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Heat Transfer Enhancement Using Graphene Oxide/Water Nanofluid in a Two-Phase Closed Thermosyphon

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Abstract: *A two-phase closed thermosyphon (TPCT) is a device for heat transmission. The TPCT is composed of three major parts: Lower evaporator, the adiabatic region in the central range and the condenser at the top. Fluids with nanoparticles (particles smaller than 100 nm) suspended in them are called nanofluids that they have a great potential in heat transfer enhancement. In the present study, Nanofluids of aqueous Graphene oxide (GO) nanoparticles suspensions are prepared in various volume concentration of 0.05–0.20% and used in a TPCT as working media. Experimental results showed that for different input powers, the heat transfer coefficient of the TPCT increases up to 33.04% when GO/water nanofluid is used instead of pure water. A decrease of 24.83% is achived in thermal resistance at 0.20 vol.% for GO/water nanofluid.*

Keywords: *Thermosyphon, Nanofluid, Thermal resistance, Heat transfer coefficient*

1. Introduction

Nanofluids, defined as fluids in which nanosized particles are suspended in a base liquid, are a novel types of working fluids used for heat transfer and coolings. Since Choi [1] first proposed the concept of using nanofluids to enhance thermal conductivity, these working fluids have shown great promise in heat transfer applications. The Two-phase closed thermosyphon heat pipes are one of the simplest and efficient types of heat pipes which can widely be employed in micro device cooling, computers, solar energy collectors, aeronautics sciences, missiles, spacecraft thermal control, micro-transportation systems, cooling loops, fuel cells and heat recovery systems.

Do et al. [2] experimentally investigated the effect of Al2O3/water nanofluids on the thermal performance of a heat pipe and found that the thermal resistance was reduced by about 40% at the evaporator-adiabatic section of the heat pipe. They concluded that the Al2O3 nanoparticles formed a thin porous coating layer at the evaporator section, and the improved surface wettability and capillary wicking performance reduced the thermal resistance of the heat pipe. Tsai et al. [3] performed an experimental investigation for a circular meshed heat pipe using gold nanofluids. They presented that the thermal resistances of the heat pipe with solutions of various-sized gold nanoparticles ranged from 0.17 to 0.215 ^{o}C/W, which was 37% lower than the thermal resistance of the heat pipe using DI water.

Solomon et al. [4] investigated the heat transfer characteristics of a copper heat pipe with nanoparticle deposition on the wick, at power levels of 100–200 W. They used a screen wire mesh wick and reported that a heat pipe coated with copper oxide nanoparticles showed a maximum reduction in thermal resistance of 40%, as compared to the bare screen wire mesh, because the deposited nanoparticles provided more nucleation sites. Kang et al. [5] investigated the influence of silver nanofluids on grooved heat pipe with circular cross section and 200 mm length and 6 mm diameter. Results demonstrated that thermal resistance of the heat pipe was decreased by 10–80% in comparison with water.

Rahimi et al. [6] studied the effect of resurfacing on the evaporator and the condenser of a closed two-phase thermosyphon. It was shown that the thermal performance of the surface modified thermosyphon was enhanced by 15% when compared to the plain surface.

Huminic et al. [7] studied the heat transfer characteristics of two-phase closed thermosyphon with iron oxide-nanofluids as working media at different inclinations, operating temperatures and nano-particle concentrations. It was evident that the nanoparticles had a significant effect on the enhancement of heat transfer characteristics of thermosyphon.

In this research, the thermal performance of a two-phase closed thermosyphon (TPCT) was investigated experimentally under different constant heat fluxes (10 – 30W) and 100% fill charge ratio. Pure water and various volume concentrations of Graphene oxide (GO)/water nanofluid (0.05 – 0.2%) were employed as working fluid.

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2. Materials and Methods

2.1. Materials

Graphene oxide (GO)/water nanofluids were prepared by dispersing GO nanoparticles into pure water as a base fluid. GO nanoparticles were synthesized from natural graphite powder by a modified Hummers method [8, 9]. Graphite fine powders (45 μm) was purchased from Wako pure chemical industries (Japan), concentrated sulfuric acids (H2SO4), sodium nitrate (NaNO3), potassium permanganate (KMnO4), hydrogen peroxide (30% H2O2), hydrochloric acid (5% HCl) and de-ionized water were used throughout Hummers method. GO/water nanofluids with four different volume concentrations at 0.05%, 0.1%, 0.15% and 0.2% were prepared for this experiment. The thermal conductivity and the viscosity of GO/water nanofluids were measured in our previous study [8].

2.2. Experimental Setup

In this study, the results of the experimental determination of the thermal performance of a TPCT are reported. Fig. 1a shows a schematic diagram of the experimental apparatus that is used in this work. Fig. 1b shows the locations of the thermocouples. The apparatus consisted of a TPCT, data logger, variable transformer, vacuum pump, digital multi-meter, flow meter, pressure gauge and thermostatic bath.

In the experiment, a copper thermosyphon is used with a long of 200 mm, an outer diameter of 15 mm, and a thickness of 1 mm. The thermosyphon charged with the working fluids and tested with an evaporator length of 70 mm and a condenser length of 80 mm. The working fluids filled approximately 100% of the volume of the evaporator. The heat energy emitted to the evaporator section of TPCT by the electric heater was removed from the condenser by circulating cooling water. Eight K-type thermocouples were fixed at the outer surface of the TPCT to monitor the temperature distribution along the wall of the TPCT. Four thermocouples were embedded on the evaporator; three were placed on the condenser and one at adiabatic section. The temperature of the circulating cold water to the condenser section is maintained at 15oC with a flow rate 1.5 L/min for all test conditions. The heat input is varied from 10W to 30W for each concentration.

3. Results and Discussion

3.1. Wall temperature distribution

Fig. 2 display the distribution of the wall temperature along the heat pipe, which was positioned vertically, with deionized water or the nanofluid as the working fluid using 10 W, 20 W and 30 W of power supplied into the heat pipe, respectively.

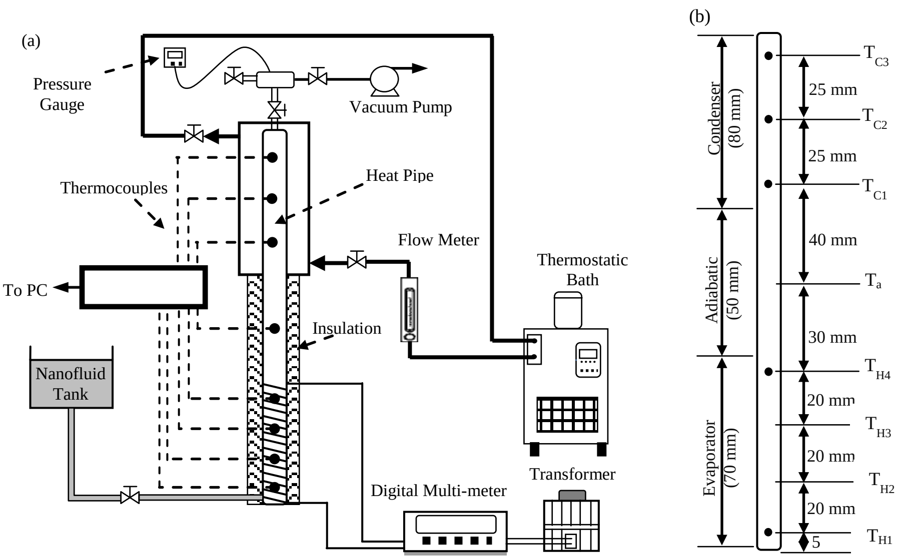

***Fig. 1 (a)** Schematic diagram of the experimental apparatus, (b) locations of the thermocouples*

From Fig.2, a gradual decrease is observed in the temperature of the pipe wall in the direction from the evaporator to the condenser. The wall temperature distribution of the nanofluid containing heat pipes in the evaporator section is lower than that of the heat pipes containing distilled water at the same input power and increasing the volume fraction of nanoparticles caused the wall temperature to decrease significantly. However, the wall temperature rapidly increased to higher values as the applied input power is increased. Based on the experimental results, the maximum reduction in the mean evaporator temperature $((T_{H1}+T_{H2}+T_{H3}+T_{H4})/4)$ compared with pure water is registered for 0.20 vol.% at different input power (5.875 ^oC, 12.47 ^oC and 7.95 ^oC for input power of 10, 20 and 30 W, respectively).

3.2. Thermal resistance

The thermal resistance (R_{th}) of the TPCT is a measure of its thermal performance, defined as the ratio of the temperature difference to a given heat load:

$$R_{th} = \frac{T_H - T_C}{Q} \quad (1)$$

In this equation, the temperatures of the evaporator and the condenser are the respective average wall temperatures, and the heating power input Q could be evaluated by Eq. (2) as follows:

$$Q = V \times I \quad (2)$$

Where, V and I are the applied voltage and current, respectively.

Fig. 3 shows the effect of volume concentration and input power on the thermal resistance of the TPCT. According to Fig. 3, the thermal resistance decreased at the heat input power increased. Also, increasing the GO nanoparticles as the dispersed phase in water can significantly reduce the overall thermal resistance of the TPCT. The thermal resistance reached its minimum value at volume concentration of 0.20% for all heating loads. When compared with pure water, the maximum reduction in thermal resistance is 24.8% for volume concentration of 0.20% at input power of 20 W.

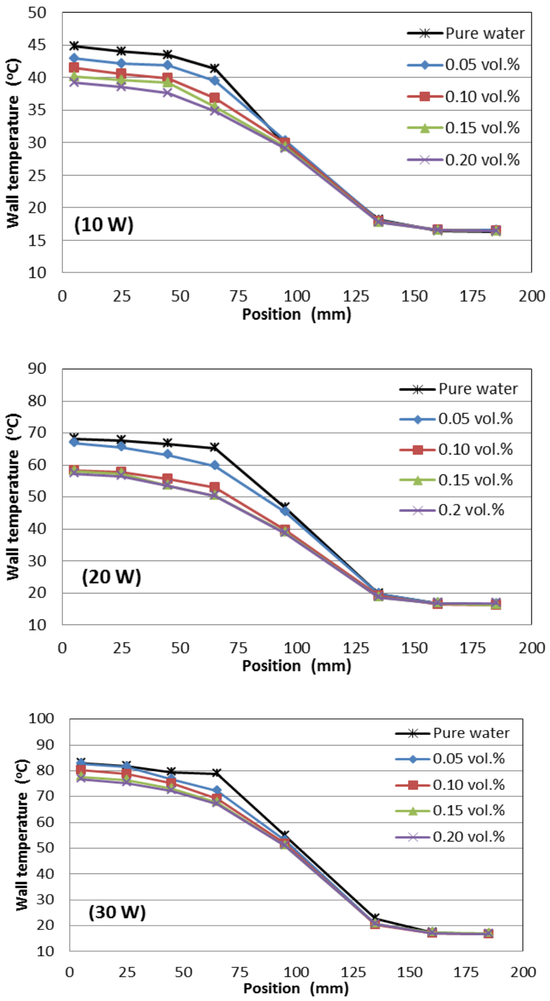

Fig. 2 *Effect of GO concentration on the wall temperature distribution at input power levels of 10, 20 and 30 W*

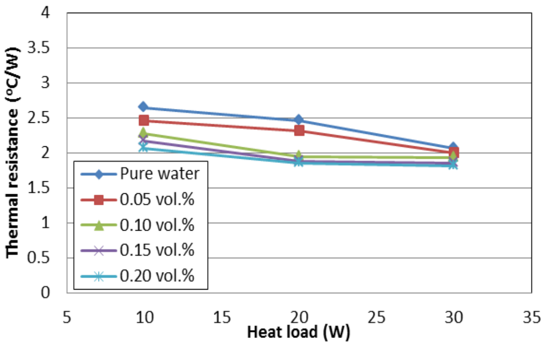

Fig. 3 *Thermal resistance as a function of concentration and input power*

3.3. Overall heat transfer coefficient

The overall heat transfer coefficient (h) is defined by the following equation:

$$h = \frac{Q}{\pi D L_e (T_H - T_C)} \quad (3)$$

Where, D is the outer diameter of the TPCT and L_e is the evaporator length.

Fig. 4 shows the effect of input heating power the overall heat transfer coefficient, when using pure water and GO/water nanofluids. Results showed that the overall heat transfer coefficient of the TPCT significantly increased with increasing the input heat power for all working fluids. For GO/water nanofluids, a higher heat transfer coefficient is registered for all volumetric concentrations of nanoparticles in comparison with those reported for pure water at a similar condition. Noticeably, with increasing the concentration of GO nanoparticles, the heat transfer coefficient of the TPCT dramatically increased. When compared with pure water, the maximum enhancement in the overall heat transfer coefficient is 33.04% for a volume concentration of 0.20% at input power of 20 W.

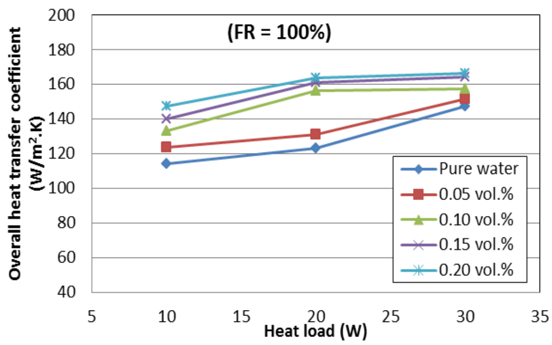

Fig. 4 *Overall heat transfer coefficient as a function of concentration and input power*

Conclusions

The objective of this study was to examine the effects of using graphene oxide nanofluids on the performance of a two-phase closed thermosyphon. Different concentrations (0.05%, 0.10%, 0.15% and

0.20%) of GO nanoparticles were dispersed in distilled water as base fluid. The following conclusions are deduced from this study:

- Significant enhancement of heat transfer performance due to suspension of GO nanoparticles was observed in comparison with pure water as the working fluid.
- The enhancement depended on the GO concentration and the input heat power.
- The wall temperature of heat pipes declined significantly as concentration of GO nanoparticles increased. The maximum reduction in surface temperature was 12.47 °C for volume concentration of 0.20%.
- The thermal resistance was lowered by 24.8% for volume concentration of 0.20% at input power of 20 W.
- The overall heat transfer coefficient of the GO nanofluids was better than that of deionized water.

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