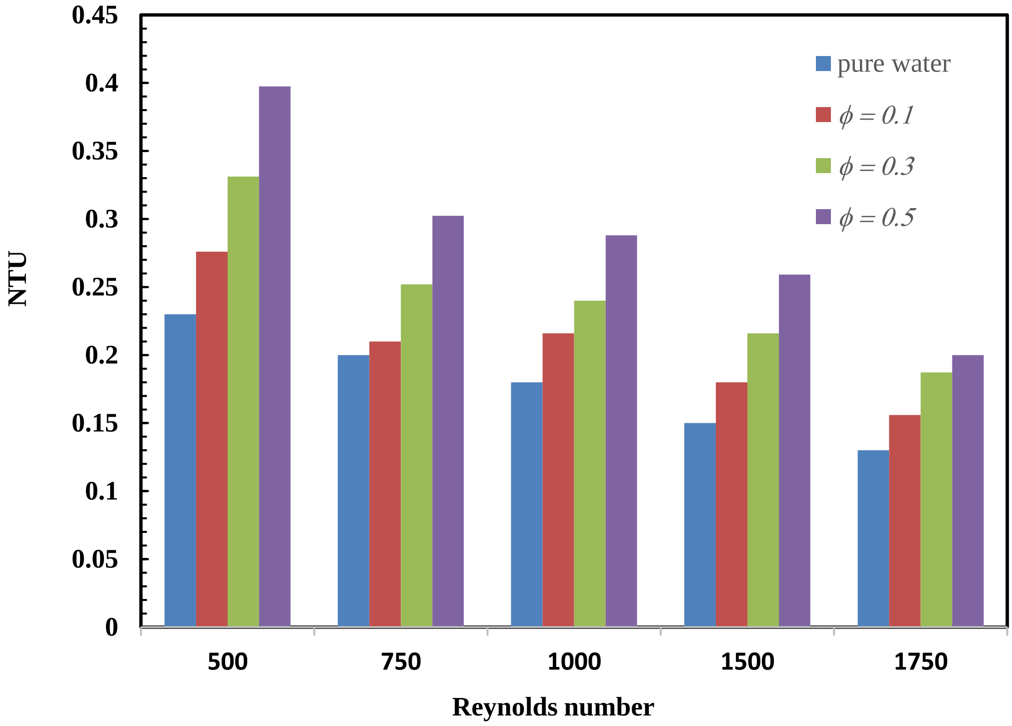


Fig. 8. NTU with different Reynolds number and volumetric concentrations

The variation in heat exchanger efficiency at various Reynolds numbers is seen in Figure 9 for a heat exchanger using titanium oxide and water in the inner tube. At the Reynolds number, where the heat capacity of the hot water is lowest, the most efficient value of the exchanger was reached in the heat exchanger with the inner tube. When there is a larger temperature differential, heat exchange efficiency improves. With nanofluid titanium oxide, however, the inner-tube heat exchanger's efficiency peaked at 500 Reynolds number. This is because the cold fluid has a lower heat capacity, which boosts the effectiveness of the heat exchanger [22].

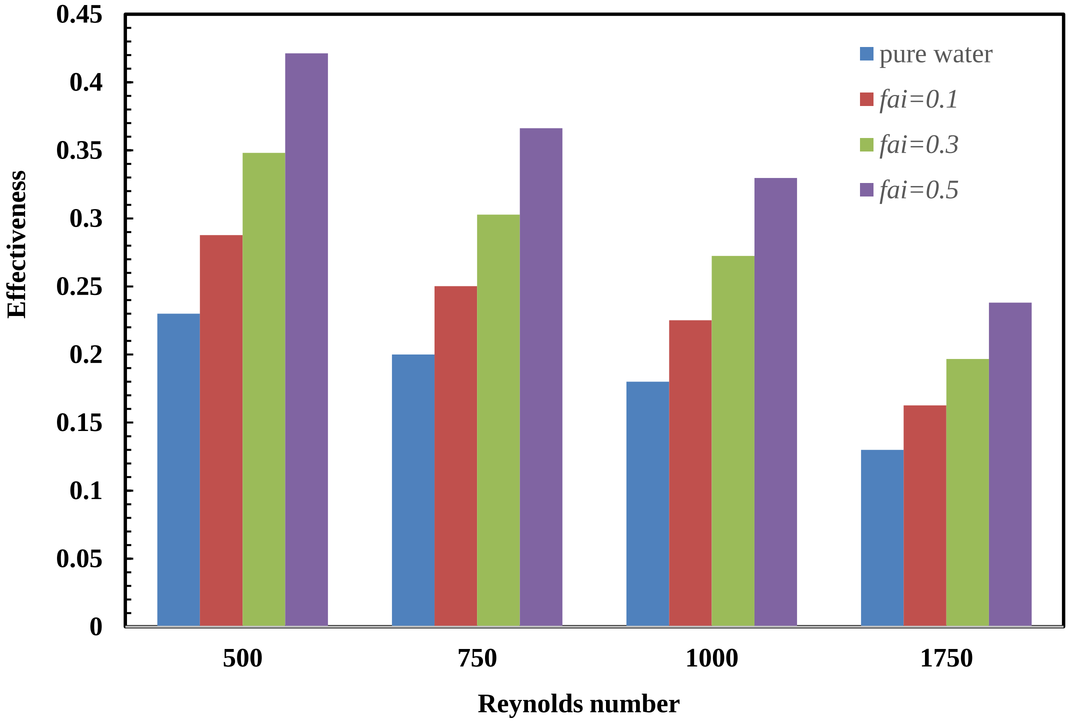


Fig. 9. The heat exchanger's effectiveness with different Reynolds number and nanofluid concentrations

4. Conclusion:

The resulting hypotheses and findings are as follows:

i. The heat transfer coefficient is increased as nanofluids concentrations increase from 0.1 to 0.5%.
ii. Improvements in heat transfer rate was 17% when using 0.5% nanofluid and 2 L/min volume flow rate.
iii. The optimum NTU is recorded when Reynolds number is 500 and a nanofluid concentration is 0.5%.
iv. The maximum effectiveness was 29% with using 0.5% nanofluid and 2 Lpm volume flow rate.

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