Improving the performance of radiator heat transfer using Al_2O_3 nanofluids from local bauxite

Jakaria Usman[1], Dani Gustaman Syarif[2], Jupiter Sitorus Pane[3]
{jakariausman01@gmail.com[1], danigus@batan.go.id[2]}

Center for Appllied Nuclear Science and Technology[1,2,3]

Abstract. To obtain an alternative cooling fluid, Al_2O_3 nanoparticles were synthesized from local bauxite. $Al(OH)_3$ precursors were extracted from bauxite using the Bayer method. Al_2O_3 nanoparticles were obtained by calcining the $Al(OH)_3$ precursors at 1200°C for 3 hours. These Al_2O_3 nanoparticles were analyzed using XRD and surface area meter. Nanofluid was prepared from these Al_2O_3 nanoparticles with nanoparticle concentrations of 1g / L, 3g / L, and 5g / L. The stability of the nanofluid was evaluated with the help of a zeta potential measuring device. The characteristic of the nanofluid heat transfer was tested using a radiator. According to XRD analysis, it was known that synthesized Al_2O_3 nanoparticles had alpha and theta phases. The specific surface area of nanoparticles was 30 m^2/g with Al_2O_3 particle size of 50.5 nm obtained from this surface area. The nanofluids were relatively stable with zeta potential of -45 mV, -45.8mV, and -45.4 mV for Al_2O_3 concentrations of 1g / L, 3g / L, and 5g / L, respectively. The nanofluids created had a heat transfer coefficient greater than water. The increase of heat transfer coefficients were 34%, 37% and 38% for each concentrations of the nanofluids.

Keywords: Al_2O_3, coolant, Heat transfer, nanofluid, radiator.

1 Introduction

The use of nanoparticles in various fields continues to increase with time. Nanoparticles are utilized, among others, in the fields of medicine, pharmacy, and mechanical engineering. One of the uses of nanoparticles in mechanical engineering is for nanofluids as cooling fluids or coolants. Nanofluid is very popular and is projected as a future coolant because its heat transfer capability is better than conventional liquids such as water. Several studies related to nanofluid as coolant have been carried out such as water nanofluid-ZrO_2 [1], water - Fe_2O_3 [2], TiO_2 [3] and water - Al_2O_3 [4] [5] [6].

To utilize local bauxite minerals and obtain data on water- Al_2O_3 heat transfer nanofluids from local materials, extraction of $Al(OH)_3$ from bauxite was carried out by the Bayer method, followed by the synthesis of Al_2O_3nanoparticles from $Al(OH)_3$, and preparing water - Al_2O_3 nanofluid. The study of water- Al_2O_3 nanofluids has been carried out in BATAN [1][2][4], however, application of the nanofluid for radiator coolant has not been done. In this study, the performance of local Al_2O_3-water nanofluid from bauxite was studied and discussed using a heat transfer system with a radiator as the main component.

2 Methodology

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Synthesis and characterization of Al_2O_3 nanoparticles

Al_2O_3 nanoparticle synthesis was started by extracting bauxite ore to produce Al_2O_3 compounds with the Bayer process. In the beginning, bauxite ore was crushed to form fine powder. The fine bauxite powder was then mixed with NaOH. The homogeneous mixture was put into water and heated at 120°C for 90 minutes in an autoclave. The mixture from the digestion process was then allowed to stand for several hours to precipitate redmud. Then filtering was done to remove the redmud contained in the solution. The next step was the precipitation process by adding HCl. The precipitate formed was washed using aquadest and then dried to remove the salt content in the sample until it became solid $Al(OH)_3$. The $Al(OH)_3$ powder was calcined at 1200°C for 3 hours. The calcined product was crushed to obtain Al_2O_3 nanoparticle powder. The Al_2O_3 powder obtained was analyzed using XRD to determine the crystal structure and the phases formed. Measuring the surface area of the powder was carried out using a surface area meter from Quantachrome.

Preparation of water - Al_2O_3 nanofluid

Nanofluid was prepared by dispersing Al_2O_3 nanoparticles (with variations of nanoparticle mass of 1 gr, 3 gr, and 5 gr) into 1 liter distilled water as the base fluid, stirring the mixture using a magnetic stirrer for 15 minutes and ultrasonicated in an ultrasonic bath for 120 minutes so that the nanoparticles were well dispersed. Then the pH of the Al_2O_3 nanofluid was adjusted to reach 10 by adding NaOH.

Measurement of water-Al_2O_3 nanofluid heat transfer on the radiator

Nanofluid is a colloidal dispersion of nanoparticles with a size of 1 - 100 nm [7] and is a heat transfer medium and mass that is better than ordinary water [8] [9]. Good nanofluid has several criteria such as particle size on a nanometer scale, higher conductivity and does not settle for a long time [10] [11][12] .

The radiator functions as an engine cooler and is used to process heat transfer from the engine to the surrounding environment. The radiator is designed to be corrugated to increase the air contact surface area with the radiator for optimal heat transfer [13]. In this study, engine heat which is the result of the fuel combustion process is replaced by using an electric stove. The heat from the electric stove will be forwarded to the fluid by convection, making the fluid hot. The hot fluid then moves towards the radiator by being pumped by an electric pump. The fluid then moves towards the upper hose on the radiator and enters the radiator by passing capillary tubes on the radiator. In these tubes, the heat that the fluid has will be absorbed by the radiator which will then make the radiator heat up. The heat collected in the radiator is released with an electric fan so the radiator cools again. The effect of heat transfer between the radiator and fluid makes the fluid experience a decrease in temperature so that when exiting the radiator through the lower hose, the fluid will have a lower temperature than when it enters the radiator. The cold fluid then moves back to the heater to absorb heat again.

Heat transfer rates and heat transfer coefficients in the experimental set of heat transfers on the radiator can be determined after analysis. In this analysis, the working fluid sample used is water and nanofluid with a concentration of 0.1% wt, 0.3% wt and 0.5% wt. The rate of heat transfer of working fluid can be determined using Equation 2.1 [14]

$$Q = \dot{m} c_p \left(T_{in} - T_{out} \right) \qquad (2.1)$$

With,

Q : heat transfer rate (W)

$\dot{m}$: mass flow rate (kg/s)

T_{in} : Inlet temperature of the nanofluid (°C)

T_{out} : Outlet temperature of the nanofluid (°C)

Specific heat (Cp) of nanofluid used in this study uses the Equation 2.2 approach[15]

$$\left(\rho C_p\right)_{nf} = \varphi\left(\rho C_p\right)_{np} + \left(1-\varphi\right)\left(\rho C_p\right)_{fd} \qquad (2.2)$$

With,

ρ : density (Kg/m^3)

φ : volume fraction of nanoparticles (%)

C_p : specific heat capacity (kJ/Kg.K)

Where the value of the density of nanofluid is expressed in the equation (2.3) [15]

$$\rho_{nf} = \varphi\rho_{np} + \left(1-\varphi\right)\rho_{fd} \qquad (2.3)$$

"Np", "fd", and "nf" are short for nanoparticles, base fluids, and nanofluid. Whereas to determine heat transfer coefficient can use equation 2.4"Np", "fd", and "nf" are short for nanoparticles, base fluids, and nanofluid. Whereas to determine heat transfer coefficient can use equation 2.4

$$U = \frac{1}{\dfrac{1}{\eta_0 h_a} + \dfrac{1}{\left(\dfrac{A_{nf}}{A_a}\right) h_{nf}}} \qquad (2.4)$$

where,

U : Overall heat transfer coefficient (W/m^2 K)

η_0 : total radiator efficiency

h_{nf} : heat transfer coefficient of the working fluid side (W/m^2 K)

h_a : heat transfer coefficient on the air side (W/m^2 K)

A_{nf} : inner surface (fluid side) area of radiator (m^2)

A_a : outer surface (air side) area of radiator (m^2)

total radiator efficiency were the values of hnf, ha, and η0 are indicated by Equation 2.5 - Equation 2.7 [14] as follows

$$h_{nf} = \frac{Q}{A_{nf}\left(T_b - T_w\right)} \qquad (2.5)$$

with,

Q : heat transfer rate (W)

T_b : Bulk temperature of nanofluid (°C)

T_w : Wall temperature respectively (°C)

A_{nf} : inner surface (fluid side) area of radiator (m^2)

$$h_a = \frac{Q}{A_a\left(T_w - T_a\right)} \quad (2.6)$$

with,

Q : heat transfer rate (W)

T_a : Bulk mean temperature of air (°C)

T_w : Wall temperature respectively (°C)

A_a : outer surface (fluid side) area of radiator (m^2)

$$\eta_0 = \left(\frac{A_f}{A_a}\right)\eta + 1 - \left(\frac{A_f}{A_a}\right) \quad (2.7)$$

Where,

$$\eta = \frac{\tanh(mL)}{mL}\text{; } m = \sqrt{\frac{2h_a}{kt}} \quad (2.8)$$

Where,

η_0 : total efficiency

η : fin efficiency

A_f : finned area (m^2)

A_a : outer surface (air side) area of radiator (m^2)

L : Length of the fin (m)

k : thermal conductivity of the aluminium on fin radiator (W/m^2 K)

t : thickness of fin radiator. (m)

The results of the determination of heat transfer rate and overall heat transfer coefficient can then be shown graphically the relationship between heat transfer rate and nanofluid concentration.

3 Results and discussion

3.1 Data of Specific Surface Area dan X-Ray Difraction of Al_2O_3 nanoparticles

The surface area of Al_2O_3 powder was measured using surface area meter NOVA 2200e. is From the measurement it was known that the specific surface area 30 m^2 /g and the particle size obtained from the specific surface area is 50.5 nm. From the results obtained it is known that particle size <100 nm thus particles can be categorized as nanoparticles.The diffraction pattern of Al_2O_3 nanoparticles used is shown in Figure 1. Al_2O_3 powder consists of two phases namely alpha (A) and Theta (T).

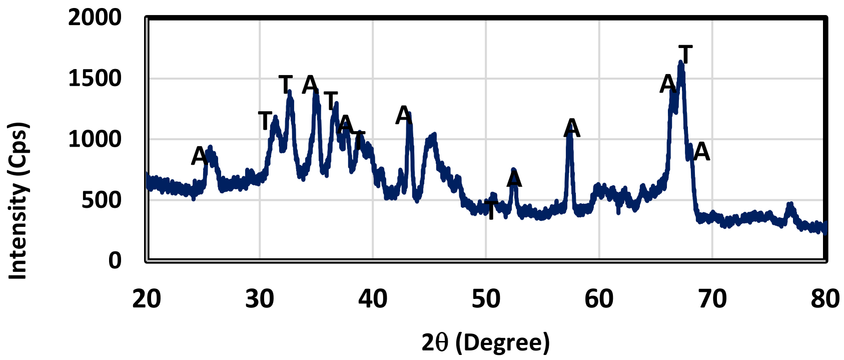

Fig. 1. The results characterization curve of Al_2O_3 particles with x-ray diffrection (A) Alpha phase and (T) Theta phase

3.2 Zeta Potential of water – Al_2O_3nanofluid

The measurement of zeta potential of nanofluid was done in order to know whether or not the formed nanofluid is a stable nanofluid and does not experience sedimentation in a sufficiently long period of time. The zeta potential of the synthesized nanofluid has the values listed in Table 1

Table 1. Data of zeta potensial of Al_2O_3 nanofluid.

Sample	Data 1	Data 2	Data 3	Mean
Water - Al_2O_3 Nanofluid 0.1% wt	-44.3	-47	-46.9	-46.0667
Water - Al_2O_3 Nanofluid 0.3% wt	-46.7	-44	-46.8	-45.8333
Water - Al_2O_3 Nanofluid 0.5% wt	-45.5	-46.1	-44.5	-45.3667

Based on the table it is known that at a concentration of 0.1% wt, water- Al_2O_3 nanofluid has a zeta potential value of -46.0067 mV, at a concentration of 0.3% wt, water- Al_2O_3 nanofluid has a zeta potential value of -45.8333 mV and at a concentration of 0.5% wt, water- Al_2O_3 nanofluid has a zeta potential value of -45,3667 mV. There is a small decrease in zeta potential value as the concentration of nanoparticles increases. This decrease is due to the increase of nanoparticle concentration. In general the nanofluids made in this study are stable because the zeta potential of them are smaller than -30 mV which means stable.

3.3 Effect of Water- Al_2O_3 Nanofluid Concentration on Heat Transfer in Radiators\

The thermal behavior of nanofluid depends on many factors such as particle shape, type, size, volume fraction and thermal properties of nanoparticles . The results of heat transfer testing on radiators using nanofluid as coolant show that there is an increase in the heat transfer rate ratio as the concentration of nanofluid is shown in Figure 2. The results of heat transfer testing on radiators using coolant nanofluid indicate that there is an increase in the heat transfer rate ratio with the increasing concentration of nanofluid shown in Figure 2.

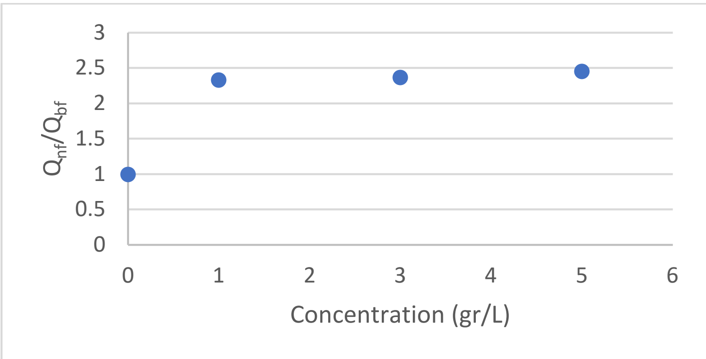

Fig. 2. the rate of nanofluid heat transfer to concentration

Tabel 2. The ratio of the heat transfer rate to the base fluid toconcentration of nanofluid

Sampel	Q_{nf}	Q_{nf}/Q_{bf}
Aquades	546,7	1
1 gr / 1 L	1277,184	2,336169
3 gr / 1 L	1296,831	2,372108
5 gr / 1 L	1344,112	2,458591

While the graph of the value of convective heat transfer coefficient (CHTC) on the concentration of nanofluid is shown in Figure 3 which shows that the CHTC nanofluid value also increases with increasing concentration of nanofluid.

The CHTC value of nanofluid is much greater than the CHTC value of the base fluid (0% wt) while the CHTC value of the nanofluid at a concentration of 0.1% wt, 0.3% wt and 0.5% wt respectively increases around 34%, 37% and 38 % of concentration below. The increase in CHTC values in nanofluid is in line with what Selvam [14] where he experimentally examined CHTC on radiators using nanofluid (water-EG) -Graphene. The results of this study indicate that the CHTC value increases with an increasing concentration of nanofluid to a concentration of 0.3% wt and experiences a non-significant increase in the concentration above 0.3% wt. The CHTC value of nanofluid with a concentration of 0.5% wt did not experience a higher increase compared to the CHTC value of nanofluid with a concentration of 0.3% wt. This can occur because the ratio of heat transfer rate in nanofluid with a concentration of 0.5% wt is not higher than the concentration of 0.3% wt. Alli in his study also stated that the heat transfer coefficient value increases with increasing work fluid flow rate. Even though in this study the workflow rate was not varied but it could be a related picture of not increasing the CHTC value of water-Al_2O_3 nanofluid with a concentration of 0.5% wt.

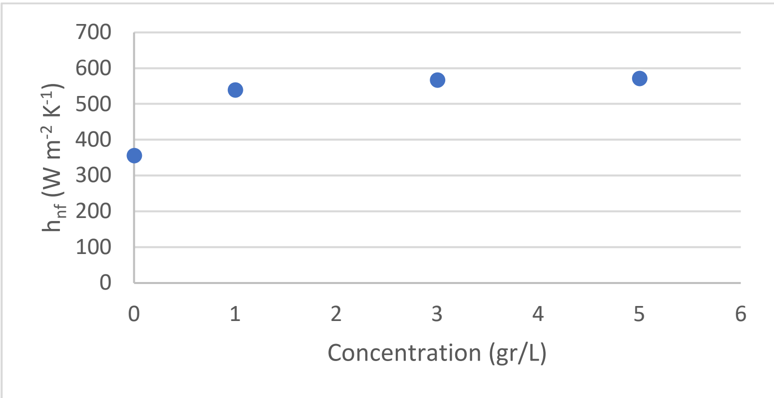

Fig. 3. CHTC of water – Al_2O_3 nanofluid in various concentration

Tabel 3. CHTC and OHTC graphs for the concentration of water- Al_2O_3 nanofluid

Sample	$h_{nanofluida}$ (CHTC)	U (OHTC)
Aquades	283,8848	31,39276
1 gr / 1 L	539,4929	61,45851
3 gr / 1 L	567,8487	63,69183
5 gr / 1 L	572,1847	65,06166

The overall heat transfer coefficient (OHTC) graph of the concentration of water- Al_2O_3 nanofluid at the inlet temperature and flow rate is kept constant at 50 ° C and 3.5 LPM shown in Figure 4 where the OHTC value increases with increasing concentration of nanofluid.

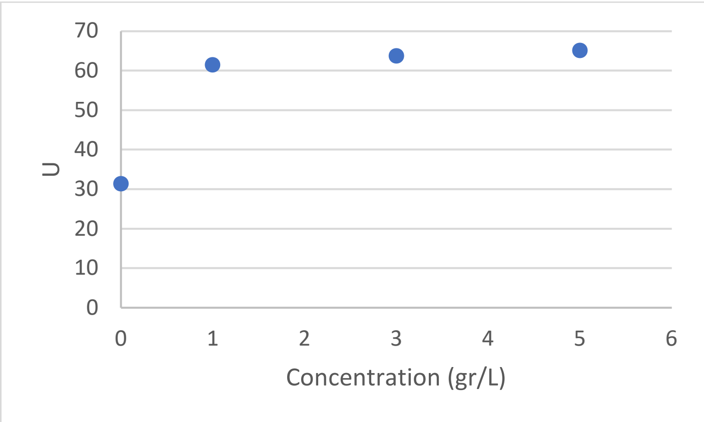

Fig. 4. OHTC of water – Al_2O_3 nanofluid in various concentration

Based on the graph above the OHTC value of nanofluid is much higher than the base fluid (water). Nanofluid has increased OHTC value with increasing concentration where the OHTC value increased from 31.39276 Wm^2K^{-1} to 61.45851 W m^2K^{-1}, 63.69183 W m^2K^{-1} and 65.06166 W m^2K^{-1} which means experiencing an increase of about 50% of the base fluid or 2 - 3% increase with the concentration of % wt below it. This is in line with what was disclosed by Selvam where the value of OHTC from nanofluid (water-EG) - Graphene has increased in the range of 10% to 50%. The OHTC value itself indicates that the heat transfer process of the radiator as a whole from the nanofluid comes out to become fan-released hot air contained in the toolset. So that nanofluid can improve the heat transfer process in general from the radiator toolset and make the nanofluid have a good chance to be an alternative to the vehicle engine cooler in the future.

4 Conclusion

Nanoparticles of Al_2O_3 having two phases i.e. alpha and theta phases have been synthesized from $Al(OH)_3$ extracted from bauxite by the Bayer method. The surface area of the Al_2O_3 nanoparticles obtained is 30 m^2/ g and particle size is 50.5 nm. Water- Al_2O_3 nanofluids prepared in this work were stable with zeta potential of -46.06 mV, -45.83 mV and -45.36 mV.

Dispersing Al_2O_3 nanoparticles into the water can increase heat transfer. The addition of Al_2O_3 by 1 gr, 3 gr and 5 gr in 1 liter of water can increase CHTC by 34%, 37%, and 38%. Besides that, it also causes an increase in OHTC by 10% to 50% compared to the base fluid and has an increase of 2-3% OHTC.

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