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HEAT TRANSFER OF CUO-WATER BASED NANOFLUIDS IN A COMPACT HEAT EXCHANGER

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ABSTRACT

Experimental works were conducted to investigate the effect of copper-oxide (CuO) nanoparticles volume concentration and the operating temperatures on the rate of nanofluids heat transfer in a compact heat exchanger. 40 nm CuO nanoparticles was mixed with demineralized water at 2% and 6% volume concentrations. Sodium Lauryl Sulphate (SLS) powder was added to enhance the mixing process and stabilize the dispersion of the nanofluids. A custom-made closed loop test rig were designed, fabricated and tested for these experiments. The test rig was set-up to represent the actual ap-plication of the nanofluids in cooling of a compact heat exchanger. Experimental runs were conducted at varying operating temperatures which include the runs for water, CuO-water at 40 ºC, 50 ºC and 60 ºC. The results indicate that by adding small amount of CuO nanoparticles into water as the base fluid, the rate of heat transfer and convection heat transfer coefficient would increases by at least 17.3% and 40% respectively. It was also discovered that CuO nanofluids with 2% volume loading produces greater increase in rate of heat transfer. Among the three operating temperatures selected for study, 40 ºC gives the best performance in heat transfer and the convection heat transfer coefficient. The results of the current work generally indicate that nanofluids have the potential to enhance the heat transfer of a compact heat exchanger if properly designed.

Keywords: compact heat exchanger, copper-oxide, nanofluids, radiator, heat transfer.

INTRODUCTION

Car radiator, one example of compact heat exchanger, is an important part in automotive cooling system. Fins attached to it enhance heat transfer from the hot coolant to the outside air. The conventional coolant used is water or water mixed with ethylene glycol (EG). Due to the low convective heat transfer on the air side, the radiator is normally placed in front of the car to maximize the cooling effect of the oncoming air. The size and the position of the radiator affect the aerodynamic drag experienced by the car which subsequently compromises the fuel consumption and emission.

Nanofluids seem to be the potential replacement of conventional coolants in radiator. Nanofluids are dilute suspensions of nanoparticles with at least one of their principal dimensions smaller than 100 nm (Choi 1995). These nanoparticles could be aluminum oxide (Al2O3), copper (Cu), copper oxide (CuO), gold (Au), silver (Ag), silica nanoparticles and carbon nanotube. There have been considerable research findings highlighting superior heat transfer performance of nanofluid. Yu et al (Yu et al. 2007) reported that about 15-40% of heat transfer enhancement can be achieved by using various types of nanofluids.

With these superior characteristics, the size and weight of an automotive car radiator can be reduced without affecting its heat transfer performance. Singh et al (Routbort et al. 2008) have determined that the use of high-thermal conductive nanofluids in radiators can lead to a reduction in the frontal area of the radiator by up to 10%. This reduction in aerodynamic drag can lead to a fuel saving of up to 5%.

The initial promise of nanofluids as advanced heat transfer fluids was based on the increased thermal conductivity of nanoparticle suspensions (Timofeeva et al. 2011). It has been shown that nanofluids exhibit much higher thermal conductivities than their base fluids even when the concentration of the suspended nanoparticles is very low (ø < 5%) (Murshed, Leong, and Yang 2008). Eastman et al (Eastman et al. 1996) found that by adding 5% volume fraction of CuO (36 nm) nanoparticles in water, the thermal conductivity can be enhanced by 60%. Wang et al (Wang, Zhou, and Peng 2003) reported a significant 17% increase in thermal conductivity for a loading of 0.4vol% of CuO (50 nm) in water. Overall, the thermal conductivity of CuO nanofluids increases with an increase in volume fraction of the suspended nanoparticles (Patel, Sundararajan, and Das 2010; Li and Peterson 2006; Mintsa et al. 2009).

The general trend, observed in the literature, is that increase in nanofluid thermal conductivity is higher with an increase in temperature (Lomascolo et al. 2015). With respect to CuO nanofluids, there are limited works (Mintsa et al. 2009; Li and Peterson 2006; Das et al. 2003) that investigate the effect of varying temperatures to the nanofluids' thermal conductivity. In a study by Mintsa et al. (2009), the effect of temperature ranging from 20 – 48oC on the CuO-water based nanofluids were investigated. Das et al. (2003) have measured the relationship between thermal conductivity and temperature for nanofluids based on Al2O3-water and on CuO-water. Temperature was varied in experiments from 21 ºC to 51 ºC. To the best of author's knowledge, there are no data for the increase in nanofluid thermal conductivity at temperatures above 51 ºC and there is limited study on CuO-water based nanofluids.

Unfortunately thermal conductivity is not the only property that determines the efficiency of heat

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transfer in the system. Convective heat transfer coefficient also plays an important role in evaluating heat transfer capability of an automotive radiator. In the forced flow system (such as in engine cooling by radiator) the coolant is pumped through the radiator, introducing convective heat transfer mechanisms and pumping power penalties.

Heris, Esfahany, and Etemad, 2006 investigated convective heat transfer of CuO/water based nanofluids under laminar flow conditions under constant wall temperature. They observed that the heat transfer coefficient increases with the Peclet number as well as the nanofluid concentrations or the volume fractions of the nanoparticles. Similar findings were indicated by Zamzamian *et al* (2011) in their experimental investigation of the forced convection heat transfer of Al2O3/EG and CuO/EG nanofluids, although their work focused on turbulent flow in a double-pipe and plate heat exchangers.

Vajjha *et al* (2010) develops correlations for the convective heat transfer and the friction factor from their experimental study of nanoparticles comprised of Al2O3, CuO and SiO2 dispersed in 60% ethylene glycol and 40% water by mass. The works were carried out in the fully developed turbulent regime of a copper tube. They observed that heat transfer coefficient showed an increase with the particle volume concentration.

Majority of the experimental studies on the heat transfer of nanofluids were constrained to the determination of their thermal conductivity, viscosity, convective heat transfer coefficient without considering the performance of the nanofluids under actual application, especially in automotive cooling. Numerical investigation of the cooling performance of a radiator using nanofluids as the coolant has been performed by Vajjha, Das, and Namburu, 2010 and Leong *et al.* 2010.

Peyghambarzadeh *et al.* 2011 conducted heat transfer experimental study in the application of Al2O3 nanofluids as coolant for car radiators in the range of 0.1 – 1 vol%. They conclude that by adding as much as 1.0% volume of Al2O3 to the base fluid (water or EG), the Nusselt number can be increased by up to 40%. Naraki *et al.* 2013 and Peyghambarzadeh *et al.* 2013 investigated the heat transfer of CuO/water and Fe2O3/water in a car radiator with a varying nanoparticle volume concentration in the range of 0.15 to 0.5 %vol. Both studies concluded that the overall heat transfer coefficient, U increases with nanoparticle volume concentration and nanofluid volumetric flowrate. It was also observed that the overall heat transfer coefficient, U decreases with increasing inlet temperature of the nanofluid.

Most of the published works concluded that nanofluids have superior heat transfer performance based on their thermo physical properties, rather than the actual application. Experimental works on nanofluids in car radiator thus far is focusing in a very low volume concentration of nanoparticle. Hence it is the objective of this work to investigate the heat transfer performance of the CuO nanofluids as the coolant in the car radiator in a higher volume loading. The effect of particle volume

fraction and temperature on the heat transfer is also examined.

EXPERIMENTAL SET-UP

In order to measure the heat transfer performance of the nanofluid in the car radiator, a closed flow loop test rig shown in Figure-1 has been designed, fabricated, assembled, tested and used. The rig includes a storage tank, a heater, a pump, a flow meter, a cross-flow finned tube heat exchanger (car radiator) and flow lines (stainless-steel tubes). The storage tank is used as the nanofluid storage and holding container during the experiments. It has the diameter of 75 mm and the height of 150 mm. The tank is fitted with an immersion heater with a power rating of 3 kW, equipped with temperature controller.
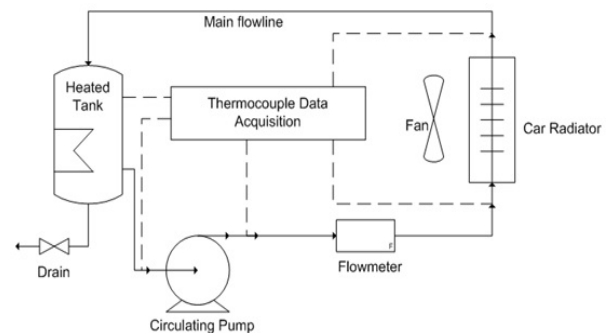

Figure-1. Schematic diagram of the experimental test rig.

The car radiator configuration is louvered fin and flat tubes with an overall dimension of 150 mm x 121 mm x 25 mm and weighs about 270 g. It is made of aluminium. A cooling fan with the size of 120 mm x 120 mm x 25 mm and rotating speed of 1200-2500 RPM was used to cool the radiator in an indirect cross-flow configuration. Type-K thermocouples were used to measure the temperatures at the inlet and the exit of the car radiator, as well as at several locations along the flow lines to ensure steady temperature distribution.

Experimental Procedures

The CuO-water nanofluids were prepared by adding several grams of CuO nanoparticles (40 nm) to 800 ml of demineralized (DM) water. The amount of nanoparticle added depends on the required volume concentration. Two concentrations has been selected which are 2% and 6% and three operating temperatures have been selected which are 40 ⁰C, 50 ⁰C and 60 ⁰C. Six samples of nanofluids were prepared. Initially the samples were mixed using ultrasonic bath, but due to ineffectiveness of the mixing process, mechanical stirrer was used. However using the stirrer did not provide a long period of stabilized dispersion of the nanoparticles. Hence, surfactant was added to the mixture, about 2% mass fraction of Sodium Lauryl Sulphate powder (SLS). The sample was then mixed using the stirrer for four hours.

Heat Transfer of Water

To provide a basis for comparison, experiments were conducted to evaluate heat transfer performance of DM water as the coolant in the test rig. 800 ml of water was circulated in the test rig for four hours at the required operating temperature of 40 °C. The flow rate for these experiments was set at 1.5 LPM as to emulate laminar flow condition.

Heat Transfer of Nanofluids

The CuO-water nanofluids which have been prepared earlier were pumped into the test rig. It was then heated and circulated under the flowrate of 1.5 LPM (under laminar condition) at the required operating temperatures of 40 ℃, 50 ℃ and 60 ℃ for the duration of four hours. Since there were six samples of nanofluids, a total six experiments were conducted. The experiments are summarized as follows:

Experiment	Vol. Conc. Of CuO	Operating Temperature
#1	2%	60℃
#2	6%	60℃
#3	2%	50℃
#4	6%	50℃
#5	2%	40℃
#6	6%	40℃

EXPERIMENTAL OBSERVATION

Properties of Nanofluids

The thermophysical properties of the prepared CuO-water nanofluid are determined at the fluids' bulk mean temperature, T_b by using the correlations widely used in the literature. The density of the nanofluid is determined using Pak and Cho's equation (Pak and Cho 1998).

$$\rho_{nf} = \varphi \rho_p + (1 - \varphi)\rho_{bf}$$

(1)

where φ is volume fraction of nanoparticle. Indices of p, bf and nf refers to nanoparticles, base fluid, and nanofluid, respectively. The specific heat of the nanofluid is calculated using Xuan and Roetzel's equation (Xuan and Roetzel 2000).

$$(C_p)_{nf} = \frac{(1-\varphi)(\rho C_p)_{bf} + \varphi(\rho C_p)_p}{\rho_{nf}}$$

(2)

Hamilton and Crosser (Hamilton and Crosser 1962) developed one of the basic models for the prediction of thermal conductivity of nanofluids as follows:

$$k_{nf} = \frac{k_p + (n-1)k_{bf} - (n-1)\varphi(k_{bf} - k_p)}{k_p + (n-1)k_{bf} + \varphi(k_{bf} - k_p)} \cdot k_{bf}$$

(3)

where n is the empirical shape factor and it is 3 for spherical nanoparticles. The viscosity model used in this work is developed by Nguyen et al (Nguyen et al. 2007) by curve-fitting experimental works conducted for CuO-water nanofluids.

$$\mu_{nf} = \mu_{bf}\left(1.475 - 0.319\varphi + 0.051\varphi^2 + 0.009\varphi^3\right)$$

(4)

Heat Transfer Coefficient

The heat transfer rate (W) is calculated from

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

(5)

where Q is the rate of heat transfer (W), $\dot{m}$ is the nanofluid mass flowrate (kg/s) and C_p is the specific heat capacity of the nanofluid (J/Kg.K). The heat transfer rate can also be determined from the Newton's Law of Cooling:

$$Q = hA_s\left(T_b - T_s\right)$$

(6)

By collecting Equation (5) and (6), the heat transfer coefficient for the nanofluid side is:

$$h = \frac{\dot{m}C_p\left(T_{in} - T_{out}\right)}{A_s\left(T_b - T_s\right)}$$

(7)

RESULTS AND DISCUSSIONS

Effect of Volume Concentration

The nanofluids are implemented by the addition of CuO nanoparticles into DM water at two different nanoparticle concentrations, i.e. 2% and 6% volume concentration. The experiments were conducted at three different operating temperatures in order to investigate the effect of temperature on the heat transfer of the nanofluids.

Figure-2 depicts the rate of heat transfer of CuO-water nanofluids at the volume concentration of 0%, 2% and 6%. Volume loading of 0% indicates no nanoparticles are added; hence the fluid used is the base fluid, DM water. As shown in the figure, the rate of heat transfer increases with the increase in nanoparticle volume concentration. It has been proven that by increasing the concentration of the nanoparticles to the base fluid, even in the slightest amount, would increase the nanofluids thermal conductivity (Murshed, Leong, and Yang 2008; Eastman et al. 1996; Wang, Zhou, and Peng 2003; Patel, Sundararajan, and Das 2010; Li and Peterson 2006; Mintsa et al. 2009) and heat transfer coefficients.
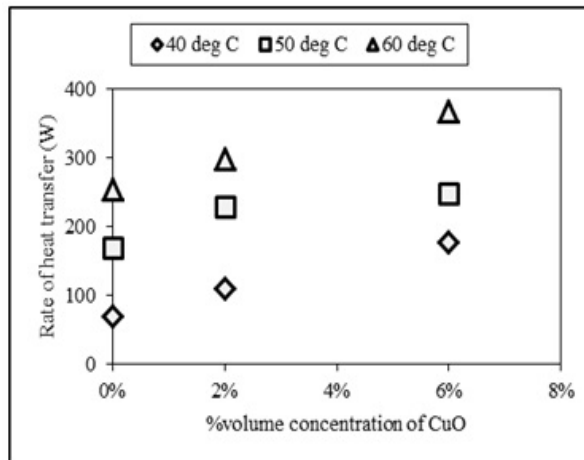
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Figure-2. Effect of CuO volume concentration on the rate of heat transfer.

By adding nanoparticles, heat transfer increases from 70 W to 177.15 W at operating temperature of 40 °C, 169.7 W to 248.8 W at operating temperature of 50 °C and 254.5 W to 368.1 W at operating temperature of 60 °C. The increase of the heat transfer is illustrated in Figure-3.

The figure shows the percentage increase of CuO-water nanofluids heat transfer from that of the base fluid alone. By adding small amount of nanoparticles to the base fluid, the heat transfer increases by at least 17.3% and at most 154%. It can be observed from these figures that the effect of nanoparticle volume concentration is more pronounced at 40 °C operating temperature at which the heat transfer increases by at least 59%. Nanofluids at this temperature would yield an average of 27.5% increase in heat transfer per each increase in CuO nanoparticle volume concentration. The increase of the heat transfer and the convection heat transfer coefficient is summarized for each operating temperature in Table-1.
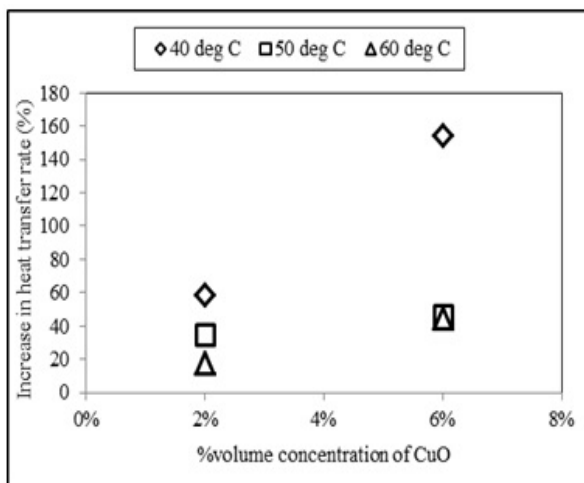
Table-1. Changes in heat transfer and heat transfer coefficient per unit vol. concentration of CuO.

		40 deg C	50 deg C	60 deg C
changes in heat transfer	W/%	19.14	18.14	20.37
	%/%	27.46	10.69	8.01
changes in heat transfer coefficient	W/m²K/%	259.3	186.4	202.7
	%/%	103.7	41.8	42.4

From the results, it can be inferred that the rate of heat transfer increases with the CuO volume concentration at an average rate of 19.2 W per unit % volume concentration. The results also indicate that at the operating temperature of 50 °C, there is no significant change in the heat transfer when the CuO volume loading was increased from 2% to 6%. Small change in heat transfer was observed at the operating temperature of 60 °C. The maximum enhancement of the rate of heat transfer from the base fluid (DI) alone occurs at 6% volume concentration at 40 °C operating temperature.

The effect of different nanoparticle volume concentration on the convection heat transfer coefficient is shown in Figure-4. At 40 °C, the heat transfer coefficient increases by 50.8% from 1255 W/m².K to 1892 W/m²K when the nanoparticle volume concentration increases from 2% to 6%. Similar percentage increment of heat transfer coefficient is also observed for operating temperature of 50 °C and 60 °C. As the nanoparticle volume concentration increases, the convection heat transfer coefficient for the nanofluid increases.

These increases in the rate of heat transfer and the convection heat transfer coefficient with nanoparticle volume concentration may be attributed to the enhanced thermal conductivity and the activation of convective heat transfer (Naraki *et al.* 2013).
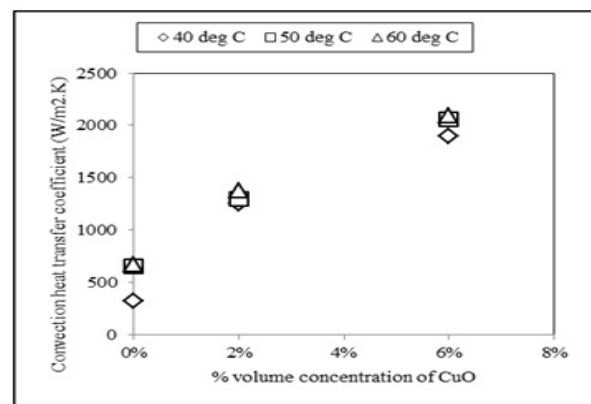

Figure-3. Effect of CuO volume concentration on the increase of heat transfer.

Figure-4. Effect of CuO volume concentration on the heat transfer coefficient.

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Figure-5 shows the effect of the CuO volume concentration on the % increase of the heat transfer coefficient. It is observed that at least 100% increment could be attained by adding nanoparticles into the base fluid. The coefficient also increases with CuO volume concentration indicating its benefit in enhancing convection heat transfer on the tube (or nanofluid) side. Table-1 shows that nanofluids would increase the convection heat transfer coefficient at an average rate of 216 W/m^2.K (or 63%) per a unit % of volume concentration. The highest increase in convection heat transfer coefficient was yielded by the nanofluids operating at 40 ºC at 6% volume loading of CuO nanoparticles.
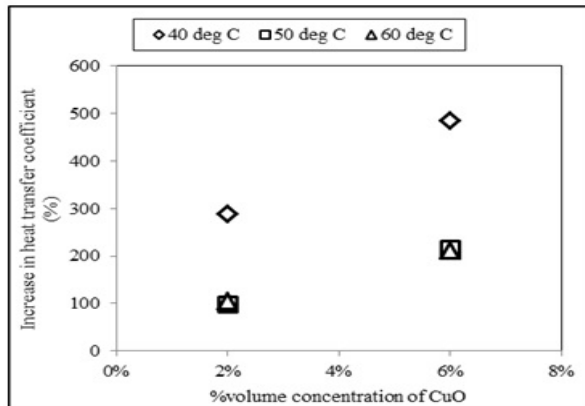

Figure-5. Effect of CuO volume concentration on the increase of convection heat transfer coefficient.

Effect of Temperature

Figure-6 compares the results of heat transfer rate of nanofluids at different operating temperatures in order to illustrate the effect of temperature variation. It shows that as temperature increase, the heat transfer rate also increases.
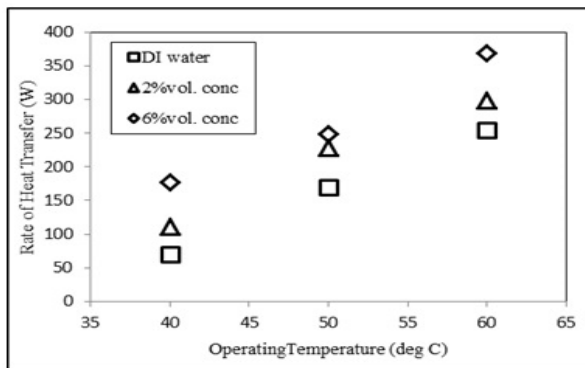

Figure-6. Effect of operating temperature on the heat transfer rate of CuO nanofluids.

At low nanoparticle volume loading of 2%, the heat transfer increases from 110.77 W to 298.5 W when the temperature increases. At volume loading of 6%, the

heat transfer increases from 177 W to 368 W. It can be observed from the figure that the increase in the rate of heat transfer at the operating temperature of 50ºC is less pronounced as compared to the other two operating temperatures.

The increase of nanofluids heat transfer with respect to the operating temperatures is illustrated by Figure-7.
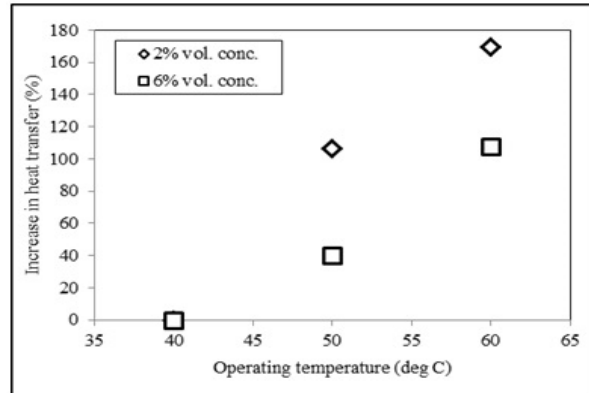

Figure-7. Effect of operating temperature on the increase of nanofluids heat transfer.

By increasing the operating temperature from 40 ºC to 60 ºC, the heat transfer would increases by at least 40% and at most 150%. Comparing the two volume concentrations, it can be observed that 2% volume loading produces greater increase in rate of heat transfer.

As temperature increases, thermal conductivity of the nanofluids increases and its viscosity reduces which consequently promotes better flow and more efficient heat dissipation process.

The increase in nanofluids heat transfer and convection heat transfer coefficient per unit change in temperature is summarized in Table-2.

Table-2. Increase of heat transfer and convection heat transfer coefficient with temperature.

		2%	**6%**
changes in heat transfer	W/°C	10.60	8.32
	%/°C	9.57	4.70
changes in heat transfer coefficient	W/m2.K/°C	5.1	13.3
	%/°C	0.4	0.7

According to the table, by adding 2% volume concentration of nanoparticles to the base fluid, the heat transfer increases at an average rate of 10.6 W (or 9.57%) per a unit change in temperature. For the case of 6% volume loading of CuO, the heat transfer would be enhanced by 4.7% per a unit change in temperature.

The effect of operating temperatures on the convection heat transfer coefficient is shown in Figure-8

and Figure-9. As temperature increases, the heat transfer coefficient increases by maximum of 10.6% and minimum of 3.14%, which can be considered to be insignificant.
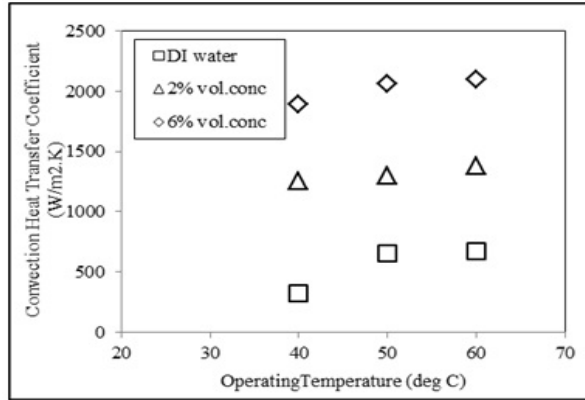

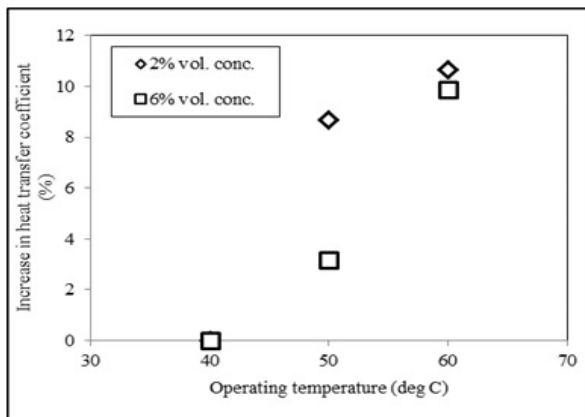**Figure-8.** Effect of temperature on the convection heat transfer coefficient.

Figure-9. Effect of operating temperature on the increase in heat transfer coefficient.

CONCLUSIONS

The following conclusions were derived from this work:

- Addition of small amount of CuO nanoparticles into DM water as the base fluid would increase the rate of heat transfer and convection heat transfer coefficient by at least 17.3% and 40% respectively.
- Heat transfer is affected by the volume concentration. As the volume loading increases, the thermal conductivity increases, which consequently increases the heat transfer.
- The rate of heat transfer and the convection heat transfer coefficient is significantly affected by the change in nanoparticle volume concentration by an average of 27.5% and 62.6% for each increase in volume loading, respectively.
- Comparing the two volume concentrations, it can be observed that 2% volume loading produces greater increase in rate of heat transfer. Thus, an optimum

value of volume concentrations may exist and further refined studies on these percentages is warranted.

- As operating temperature increases, the heat transfer rate and the convection heat transfer coefficient increases by at least 40% and 3.15% respectively.
- Among the three operating temperatures selected for study, 40 °C gives the best performance in heat transfer and the convection heat transfer coefficient.
- Nanofluids shows promising potential as the coolant for automotive radiator and more ranges of operating temperature and volume concentrations may need to be explored in order to better understand its full potential.

REFERENCES

[1] Choi, Stephen U S. 1995. "Enhancing Thermal Conductivity of Fluids with Nanoparticles." Proceedings of the 1995 ASME International Mechanical Engineering Congress and Exposition 231: 99–105.

[2] Das, S K, N Putra, P Thiesen, and W Roetzel. 2003. "Temperature Dependence of Thermal Conductivity Enhancement for Nanofluids." Journal of Heat Transfer 125: 567. doi:10.1115/1.1571080.

[3] Eastman, J. A., U. S. Choi, S. Li, L. J. Thompson, and S. Lee. 1996. "Enhanced Thermal Conductivity through the Development of Nanofluids." MRS Proceedings. doi:10.1557/PROC-457-3.

[4] Hamilton, RL, and OK Crosser. 1962. "Thermal Conductivity of Heterogeneous Two-Component Systems." Industrial & Engineering Chemistry … 1: 187–91. doi:10.1021/i160003a005.

[5] Heris, S. Zeinali, M. Nasr Esfahany, and G. Etemad. 2006. "Investigation of CuO/Water Nanofluid Laminar Convective Heat Transfer through a Circular Tube." Journal of Enhanced Heat Transfer. doi:10.1615/JEnhHeatTransf.v13.i4.10.

[6] Leong, K. Y., R. Saidur, S. N. Kazi, and a. H. Mamun. 2010. "Performance Investigation of an Automotive Car Radiator Operated with Nanofluid-Based Coolants (nanofluid as a Coolant in a Radiator)." Applied Thermal Engineering 30 (17-18). Elsevier Ltd: 2685–92. doi:10.1016/j.applthermaleng.2010.07.019.

[7] Li, Calvin H., and G. P. Peterson. 2006. "Experimental Investigation of Temperature and Volume Fraction Variations on the Effective Thermal Conductivity of Nanoparticle Suspensions (nanofluids)." Journal of Applied Physics 99. doi:10.1063/1.2191571.

[8] Lomascolo, Mauro, Gianpiero Colangelo, Marco Milanese, and Arturo De Risi. 2015. "Review of Heat Transfer in Nano Fl Uids : Conductive, Convective and Radiative Experimental Results." Renewable and Sustainable Energy Reviews 43. Elsevier: 1182–98. doi:10.1016/j.rser.2014.11.086.

[9] Mintsa, Honorine Angue, Gilles Roy, Cong Tam Nguyen, and Dominique Doucet. 2009. "New Temperature Dependent Thermal Conductivity Data for Water-Based Nanofluids." International Journal of Thermal Sciences 48: 363–71. doi:10.1016/j.ijthermalsci.2008.03.009.

[10] Murshed, S. M S, K. C. Leong, and C. Yang. 2008. "Investigations of Thermal Conductivity and Viscosity of Nanofluids." International Journal of Thermal Sciences 47: 560–68. doi:10.1016/j.ijthermalsci.2007.05.004.

[11] Naraki, M., S. M. Peyghambarzadeh, S. H. Hashemabadi, and Y. Vermahmoudi. 2013. "Parametric Study of Overall Heat Transfer Coefficient of CuO/water Nanofluids in a Car Radiator." International Journal of Thermal Sciences 66: 82–90. doi:10.1016/j.ijthermalsci.2012.11.013.

[12] Nguyen, C. T., F. Desgranges, G. Roy, N. Galanis, T. Maré, S. Boucher, and H. Angue Mintsa. 2007. "Temperature and Particle-Size Dependent Viscosity Data for Water-Based Nanofluids - Hysteresis Phenomenon." International Journal of Heat and Fluid Flow 28: 1492–1506. doi:10.1016/j.ijheatfluidflow.2007.02.004.

[13] Pak, Bock Choon, and Young I. Cho. 1998. "Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles." Experimental Heat Transfer. doi: 10.1080/08916159808946559.

[14] Patel, Hrishikesh E., T. Sundararajan, and Sarit K. Das. 2010. "An Experimental Investigation into the Thermal Conductivity Enhancement in Oxide and Metallic Nanofluids." Journal of Nanoparticle Research 12: 1015–31. doi: 10.1007/s11051-009-9658-2.

[15] Peyghambarzadeh, S. M., S. H. Hashemabadi, M. Naraki, and Y. Vermahmoudi. 2013. "Experimental Study of Overall Heat Transfer Coefficient in the Application of Dilute Nanofluids in the Car Radiator." Applied Thermal Engineering 52: 8–16. doi:10.1016/j.applthermaleng.2012.11.013.

[16] Peyghambarzadeh, S.M., S.H. Hashemabadi, M. Seifi Jamnani, and S.M. Hoseini. 2011. "Improving the Cooling Performance of Automobile Radiator with Al2O3/water Nanofluid." Applied Thermal Engineering. doi:10.1016/j.applthermaleng.2011.02.029.

[17] Routbort, Jules, Dileep Singh, W Yu, G Chen, D Cookson, R Smith, and T Sofu. 2008. Effects of Nanofluids on Heavy Vehicle Cooling Systems.

[18] Timofeeva, Elena V, Wenhua Yu, David M France, Dileep Singh, and Jules L Routbort. 2011. "Nanofluids for Heat Transfer: An Engineering Approach." Nanoscale Research Letters 6 (1). Springer Open Ltd: 182. doi: 10.1186/1556-276X-6-182.

[19] Vajjha, Ravikanth S., Debendra K. Das, and Devdatta P. Kulkarni. 2010. "Development of New Correlations for Convective Heat Transfer and Friction Factor in Turbulent Regime for Nanofluids." International Journal of Heat and Mass Transfer 53 (21-22). Elsevier Ltd: 4607–18. doi:10.1016/j.ijheatmasstransfer.2010.06.032.

[20] Vajjha, Ravikanth S., Debendra K. Das, and Praveen K. Namburu. 2010. "Numerical Study of Fluid Dynamic and Heat Transfer Performance of Al2O3 and CuO Nanofluids in the Flat Tubes of a Radiator." International Journal of Heat and Fluid Flow 31: 613–21. doi:10.1016/j.ijheatfluidflow.2010.02.016.

[21] Wang, Bu Xuan, Le Ping Zhou, and Xiao Feng Peng. 2003. "A Fractal Model for Predicting the Effective Thermal Conductivity of Liquid with Suspension of Nanoparticles." International Journal of Heat and Mass Transfer 46: 2665–72. doi: 10.1016/S0017-9310(03)00016-4.

[22] Xuan, Yimin, and Wilfried Roetzel. 2000. "Conceptions for Heat Transfer Correlation of Nanofluids." International Journal of Heat and Mass Transfer 43: 3701–7. doi: 10.1016/S0017-9310(99)00369-5.

[23] Yu, W, Dm France, Sus Choi, and Jl Routbort. 2007. "Review and Assessment of Nanofluid Technology for Transportation and Other Applications." Renewable Energy, Medium: ED. doi: 10.2172/919327.

[24] Zamzamian, Amirhossein, Shahin Nasseri Oskouie, Ahmad Doosthoseini, Aliakbar Joneidi, and Mohammad Pazouki. 2011. "Experimental Investigation of Forced Convective Heat Transfer Coefficient in Nanofluids of Al2O3/EG and CuO/EG in a Double Pipe and Plate Heat Exchangers under Turbulent Flow." Experimental Thermal and Fluid Science 35 (3). Elsevier Inc.: 495–502. doi:10.1016/j.expthermflusci.2010.11.013.