24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-0348
EXPERIMENTAL ANALYSIS ON THE THERMAL PERFORMANCE OF MWCNT/WATER NANOFLUIDS IN A CAR RADIATOR

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Abstract. *This paper presents the results of experimental research on heat transfer and thermal performance characteristics of multi-walled carbon nanotubes (MWCNTs) in distilled water for their application in the automotive cooling system. The two-step method through high-pressure homogenization has been used to disperse the nanoparticles in distilled water. The influence of operating parameters such as mass concentration ranging from 0.05 to 0.16 wt%, nanofluid inlet temperature varying from 50 to 80 °C was evaluated experimentally. An experimental bench composed of a wind tunnel, which simulates the air flow through an automotive heat exchanger (radiator) and a hot fluid circuit which circulates the nanofluid inside the radiator was built to evaluate the thermal performance of nanofluids. The air mass flow rate was maintained constant at 0.175 kg/s and from 30 to 70 kg/s for the nanofluid. The drops in temperature and heat transfer rate of the heat exchanger have been investigated. There was a slight decrease in heat transfer rate, up to 5% for all test conditions. On the other hand, as the nanoparticle concentration increased, the heat transfer rate decreased.*

Keywords: *thermal conductivity, nanofluid, automotive cooling systems, heat transfer.*

NOMENCLATURE

a	Parameter that depensds on Reynold	***Nondimensional***	
A	Area [m^2]	*Nu*	Nusselt number
C_p	Specific heat [J/ kg K]	*Re*	Reynolds number
C_D	Discharge coefficient	***Subscripts***	
k	Thermal conductivity [W/m K]	*air*	air
$\dot{m}$	Mass flow rate [kg/s]	*bf*	base fluid
$\dot{Q}$	Heat tranfer rate [W]	*in*	inlet
T	Temperature [°C]	*liq*	liquid
wt	Mass concentration [%]	*lm*	Logarithmic mean
ΔT	Differential temperature [°C]	*out*	outlet
μ	Dynamic viscosity [Pa.s]	***Abbreviation***	
ρ	Density [kg/m^3]	*CNT*	Carbon nanotube
		MWCNT	Multi-walled Carbon nanotube

1. INTRODUCTION

The enhancement of the heat transfer is an important challenge nowadays in terms of energy and materials saving, sustainable development, thermal control, miniaturization, etc. Accordingly, optimization of the devices is a common practice that seeks to improve performance focused on miniaturization, downsizing and consequently reducing costs.

The advent of nanotechnology, in recent decades has resulted in a possibility of a wide range of applications, including thermal systems. In this condition, the concept of nanofluid emerged as a new class of fluids consisting of nanoparticles (metals, oxides, carbon nanotubes, etc.), sizing normally between 1 and 100 nm dispersed in a base fluid (water, ethylene glycol, oil) Choi (1995). The common fluids have low thermal conductivity and innovations in thermal systems have only occurred in terms of equipment and materials. Therefore, according to Yu and Choi (2001), Ding et al. (2007) there is a need to develop new compounds to improve heat transfer in thermal systems. Solids have higher thermal conductivity compared to liquids. In this sense, nanofluids tend to have a higher thermal conductivity compared to base fluid.

A great number of studies about the thermal properties of nanofluids can be found in the literature. Physical classic models such as Maxwell (1873), Hamilton and Crosser (1962), Xie et al. (2005), Leong et al. (2006), analyzed by Oliveira et al. (2012), failed to predict the experimental data. The same discrepancy was observed for predicting viscosity. Many experimental studies have been reported and most of them showed an anomalous increase in the thermal conductivity and the viscosity of nanofluids. The nature of the multiscale nanofluids leads to non-trivial relationship between the geometric, physical, and chemical characteristics and the resulting thermal and physical properties. In fact, heavily dependent sensitivity of these properties is the main reason for some contradictory results between experimental evidence and theoretical considerations presented in the literature.

The works of Eastman et al. (1997), Lee et al. (1999) and Das et al. (2003) conducted experimental studies of thermal conductivity in nanofluid of different materials (metals and oxides) and achieved great improvement compared to the base fluid. Liu et al. (2006) measured the thermal conductivity of nanofluids containing carbon nanotubes dispersed in ethylene glycol and synthetic oil. The thermal conductivity increased up to 12.4% for suspensions CNT/Ethylene-glycol 1.0% vol and 30% engine oil-synthetic CNT suspensions at 2% vol. Increased thermal conductivity and higher specific surface area of CNT had a great impact on thermal performance. The CNT dispersed in the base fluid can form an extensive three-dimensional network that facilitates heat transfer. They found an increase on thermal conductivity for the tested nanofluids. Cárdenas et al. (2015) conducted an experimental study of different MWCNTs. In terms of thermal conductivity, they found that the sample nanofluid with the highest aspect ratio (long diameter) had the highest increase of 17% as compared to the base fluid of distilled water. On the other hand, the viscosity of the same nanofluid sample increased by 11.3%. The same trend was observed by Oliveira et al. (2016). According to Ali et al. (2015), if nanofluids are used as refrigerants in automotive radiators, several thermal and physical properties as thermal conductivity, specific heat, density, and viscosity have to be taken into account to assess its overall cooling efficiency.

This is related to the strong influence of the heat transfer as well as the required pumping power, respectively. Chougule and Sahu (2014) evaluated experimentally the automotive radiator thermal performance operating with CNT/H_2O nanofluids. The tests were conducted maintaining the inlet temperature of the liquid in 90°C and the inlet air temperature in 35°C, while the liquid flow rate was varied from 2 to 5 L/min, and the nanoparticle concentration from 0.15% to 1%. An increase in heat transfer of 90.76% was achieved by applying nanofluid compared to pure water circulating at a rate of 5 L/min. Recently, Sonage and Mohanan (2015) synthesized nanofluids Zn/H_2O and ZnO/H_2O with nanoparticles diameter of 35 nm and 41 nm in different concentrations. The nanofluid was theoretically evaluated in an automobile radiator to obtain benefits from its use. If water is replaced by Zn- H_2O nanofluid at a concentration of 0.5% wt, it is estimated that the size of the radiator and the amount of fluid and pumping power will be reduced**,** therefore revealing that nanofluids are energetically efficient for the engine's cooling system.

This paper reports the results of an experimental research focused on thermal performance of MWCNT/water nanofluids in a car radiator. The range of the mass flow rate ranged from 30 to 70 g/s, the inlet temperature from 50 to 80 °C and the concentration from 0 to 0.16% wt. Furthermore, the nanofluids properties were measured experimentally.

2. EXPERIMENTAL PROCEDURE

The physical and thermal properties of the nanofluids need special requirements since there is a strong dependence on the characteristics of the base fluid and the nanoparticles as well as the behavior of nanoparticles is also affected by the production techniques. Generally the structure of a nanoparticle is composed by a solid core that defines the main features of nanoparticles such as thermal, electrical and magnetic behavior, and a chemically bonded coating on the surface that defines the stability of the suspension and the behavior of the dispersion as showed by Das et al. (2007). In the present study, the nanofluids were prepared using a high-pressure homogenization process, which is a two-step preparation method. A solution containing 3%wt multi-walled carbon nanotube was purchased from Nanostructured & Amorphous Materials, Inc. The values of specific heat and density of the carbon nanotubes were provided by the manufacturer, C_P = 710 J/kgK and ρ = 2.1 g/cm³. In high-pressure homogenization process, the nanoparticle agglomeration is broken contributing to the homogeneity and stability of the suspension, according to Bandarra Filho et al. (2014).

To evaluate the thermal performance of nanofluids with carbon nanotubes, an experimental bench was constructed in order to determine the heat transfer rate in automotive radiators. Table 1 shows the geometric characteristis of the tested radiator. The experimental setup consists of a wind tunnel to simulate the air conditions and a hot fluid circuit that simulates the heat generated by the engine. These conditions are necessary to evaluate thermo-physical properties of the nanofluids.

Table 1. Geometric characteristics of the tested radiator.

Geometry	Measurement
Width	480 mm
Height	300 mm
Thickness	30 mm
Tube dimensions (width x height)	13mm x 3 mm
Number of tubes	31

The viscosity of nanofluids was measured using a viscometer SVM 3000, manufactured by Anton Paar Inc. The measurement principle with Peltier thermostat allows a wide range of viscosity and temperature with a single system. This equipment is compact with the advantage that only small amounts of sample are required. The thermal conductivity of nanofluids was measured using a transient hot bridge sensor manufactured by Linseis Inc. The transient hot bridge is an evolution of transient hot wire method, however it remains a transient method, which is better than the stationary one, especially due to shorter measuring time. Also, thermal diffusivity is measured in parallel with the thermal conductivity. In this method, a strip that is immerged in the fluid sample emits a constant heat flux during the measurement.

Figure 1 shows the schematic diagram of the experimental setup. The air circuit was constructed to control and measure the air conditions before and after passing through the automotive radiator. The air is heated by a set of electrical resistors of 6 kW, adjusted by a PID controller. After the heating, the airflow passes through the beams of a rectifying honeycomb section where the heat exchanger is located, in addition to temperature, differential pressure and airflow measurement devices, following the specifications of the standards Ashrae 41.1, 41.2 and 41.3.

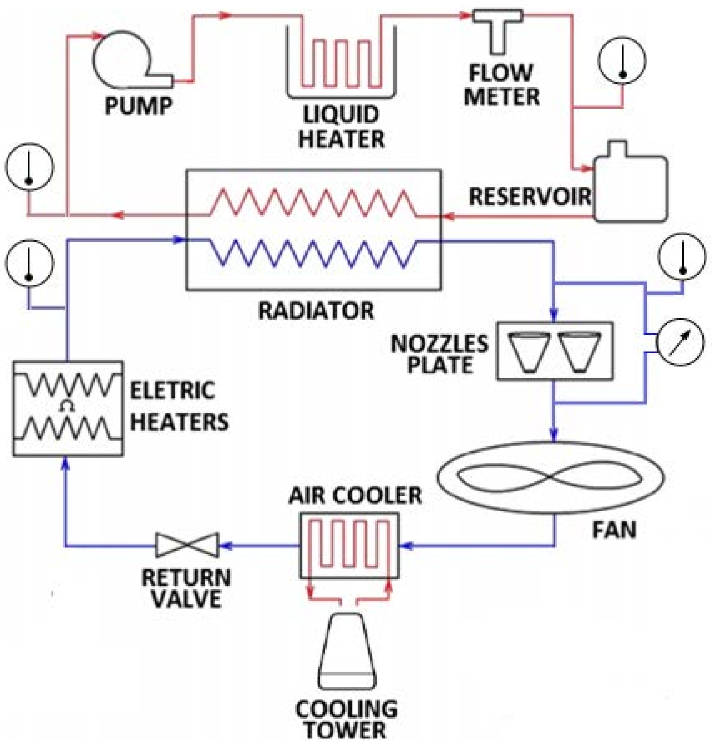

Figure 1. Schematic diagram of the experimental setup.

To measure the airflow, the wind tunnel has five nozzle plates and the differential pressure of the air is measured by a U-tube manometer. From this differential pressure, the mass flow rate of the air can be determined using the following equations:

$$\dot{m}_i = \frac{A_1 \cdot \sqrt{2 \cdot \rho_{air} \cdot \Delta P_{air}}}{\sqrt{1 - \left[\frac{A_i}{A_{tun}}\right]^2}} \tag{3}$$

$$\dot{m}_{air} = \sum C_{d,i} \cdot \dot{m}_i \tag{4}$$

The index i = 1,2,3, 4 and 5 indicates the nozzle and C_d, i is the discharge coefficient for each nozzle.

$$C_{d,i} = 0.9975 - 0.00653 \cdot \left[\frac{10^6}{\mathrm{Re}_{d,i}}\right]^a \tag{5}$$

The hot fluid circuit consists in a micropump for high temperature applications and the flow rate was controlled using an inverter drive. The mass flow rate was measured using a coriolis mass flow meter and then a coil heat exchanger is used for the temperature control. The inlet and outlet temperatures were measured by RTD (*resistance temperature detector*) sensors. The heat exchange rate ws determined by the equations (6) and (7), respectively.

$$\dot{Q} = \dot{m}_{liq} \cdot C_{p,liq} \cdot \Delta T_{liq} \tag{6}$$

$$\Delta T_{liq} = T_{in,liq} - T_{out,liq} \tag{7}$$

3. RESULTS AND DISCUSSION

3.1 Viscosity

The viscosity of the samples were measured in the temperature range varying from 30°C to 90°C, using concentrations of 0.05, 0.08, 0.16 wt%, respectively. Fig. 2 shows that the viscosity has a significant increase for the nanofluid when compared to the water as well as with the increase the concentration of the nanoparticles. The nanofluid viscosity decreases exponentially with the temperature. For 30 °C, the viscosity increases 8.5, 20.6 and 54% for concentrations of 0.05, 0.08 and 0.16 wt%, respectively.

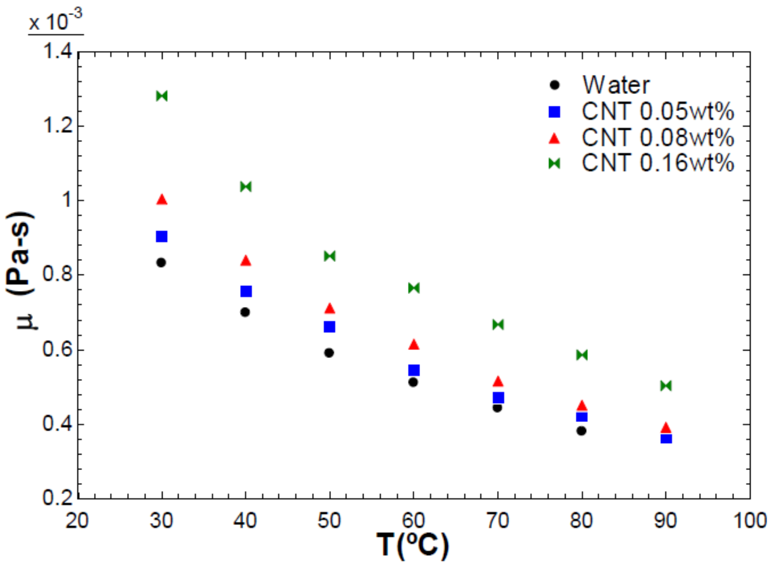

Figure 2 – Experimental results of the viscosity according to the temperature.

3.2 Thermal conductivity

Typically, thermal conductivity of nanofluids is larger than the base fluid, whereas its specific heat capacity is smaller. The thermal conductivity of MWCNT-water at different concentrations and temperatures is shown in Fig. 3. Tests were conducted with temperatures of 25 and 50 °C.

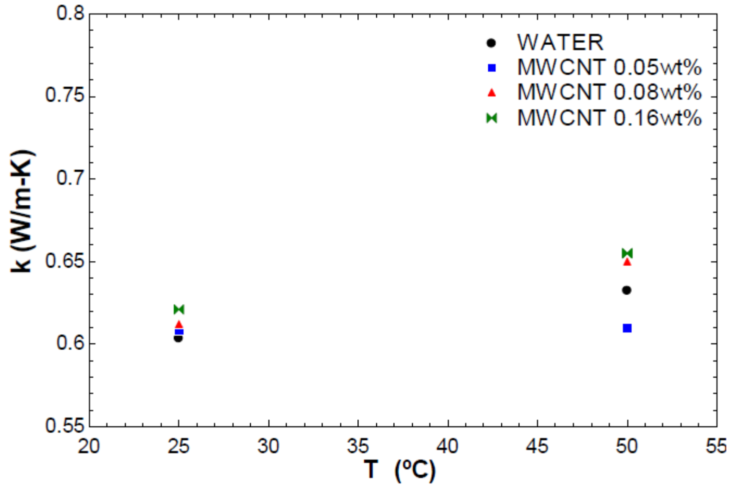

Figure 3 – Experimental results of thermal conductivity according to the temperature.

The experimental results showed a slightly increase on thermal conductivity compared to that of the base fluid. The increase in thermal conductivity was about 5% at a temperature of 50°C for concentrations of 0.08 and 0.16wt%, respectively. For 25°C the enhancement in the thermal conductivity was lower, 1.6% for 0.16wt% concentration. There was a small decrease in thermal conductivity for concentrations of 0.08wt%. It is important to mention that the results of the thermal conductivity are within the maximum uncertainty range of the experiments, i.e. 3% of the measured value.

3.3 Heat Transfer

- Validation of the results

The Nusselt number was experimentally obtained for distilled water and compared with the Dittus and Boelter (1930) correlation :

$$Nu = 0.023 \cdot \mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{0.3} \tag{8}$$

The heat transfer rate was also compared between the two main circuits (air and hot fluid) of the experimental setup, i.e., verification of the energy balance was carried out over the control volume of the radiator (air and water) using the equations (9) and (10):

$$\dot{Q}_{liq} = \dot{m}_{liq} \cdot C_{p,liq} \cdot \Delta T_{liq} \tag{9}$$

$$\dot{Q}_{air} = \dot{m}_{air} \cdot C_{p,air} \cdot \Delta T_{air} \tag{10}$$

Assuming no heat losses to the environment, $\dot{Q}_{liq} = \dot{Q}_{air}$. The error in the energy balance was calculated as described in Eq. (11).

$$error(\%) = \frac{\dot{Q}_{liq} - \dot{Q}_{air}}{\dot{Q}_{liq}} \cdot 100 \tag{11}$$

This error ranged from 1 to 10%, indicating that the experimental results for heat transfer rates are reliable and according to the Ashrae Standard 33 (2000) and Asme PTC. 30 (1991).

-Thermal performance

MWCNT/water nanofluids were tested in the experimental bench, at concentrations of 0.05, 0.08 and 0.16 wt%, mass flow rates ranging from 30 to 70 g/s focus on the thermal performance of nanofluids. The tests were conducted at different inlet temperatures 50, 60, 70 and 80 °C to evaluate the effect of this parameter. As expected, the heat transfer rate increases as the mass flow increases. In general, the nanofluid heat transfer rate decreases when the concentration increased. At 0.5% concentration by weight, the heat transfer rate results were almost the same of the distilled water. In case of 0.08 wt%, the heat transfer rate obtained values between 3 and 8.8% lower than the baseline fluid. The major difference was achieved for the inlet temperature of 50ºC and mass flow rate of 30g/s. For 80°C and 70 g/s, the decrement was lower, about 3%. These results can be seen in Fig. 4a. Finally, at the highest concentration, 0.16 wt%, Fig. 4b, the heat transfer rate presented results more significant, ranging from 7.3% for 80° C and 70 g/s, and 17% for inlet temperature 80 ºC and 30 g/s.

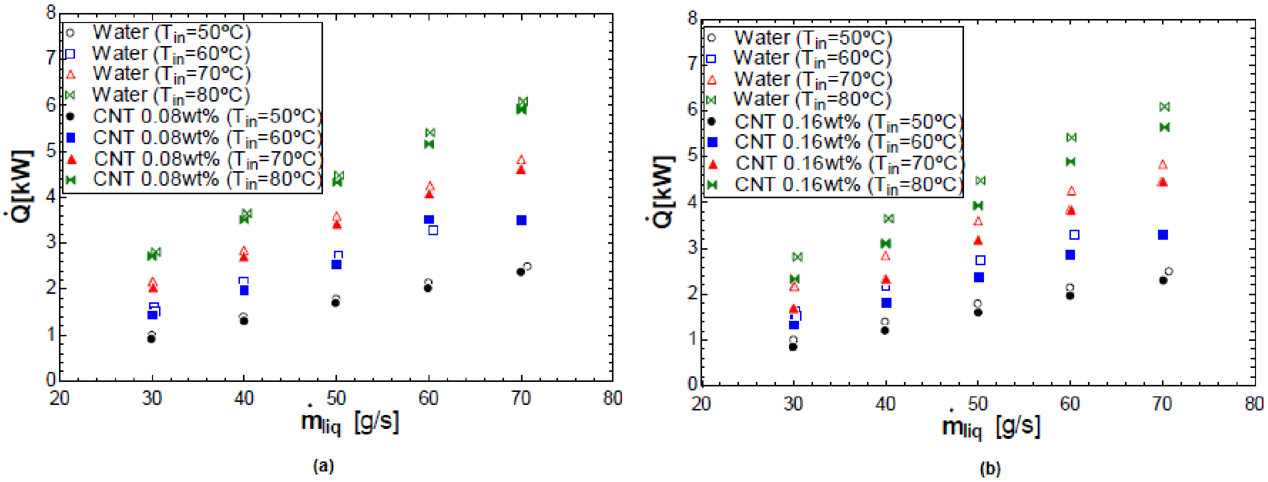

Figure 4. Comparison of the heat transfer rate obtained for distilled water and nanofluid in relation to the mass flow rate. (a) 0.08wt% and (b) 0.16 wt%.

4. CONCLUSIONS

A two-step synthesis method was used to prepare the MWCNT/water nanofluids. In this work, thermal properties were measured and the thermal performance in an automotive radiator was evaluated. The heat transfer and the Nusselt number were obtained experimentally for validation of the experimental set. The analysis of experimental results allowed the following conclusions.

The thermal conductivity of the nanofluids was analyzed and the experimental results showed that is slightly higher than distilled water to 50°C, with concentrations of 0.08% and 0.16% wt. For room temperature, the nanofluid thermal conductivity was closer to the water, indicating that the improvement in thermal conductivity can be enhanced at higher temperatures. The experimental results for viscosity of nanofluids resulted significantly higher than that of the base fluid, showing a maximum enhancement of 54% for concentration of 0.16%wt at 30ºC. The viscosity was strongly dependent on temperature and it decreased when temperature increases. For higher temperatures, the increment of the viscosity was lower, 40% for concentration of 0.16%wt at 80ºC. The higher heat transfer rates were obtained with distilled water instead of nanofluid, indicating that this nanofluid is not ideal to replace the cooling fluid in these conditions. Thus, new tests will be carried out with different concentrations and nanofluids.

5. ACKNOWLEDGEMENTS

The authors acknowledge the support given to the reported investigation by CAPES, CNPq, FAPEMIG.

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