

The Effects of Nanofluid (Al_2O_3 /De-ionized Water) with Different Concentrations in Improving the Transportation of heat in Small Space

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Abstract. An experimental study on forced convective heat transfer and flow thermophysical properties of a nanofluid consisting of three various concentrations of Al_2O_3 nanofluids (0.13, 0.25 and 0.64%) vol.% and deionized water which flows in a cooling coil made of copper pipe (heat exchanger) under laminar flow conditions are investigated. The Al_2O_3 nanoparticles of 90 nm diameter are used in this study. Working fluid flow rate of 0.5 L/min to have the fully laminar regime ($1320.4 < \text{Re} < 1169.5$). The results demonstrate that the heat transfer coefficient of Al_2O_3 /deionized water nanofluid when concentration 0.64 vol.% is slightly higher than that of the deionized water alone at same conditions (inlet temperature and mass flow).

1. Introduction

Transportation of heat is one of the significant manufacturing processes. Traditional heat transfer working fluids like oil, ethylene glycol, water, etc, have not given enough performance for cooling systems because of their comparatively low thermal conductivity. It was noted that most recent research areas are interested in transport of heat improvement by forced convection, it has been already demonstrated that adding a nanoparticle to these traditional working fluids could improve their thermal performance, Wang et al (1999). Thence, the development of highly efficient working fluids is disbanding the disadvantages of traditional fluids has become one of the most significant priorities in the cooling systems.

2. Experimental Apparatus

As shown in figure 1, the experimental devices used includes working fluid flow lines (copper pipes), a centrifugal pump, a flowmeter, a tank of working fluids, two-water bath (one to control the working fluid temperature and another one is for controlling the heat sources temperature, i.e., the water tank that simulates the battery), two cooling coils (heat exchanger), data logger and twelve-thermocouples (K-type) were used for temperature measurement. The working fluid was pumped to the copper tube coils (heat exchanger) in the test compartment from a tank that the temperature was controlled by the first temperature bath. A water that the temperature was being controlled from the second temperature bath



was pumped toward tank (simulated battery) in the test compartment as the heat load of the battery. A heat exchange occurs in the test compartment and the temperature differences between the inlet and outlet of the working fluid flows were measured. The details of tested conditions were shown in table 1. Al_2O_3 /deionized water nanofluids had been prepared by two-step method so that dispersing Al_2O_3 nano-powder in deionized water and stirring the mixture for approximately 3-5 hrs, then the mixture was placed in an ultrasonic bath about than 8-12 h to complete the mixing processes.

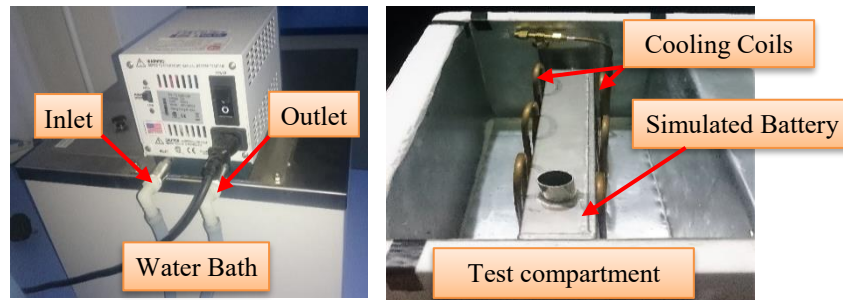


Figure 1. Design of Cooling System

The purpose of the conducted experiment is to study the heat exchange or heat removal rate from the simulated battery model to the working fluid inside the cooling coil for heat exchange rate enhancement. Utilizing de-ionized water and Al_2O_3 /deionized water as the working fluid for cooling system design.

Table 1. Specifications and test conditions

Elements	Specifications
Volume flow rate of the pump (Q)	0.5 L/min.
The surface area of copper tube (one coil) (A_{st})	0.0346 m ²
Cross-sectional area of copper tube (one coil) (A_{ci})	$1.9635 \times 10^{-5} \text{ m}^2$
length of one coil (L)	2.2 m
Number of coils (N)	2
The ambient temperature in the compartment	39 °C
Working fluid temperature in the tank	29 °C
Test compartment size	(0.435×0.27×0.07) m ³

3. Shape and Size Nanoparticles

It is necessary to investigate the nanoparticles size and shape, as spherical shape particles give higher thermal conductivity improvement from cylindrical particles Xie et al (2003). Wu et al (2010) proposed the Scanning Electron Microscope (SEM) was the used to study the shape, and size of nanoparticles. Deionized water was used as the base fluid. The nanoparticles (Al_2O_3 , 99.8% metals oxide) was purchased from US-Research Nanomaterial.

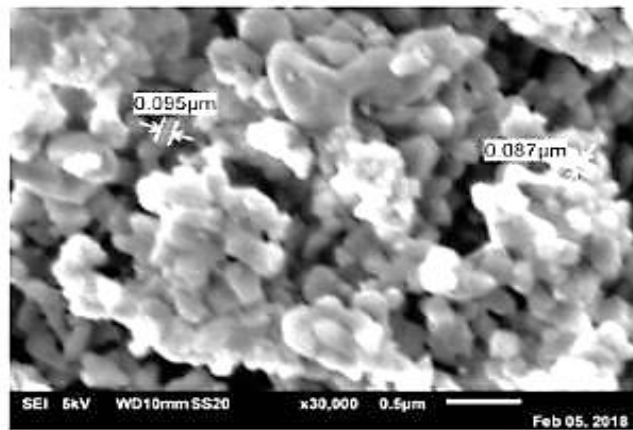


Figure 2. SEM image of dry Al_2O_3 nanoparticles

Figure 2, the SEM image of dry Al_2O_3 nanoparticles which shows the nanometre-sized (87-95nm), and most of the nanoparticles are spherical in shape.

4. Thermophysical Properties of Working Fluids

The values for thermophysical properties of the nano-fluid (Al_2O_3 /De-ionized Water) at different concentrations are taken at the average temperature of working fluid in cooling coils.

The density of Al_2O_3 /de-ionized water is the calculated values by using analytical models suggested by Pak and Cho (1998), while thermal conductivity, viscosity, and specific heat have been measured by using a KD2 Pro, viscometer (model LVDV- Pro, Brookfield Instruments) and differential scanning calorimetry(DSC) respectively.

4.1. Influence of particle concentrations and temperature on thermal conductivity

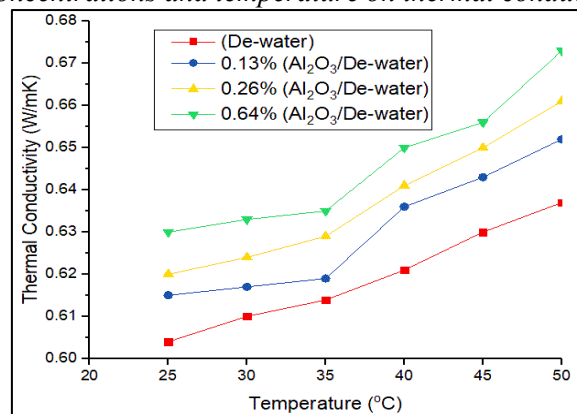


Figure 3. Influence of fraction concentration and temperature on Al_2O_3 /de-ionized water nanofluid thermal conductivity

Figure 3, it is noted that the thermal conductivity increments with increasing volume concentration and temperature. The measured thermal conductivity of 0.13%, 0.26% and 0.64% nanofluid at 50°C is 6.0%, 6.6% and 6.8% respectively higher than the nanofluid at 25°C. This is due to the high temperature, which resulting in the viscosity decreases.

4.2. Influence of particle concentrations and temperature on dynamic viscosity

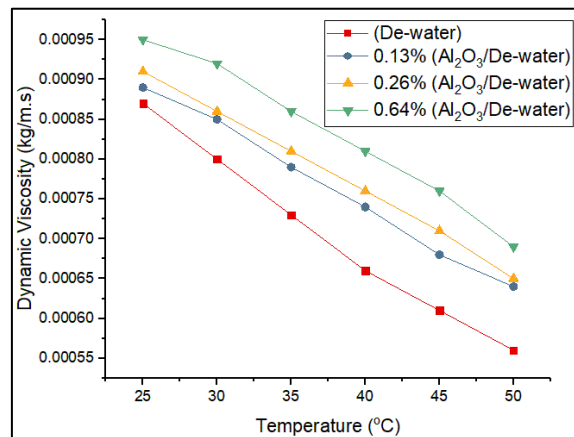


Figure 4. Influence of fraction concentration and temperature on Al₂O₃/de-ionized water nanofluid viscosity

Figure 4, shows the nanofluid (Al₂O₃/de-ionized water) viscosity decreases with increasing temperature. The 0.13% nanofluid at 50 °C is 39% lower than those at 25°C. The 0.26% and 0.64% nanofluid also show similar observation with 40% and 42% decrement respectively. This is because at elevated temperature the shear stress decreases which leads to Brownian motion and intense the nanoparticle. And it is observed that the dynamic viscosity of nanofluid (Al₂O₃/de-ionized water) increases with increasing nanoparticle volume concentration in de-ionized water.

4.3. Influence of particle concentrations and temperature on specific heat

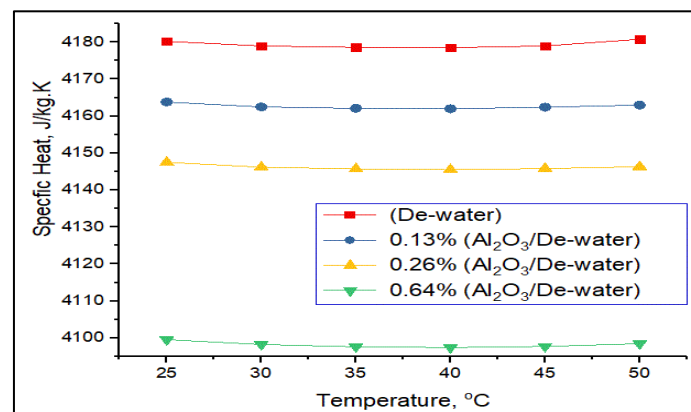


Figure 5. Influence of fraction concentration and temperature on Al₂O₃/de-ionized water nanofluid specific heat

Figure 5, it is noted that the specific heat capacity of Al₂O₃/ de-ionized water decreases moderately with increasing temperature, and decreases substantially as the particle volume concentration. This data indicates that less heat input is required to increase the temperature of Al₂O₃/de-ionized water at higher particle volume concentration. Thence, lower the specific heat of Al₂O₃/de-ionized water can lead to higher convective heat transfer.

4.4. Influence of particle concentrations and temperature on density

The density of nanofluid and base fluid are calculated at the average bulk temperature, which proposed by Pak and Cho (1998) and Abbasian and Amani (2012) respectively.

$$\rho_{nf} = \phi \rho_{np} + (1 - \phi) \rho_{bf} \quad (1)$$

$$\rho_{bf} = -9.339158 \times 10^{-8} T_b^4 + 1.364893 \times 10^{-4} T_b^3 - 0.07714568 T_b^2 + 19.251515 T_b - 764.475639 \quad (2)$$

In Equations (1,2), ρ is density of working fluids, ' T_b ' indicates bulk temperature which is the average values of inlet and outlet temperature of the deionized water moving through the heat exchanger, ' ϕ ' indicates volume concentration, 'np' indicates (Al_2O_3) nanoparticle, 'nf' indicates (Al_2O_3 /deionized water) nanofluid and 'bf' indicates deionized water (base fluid).

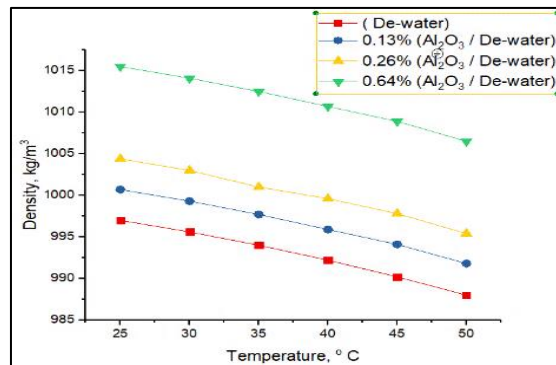


Figure 6. Influence of fraction concentration and temperature on Al_2O_3 /de-ionized water nanofluid density

Figure 6, it is noted that the density of Al_2O_3 /de-ionized water increases substantially with increasing particle volume concentration and decreases with increasing temperature. The thermophysical properties of the base fluid and nanofluid as the experimental working fluid, at a volume concentration of 0.13 %, 0.26 % and 0.64% of Al_2O_3 nanofluids.

Table 2. Summary of thermophysical properties of working fluids

Volume concentration	0 %	0.13 %	0.26 %	0.64 %
Thermal conductivity, W/m.K	0.610	0.618	0.624	0.633
Dynamic viscosity, kg/m.s	0.00080	0.00085	0.00086	0.00092
Specific heat, J/kg K	4179.1	4162.5	4146.2	4098.2
Density, kg/m ³	996	999	1003	1014

5. Calculation of Heat Transfer Procedure

To get the coefficient of heat transfer (h) and Nusselt number (Nu), the following method has been performed. According to Newton's cooling law:

$$Q = h A \Delta T = h A (\Delta T_b - \Delta T_w) \Rightarrow \frac{Q}{A} = q = h (\Delta T_b - \Delta T_w) \quad (3)$$

Heat transfer rate can be defined as:

$$Q = \dot{m} \cdot C_p \Delta T = \dot{m} \cdot C_p (T_{in} - T_{out}) \quad (4)$$

Regarding the equation of Q in the above equations:

$$h = \frac{Nu_{av} k}{d_i} \quad (5)$$

Nusselt number was determined from Kay's correlation which is referred than Hausen.

$$Nu_{av} = \frac{h d_i}{k} = 3.66 + \frac{0.0668 Re Pr (d_i/L)}{1 + 0.04 [(d_i/L) Re Pr]^{2/3}} \quad (6)$$

$$Pr = \frac{\text{Molecular diffusivity of momentum}}{\text{Molecular diffusivity of heat}} = \frac{\nu}{\alpha} = \frac{\mu \times C_p}{k} \quad (7)$$

Where Q is the heat transfer rate, \dot{m} is the mass flow rate, A is the area of cooling coils pipes, ΔT is the temperature variation of the cooling working fluids, T_{in} and T_{out} are inlet and outlet temperatures, T_w is tube wall temperature, T_b is bulk temperature, d_i is inside diameter of the pipe, C_p is the specific heat of working fluids, μ is the dynamic viscosity of working fluid, k is the thermal conductivity of working fluids and Nu_{av} is average Nusselt number for the total heat exchanger.

6. Results and Discussions

Firstly, before conducting methodical experiments on the application of nanofluids as working fluid in the heat exchanger, some experiments were carried out on deionized water for verification the heat exchanger and accuracy of the experimental setup. Noting that the Nusselt number increase with increasing the Reynolds number.

Table 3, shows the calculation results of three important non-dimensional quantities for nanofluid and base fluid. As expected, the Nusselt number is seen to rise with increasing the Reynolds number, while the Prandtl number is increasing with increases of volume fraction.

Table 3. Results of non-dimensional quantities for (Al₂O₃/ De-ionized water) at bulk mean temperature with different concentrations

Types	0 %	0.13%	0.26%	0.64%
Reynolds number	1320.42	1254.74	1237.42	1169.52
Prandtl number	5.480	5.695	5.714	5.956
Nusselt number	4.5330	4.5234	4.5160	4.5045

Table 4 shows the results of heat transfer coefficient and heat transfer rate for base fluid and nano-fluid. Noted that, while conducting the experiment, all piping surfaces were insulated, excluding from the heat exchange zone.

Table 4. Summary of heat transfer coefficient, mass flow rate and heat transfer rate for nano-fluid (Al₂O₃/ De-ionized water) at bulk mean temperature with different concentrations

Volume Concentrations (%)	The coefficient of heat transfer (h) W/m ² .°C	Heat transfer rate (Q) W
0	553.03	30.90
0.13	558.73	38.62
0.26	563.60	50.64
0.64	570.30	78.84

7. Conclusions

In this paper, the heat transfer rate of two working fluid in the simulated battery cooling system (heat exchanger) has been measured experimentally. The working fluids are base fluid (deionized water) and nanofluid (Al₂O₃/deionized water) at various volume concentrations without surfactants. The results are concluded as follows:

- After preparation of the nanofluid and then based on the photo capturing method to check the stability of nanoparticles inside the deionized water, it was noted that Al₂O₃/deionized water nanofluid can be made fairly stable by using magnetic stirrer and ultra-sonication.

- It was observed that the nanofluid at the volumetric concentration of 0.13%, had stabilized for one week after preparation.
- Dispersion of the Al_2O_3 nanoparticles stable into the deionized water increases the viscosity and thermal conductivity of the Al_2O_3 /deionized water nanofluid, this augmentation increases with the increase in nanoparticle volume concentrations.
- Experimentally, noted that the dispersion of the Al_2O_3 nanoparticles in deionized water gives significantly improve the heat transfer rate of the heat exchanger. The degree of the heat transfer improvement depends on the amount of Al_2O_3 nanoparticle added to deionized water. When the volume concentration of 0.64 vol. %, the heat transfer rate improvement of 60 % compared to deionized water was recorded.

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