The Comparison between the Performance of Water and CuO/Water nanofluid in Improving the Heat Transfer of Small Spaces

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Abstract. This paper examines the design of heat exchanger made of copper pipe for cooling small space system and the effects of water and CuO/distilled water like coolants channeling inside the heat exchanger to increase the transportation of heat between the compartment and the heat exchanger and comparison between them. The nano-fluid was prepared by dispersing a nanoparticle (CuO) in base fluid (distilled water). Nano-fluid with a nominal diameter of 50 nm at volume frictions (0.27 vol. %) at compartment temperature was used for these investigations. The analysis showed that secondary cooling system by means of nano-fluid (CuO/distilled water) has advantages in enhancing the flow rate heat transfer, best from base fluid (distilled water) also in Nusselt number.

1. Introduction

The nano-fluid process is a recent development in heat transfer area. A considerable amount of past research and experiments have been published on nano-fluid; covering the aspect of improving heat transfer performance [1] and miniaturization designs [2]. Recently, most industries have become aware of its significance. Researchers have identified many different ways to determine the abilities of heat transfer for nano-fluid through experimental data. In relation to this, the availability of nano-fluid in liquid phase provides more reliable application [3]. The usage of forced convective heat transfer application varies in its utilization in automotive, industrial cooling, solar devices and chemical industry [4]. In light of these researchers and experiments, the work of an analytical study on the operations of the heat transfer in cooling small spaces system by using conventional fluid (water) and also nano-fluid (CuO/water) to improve heat transfer is concluded.

2. Research design
A cooling system in this paper is a closed system, and the purpose of secondary cooling is to remove heat generated from small spaces to the surrounding space, for the rate heat transfer improvement, as shown in Figure 1. Using distilled water and CuO/distilled water, such as coolant for this system.

Figure 1. Design of Cooling System

The values for thermophysical properties of the base fluid (distilled water) and nano-fluid (CuO/distilled water) are taken at the average temperature 22 °C and 23.5 °C respectively of cooling coils.

Table 1. Elements constant in this study

| Elements                                | Results                      |
|-----------------------------------------|------------------------------|
| The inner surfaces of the copper tube   | smooth                       |
| Volume flow rate of the pump (Q)        | 9 Lit/min                    |
| The surface area of copper tube (one coil) \(A_{si}\) | 0.022 m²                     |
| The cross-sectional area of copper tube (one coil) \(A_{ci}\) | \(1.9635 \times 10^{-5}\) m² |
| length of one coil                      | 1.4 m                        |
| Number of coils                         | 12                           |
| Gravity acceleration (g)                | 9.81 m/s²                    |
| Diameter of (CuO) nanoparticles         | 50nm                         |
| Volume concentration of (CuO) nanoparticles | 0.27 %                      |
| The ambient temperature in the compartment | 31 °C                      |
| Dimensional of compartment              | \((82.5*49*19)\) cm³         |

Correlations given in literature are used to find the thermophysical properties of distilled water and CuO/distilled water.

Table 2. Thermophysical properties relationships of distilled water [5]

| Thermophysical properties | Relationships                                                             |
|---------------------------|--------------------------------------------------------------------------|
| Thermal Conductivity \(k_{bf}\) (W/m.°C) | \[
  k_{bf} = 0.56502 + 0.002636T - 0.0001251T^{1.5} - 1.51549 \times 10^{-6}T^2 - 0.00094129 T^{3/2}
\] \(1\) |
| Dynamic Viscosity \(\mu_{bf}\) (Pa.s) | \[
  \mu_{bf} = \frac{1}{557.8248 + 19.4084 T + 0.13604 T^2 - 3.11608 \times 10^{-4}T^3}
\] \(2\) |
| Density \(\rho_{bf}\) (kg/m³) | \[
  \rho_{bf} = 999.7968 + 0.0683 T - 0.01074 T^2 + 0.0008214 T^{2.5} - 2.30309 \times 10^{-5}T^3
\] \(3\) |
Specific Heat (kJ/kg K) 
\[ C_{p_{nf}} = 4.2174 - 0.005618 T + 0.001299 T^2 - 0.0001153 T^3 + 4.14964 \times 10^{-6} T^{2.5} \] (4)

| Table 3. Thermophysical properties relationships of CuO/ distilled water |
|---------------------------------------------------------------|
| **Thermophysical properties** | **Relationships** |
| Thermal Conductivity (W/m.°C) [6] | \( K_{nf} = K_{bf} + K_{bf} \left[ 3.761 \phi + 0.0179 T - 307 \right] \) (5) |
| Dynamic Viscosity (Pa.s) [7] | \( \mu_{nf} = (1+2.5 \phi_p) \mu_{bf} \) (6) |
| Density (kg/m³) [8] | \( \rho_{nf} = \phi \rho_p + (1-\phi) \rho_{bf} \) (7) |
| Specific Heat (kJ/kg K) [8] | \( C_{p_{nf}} = \frac{\phi \rho_p C_{p_p} + (1-\phi)(\rho_{bf} \times C_{p_{bf}})}{\rho_{nf}} \) (8) |

3. Results

As shown in Figure 2 (b), a relationship between thermal conductivity and the increment of temperature is studied. From the graph, it shows the thermal conductivity of distilled water, and the x-axis shows the increment of temperature from 0 °C to 40 °C.

![Figure 2](image_url)

**Figure 2.** Relationship of Thermophysical Properties of the Distilled Water and Temperature

What we can explain from this graph is that as the temperature increased, the thermal conductivity is also gradually increased. This increment is because of the increment of the temperature of the distilled water it will change the property characteristic of the substance as from the empirical formula studied from Popiel and Wojtkowiak relations [5].

Figures 2 (a), 2 (c) and 2 (d), show the density, dynamic viscosity, specific heat of distilled water variation of as the temperature increases from 0 °C to 40 °C. This data is important to the study of the heat transfer coefficient for base fluid (distilled water).

Tables 4 shows the calculation result of heat transfer coefficient and mass flow rate for base fluid. The bulk mean temperature was 22 °C. Noted that, while conducting the experiment, all piping surfaces were insulated, excluding the cooling coils to prevent heat exchange processes at the unnecessary area.

| Table 4. Summary of heat transfer coefficient, mass flow rate and heat transfer rate for water when bulk mean temperature \( (t_b) = 22 °C \) |
|---------------------------------------------------------------|
| **Base fluid** | **Coefficient of heat transfer (h) W/m².°C** | **Mass flow rate (m) ** | **Heat transfer rate (Q) ** |
|---------------------------------------------------------------|
| ![Chart](chart_url) |
| ![Chart](chart_url) |
As shown in Figure 3 (b), a relationship between thermal conductivity and the increment of temperature is studied. From the graph, it shows the thermal conductivity of nano-fluid (CuO/water), and the x-axis shows the increment of temperature from 0 °C to 40 °C.

![Graph](image)

**Figure 3.** Variation in the Thermophysical Properties of Nano-fluids (CuO/Distilled Water) with Temperature for Constant Volume Concentrations

What we can explain from this graph is that as the temperature increased this lead to a significant increase in thermal conductivity. This increment is because of the increment of the temperature of nano-fluid it will change the property characteristic of the substance as from the empirical formula studied, from Li and Peterson formula [5].

Figures 3(a), 3(c) and 3(d), show the density, dynamic viscosity, specific heat of (CuO/distilled water) variation of as the temperature increases from 0 °C to 40 °C. This data is important to the study of the heat transfer coefficient for base fluid (CuO/distilled water).

Table 5 shows the calculation result of heat transfer coefficient and mass flow rate for nano-fluid. The bulk mean temperature was 23.5 °C. Noted that, while conducting the experiment, all piping surfaces were insulated, excluding the heat exchanger to prevent heat exchange processes at the unnecessary area.

| Nano-fluid                | Coefficient of heat transfer (h) W/m²°C | Mass flow rate (m) | Heat transfer rate (Q) |
|---------------------------|----------------------------------------|--------------------|------------------------|
| CuO/distilled water       | 3088.2                                 | 0.0081 kg/sec      | 4794 W                 |

4. Discussions

Comparison of thermophysical properties for water and CuO/distilled water:

Figure 4 (a) shows the variation of densities of water and CuO/distilled water for different temperatures. This graph indicates that as the temperature increases, there is a decrease in density of nano-fluid (CuO/distilled water); also there is a decrease in density of water. The graph also shows that the density of nano-fluid (CuO/distilled water) is higher than the density of water.
Figure 4: Comparison of Thermophysical Properties of (Distilled Water) and (CuO/Distilled Water) with Different Temperature

Figure 4(b) shows the increment comparison thermal conductivities of water and CuO/distilled water (0.27 vol.% concentration at different temperatures). This graph indicates that as the temperature increases, there is a significant increase in thermal conductivity of nano-fluid (CuO/distilled water), while there is a slight increase in thermal conductivity of water. This significant increase in thermal conductivity of nano-fluid was due to the presence of nanoparticles (CuO) dispersed in water.

Figure 4(c) shows the dynamic viscosity variation of water and nano-fluid. This graph indicates that as the temperature increases, there is a decrease in dynamic viscosity of nano-fluid; also there is a decrease in dynamic viscosity of water. The graph also shows that dynamic viscosities of nano-fluid and water are close to each other.

Figure 4(d) shows the variation of specific heats of distilled water and nano-fluid at different temperatures. It is noted that as the temperature increases, there is a decrease in specific heat of nano-fluid; also there is a decrease in specific heat of distilled water. The graph also shows that the specific heat of distilled water is higher than the specific heat of nano-fluid.

Comparison of calculations for water and CuO/distilled water:

Table 6 shows the calculation results of head loss, pressure drop, heat transfer coefficient, mass flow rate and heat transfer rate for nano-fluid (CuO/distilled water) and water. When the average temperature was 22 °C of water and the bulk mean temperature was 23.5 °C of nano-fluid (CuO/distilled water). It shows that there are improvements in heat transfer coefficient and heat transfer rate of (CuO/distilled water), while there is a slight increment in pressure drop, compared to that for (distilled water).

| Types                  | (distilled water) | (CuO/distilled water) |
|------------------------|-------------------|-----------------------|
| Total head loss (m)    | 5.15              | 4.96                  |
| Total pressure drop (kPa) | 50.40921      | 50.77806              |
| Heat transfer coefficient ( W/m²·°C) | 704.8        | 3088.2                |
| Mass flow rate (kg/s)  | 0.008             | 0.0081                |
| Heat transfer rate (kW) | 1.632           | 4.794                 |

Comparison of non-dimensional values for distilled water and CuO/distilled water:
Table 7 shows the calculation results of non-dimensional for nano-fluid and base fluid. When the bulk mean temperature was 22 °C of base fluid (distilled water) and the average temperature was 23.5 °C of nano-fluid (CuO/distilled water). We note that there is an increase in Reynolds number and Nusselt number of (CuO/distilled water), while the Prandtl number and Peclet number are decreasing comparatively with (distilled water).

Table 7. Results of non-dimensional values for water and (CuO / water)

| Types           | (distilled water) $t_b= 22^\circ$C | (CuO/distilled water) $t_b= 23.5^\circ$C |
|-----------------|-------------------------------------|------------------------------------------|
| Reynolds number | 2121.3                              | 2213                                     |
| Prandtl number  | 6.6                                 | 5.6                                      |
| Peclet number   | 14000                               | 12378                                    |

5. Conclusions
The heat transfer rate for base fluid (distilled water) and nano-fluid (CuO/distilled water) flowing in cooling coils was investigated. It is found that the heat transfer rate improvement is attained by using 50 nm diameters of nanoparticles dispersed in distilled water with volume concentrations of 0.27 % of nano-fluid (CuO/distilled water) used in cooling coils when processed under the laminar flow. Results showed the following:
1- The thermal conductivity of CuO/distilled water nano-fluid improved 5.83 % compared to distilled water.
2- The heat transfer coefficient of CuO/distilled water nano-fluid improved 61.888 % compared to distilled water.
3- The heat transfer rate of CuO/distilled water nanofluid improved 49 % compared to distilled water.
4- The Nusselt number of CuO/water nano-fluid increased 25.7 % compared to distilled water.

References
[1] Y. Li, J. Zhou, S. Tung, E. Schneider and SH. Xi. A review on development of nanofluid preparation and characterization. Powder Technology, 196, 89. (2009).
[2] S.U.S. Choi, D.A. Singer and H.P. Wang. Development and application of non-Newtonian flows. ASME, New York, vol. FED 231, p.99. (1995).
[3] N. A. Bin-Abdun., Z. M. Razlan, A. B. Shahriman, K. Wan, D. Hazry, S. F. Ahmed "Base fluid in improving heat transfer for EV car battery" (AIP Conference, 2015), 090036. http://doi.org/10.1063/1.4915880
[4] K.V. Wang and O. Leon, Applications of nanofluids: current and future. Adv. Mech. Eng., 1-11. (2010).
[5] C. O. Papiel, and J. Wojtkowiak, Simple Formulas for Thermophysical Properties of Liquid Water for Heat Transfer Calculations (from 0°C to 150°C). Heat Transfer Engineering, 19(3), 87-101. (1998, January).
[6] C. H. Li, G. P. Peterson. Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). Journal of Applied Physics, 99(08), 084314. (2006).
[7] J. F. Brady, The Einstein viscosity correction in n dimensions. Int. Journal multiphase flow, 10(I), 113–114. (1984).
[8] B. C. Pak and Y. I. Cho. Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles. Experimental Heat Transfer, 11(2), 151-170. (1998, April).

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