EFFECT OF FILLING RATIO ON HEAT TRASFER PERFORMANCE IN MULTI-HEAT PIPE WITH GRAPHENE OXIDE NANOFLUID

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Abstract: *This experimental study is performed to investigate heat transfer performance of a multi-heat pipe cooling device in the condition of different filling ratio (40%, 60%, 80% and 100%) under constant heat flux conditions. Here, pure water and graphene oxide (GO) nanofluid are employed as working fluid. Temperature fields and thermal resistance are measured for different filling ratio, heat fluxes and volume concentrations. It was found that (i) the thermal performance of heat pipe increases with increasing the concentration of GO nanoparticles in the base fluid, while the maximum heat transfer enhancement yields at 0.2% volume concentration, (ii) GO/water nanofluid shows lower thermal resistance compared to pure water, (iii) the optimal thermal resistance is obtained at 100% filling charge ratio with 0.2% volume concentration, and (iv) heat transfer coefficient of the heat pipe significantly increases with an increase in heat flux and GO nanoparticles concentration.*

Keywords: *Multi-heat pipe; graphene oxide; gilling ratio; volume fraction; thermal resistance.*

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1. Introduction

A multi-heat pipe is a device that transfers heat from the hot interface to the cold one by phase change and convection of the working fluid. Vapor is generated at the heat source level (evaporator) and it condenses at the heat sink level (condenser). The liquid returns from the evaporator to the condenser through a capillary structure. Heat pipes have a variety of advantages, such as high heat removal rate per unit volume, a fully passive working principle, and easy applicability. Heat pipes have been used in various thermal engineering fields such as computer CPUs, solar energy collectors and micro device transmitting equipment.

Kim and Bang I. [1] experimentally observed the effect of the working fluid fill ratio and the cross sectional area of the vapor path on the heat removal capacity and thermal performance of an annular thermosyphon that contains a neutron absorber. They observed that increasing the fill ratio enhanced the entrainment limit by 18%. Sarafraz and Hormozi [2] studied experimentally the effect of different operating parameters such as applied heat flux to the evaporator section, fill charge ratio of working fluid, tilt angle of the heat pipe and volume concentration of nanoparticle on the thermal performance and efficiency of the thermosyphon heat pipe. At 5% vol., the best fill charge ratio is 50% and 70% for alumina-water/EG and alumina-water/DEG nanofluids respectively. Lips et al. [3] carried out experiments to observe the effect of the filling ratio and vapor space thickness on the thermal performance of a flat plate heat pipe (FPHP) using n-pentane in horizontal orientation. They concluded that a small vapor space thickness induces liquid retention in the FPHP sides and corners and thus reduces the thermal resistance of the system even for a liquid quantity greater than the optimum value. Mameli et al. [4] focused on the combined effect of the inclination angle and filling ratio at different heat input levels on the device operation stability and the thermal performances of a multi-turn closed loop pulsating heat pipe (CLPHP) made of copper. The test fluid was FC-72. Results showed that this CLPHP is very much sensitive to the inclination angle and that the vertical operation is affected by unstable operation at high input levels. At 0.5 filling ratio, the best performance was obtained and the minimum with 0.7 FR. Barua et al. [5] investigated experimentally the thermal performance of a closed loop pulsating heat pipe using two different working fluids (water and ethanol) at various filling ratios (100%, 82.5%, 63%, 41.3% and 28%). For water at lower and higher heat input, lower filling ratio

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showed less thermal resistance and optimum heat transfer was obtained at nearly 30% filling ratio. For ethanol at low heat input, the best performance was obtained at high filling ratio beyond 50% in the basis of heat transfer. For high heat input, ethanol showed high heat transfer rate at high heat input for all filling ratio. Pote A. and Pachghere [6] performed an experiment using ZnO/water nanofluid of 100 nm to investigate the effect of concentration of zinc oxide nanoparticles on thermal resistance of a closed loop pulsating heat pipe (CLPHP). Experiment was conducted in vertical orientation with 50% filling ratio. They found that thermal resistance of CLPHP using ZnO/water nanofluid as working fluid was better than thermal resistance when pure water is used. Verma et al. [7] studied experimentally the effect of filling charge ratio, inclination angle and heat flux on the start-up and thermal performance in terms of thermal resistance and heat transfer coefficient of a pulsating heat pipe using methanol and de-ionized (DI) water. They concluded that the minimum start-up power and thermal resistance were obtained at 50% and 40% filling ratio for DI water and methanol, respectively. Qu et al. [8] investigated experimentally the performance of a stainless steel oscillating heat pipe (OHP) charged with base water and spherical Al_2O_3 particles of 56 nm in diameter. The effects of filling ratios, mass fractions of alumina particles and power inputs on the total thermal resistance of the OHP were investigated. They showed that the maximum thermal resistance was decreased by 0.14 $^oC/W$ (or 32.5%) when the power input was 85.8W at 70% filling ratio and 0.9% mass fraction. Lin et al. [9] studied the effect of silver nanofluid (20 nm in diameter) on copper pulsating heat pipe thermal performance. The thermal performance was studied at different concentration (100ppm and 450 ppm), various filled ratio (20%~80% FR) and different heat power (5W~85W). The results showed that the best filled ratio was 60% and the better working fluid was 100 ppm of silver nanofluid. Khandekar et al [10] investigated the effect of working fluid (water, ethanol and R-123) and filling ratio on the thermal performance of closed loop pulsating heat pipe in vertical and horizontal orientation. They found that the best performance was measured at low filling ratio for all working fluids. Salem et al. [11] measured thermal conductivity of graphene oxide/water nanofluid with different volume concentration ranged from 0.05% to 0.2% using transient hot wire method (KD2 thermal property meter). They showed that the thermal conductivity was enhanced with reference to pure water. Also, it was increased by increasing nanoparticles concentration.

In the present work, experimental studies have been conducted on the thermal performance of a copper multi-heat pipe charged with pure water and graphene oxide (GO)/water nanofluids as working fluid. The experiment was performed at different volume concentration (0.05%, 0.1%, 0.15% and 0.2% vol.), various filling charge ratio (40%, 60%, 80% and 100% FR) and different heat flux (10W~30W).

2. Materials and Methods

Graphene oxide nanofluid is 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 [11,12]. Graphite fine powders (45 µm) was purchased from Wako pure chemical industries (Japan), concentrated sulfuric acids (H_2SO_4), sodium nitrate ($NaNO_3$), potassium permanganate ($KMnO_4$), hydrogen peroxide (30% H_2O_2), hydrochloric acid (5% HCL) and deionized 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. Figure 1 represents a multi-heat pipe which consists of evaporator, adiabatic section and condenser. A multi-heat pipe was made of copper in laboratory of Kumamoto university-Japan. The external dimensions for heating and cooling sections are 45 × 45 × 8mm, and the internal dimensions are 42 × 42 × 5mm. The adiabatic section is consisted of four parallel circular tubes whose dimension is ϕ6 (external diameter) × ϕ5 (inlet diameter) × 45 mm (length). As shown in figure, twelve k-type thermocouples were installed on the test section, with five of them embedded in the evaporator section (H1, H2, H3, H4, and H5), four in the adiabatic section (a1, a2, a3, and a4), and three in the condenser (C1, C2 and C3).

As shown in Figure 2, the experimental setup consists of a test section (multi-heat pipe) which connected with burette (NALJENE, USA) to calculate the amount of working fluid that filled the heat pipe. Vacuum pump (ULVAC KIKO, Japan) was connected with vacuum gauge to generate vacuum pressure inside the heat pipe. The evaporator section was electrically heated by heater block (HAKKO, Japan) made from cooper containing five heaters (five heaters are not shown in the figure) which connected with transformer (YAMABISHI, Japan) and its voltage and power were measured by digital multi-meter (HIOKI, Japan). The condenser section was cooled by immersing it into the plastic cooling chamber and water was used as the coolant fluid which pumped from the thermostatic bath (NCC-1100, Japan). The cooling water flow rate was measured by flow meter ((KOFLOC, Japan). Both evaporator and adiabatic sections were thermally insulated with glass fiber to prevent heat loss. The surface temperatures of the heat pipe were measured using twelve k-type thermocouples (Figure 1). The test section was evacuated using the vacuum pump to remove the non-condensable gases. Cooling water was then supplied from thermostatic bath to the cooling chamber at a volume flow rate of 1.5 l/min and 15°C. The test section was then charged with the working fluid. The filling charge ratios (FR) (volume ratio of the working fluid to the internal volume of the evaporator section) were varied at 40%, 60%, 80% and 100% for each working fluid. The vacuum pressure inside the test section was set to 9.5 kPa for all cases. The test section was heated gradually until a steady state was attained.

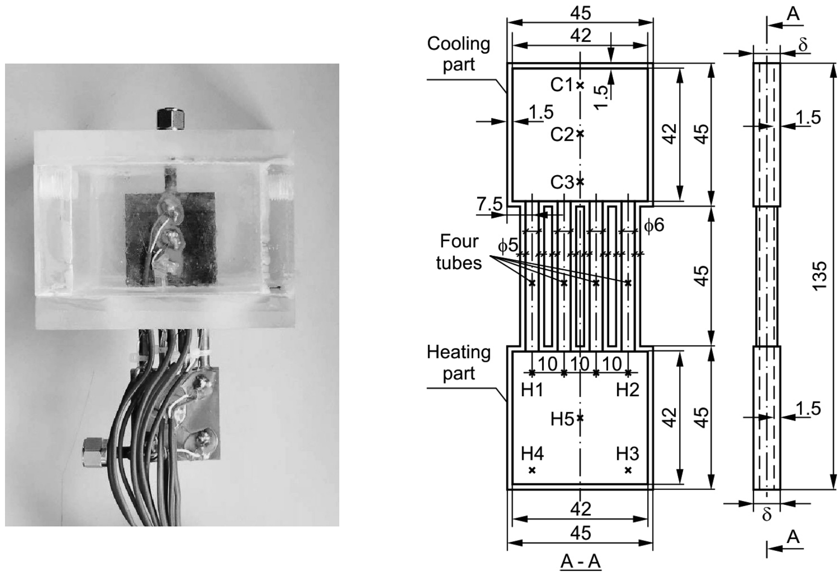

Figure 1. *Multi-heat pipe with thermocouple locations (all dimensions are in mm)*

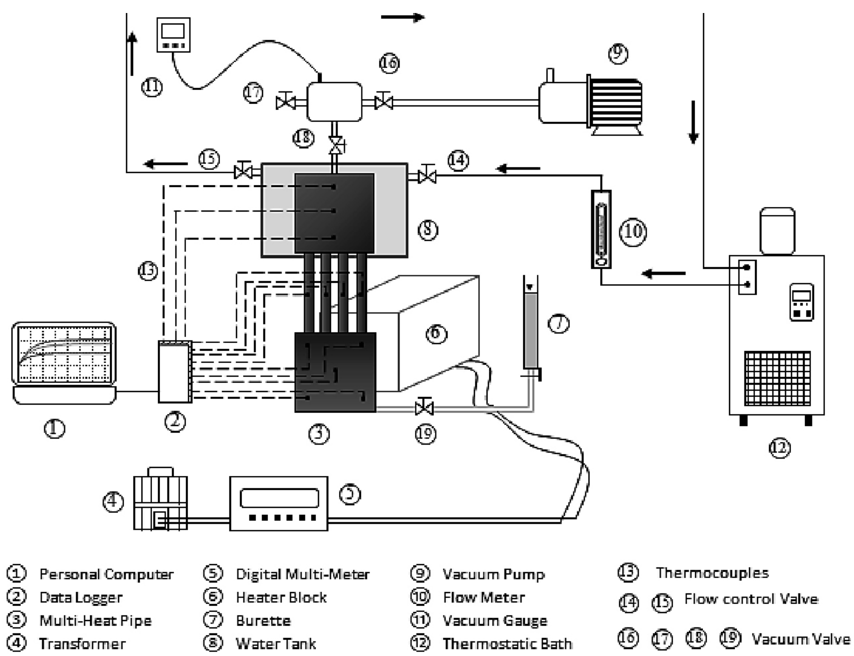

Figure 2. *Schematic of experimental set-up*

3. Results and discussion

The experiments are carried out by using four various filling ratios (40%, 60%, 80% and 100%) with multi-heat pipe kept in vertical position (the evaporator section at the bottom and condenser section at the top). Heat pipe with pure water as working fluid used in the comparison of results to understand the effects of volume concentration of GO/water nanofluids on the heat pipe thermal performance with different filling charge ratios and input heat power.

The evaporator and condenser wall temperature, therefore, are calculated as the arithmetic average of the thermocouples located in the evaporator and condenser sections. The mean temperature of evaporator and condenser sections are calculated and plotted against the heat load at different volume concentrations and filling ratios in Figure 3.

The results indicate that an increase of heat flux leads to increase the evaporator and condenser wall temperature at different volume concentration and filling ratio. This is due to high heat flux causes an increase of the evaporation of working fluid leading to increase pressure in the heat pipe affecting higher saturation temperature of working fluid in heat pipe. The wall temperature of the heat pipe reduces from evaporator to condenser section. Also, a rough comparison between pure water and GO/water nanofluids shows that presence of GO nanoparticles significantly reduces the evaporator temperature and slightly increases the condenser temperature, which means that the thermal performance of the heat pipe greatly enhances, when GO nanoparticles are added into pure water.

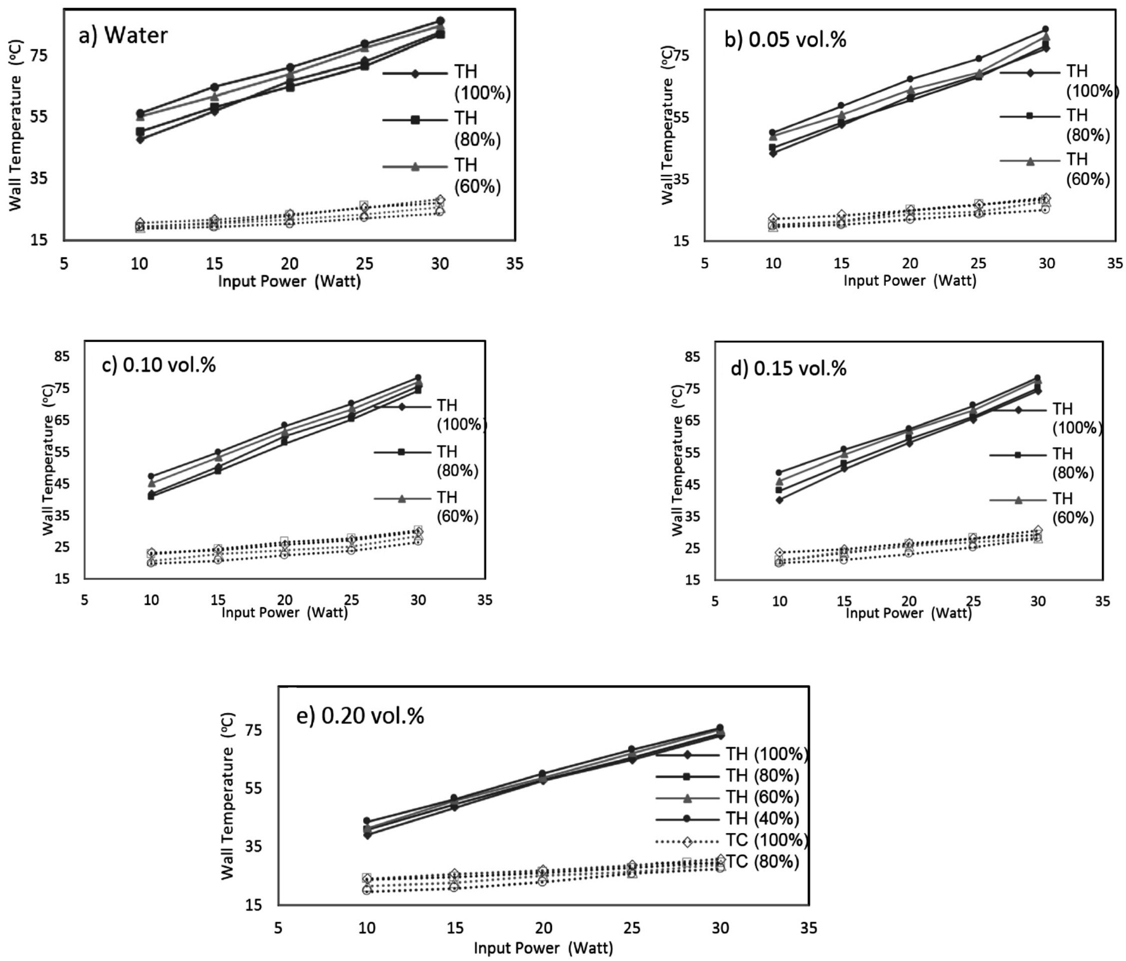

Figure 3. *Wall temperatures as a function of input heat load and filling ratio*

Based on the experimental results, the mean wall temperature of evaporator reduced as the filling charge ratio increased for volume concentration 0.15% and 0.2% at the same input heat flux. For pure water, 0.05% and 0.1% volume concentration, evaporator temperature decreases with the rise of filling ratio till 80%, but it decreased when the filling ratio reached 100% for 0.1% vol. at different heat load and after 15W for pure water and 0.05%volume concentration. The condenser temperature increases in slow rate with increment of filling ratio. The highest condenser temperature is obtained at 100% filling ratio for pure water, 0.05%, 0.15% and 0.2% vol. and at 80% for 0.1% volume concentration.

For 0.2% volume concentration, the rate of change of evaporator wall temperature with different filling ratio is very small because the viscosity is too high [11]. The maximum percentage of temperature reduction in the evaporator section compared with pure water is obtained at 0.2% volume fraction (the temperature reduced by 17.82%, 18.76%, 25.24% and 22.10% for 100%, 80%, 60% and 40% filling ratio, respectively). The overall heat transfer coefficient of the heat pipe calculated using the surface temperature of evaporator and condenser section using Equation (1).

$$h = \frac{Q}{A_e(T_H - T_C)} \tag{1}$$

where: A_e is the cross section area of the evaporator section.

Figure 4 shows the overall heat transfer coefficient against the heat load for all the filling charge ratios and the volume concentrations. For GO/water nanofluid, 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. The GO nanoparticles in the heat pipe not only increased the fluid thermal conductivity but also enhanced the heat transfer coefficient due to the particles migration. It is clear from Figure 4 that the increase of the heat load intensifies the heat transfer coefficient of the heat pipe for each filling ratio.

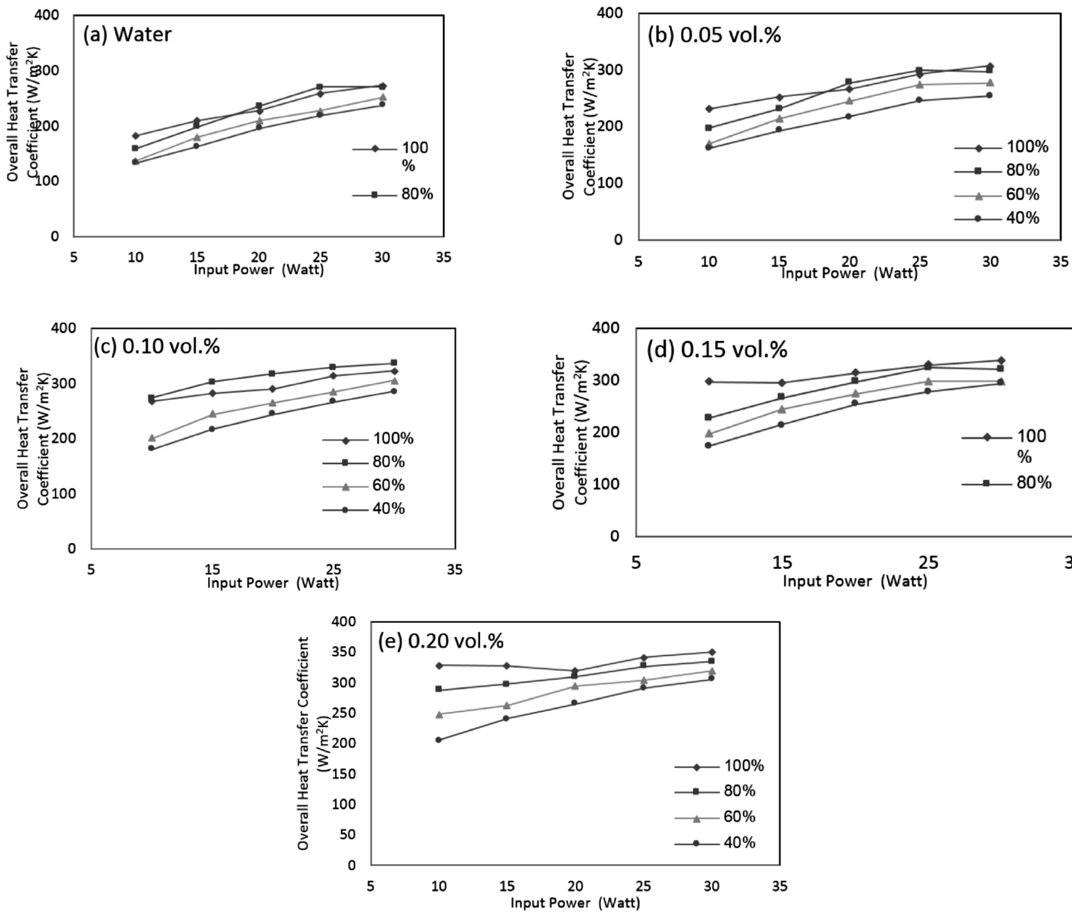

Figure 4. *Overall heat transfer coefficient as a function of input heat load and filling ratio*

Results demonstrate that the heat transfer coefficient of heat pipe drastically increases with increasing the filling charge ratio at the same input heat fluxes, because the temperature difference between the evaporator and condenser section decreases with increasing the filling charge ratio. The optimum heat transfer coefficient was obtained at 100% filling ratio for 0.15 vol.% and 0.2 vol.% and at 80% for 0.1% volume concentration. For pure water and 0.05 vol.%, the heat transfer coefficient increases with the rise of filling ratio till 15W input heat load. Beyond 15W, the maximum heat transfer coefficient was obtained at 80% filling ratio.

4. Conclusion

In this work, thermal characterizations of a copper multi-heat pipe have been experimentally performed with five different heat fluxes (10W, 15W, 20W, 25W and 30W), four different filling charge ratios

(40%, 60%, 80% and 100%) and different volume concentrations of graphene oxide/water nanofluids (0.05%, 0.1%, 0.15% and 0.2%) in vertical orientation. The main outcomes are resumed below:

- The heat transfer performance of a multi-heat pipe is apparently improved after the addition of GO nanoparticles in the working fluid.

- 0.2% is the optimal volume concentration of GO/water nanofluids to achieve the maximal heat transfer enhancement for the filling ratios 40%, 60%, 80% and 100%.

- Compared with the pure water, the maximal decrease of evaporator temperature is 17.82%, 18.76%, 25.24% and 22.10% for 100%, 80%, 60% and 40% filling ratio at 0.2% volume concentration.

- With increasing the input heat power and volumetric concentration of nanofluid, the overall thermal resistance of the heat pipe is increased.

- The optimal thermal resistance of a multi-heat pipe is obtained at 100% filling charge ratio for 0.2% volume concentration.

- For all working fluids and filling ratios, the overall heat transfer coefficient of this multi-heat pipe increases by increasing the input heat power.

- For all filling ratios, the overall heat transfer coefficient improves with increasing the volumetric concentration of GO/water nanofluids.

- The overall heat transfer coefficient depends greatly on the filling ratio, and the lower filling ratio (40%) yields smaller heat transfer coefficient.

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