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# The Use of Nanofluids in Domestic Water Heat Exchanger

*Y. K. Lee*
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.
*y.keen.01@gmail.com*

**Abstract** – *Recent development of nanotechnology has led to the concept of using suspended nanoparticles in heat transfer fluids to improve the heat transfer properties of the base fluids. The heat transfer enhancement by nanofluids is the significant concern in the efficiency of domestic water heat exchanger system. A computational investigation of the heat transfer in a domestic water heat exchanger was conducted on the water and water-based nanofluids. Copper (Cu) nanoparticle and alumina ($Al_2O_3$) nanoparticles were selected in the water-based nanofluids. Volume fraction of nanoparticle in the nanofluids was set at 0.5 %, 1.0 %, 1.5 %, 2.0 %, 2.5 %, and 3.0 %. The density, thermal conductivity, and dynamic viscosity of the water-based fluid increased, while the specific heat capacity of the water-based fluid decreased with the addition of copper, as well as alumina nanoparticles. The addition of copper nanoparticle into the water-based heat transfer fluid increases the domestic hot water temperature significantly. The efficiency of domestic water heat exchanger system was optimum when 1.5 % copper or alumina nanoparticles was added into the water-based heat transfer fluid.* 

**Keywords:** Domestic water heat exchanger, Nanofluids, Heat transfer fluids, Heat pump domestic water heating system

## 1.0 INTRODUCTION

The recent development of nanotechnology has led to the concept of using suspended nanoparticles in heat transfer fluids to improve the heat transfer coefficient of the base fluids. Most studies done on the nanofluids in heat transfer systems such as the heat exchangers recently have reported that the presence of nanoparticles in heat transfer fluids increased the effectiveness of thermal conductivity of the heat transfer fluids and consequently enhanced the heat transfer characteristics of the heat transfer system. Since metals in solid form have much higher thermal conductivity than fluids, the idea of using metallic particles to increase the thermal properties of the heat transfer fluids been proposed. Nanofluids with appropriate selection of the base fluid type, as well as appropriate selection of the nanoparticles in terms of material, size, shape, and concentration in the base fluid, can perform much better coolant than the conventional heat transfer fluids.

The heat transfer phenomena of nanofluids in heat exchanger are still not fully understood yet. Thus, nanofluids are the plausible solution for the heating challenge in the domestic water heat exchanger system. Nanofluids consisting of metallic particles in the fluids are considered to have a great potential for the heat transfer enhancement. Hence, nanofluids are considered to have high suitability for the application in the practical heat transfer processes. The heat

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transfer enhancement by nanofluids is a significant concern in the efficiency of domestic water heat exchanger system in the present study.

The main objective in the present study is to conduct a computational investigation of the heat transfer in a domestic water heat exchanger. Therefore, the heat transfer enhancement by different types of water-based nanofluids was investigated in the present study. This research is aimed to compare the computational results of the thermal conductivity and the heat transfer capabilities of water and water-based nanofluids in a domestic water heat exchanger system. Hence, the efficiency of the domestic water heat exchanger system was analysed in this research.

This present study is limited to the water-based nanofluids with single-phase model. Due to the extreme size and the low concentration of the suspended nanoparticles, the nanoparticles are assumed to move with the same velocity as the base fluid. The wall of the domestic water heat exchanger tank is insulated and therefore, the wall conditions are assumed in an adiabatic boundary condition. The wall of the domestic water heat exchanger tank is assumed smooth, and the roughness of the wall is negligible. The nanofluids proposed in the domestic water heat exchanger system of this present study are Newtonian. The heat transfer of the computational models is considered as a steady state process. The radiative and gravitational effects are considered as negligible in the computational models. By considering the local thermal equilibrium, the nanoparticle–liquid mixture may then be approximately considered to behave as a conventional single-phase homogenous fluid with properties that are to be evaluated as the functions of those of the constituents. Water was selected as the base fluid in the domestic water heat exchanger system. Copper (Cu) and Alumina ($Al_2O_3$) nanoparticles were selected in the water-based nanofluid. Volume fraction of nanoparticle in the nanofluid was set at 0.5 %, 1.0 %, 1.5 %, 2.0 %, 2.5 %, and 3.0 % in the domestic water heat exchanger system.

Heat exchanger has been invented for transferring heat from one medium to another medium in many heat transfer systems, but it is not limited to the air-conditioning condensers, refrigeration evaporators, power plant combustion engines, petroleum refineries, and car radiators. Heat exchanger is also applicable in domestic water heaters. Shell and tube heat exchanger is the most common type of heat exchanger that is widely used in industry. Shell and tube heat exchanger consists of a shell with a bundle of tubes. The shell is a large pressure vessel that comprises a bundle of tubes inside the vessel. Parallel-flow arrangement can be designed for the shell and tube heat exchanger, in which the two fluids enter the heat exchanger at the same end and travel in parallel to one another to the other side of the heat exchanger. A circulating fluid flows through the tubes while another circulating fluid flows through the shell to transfer heat between the two fluids, either from the tube side to the shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side of the heat exchanger.

Domestic water heating system using heat pump is a promising technology in both residential and commercial applications due to the use of same mechanical principles as refrigerators and air conditioners. Heat pump takes heat from the environment and concentrates it to heat the domestic water to be used in either domestic hot water or space heating applications [1]. Heat pump domestic water heating system consists of domestic water heat exchanger, heat pump, circulator, piping and valves. The domestic water heat exchanger absorbs the heat from the heat pump and then transfers the heat into the domestic water system. Heat pump is one of the energy sources that can be collected from the waste heat by the refrigeration cycle or the ambient air. Various heat pumps are available to be used for the domestic water heating system, e.g. the air-source heat pumps, ground-source heat pumps, solar-assisted heat pumps, direct-

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expansion solar-assisted heat pumps, integrated solar-assisted heat pumps, gas engine driven heat pumps, and multi-function heat pumps [2]. Domestic water is drawn from water main and then flows into the heat exchanger coil. Heat transfer fluid is drawn from heat pump and then circulates in the heat exchanger tank. The domestic water is transferred from lower temperature to higher temperature. On the other hand, the heat transfer fluid is transferred from higher temperature to lower temperature. The heat transfer process occurs between the domestic water and the heat transfer fluid in the heat pump domestic water heating system.

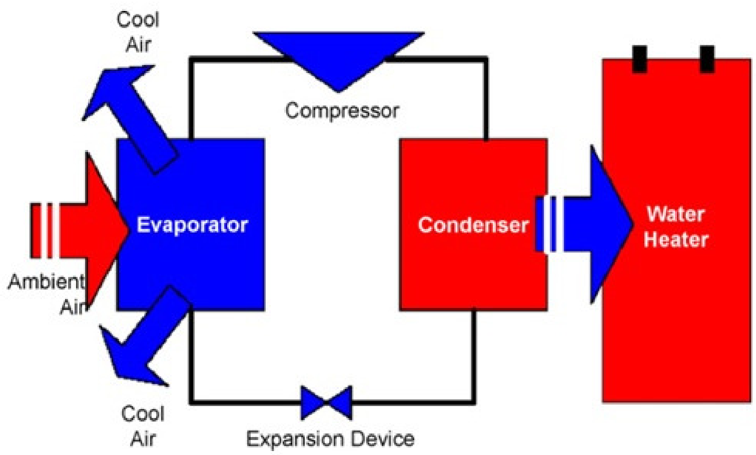


**Figure 1:** A schematic of domestic water heating system [1].

Maxwell [3] was the one originally proposed the idea of using metallic particles to increase the thermal properties of heat transfer fluids by knowing the fact that metals in solid form have much higher thermal conductivity than the base fluids. Mapa and Mazhar [4] tested the effect of nanofluids in the mini heat exchanger, and they concluded that the nanofluids enhanced the heat transfer rate of the mini heat exchanger, and stated that the presence of the nanoparticles reduced the thermal boundary layer thickness [4]. Pawel et al [5] concluded that experiments on the nanofluids have indicated a significant increase in the thermal conductivity compared to the liquids without nanoparticles or larger particles, and the extent of thermal conductivity enhancement sometimes greatly exceeded the predictions of well-established theories. Pawel et al [5] also reported that the increment of thermal conductivity depends greatly on the features of nanoparticles such as high particle mobility and large surface-to-volume ratio. Jongwook and Zhang [6] reported that the nanofluid technology has been studied and developed by many research groups worldwide. The effects of the particle volume concentration, particle material, particle size, particle shape, base fluid material, temperature, additive, and acidity on the heat transfer enhancement have been investigated experimentally by multiple research groups. In an experimental analysis done by Heris et al. [7], the heat transfer coefficient increased with an increasing Peclet number, as well as increasing volume fraction, and alumina-water based nanofluids showed larger enhancement than the copper oxide water-based nanofluids. Heris [8] reported that more heat transfer enhancement, as high as 40%, was observed with alumina particles, while the thermal conductivity enhancement was less than 15%. In addition, Heris et al [7] concluded on his experimental investigation that the heat transfer enhancement by the nanofluids depends on the increment of thermal conductivity. Sadik and Anchasa [8] highlighted that nanofluids significantly improved the heat transfer capability of conventional heat transfer fluids such as oil or water by suspending nanoparticles in these base liquids. In another experimental analysis done by Farajollahi et al. [9], the heat transfer of the nanofluids in a shell and tube heat exchanger was studied. Farajollahi also reported that the addition of

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nanoparticles to the base fluid enhanced the heat transfer performance and increased the heat transfer coefficient of the base fluid [9]. He concluded that the γ–$Al_2O_3$/water and $TiO_2$/water nanofluids have proven that the heat transfer characteristics of the nanofluids improved significantly, while the addition of nanoparticles to the base fluid enhanced the heat transfer performance and results in a larger heat transfer coefficient than that of the base fluid. Saidu et al [10] reported that the use of the nanofluids in the heat exchanger, which operates under the laminar conditions, will be more advantageous than under the turbulent conditions. Gabriela [11] investigated the heat transfer characteristics in double tube helical heat exchangers using nanofluids and reported that the use of CuO and TiO2 nanoparticles dispersed in water can significantly enhance the convective heat transfer in the laminar flow regime, and the enhancement increased with the Dean Number, as well as the particle concentration level. Soleimani et al [12] reported that the velocity components increased with an increase of the nanoparticles volume fraction, which enhanced energy transport within the nanofluids. They also explained that the addition of the high thermal conductivity nanoparticles increased the conduction and enhanced the effectiveness of heat transfer [12].

The concept of nanofluids is the idea of using nanometer-sized particles to create stable and highly conductive suspensions, primarily for suspension stability. Nanofluids are solid-liquid composite materials, in which the engineered fluids (i.e. composite) consisting of suspended nanoparticles (i.e. solid) with an average size below 100 nm in conventional heat transfer fluids (i.e. liquid). Nanofluids are dilute suspensions of the nanoparticles that have superior properties like high thermal conductivity, minimal clogging in the flow passage, reduced pumping power, long term stability and homogeneity [10]. Therefore, nanofluids have a wide range of potential application where improved heat transfer is required. The two important elements of the nanofluids are the nanoparticle material types and the base fluid types. Nanoparticles used in the nanofluids have been made of various materials, such as oxide ceramics ($Al_2O_3$, CuO), metals (Cu), and semiconductors ($TiO_2$). The thermophysical properties of solid particles are shown in Table 1. The common base fluids are water, ethylene glycol, and oil. The thermal conductivity of the nanoparticle materials, either metallic or non-metallic, is typically higher than the base fluids, thus results in a significant increase in the heat transfer coefficient. Hence, effective thermal conductivity of nanofluids is expected higher than base fluids. The thermophysical properties of the base fluids are shown in Table 2.

**Table 1:** Thermal properties of nanofluids. [13]

| | $Al_2O_3$ | CuO | Cu | $TiO_2$ |
|---|---|---|---|---|
| Specific heat capacity, cp (J/kgK) | 773 | 551 | 385 | 692 |
| Density, ρ (kg/m3) | 3,960 | 6,000 | 8,940 | 4,250 |
| Thermal conductivity, k (W/mK) | 40 | 33 | 401 | 8.4 |

**Table 2:** Thermophysical properties of base fluids. [14]

| | Water | Ethylene Glycol |
|---|---|---|

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| | | |
|---|---|---|
| Specific heat capacity, $c_p$ (J/kgK) | 4,179 | 2,090 |
| Density, ρ (kg/m3) | 997.1 | 1,113.2 |
| Thermal conductivity, k (W/mK) | 0.613 | 0.253 |

Nanofluids can be produced by either the single-step or two-step production methods. The single-step production method involves condensing e nanopowders from the vapor phase directly into a flowing low-vapor pressure liquid. As such, the nanoparticles are made by either using physical vapour deposition (PVD) technique or liquid chemical method, and then dispersed in the liquid simultaneously [15,16]. The two-step production method first involves the production of nanoparticles and then mixed with the base fluids. In the two-step production method, the nanoparticles can be produced either by using the inert gas condensation (IGC), mechanical grinding, chemical vapour deposition (CVD), chemical precipitation, microemulsions, thermal spray, or spray pyrolysis [15,16]. As nanopowders are commercially available nowadays, the two-step production method is more extensively used to produce nanofluids. Nevertheless, the issue of stabilization of the nanoparticle suspensions in the base liquid is still a concern in the production of nanofluids. The stability of nanofluids can be determined using the sedimentation photograph method and zeta potential analysis method. The most important factors in determining the stability of nanoparticle suspensions are its concentration, the dispersant, viscosity of base fluid, PH value, diameter, density and duration of ultrasonic vibration [17]. The addition of surface active agents and the control of liquid PH are used to overcome this stabilization issue of nanoparticle suspensions in the base liquid. Salt and oleic acid were used as the stabilizers to increase the stability of copper-oil based nanofluids and copper-water based nanofluids [17].

## 2.0 RESEARCH METHODOLOGY

The main objective of this research is to conduct a computational investigation of the heat transfer in a domestic water heat exchanger. The heat transfer enhancement by different types of water-based nanofluids as the heat transfer fluids was investigated. The computational results, the heat transfer capabilities of the water and the water-based nanofluids in the domestic water heat exchanger system, as well as the efficiency of the domestic water heat exchanger system were analyzed and compared. A domestic water heat exchanger was modeled by a three-dimensional modeling software SolidWorks version 2012. A domestic water heat exchanger was then analyzed by the add-ins of flow simulation of SolidWorks version 2012. The research parameters were selected to establish the measurement of the temperature of the hot water produced by the domestic water heat exchanger.

The temperature dependency of different physical properties of the heat transfer fluids has been considered to improve the accuracy of the calculations. There are a number of well-known correlations for calculating the thermophysical properties of the nanofluids, which are often cited by many researchers. The density and effective specific heat capacity of the nanofluid can be calculated based on the volume fraction of the nanoparticle and the heat capacity concept [3,18].

$$\rho_{uf} = (1-\phi)\rho_{bf} + \phi\rho_{np} \tag{1}$$

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$$\left(\rho C_p\right)_{nf} = (1-\phi)(\rho\beta)_{bf} + \phi(\rho\beta)_{np} \tag{2}$$

The properties such as thermal expansion coefficient and thermal diffusivity of the nanofluid can be calculated using the following equations [19].

$$(\rho\beta)_{nf} = (1-\phi)(\rho\beta)_{bf} + \phi(\rho\beta)_{np} \tag{3}$$

$$\alpha_{nf} = \frac{k_{nf}}{\left(\rho C_p\right)_{nf}} \tag{4}$$

The effective dynamic viscosity of the nanofluid can be calculated from the following equation [12]. The selected model of effective dynamic viscosity of the nanofluid is referred from the Brinkman's model, which is one of the earliest models used to obtain the dynamic viscosity for the nanofluid [19].

$$\mu_{nf} = \frac{\mu_{nf}}{(1-\phi)^{2.5}} \tag{5}$$

The effective thermal conductivity of the nanofluid can be calculated from the following equation [3,19]. The effective thermal conductivity of the nanofluid can be calculated using the Maxwell model as above because the effective thermal conductivity of the nanofluid relies on the thermal conductivity of the nanoparticles, base fluid and volume fraction of the nanoparticles.

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} - 2\phi\left(k_{bf} - k_{np}\right)}{k_{np} + 2k_{bf} - \phi\left(k_{bf} - k_{np}\right)} \tag{6}$$

Water was selected to flow within the coils in order to produce the hot water from the domestic water heat exchanger. Water and water-based nanofluids were selected to flow within the domestic water heat exchanger tank as the heat transfer fluid. The thermal conductivity of the common heat transfer liquids and solids of metal and metal oxide was compared and is shown in the Fig. 2. Since water has the best thermal conductivity, it was selected as the base fluid of the nanofluids in the present study. On the other hand, copper and alumina were selected as the nanoparticles of the nanofluids in the present study.

The density of the nanofluids can be estimated the Eq. 1, which is based on the nanoparticle volume fraction. The density of water is 982.86kg/m$^3$, the density of copper is 8940.00 kg/m$^3$ and the density of alumina is 3960.00 kg/m$^3$.

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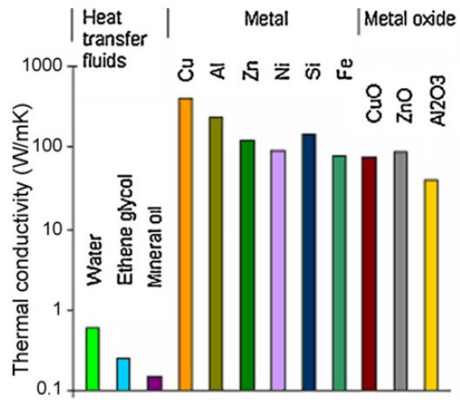


**Figure 2:** Comparison of the thermal conductivity of common heat transfer liquids and solids of metal and metal oxide. [15]

**Table 3:** Density of the nanofluids.

| Water-based Nanofluids | Density ($kg/m^3$) |
|---|---|
| 0.5% Copper | 1022.65 |
| 1.0% Copper | 1062.43 |
| 1.5% Copper | 1102.22 |
| 2.0% Copper | 1142.00 |
| 2.5% Copper | 1181.79 |
| 3.0% Copper | 1221.57 |
| 0.5% Alumina | 997.75 |
| 1.0% Alumina | 1012.63 |
| 1.5% Alumina | 1027.52 |
| 2.0% Alumina | 1042.40 |
| 2.5% Alumina | 1057.29 |
| 3.0% Alumina | 1072.17 |

**Table 4:** Specific heat capacity of the nanofluids.

| Water-based Nanofluids | Specific Heat Capacity (J/kgK) |
|---|---|
| 0.5% Copper | 3904.91 |
| 1.0% Copper | 3756.07 |
| 1.5% Copper | 3617.98 |
| 2.0% Copper | 3489.51 |
| 2.5% Copper | 3369.69 |
| 3.0% Copper | 3257.67 |
| 0.5% Alumina | 4000.46 |
| 1.0% Alumina | 3937.03 |
| 1.5% Alumina | 3875.45 |
| 2.0% Alumina | 3815.62 |
| 2.5% Alumina | 3757.48 |
| 3.0% Alumina | 3700.95 |

The effective specific heat capacity of the nanofluids can be estimated from Eq. 7, which is based on the volume fraction of the nanoparticle and the heat capacity concept. The specific

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heat capacity of the water is 4065.80 J/kgK, the specific heat capacity of copper is 385 J/kgK and the specific heat capacity of Alumina is 773 J/kgK.

$$\left(C_p\right)_{nf} = \frac{(1-\phi)\left(\rho C_p\right)_{bf} + \phi\left(\rho C_p\right)_{np}}{\rho_{nf}} \tag{7}$$

The effective dynamic viscosity of the nanofluids can be estimated from Eq. 5, which is based on the volume fraction of the nanoparticles and dynamic viscosity concept. The dynamic viscosity of the water is 0.000454 Pa.s.

**Table 5:** Dynamic viscosity of the nanofluids.

| Water-based Nanofluids | Dynamic Viscosity (Pa.s) |
|---|---|
| 0.5% Copper | 0.000460 |
| 1.0% Copper | 0.000466 |
| 1.5% Copper | 0.000471 |
| 2.0% Copper | 0.000478 |
| 2.5% Copper | 0.000484 |
| 3.0% Copper | 0.000490 |
| 0.5% Alumina | 0.000460 |
| 1.0% Alumina | 0.000466 |
| 1.5% Alumina | 0.000471 |
| 2.0% Alumina | 0.000478 |
| 2.5% Alumina | 0.000484 |
| 3.0% Alumina | 0.000490 |

The effective thermal conductivity of the nanofluids can be estimated based on the volume fraction of the nanoparticles and thermal conductivity concept. The thermal conductivity of the water is 0.6541 W/mK, the specific heat capacity of copper is 401.0000 W/mK and the specific heat capacity of alumina is 40.0000 W/mK.

**Table 6:** Thermal conductivity of the nanofluids.

| Water-based Nanofluids | Thermal Conductivity (W/mK) |
|---|---|
| 0.5% Copper | 0.6639 |
| 1.0% Copper | 0.6738 |
| 1.5% Copper | 0.6838 |
| 2.0% Copper | 0.6939 |
| 2.5% Copper | 0.7042 |
| 3.0% Copper | 0.7145 |
| 0.5% Alumina | 0.6635 |
| 1.0% Alumina | 0.6730 |
| 1.5% Alumina | 0.6825 |
| 2.0% Alumina | 0.6922 |
| 2.5% Alumina | 0.7020 |
| 3.0% Alumina | 0.7118 |

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The mass flow rate of the nanofluids can be estimated from Eq. 8 based on the density of the nanofluids and volumetric flow rate. The volumetric flow rate of heat transfer fluids is set at 0.03 $m^3/s$. The mass flow rate of the water is 29.4858 kg/s.

$$m_{nf} = \rho_{nf} \times Q \quad (8)$$

The boundary conditions of the domestic water heat exchanger tank are identified as the temperature of the water inlet and the refrigerant inlet, as well as the volumetric flow rate of the water outlet and the refrigerant outlet from the domestic water heat exchanger tank. The water inlet and water outlet are the boundaries of the domestic water heat exchanger coil.

**Table 7:** Mass flow rate of the nanofluids.

| Water-based Nanofluids | Mass Flow Rate (kg/s) |
|---|---|
| 0.5% Copper | 30.6795 |
| 1.0% Copper | 31.8729 |
| 1.5% Copper | 33.0666 |
| 2.0% Copper | 34.2600 |
| 2.5% Copper | 35.4537 |
| 3.0% Copper | 36.6471 |
| 0.5% Alumina | 29.9325 |
| 1.0% Alumina | 30.3789 |
| 1.5% Alumina | 30.8256 |
| 2.0% Alumina | 31.2720 |
| 2.5% Alumina | 31.7187 |
| 3.0% Alumina | 32.1651 |

A domestic water heat exchanger coil was designed to draw the domestic water gravitationally from the domestic water storage tank at a working temperature of 300.15 K. On the other hand, the refrigerant inlet and the refrigerant outlet are the boundaries of the domestic water heat exchanger tank. The domestic water heat exchanger tank was designed to draw the refrigerant from the heat pump at a working temperature of 60 ºC (or 333.15 K). The volumetric flow rate of the water outlet and the refrigerant outlet are also part of the boundary conditions of the domestic water heat exchanger tank. The water outlet was set at a volumetric flow rate of 0.02 $m^3/s$. On the other hand, the refrigerant outlet was set at a volumetric flow rate of 0.03 $m^3/s$.

The data of the boundary conditions defined in this computational analysis is referred to the current plumbing design practiced in the building industry of Malaysia and Singapore. The domestic water heat exchanger was designed to produce hot water of 333.15 K from a normal water supply of 330.15 K by the heat recovery process or the thermal stratification process. The computational analysis of the water outlet and the refrigerant outlet temperatures modeled by SolidWorks were verified against the current plumbing design used in the building industry. The accuracy of the hot water temperature analyzed by SolidWorks model was approximately ± 3.23 K or 99.03 %.

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## 3.0 RESULTS AND DISCUSSIONS

SolidWorks modeling software computes the water leaving temperature and refrigerant leaving temperature from the domestic water heat exchanger. The results of the water leaving temperature and refrigerant leaving temperature, as well as the effects of different base fluids, different nanoparticles and the concentration of nanoparticle are discussed.

**Table 8:** Temperature of the heat transfer fluids at the refrigerant outlet.

| Type of Heat Transfer Fluids | Temperature (K) |
|---|---|
| Water | 325.8451 |
| 0.5% Copper Water-based Nanofluid | 325.7977 |
| 1.0% Copper Water-based Nanofluid | 325.9387 |
| 1.5% Copper Water-based Nanofluid | 326.3259 |
| 2.0% Copper Water-based Nanofluid | 326.0117 |
| 2.5% Copper Water-based Nanofluid | 325.5986 |
| 3.0% Copper Water-based Nanofluid | 325.3945 |
| 0.5% Alumina Water-based Nanofluid | 326.0040 |
| 1.0% Alumina Water-based Nanofluid | 326.1586 |
| 1.5% Alumina Water-based Nanofluid | 326.4523 |
| 2.0% Alumina Water-based Nanofluid | 326.1867 |
| 2.5% Alumina Water-based Nanofluid | 325.8864 |
| 3.0% Alumina Water-based Nanofluid | 325.6777 |

Water, copper and alumina water-based nanofluids have been focused in this computational investigation. Furthermore, this computational investigation focuses on the different volume fraction of the nanoparticles, which are 0.5 %, 1.0 %, 1.5 %, 2.0 %, 2.5 %, and 3.0 % of nanoparticles within the base fluids. The results of the refrigerant outlet temperature and = water outlet temperature for different heat transfer fluids used in the domestic water heat exchanger are tabulated in Table 8 and Table 9 respectively.

The density, specific heat capacity, dynamic viscosity, thermal conductivity and mass flow rate of the nanofluids were compared against the base fluid and are illustrated in Figs. 3-7 respectively.

The addition of copper or alumina nanoparticles in the water-based fluid leads to the increment of the density, dynamic viscosity, and thermal conductivity of the heat transfer fluid. However, the specific heat capacity of the water-based fluid reduced with the addition of copper and alumina nanoparticles.

**Table 9:** Temperature of the domestic water at the water outlet.

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| Type of Heat Transfer Fluids | Temperature (K) |
|---|---|
| Water | 336.3835 |
| 0.5% Copper Water-based Nanofluid | 336.6924 |
| 1.0% Copper Water-based Nanofluid | 337.4153 |
| 1.5% Copper Water-based Nanofluid | 337.8081 |
| 2.0% Copper Water-based Nanofluid | 338.1677 |
| 2.5% Copper Water-based Nanofluid | 338.7352 |
| 3.0% Copper Water-based Nanofluid | 338.8775 |
| 0.5% Alumina Water-based Nanofluid | 336.1640 |
| 1.0% Alumina Water-based Nanofluid | 336.5309 |
| 1.5% Alumina Water-based Nanofluid | 336.5874 |
| 2.0% Alumina Water-based Nanofluid | 336.6474 |
| 2.5% Alumina Water-based Nanofluid | 336.9254 |
| 3.0% Alumina Water-based Nanofluid | 337.0106 |

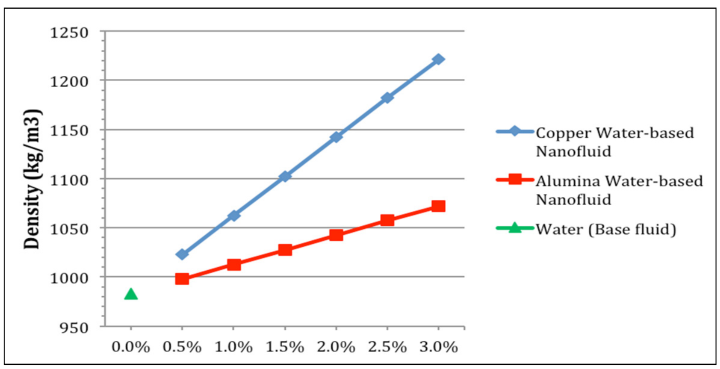


**Figure 3:** Density of heat transfer fluids

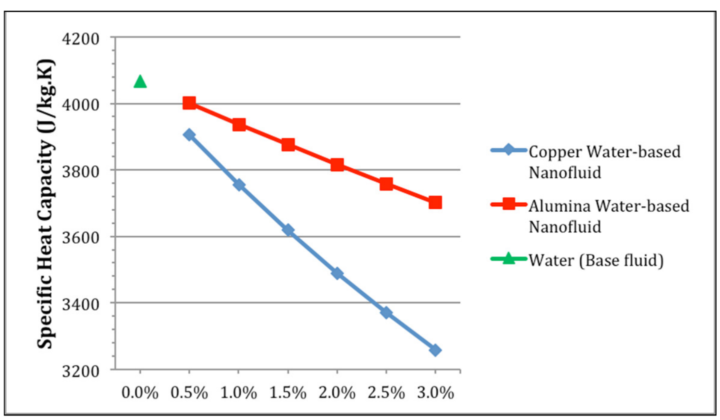


**Figure 4:** Specific heat capacity of heat transfer fluids.

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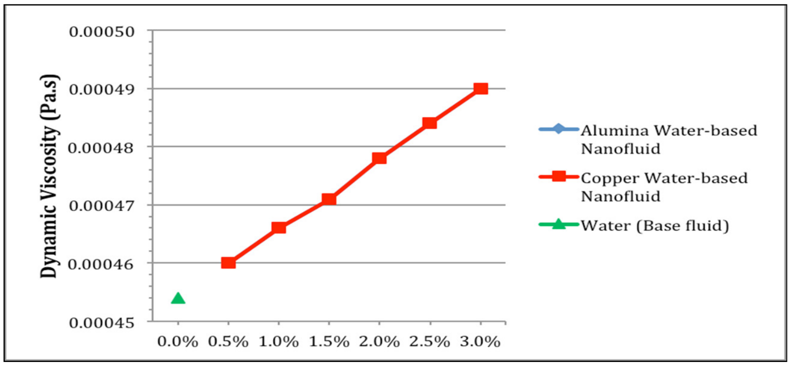


**Figure 5:** Dynamic viscosity of heat transfer fluids.

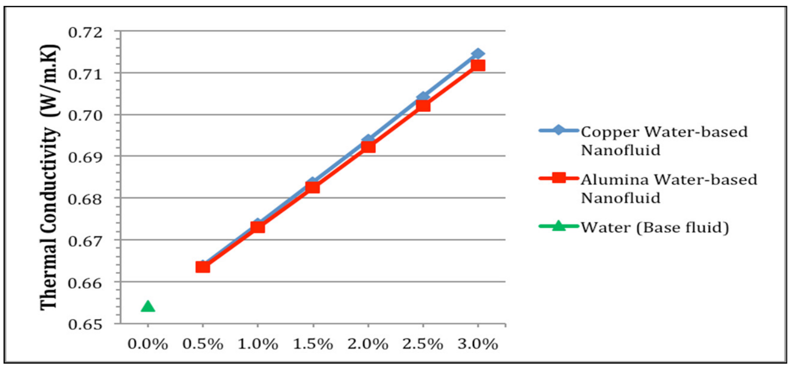


**Figure 6:** Thermal conductivity of heat transfer fluids.

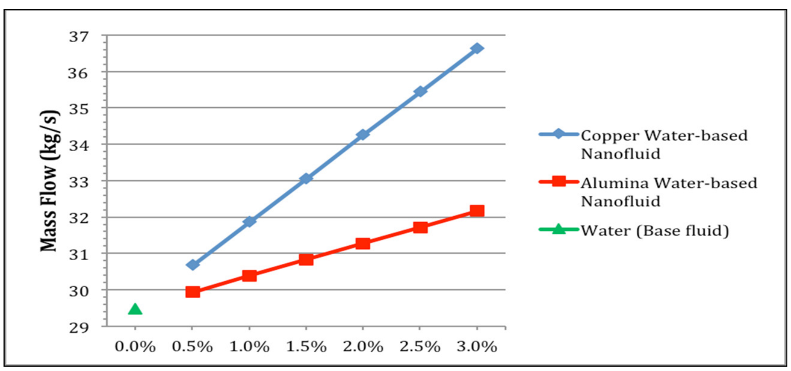


**Figure 7:** Mass flow of heat transfer fluids.

The efficiency of the domestic water heat exchanger can be estimated from Eq. 9. The temperature difference of the different heat transfer fluids and domestic water produced by the domestic water heat exchanger are presented in Table 10 and Table 11 respectively. Furthermore, the efficiency of the domestic water heat exchanger is illustrated in Fig. 8.

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$$\left.\begin{aligned} \eta &= \frac{Work\ done\ by\ domestic\ water\ heat\ exchanger}{Heat\ input\ in\ domestic\ water\ heat\ exchange} \\ \eta &= 1 - \frac{T_C}{T_H} \\ \eta &= 1 - \frac{(3y)_{n.x}}{(3y)_{v,w}} \end{aligned}\right\} \qquad (9)$$

From Table 11, it is shown that the water temperature from the domestic water heat exchanger's output with the use of copper water-based nanofluids is significantly higher than for the alumina water-based nanofluids. Water-based nanofluids with more than 1.0 % volume fraction of nanoparticles generally produced higher temperature of domestic water than for the water-based fluids. From Fig. 8, it is shown that the efficiency of domestic water heat exchanger is optimum when 1.5 % copper or alumina nanoparticles is added into the water-based heat transfer fluid.

**Table 10:** Temperature difference of the heat transfer fluids produced by the domestic water heat exchanger.

| Type of Heat Transfer Fluids | Temperature Difference (K) |
|---|---|
| Water | 4.1549 |
| 0.5% Copper Water-based Nanofluid | 4.2023 |
| 1.0% Copper Water-based Nanofluid | 4.0613 |
| 1.5% Copper Water-based Nanofluid | 3.6741 |
| 2.0% Copper Water-based Nanofluid | 3.9883 |
| 2.5% Copper Water-based Nanofluid | 4.4014 |
| 3.0% Copper Water-based Nanofluid | 4.6055 |
| 0.5% Alumina Water-based Nanofluid | 3.9960 |
| 1.0% Alumina Water-based Nanofluid | 3.8414 |
| 1.5% Alumina Water-based Nanofluid | 3.5477 |
| 2.0% Alumina Water-based Nanofluid | 3.8133 |
| 2.5% Alumina Water-based Nanofluid | 4.1136 |
| 3.0% Alumina Water-based Nanofluid | 4.3233 |

**Table 11:** Temperature difference of the domestic water produced by the domestic water heat exchanger.

| Type of Heat Transfer Fluids | Temperature Difference (K) |
|---|---|
| Water | 36.2335 |
| 0.5% Copper Water-based Nanofluid | 36.5424 |
| 1.0% Copper Water-based Nanofluid | 37.2653 |
| 1.5% Copper Water-based Nanofluid | 37.6581 |
| 2.0% Copper Water-based Nanofluid | 38.0177 |
| 2.5% Copper Water-based Nanofluid | 38.5852 |
| 3.0% Copper Water-based Nanofluid | 38.7275 |
| 0.5% Alumina Water-based Nanofluid | 36.0140 |
| 1.0% Alumina Water-based Nanofluid | 36.3809 |
| 1.5% Alumina Water-based Nanofluid | 36.4374 |
| 2.0% Alumina Water-based Nanofluid | 36.4974 |
| 2.5% Alumina Water-based Nanofluid | 36.7754 |
| 3.0% Alumina Water-based Nanofluid | 36.8606 |

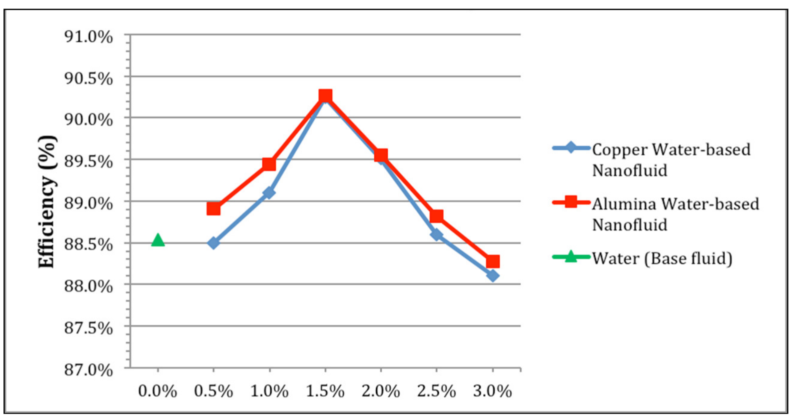


**Figure 8:** Efficiency of domestic water heat exchanger.

## 4.0 CONCLUSIONS AND RECOMMENDATIONS

The results from this computational investigation show that the efficiency of domestic water heat exchanger is optimum when 1.5 % copper or alumina nanoparticles is added into the water-based heat transfer fluid. The results also show that the addition of copper or alumina nanoparticles into the water-based heat transfer fluid increases the domestic hot water temperature. Copper nanoparticles significantly increase the domestic hot water temperature. The application of nanofluids as a strong candidate for enhancing the heat transfer in the domestic water heating system is found in the present study. Further research work in the same area is required to analyse the overall system effectiveness of using nanofluids in the domestic water heat exchanger. Therefore, it is recommended that the overall heat pump domestic water heating system to be investigated in the future. Heat pumps, in-line heaters or any possible heat source is also recommended to be included in the computational model for system simulation.

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