Experimental Investigation of Double Pipe Heat Exchanger Performance based on Alumina and Copper Oxide Working Nanofluids

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Abstract. The heat transfer performance of heat exchanger is greatly depending on the thermal conductivity and heat transfer capacity of the working fluid. One of the important methods to improve the thermal conductivity of the heat transfer fluid is by adding nano particles of materials with high thermal conductivity. In the present study, an experimental work was conducted to investigate the performance enhancement of double pipe heat exchanger using Alumina (Al₂O₃) and Copper oxide (CuO) nano particles mixed with engine oil as a working fluid. The thermal performance of heat exchanger was investigated at particles concentrations 0.05% and 0.1% of Al₂O₃ and CuO nano particles to determine the most effective factors on heat transfer enhancement. The results revealed that, the enhancement percentage in Nusselt number (Nu) for nanofluid at 0.05% particles concentration compared to pure oil was 9% and 6% for CuO and Al₂O₃ nanofluids respectively. While at 0.1% concentration, the enhancement percentage in Nu was about 17% and 15% for CuO and Al₂O₃ nanofluids respectively. The enhancement percentage in value of overall heat transfer coefficient for CuO nanofluid was 6.5% compared to Al₂O₃ nanofluid at 0.1% concentration. The enhancement percentage in the heat exchanger effectiveness was about 12% for CuO nanofluid compared with that for Al₂O₃ at 0.1% concentration. Adding the CuO and Al₂O₃ nano particles has improved the thermal conductivity of base fluid (oil) and led to a significant enhancement in heat transfer rate and thermal performance of the heat exchanger.

Keywords: Nanofluid, Alumina, Copper oxide, Heat Exchanger, Thermal performance.

1. Introduction:
Heat exchanger is a device used to exchange heat between two fluids separated by solid surface with different temperatures. It is considered one of the most important heat and mass transfer apparatus which plays an essential part in various engineering applications, such as in electric power generation, refrigeration and air-conditioning, oil refining and chemical engineering. The heat transfer performance of heat exchanger is greatly depending on the thermal conductivity of heat transfer medium (fluid). The efficiency of the heat exchanger can be significantly enhanced with high thermal conductivity of the transfer medium and limited when low thermal conductivity medium is used [1]. One of the important methods to improve the thermal conductivity of the transfer medium is by adding nano particles of materials with high thermal conductivity [2, 3]. Nano fluid is prepared from nanometers sized particles (less than 100 nm) such as metal, oxide, and carbide which are mixed and
dispersed in the fluid like water, oil, ethylene, glycol and used to increase the heat transfer rate in heat exchanger [4]. Technology of the nano materials has been developed in the last decade, thus it can be developing various types of nanofluids to be used as heat transfer medium. The effect of rapid mixing of relatively high thermal conductivity nano particles with the fluid strengthens the energy transport inside the nano fluids by modifying the temperature profiles. Nanofluids have received a much attention and become an intensive research topic, because of their improved thermal properties and possible heat transfer applications [5].

Many researchers had studied the methods of improving the heat exchanger performance by adding nano particles to the heat exchange fluids. Raman [6] studied experimentally the performance of a counter flow heat exchanger using different nanofluids used which is a mixture of coolant and nano iron particles. Alpesh [7] inspected the experimental data and concluded that, the main influence the nanofluids heat transfer characteristics was depending on particle size, properties of the nanoparticles and volume concentration. Reza et al. [8] studied the of Nusselt number (Nu) and heat transfer coefficient enhancement of nanofluid containing nanoparticles Al2O3 with a particle size of 20 nm and volume concentration of 0.1%–0.3% in heat exchanger at counter flow arrangement. Results showed that, if the volume fraction of nano particles increased the heat transfer also increases. Bhanuteja and Azad [9] studied the CuO nanofluid and showed that, when the volume concentration of nanoparticles increased, the CuO nanofluid specific heat capacity decreases gradually. Jaafar et al. [10] investigated the heat transfer characteristics of a nanofluid consisting of water and Al2O3 nan particles with various volume concentrations (0.3–2) % flowing in counter turbulent flow shell and tube heat exchanger. Results showed that, at the same mass flow rate and under similar thermal conditions, the nanofluid convective heat transfer coefficient was higher than that of the base liquid. Lazarus et al. [11] studied experimentally the convective heat transfer with low volume concentration 0.003% of CuO to water nanofluid. Effect of mass flow rate and inlet temperatures in range of 100-170 °C on the heat transfer coefficient in the entry region under laminar flow condition was studied. As the Reynolds number increased, the heat transfer enhancement was increased considerably. Hasanuzzaman et al. [12] calculated the convective heat transfer coefficient of water and nanofluids consisting from nano particles of Cu, Al, Al2O3 and TiO2 at 2% concentration with water in counter flow heat exchanger. The results revealed that, the convective heat transfer coefficient of Cu, Al, Al2O3 and TiO2 nanofluids were 81 %, 63%, 66% and 64% higher than that for pure water respectively. Ramon et al. [13] conducted numerical study to investigate the convection of the nanofluids flow in straight tube and straight microtube. Several parameters had been studied by using various type of base fluids including, turbine oil, ethylene glycol and water with nanoparticles CuO, Al2O3, SiO2, TiO2, and ZnO. The results showed that, Nu was considerably enhanced up to 16% at volume concentration of 4% with increase in concentrations of nanoparticles. Mohammad et al. [14] studied experimentally and theoretically the behavior of CuO nano particles and water thermophysical properties and thermal performance. They found that, the concentration, material, and size of nanoparticles have important roles in the heat transfer coefficient of CuO with water nanofluids. Chavda [15] and Mushtaq et al. [16] conducted experimental study to investigate the performance of counter and parallel flow double pipe heat exchanger using nanofluids of water and nano particles CuO, Al2O3 and TiO2. The results revealed that, the heat exchanger performance was improved with increasing of nanoparticles concentration. Minsuk and Seungro [17] evaluated experimentally the performance of Al2O3 nanoparticles with water at volume concentrations 0.38%, 0.81%, and 1.30% for turbulent flow in circular tube. It is found that the heat transfer coefficient increased with increasing in Al2O3 concentration by up to 19%.

In the present study, an experimental work was accomplished to investigate the performance enhancement of double pipe heat exchanger using Alumina (Al2O3) and Copper oxide (CuO) nano particles mixed with engine oil. The performance of heat exchange between nanofluid (oil) and cooling water was investigated at different mixing ratios of Al2O3 and CuO nano particles to determine the most effective factors on heat exchange enhancement.
2. Methodology

2.1 Heat Exchanger Analysis

The heat exchanger considered in the current study is coil type double pipe heat exchanger where the nanofluid (hot oil) flows inside tube and the cooling water flows inside the shell. To investigate the thermal performance of heat exchanger with nanofluids, the heat transfer characteristics such as overall heat transfer coefficient, thermal effectiveness, thermal efficiency, Nusselt number and further parameters are determined as follows:

The overall heat transfer coefficient \( U \) of double pipe heat exchanger can be determined by the following equation [18]:

\[
U = \frac{Q}{A\cdot LMTD}
\]

Where: \( U \) is overall heat transfer coefficient \((\text{W/m}^2\cdot\text{°C})\), \( Q \) is heat transfer rate \((\text{W})\), and \( A \) is total surface area \((\text{m}^2)\).

Logarithmic mean temperature difference \((\text{LMTD})\) can be expressed by:

\[
\text{LMTD} = \frac{(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})}{\ln\left(\frac{T_{h1} - T_{c2}}{T_{h2} - T_{c1}}\right)}
\]

Where: \( T_{h1} \) and \( T_{h2} \) are inlet and outlet hot fluid (oil) temperatures, \( T_{c1} \) and \( T_{c2} \) are inlet and outlet cold fluid (water) temperatures.

The heat transfer rate \( Q \) is determined by:

\[
Q = V \cdot \rho_n \cdot C_{p_n} \cdot (T_{h1} - T_{h2})
\]

Where: \( V \) is volume flow rate of nanofluid \((\text{m}^3/\text{s})\), \( \rho_n \) is density of nanofluid \((\text{kg/m}^3)\), \( C_{p_n} \) is the specific heat of nanofluid \((\text{J/kg}\cdot\text{°C})\).

Convection heat transfer coefficient \( h_n \) of the nanofluid \((\text{W/m}^2\cdot\text{°C})\) can be determined using the following equation:

\[
h_n = \frac{Q}{A_i \cdot \Delta Tn}
\]

\[
A_i = \pi D_i L
\]

Heat exchanger effectiveness \((\varepsilon)\) can be calculated by:

\[
\varepsilon = \frac{Q}{Q_{max}}
\]

Where:

\[
Q_{max} = (V \cdot \rho \cdot C_p)_{min} \cdot (T_{h1} - T_{c1})
\]

\( A_i \) is internal surface area of the tube in the heat exchanger \((\text{m}^2)\), \( \Delta Tn \) is the temperature difference between inlet and outlet nanofluid \((\text{°C})\), \( D_i \) and \( L \) are inner diameter and length of the tube \((\text{m})\), \( T_{c1} \) is inlet cold fluid temperature \((\text{°C})\).
(V, ρ . Cp) min represents the minimum value of the cold and hot fluid.

Nusselt number (Nu) is calculated by:

\[
Nu = \frac{h_n D_i}{k_n}
\]  

Reynolds number Re for nanofluid side can be determined by:

\[
Re = \frac{\rho_n D_i V_i}{\mu_n}
\]  

Where: \( k_n \) is the thermal conductivity of nanofluid (W/m°C), \( V_i \) is velocity (m/s) of the nanofluid inside the tube, \( \mu_n \) is dynamic viscosity of nanofluid (kg/m s).

2.2 Thermophysical Properties of Nanofluid

Thermophysical properties of the nanofluid are determined based on fraction of nanoparticles CuO and Al₂O₃ in base fluid (oil). Table 1 illustrate the thermophysical properties of nanoparticles.

The density of nanofluid \( \rho_n \) can be determined based on nanoparticle density \( \rho_p \) and base fluid density \( \rho_f \) as follows [18].

\[
\rho_n = \phi \rho_p + (1 - \phi) \rho_f
\]  

where: \( \phi \) is the nanoparticles volume concentration in the base fluid (Oil).

Estimated value of nanofluid specific heat \( Cp_n \) is calculated using the same method of calculating the density, based on specific heat of nanoparticles \( Cp_p \) and specific heat of base fluid \( Cp_f \) as follows:

\[
Cp_n = \phi Cp_p + (1 - \phi) Cp_f
\]  

Nanofluid thermal conductivity \( k_n \) can be estimated based on \( k_p \) and \( k_f \) which represent the thermal conductivity of nanoparticles and base fluid respectively using the following equation [18, 19].

\[
k_n = k_f \frac{kp + 2kf + 2\phi(kp - kf)}{kp + 2kf - \phi(kp - kf)}
\]  

Absolute viscosity of nanofluid \( \mu_n \) can be determined using the following equation:

\[
\mu_n = \mu_f (1+2.5\phi)
\]  

Where: \( \mu_f \) is viscosity of base fluid.

Volume concentration \( \phi \) of the nanoparticles is determined using the following equations [15].

\[
\phi = \frac{V_p}{(V_p + V_f)} \times 100
\]  

Equation (12) can be rewritten as follows:

\[
\phi = \frac{m_p}{(m_p + m_f)} \times 100
\]
Where: \( V_p, m_p \) and \( \rho_p \) are volume, mass and density of nano particles respectively, \( V_f, m_f \) and \( \rho_f \) are volume, mass and density of base fluid (oil) respectively.

Two ratios 0.05\% and 0.1\% of volume concentration \( \phi \) for nano particles \( \text{Al}_2\text{O}_3 \) and \( \text{CuO} \) are used in the present study.

3. Experimental Work:

3.1 Experimental Setup and Procedure

The experimental setup used in the present work to accomplish the experimental analysis consists of double pipe heat exchanger of type coil pipe with hot and cold fluid circuits. Hot circuit represents nanofluid (oil and nano particles) and cold circuit represents the cooling tap water. Each fluid loop consists of, storage tank, circulating pump, flow meter and manual valves to control the flow as shown in the figure 1. The test rig is equipped with K-type thermocouples of range -200 °C to 1250 °C and data logger of model PCE-T 1200 was used to record and display the input and output temperatures for the hot and cold fluid streams.

The tube of the heat exchanger is made from carbon steel with 3240 mm length, internal diameter of 13.2 mm and outer diameter of 20 mm, while the outer pipe (shell) is made from copper with outer diameter of 35mm. Heat exchanger unit and pipes are properly insulated to reduce the heat loss. The storage tank of the hot nanofluid (oil) is 10 liters capacity made from stainless-steel and equipped with electrical heater of 2000 W power and thermostat to maintain the nanofluid at desired temperature. The experimental work and measurements of the heat exchanger system are conducted in the refrigeration workshop of the Engineering Technical College- Baghdad.

All tests performed on the heat exchanger were at counter flow arrangement under approximately constant temperatures of hot oil and cold water 60 °C and 20 ±2 °C respectively. After heating the oil in the tank to the set point temperature about 60 °C, the cold and hot fluid loops are opened and when reach to steady state, cold and hot fluids flowrates and the temperatures at input and output streams are recorded. This procedure is repeated for \( \text{Al}_2\text{O}_3 \) and \( \text{CuO} \) nanofluid at approximately similar test conditions.

3.2 Preparation of Nano fluid

Spherical nano particles \( \text{Al}_2\text{O}_3 \) of diameter 80 nm and \( \text{CuO} \) of diameter 50 nm were used to prepare the nanofluid using one-step method [15]. The nano particles were added gradually to the engine oil as base fluid at specified volume concentration 0.05\% and 0.1\% and then properly mixed using violent stirring. Nano particles and oil suspension were then stirred by ultrasonic equipment for about 45 minutes to ensure proper dispersion before used in the heat exchanger. This process was repeated for each volume concentration and for each test. The thermophysical properties of engine oil and nanoparticles used in the current work are illustrated in the Table 1.

| Properties                  | \( \text{Al}_2\text{O}_3 \) | \( \text{CuO} \) | Engine Oil |
|-----------------------------|-----------------------------|-----------------|------------|
| Density (kg/m\(^3\))        | 3800                        | 6500            | 863.9      |
| Specific heat (J/kg. K)     | 770                         | 530             | 2048       |
| Conductivity (W/m. K)       | 20.3                        | 29.8            | 0.1404     |
| Nano-particles diameter (nm)| 80                          | 50              |            |
4. Results and discussion:

To investigate the effect of adding nano particles with relatively high thermal conductivity to the base fluid (oil) on thermal performance of the double pipe heat exchanger, two nanofluids consisted from oil with Al₂O₃ and oil with CuO particles are considered in the current study. Heat transfer characteristics such as, overall heat transfer coefficient, convection heat transfer coefficient, Nusselt number and heat exchanger effectiveness are investigated at volume concentration of nanoparticles 0.05% and 0.1%. The variation of average Nusselt number (Nu) with Reynolds number (Re) for nanofluid with different CuO particles concentrations and pure oil is shown in the figure 2. It can be observed in this figure that, the value of Nu increases with increasing in Re for all nano particles concentrations and pure oil, in addition to that the value of Nu increases with increasing in nano particles concentration. The enhancement percentages in Nu for nanofluid compared to pure oil were 9% and 17% for nano particles concentrations 0.05% and 0.1% respectively. The enhancements in Nu for nanofluids is attributed to the relatively higher thermal conductivity and further preferable thermophysical properties of nano particles compared with pure oil. Similar behavior can be seen in the figure 3 for Al₂O₃ nanofluid, but the enhancements in Nu were 6% and 15% for nano particles concentrations 0.05% and 0.1% respectively.

Variation of overall heat transfer coefficient (U) with Re for CuO and Al₂O₃ nanofluids with 0.05% nanoparticles concentrations is depicted in the figure 4. It can be seen, the improvement in U for CuO nanofluid was greater than that for Al₂O₃ nanofluid due to the higher thermophysical properties of CuO nano particles compared with Al₂O₃. The thermal conductivity of CuO is relatively greater which enhanced the heat transfer capacity of the nanofluid and resulted in a significant improvement in the overall heat transfer coefficient. At average value of Reynolds number (Re =500), the enhancement percentage in value of U for CuO nanofluid was 6% compared to Al₂O₃ nanofluid. Similar trend in value of overall heat transfer coefficient can be observed in the figure 5 for 0.1% nanoparticles concentration, but the enhancement percentage in U for CuO nanofluid was 6.5% compared with Al₂O₃ nanofluid. In the heat exchanger, the convection heat transfer coefficient is directly proportional to the overall heat transfer coefficient. If the convection heat transfer is increased, the overall heat transfer coefficient also increases.
Figure 2. Nusselt number versus Re for Nanofluid with different CuO particles concentrations and pure oil.

Figure 3. Nusselt number versus Re for Nanofluid with different Al₂O₃ particles concentrations and pure oil.

This behavior can be observed in the figure 6 which show the variation of average convection heat transfer coefficient of nanofluid (hₐ) with Re for 0.05% concentrations of CuO and Al₂O₃ nanofluids. The enhancement percentage in hₐ for CuO nanofluid was about 7.4% compared with that for Al₂O₃. For the 0.1% concentration of CuO and Al₂O₃ nanofluids, the enhancement percentage in hₐ for CuO nanofluid was about 14% compared with that for Al₂O₃ as shown in figure 7.
Figure 4. Overall heat transfer coefficient versus Re for CuO and Al$_2$O$_3$ Nanofluids with 0.05% particles concentration.

Figure 5. Overall heat transfer coefficient versus Re for CuO and Al$_2$O$_3$ Nanofluids with 0.1% particles concentration.
Figure 6. Variation of average heat transfer coefficient with Re for 0.05% particles concentration of CuO and Al$_2$O$_3$ Nanofluids.

Figure 7. Variation of average heat transfer coefficient with Re for 0.1% particles concentration of CuO and Al$_2$O$_3$ Nanofluids.

The variation of heat exchanger effectiveness with Re for 0.1% concentration of CuO and Al2O3 nanofluids is illustrated in the figure 8. A significant increase in heat exchanger effectiveness for CuO nanofluid can be observed compared with that for Al2O3 due to the preferable thermal properties of CuO nano particles versus that for Al2O3. The enhancement percentage in the heat exchanger
effectiveness was about 12% for CuO nanofluid compared with that for Al₂O₃. Figure 9 shows the variation of heat exchanger duty with Re for 0.1% concentration of CuO and Al₂O₃ nanofluids. The enhancement percentage in heat exchanger duty for CuO nanofluid was about 7.2% compared with that for Al₂O₃. Adding the CuO and Al₂O₃ nano particles could improve the thermal conductivity of base fluid (oil), increase the heat transfer surface area within nanofluid and produce turbulence in the flow due to the particles dispersion. These effects could significantly enhance the heat transfer rate and then thermal performance of the heat exchanger. Thus, employing the nanofluid as working fluid in the heat exchanger is considered one of the effective approaches for heat transfer enhancement by improving the heat transfer characteristics.

![Figure 8](image1.png)

**Figure 8.** Heat exchanger effectiveness versus Re for Nanofluids with 0.1% of CuO and Al₂O₃ particles concentrations.

![Figure 9](image2.png)

**Figure 9.** Heat exchanger duty versus Re for Nanofluids with 0.1% of CuO and Al₂O₃ particles concentrations.
4. Conclusion
From investigating the results, it can be concluded that adding the CuO and Al₂O₃ nano particles could improve the thermal conductivity of base fluid (oil) and lead to a significant enhancement in heat transfer rate and thermal performance of the heat exchanger. Employing the nanofluid in the heat exchanger is considered one of the effective approaches for heat transfer enhancement by improving the heat transfer characteristics. The results have revealed that, the enhancement percentage in Nu for nanofluid at 0.05% particles concentration compared to the pure oil was 9% and 6% for CuO and Al₂O₃ nanofluids respectively. While at 0.1% concentration, the enhancement percentage in Nu was 17% and 15% for CuO and Al₂O₃ nanofluids respectively. The enhancement percentage in value of overall heat transfer coefficient for CuO nanofluid was 6.5% compared to Al₂O₃ nanofluid at 0.1% concentration. The enhancement percentage in the heat exchanger effectiveness was about 12% for CuO nanofluid compared with that for Al₂O₃ at 0.1% concentration.

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