3rd International Conference on Engineering and ICT (ICEI2012)
Melaka, Malaysia
4 – 5 April 2012

NANOFLUID AS COOLANT IN AUTOMOTIVE COOLING SYSTEM–HEAT TRANSFER CHARACTERISTICS OF CAR RADIATOR USING CU-BASED NANOFLUID

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Abstract— **Nanofluid is a potential fluid with enhanced thermal physical properties as compared to conventional fluid. The conventional fluids such as water and ethylene glycol acted as coolants in automotive cooling system could show superior properties through dispersion of nanoparticles. The nanoparticles are either metal, non-metal or carbon nanotube (CNT) is in nano-size between 1-100 nm. This study focused on heat transfer characteristics of Cu/water nanofluid in an automotive radiator by analyzing the thermal physical properties of the coolant; thermal conductivity (*k*) and heat transfer coefficient (*h*). The mixture of solid nanoparticles and coolant showed that the thermal properties of the coolant were increasing with copper (Cu) nanoparticle volume fraction. By adding 10 % of nanoparticle suspension, the heat transfer coefficient of the nanofluid was increased up to 26000 $W.m^{-2}K^{-1}$ with 92 % of percentage enhancement. Consequently, it also enhanced the heat transfer rate in the cooling system. The results showed good indicator for automotive industry to design an eco-car that sustain the energy and minimizing the environmental impact.**

Keywords—**Nanofluid; Heat transfer; Automotive radiator; Thermal conductivity.**

I. INTRODUCTION

Researchers around the world have conducted many investigations on nanotechnology in order to begin with its massive implementation in many sectors such as air-conditioners, automotive, electronics, and medical. One area that has been studied and developing currently is nanofluid; a potential fluid with superior properties to replace conventional fluid. The term "nanofluids" has been introduced by Choi in 1995 at Argonne Research Laboratory as an advanced fluid that showed superior heat transfer properties with nanoparticle suspensions [1].

The nanofluids could be grouped based on their application which occasionally called as nanolubricant or nanorefrigerant, which is also one kind of nanofluids. A lot of nanofluids studies are based on thermal conductivity and heat transfer coefficient since the properties show significant influence in a heat transfer process. Other properties such as viscosity, density and surface tension of nanofluids have also been explored to obtain reliable results. The nanofluids have superior thermal properties which have been proved since past decades by many researchers. Today's trend is to develop the nanofluids in many industries and ensure it is a new energy-efficient heat transfer fluid in real world application.

In developing nanofluids, it is not only the superior properties are considered, but the stability and dispersion of nanofluids are also the main areas that challenged its relevance in mass application. Suitable material of nanoparticle is crucial to be identified in order to be suspended in different types of base fluids. The size of nanoparticles, temperature, and optimum concentrations must be considered carefully. These are important to obtain high thermal conductivity and heat transfer coefficient of nanofluids without causing agglomeration, instability, corrosion, high pressure drop and pumping power [2, 3].

An automotive cooling system usually consists of radiator, water pump, thermostat, radiator pressure cap, and electric cooling fan [4]. The radiator is the main component as it was designed to remove heat from an engine block with circulated coolants. In fact, the coolants have poor heat transfer properties in nature. Generally, the coolant in the radiator is water or water with additional liquid of ethylene glycol (anti-freezing fluid), which flows inside the tubes. Another coolant is outside air which flows through the fins to cool down the temperature of water inside the tubes.

Since researchers and engineers from automotive industries have been competing for green technology, compact system and low fuel consumption, consequently it has developed the study of nanofluids. By introducing nanofluids with high heat transfer properties, the radiator size can be reduced but offering same heat transfer rate. The frontal area of a car can be redesigned to reduce aerodynamic drag so that less fuel consumption is required [5, 3]. Therefore, it is important to investigate the nanofluids thermal physical properties.

Argonne researchers proved that despite nanofluids thermal conductivity depends on temperature and particle volume fraction, it showed high thermal conductivity than conventional radiator coolants [6].

The heat transfer rate and thermal performance of Cu/EG coolant in an automotive radiator can be enhanced by increasing the particle volume fraction from 0 % to 2 % [3]. The heat transfer enhancement depends on air and coolant Reynolds number (*Re*) which is increasing with nanoparticle concentration. Mare et al. [7] experimentally proved that the convective heat transfer coefficient of CNTs nanofluid increased about 50% in comparison to water for the same Reynolds number. Despite, there are also withdrawn from investigating the natural convective heat transfer of nanofluids as the suspension of nanoparticles caused higher viscosity and pressure drop [8].

In this study, the aim is to improve the heat transfer capabilities in automotive cooling system by investigating the effect of copper nanoparticles volume fraction on coolant thermal conductivity and heat transfer coefficient. The enhanced heat transfer properties of the coolant are used to determine the total heat transfer rate of a car radiator.

II. Methodology

By using mathematical modeling, the effect of nanoparticles dispersion from 1 to 10 % was investigated. Three different sizes of nanoparticles; 10 nm, 50 nm and 100 nm are used to identify the effect of nanoparticle size on nanofluid thermal conductivity. The properties of water, air and copper are shown in Table 1. The thermal conductivity of copper is significant higher than water. For this reason, the main basis of suspending the copper particles is to enhance the thermal conductivity of the conventional coolant.

The highest thermal conductivity of the nanofluid is used to determine the heat transfer rate of a louvered-fin flat tube radiator as shown in fig. 1. The radiator with conventional coolant (water with 0 % nanoparticles suspension) could experience heat transfer rate of 64.354 kW. The coolant volumetric flow is 0.11 $m^3.min^{-1}$, meanwhile the air volumetric flow and air velocity are 66.5 $m^3.min^{-1}$ and 4.47 $m.s^{-1}$. This study used exact working condition and radiator specification except the conventional coolant (water) is changed to Cu/water nanofluid. Assuming the inlet temperature of the coolant is 368 K, and the outside air is 303 K. From the data, the analyses have been done by using Microsoft Office Excel 2007.

Table 1. Geometry description of automotive radiator [4]

Radiator Dimensions	
Radiator length, *rL* (m)	0.4572
Radiator width, *rW* (m)	0.4318
Radiator height, *rH* (m)	0.0246
Tube width, *tW* (m)	0.0246
Tube height, *tW* (m)	1.56×10^{-3}
Fin width, *fW* (m)	0.0246
Fin height, *fH* (m)	0.0119
Fin thickness, *fT* (m)	2.54×10^{-5}
Distance between fins, *fD* (m)	1.59×10^{-3}
No. of tubes	33

Table 2. Properties of coolants and nanoparticle [9]

Properties	**Water (368 K)**	**Air (303 K)**	**Cu (300K)**
Density, ρ [$kg.m^{-3}$]	962	1.15	8933
Thermal Conductivity, k [$W.m^{-1}K^{-1}$]	0.678	0.0263	401
Specific heat, C_p [$Jkg^{-1}.K$]	4212	1007.12	385
Dynamic viscosity, μ [$kgm^{-1}s^{-1}$]	2.96×10^{-4}	1.86×10^{-5}	-

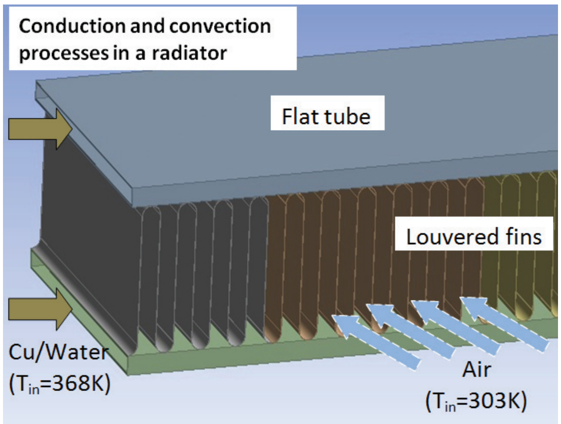

Figure 1. Louvered-fins and flat tube

The effective thermal conductivity of nanofluid k_{eff}, considered the effect of interfacial layers which have been developed around the nanoparticles as suspending metallic particles in the coolant. The effective thermal conductivity can be calculated from Eq. 1 [10],

$$k_{eff} = \frac{(k_p - k_{lr})\phi_1 k_{lr}\left[2\beta_1^3 - \beta^3 + 1\right] + (k_p + 2k_{lr})\beta_1^3\left[\phi_1\beta^3(k_{lr} - k_f) + k_f\right]}{\beta_1^3(k_p + 2k_{lr}) - (k_p - k_{lr})\phi_1\left[\beta_1^3 + \beta^3 - 1\right]}$$

where k_p is the thermal conductivity of nanoparticle, k_l is the thermal conductivity of interfacial layer, k_f is the thermal conductivity of coolant, ϕ is the particle volume fraction, $\beta = 1 + \gamma$, $\beta_1 = 1 + \gamma / 2$, and $\gamma = h/a$ is the interfacial layer thickness over the radius of nanoparticle.

The dynamic viscosity of nanofluid, μ_{nf} is obtained from Brinkman model [3] which considered only two parameters: a) the conventional coolant viscosity, μ_f and b) the nanoparticle concentration.

$$\mu_{nf} = \mu_{nf}\frac{1}{(1-\phi)^{2.5}} \quad (2)$$

The density, ρ_{nf} and specific heat, $C_{p,nf}$ of the nanofluid can be calculated from Eq. 3 and Eq. 4 [3],

$$\rho_{nf} = (1 - \phi)\rho_f + \phi\rho_p \quad (3)$$

$$C_{p,nf} = \frac{(1 - \phi)\rho_f C_{p,f} + \phi\rho_p C_{p,p}}{\rho_{nf}} \quad (4)$$

where ρ_f and ρ_p are the densities of coolant and nanoparticle, meanwhile $C_{p,f}$ and $C_{p,p}$ are the specific heat of coolant and nanoparticle. To determine the heat transfer rate, the universal heat transfer equation is used [4],

$$\frac{1}{UA} = \frac{1}{h_c A_c} + \frac{1}{h_a A_a} \quad (5)$$

where h_c is the heat transfer coefficient of the coolant ($W.m^{-2}K^{-1}$), h_a is the heat transfer coefficient of air meanwhile A_c and A_a are the coolant surface area and air surface area (m^2). To determine the heat transfer coefficent, Nusselt number (*Nu*) must be identified. The Dittus Boelter equation is used since the flow inside the tubes is turbulent based on the calculated Reynolds number, *Re*. The Dittus Boelter equation, Reynolds number and Prandtl number, *Pr* as well as the heat transfer coefficient can be calculated as following [3],

$$h_c = \frac{Nu\, k_{eff}}{D_H} \quad (6)$$

$$Nu = 0.023 Re^{0.8} Pr^{0.3} \quad (7)$$

$$Pr = \frac{C_{p,nf}\, \mu_{nf}}{k_{eff}} \quad (8)$$

$$Re = \frac{\rho_{nf} v D_H}{\mu_{nf}} \quad (9)$$

where v is the velocity of the nanofluid, (ms^{-1}), and D_H is the hydraulic diameter. The hydraulic diameter can be determined by using the following equations [4],

$$D_H = \frac{4A_{min}}{WP} \quad (10)$$

$$A_{min} = tW.tH \quad (11)$$

$$WP = 2(tW + tH) \quad (12)$$

In order to find the heat transfer coefficient of the air, the universal, *UA* heat transfer coefficient can be determined from,

$$NTU = \frac{UA}{C_{min}} \quad (13)$$

where *NTU* is the number of transfer units and C_{min} is obtained by comparing the thermal capacity rate of the nanofluid and the air. The thermal capacity rate can be calculated by using Eq. 14, which is important in deciding C_{min} and C_{max}.

$$CR = C_p\, \mu\rho \quad (14)$$

The heat exchanger (radiator) effectiveness can be determined by,

$$\varepsilon = 1 - e^{-\frac{C_{max}(1 - e^{-C_{ratio}Ntu})}{C_{min}}} \quad (15)$$

where $C_{ratio} = C_{min}/C_{max}$ [4] .To find the total transfer rate *Q* (W), the different between the nanofluid temperature, $T_{nf,in}$ and air temperature, $T_{a,in}$ must be identified and substituting in the following equation [3],

$$Q = \varepsilon C_{min}(T_{nf,in} - T_{air,in}) \quad (16)$$

III. Results and Discussion

Fig. 1 shows the enhancement of nanofluid thermal conductivity with particle volume fraction. By suspending 10% of copper nanoparticles in water, the thermal conductivity of the nanofluid can be enhanced more than 100%. The result proved that the thermal conductivity of nanofluid is increasing significantly with nanoparticles concentrations. The increasing size of nanoparticles has decreased the thermal conductivity of nanofluids. The smallest copper diameter of 10 nm demonstrated highest thermal conductivity enhancement compared to others.

The localized convection in the coolants because of nanoparticles Brownian motion is one of the reasons that enhance the thermal conductivity [10]. Besides, the formation of interfacial layer between the copper nanoparticles and basefluid (water) is also contributing to the percentage of enhancement. The interfacial layer thermal conductivity (k_l) is two times higher as compared to the basefluid [10]. Therefore, instead of depending on the nanoparticles concentrations and particle sizes, interfacial layers are also contributing to improve the overall thermal conductivity of nanofluids.

By using different nanoparticle volume fraction, the viscosity of nanofluids is also increasing and influencing the values of Reynolds number. The viscosity of nanofluids solely depends on nanoparticle volume fraction according to Brinkman model. By increasing the viscosity, the Reynolds number should be smaller. However, another important thermal physical property that need to be considered in determining the Reynolds number is the density of nanofluids. The greater effects on density due to nanoparticle suspension have increased the Reynolds number in this study.

In this study, the nanoparticle volume fraction showed more significant effects on density rather than viscosity of the nanofluid. Therefore, the Reynolds number is increasing with nanoparticles concentration. The Reynolds number is important to be used in identifying the type of flow in the tubes. As the Reynolds number is increasing from 15000 to 21000, it shows that the turbulence flow inside the tubes becomes more "chaos". Since the advanced coolant consists of nanoparticles, the turbulence caused more conduction and convection as more contacts occurred between the nanoparticles and tubes wall. This contributes to higher heat transfer rate in the cooling process.

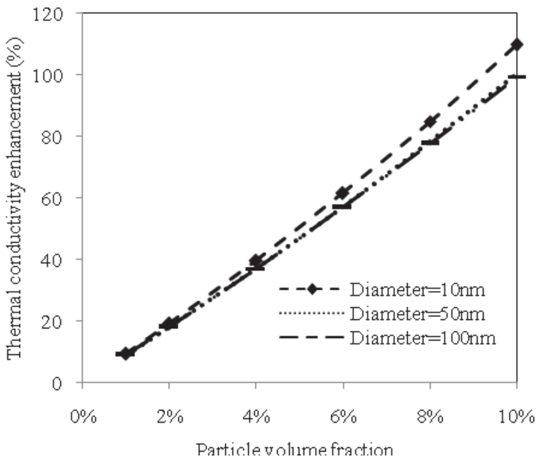

Figure 2. Nanofluid thermal conductivity as a function of nanoparticle volume fraction

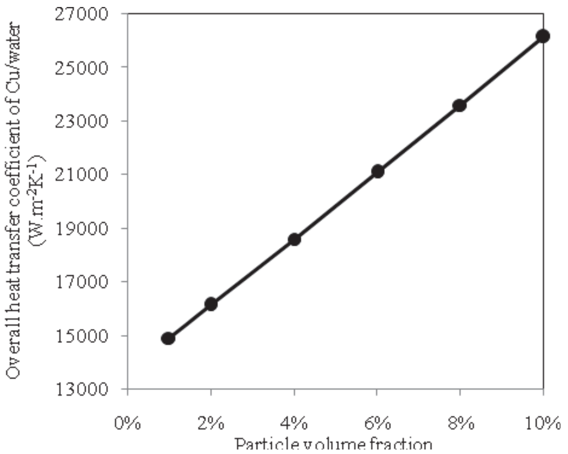

Figure 3. Overall heat transfer coefficient as a function of nanoparticle volume fraction

Fig. 3 shows overall heat transfer coefficient of nanofluid with the effect of particle volume fraction. The heat transfer coefficients are increasing with particle concentration. It started almost 9 % of percentage enhancement, and constantly increasing up to 92 % with 10 % of nanoparticle suspension. The heat transfer rate of the radiator is also increasing from 64356 W to 64376 W as shown in Fig. 4. The overall heat transfer rate enhancement shows insignificant value which is about 0.03 %. There are many factors contributed to this result. The one that is concerned is the flow rate of the outside air. This study assumed that the air flow rate is constant by focusing the influence of particle concentration on the thermal conductivity and heat transfer coefficient of nanofluid.

The temperature of coolants should be varied due to operating temperature and air flow. Higher temperature and air flow tend to increase the heat transfer rate. The fins construction is also one of the important factors that could influence the heat transfer rate. By extending the surface area and choosing high conductive material, the heat transfer rate can be enhanced accordingly. This study showed that nanofluids as the advanced coolant has increased the heat transfer rate of the radiator. Therefore, the combination of the major factors that influence the heat transfer characteristics of the radiator will produce high energy-efficiency heat exchanger.

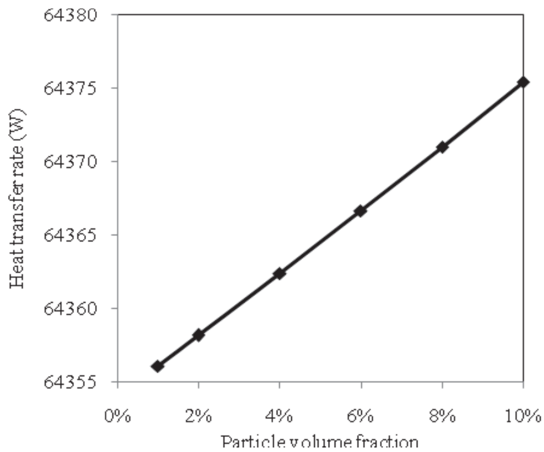

Figure 4. Heat transfer rate of a louvered-fin and flat tube radiator

IV. Recommendation for future work

Radiator is a component of the automotive cooling system. There are other components that linking to each other such as water pump and hoses. By using nanofluid as the new coolant, there are possibilities of nanoparticles agglomeration and sedimentation inside the tubes, hoses and clogging the water pump. The erosion issue on the system cannot be neglected as adding metallic particle will risk the existing system. These will lead to parts wear, increased pressure drop, and more energy consumption. Therefore, more investigations on other parts need to be done to introduce nanofluid as the advanced-coolant in the cooling system. It is important to have practical knowledge of nanofluids performance in real world cooling system so that the important aspects such as fuel consumption, construction cost, quality and safety can be identified before high-volume production is proposed.

V. Conclusion

The thermal conductivity of Cu/Water nanofluid is increasing significantly with nanoparticle volume fraction of 1 % to 10 % but decreasing with the increment of particle size. The suspension of nanoparticles has increased the heat transfer coefficient of the nanofluid significantly up to 26000 $W.m^{-2}K^{-1}$ with the percentage enhancement is about 92 %. The overall heat transfer rate of louvered-fin and flat tube radiator shows the percentage enhancement is approximate to 0.03 % as considering both types of coolants; the nanofluids and air.

REFERENCES

[1] Choi S.U.S. Developments and applications of non-newtonian flows, ASME FED, 66 (1995) 99–105.

[2] R. Saidur, K. Y. Leong, H.A. Mohammad, A Review on Application and Challenges of Nanofluids, *Renewable and Sustainable Energy Reviews* 15 (2011) 1646 –1668.

[3] K.Y. Leong, R. Saidur , S.N. Kazi, A.H Mamun, Performance Investigation of an Automotive Car Radiator Operated with Nanofluid-based Coolants (Nanofluid as a Coolant in a radiator), *Applied Thermal Engineering* 30 (2010) 2685– 2692.

[4] Waterloo Maple Inc. (2008). Designing a more effective car radiator, Retrieved Dec 2, 2011 from http:// www.maplesoft.com/view.aspx?SF=6403/Radiator.pdf

[5] Wong, K.V., & Leon, O.D., Review article- Applications of nanofluids: Current and future, *Advances in Mechanical Engineering* (2010) doi: 10.1155/2010/519659

[6] Choi S. Nanofluids for improved efficiency in cooling systems, Retrieved Dec 2, 2011 from http://www1.eere.energy.gov/vehiclesandfuels/pdfs/hvso_2006/13_choi.pdf.

[7] Mare, T., Halelfadl, S., Sow, O., Estelle, P., Duret, S., Bazantay, F. Comparison of the thermal performances of two nanofluids at low temperature in a plate heat exchanger, *Experimental Thermal and Fluid Science* 35 (2011) 1535–1543

[8] Calvin, H. L., & Peterson G.P. Experimental studies of natural convection heat transfer of Al2O3/DI water nanoparticle suspensions (Nanofluids), *Advanced in Mechanical Engineernig*, (2010) 1535-1543 doi:10.1155/2010/742739

[9] Yunus A. Cengal, *Heat Transfer – A Practical Approach.*MC Graw-Hill, Singapore, 2004.

[10] K.C Leong, C. Yang, S.M.S. Murshed, A Model for Thermal Conductivity of Nanofluids – The Effect of Interfacial Layer, *Journal of Nanoparticles Research* 8 (2006) 245 – 254.