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Technical Notes

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Nanofluid Effect on Heat Transport Capability in a Well-Balanced Oscillating Heat Pipe

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I. Introduction

RECENTLY, the oscillating heat pipe (OHP) charged with nanofluids has drawn researchers' attention, due to the heat transfer enhancement of strong oscillating motion of the working fluid and higher effective thermal conductivity of nanofluid. In 1990, Akachi [1] developed a new device, called the oscillating heat pipe. It uses the pressure change in volume expansion and contraction during phase change to excite the oscillation motion of the liquid plugs and vapor bubbles, which can significantly increase the heat transport capability. Over the last several years, extensive research on the OHP has been conducted [2–5]. It shows that by using the thermal energy to be removed, the oscillating motion generated in the OHP can significantly enhance heat transfer. Choi [6] pioneered a new kind of ultra-high-thermal conductivity fluid, called nanofluid, by uniformly suspending a very small quantity, preferably less than 1% by volume, of nanoparticles in conventional coolants. For example, a small amount less than 1% volume fraction of copper nanoparticles or carbon nanotubes dispersed in ethylene glycol or oil can increase their thermal conductivity by 40 and 150%, respectively [7,8]. The key features of nanofluids are the thermal conductivities far above those of traditional solid/liquid suspensions, the nonlinear relationship between thermal conductivity and concentration, strongly temperature-dependent thermal conductivity, and a significant increase in critical heat flux. These key features make nanofluids strong candidates for the next generation of coolants by improving the design and performance of thermal management systems.

Ma et al. [9] recently showed that an oscillating heat pipe charged with nanofluids can significantly increase the heat transport capability in an unbalanced OHP. For example, at the input power of 80.0 W, the diamond nanofluid can reduce the temperature difference between the evaporator and the condenser from 40.9 to 24.3°C. In the current investigation, the nanofluid effect on the heat transfer capability in a well-balanced OHP was investigated.

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II. Prototype and Experimental Setup

Figure 1 shows a schematic of the experimental system, including the OHP. As shown, the setup consisted of a well-balanced OHP, a cooling bath, a power supply, and a data acquisition system. The OHP was fabricated from copper tubing with an inside diameter of 1.6 mm and a wall thickness of 0.75 mm. The OHP was formed in a perfectly round ring with no turns. In this way, the effect of the vapor bubble as the spring constant on the oscillating motion could be studied experimentally, which helps to better understand the oscillating motion mechanisms. As shown in Fig. 1, the OHP had six heating sections and six cooling sections. Each heating section was heated by a wire heater with an electrical resistance of 0.79 Ω. The length for each heating section was 12 mm. Each cooling section with a length of 12.0 mm was directly connected to the Julabo F34 cooling bath. The length of each adiabatic section, that is, between the heating section and the cooling section, was 188 mm. All adiabatic sections were insulated by insulation materials. The temperature variations on the evaporating, adiabatic, and condensing sections were measured by T-type thermocouples (each section had one thermocouple). The temperature data were directly sent to the data acquisition system with a resolution of ±0.1°C. The nanofluid used in this study was high-performance liquid chromatography (HPLC)-grade water containing 1.0 vol % CuNi nanoparticles ranging from 40 to 150 nm, as shown in Fig. 2. The nanoparticles were fabricated by 20 kW RF plasma with a high frequency of 13.56 MHz.

Before the start of the experiment, the system was allowed to reach steady state, such that the temperatures of the cooling media and the

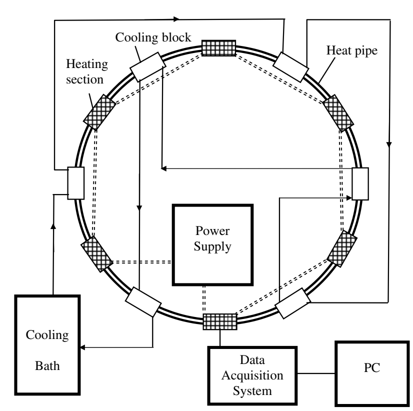

Fig. 1 Schematic of the experimental setup.

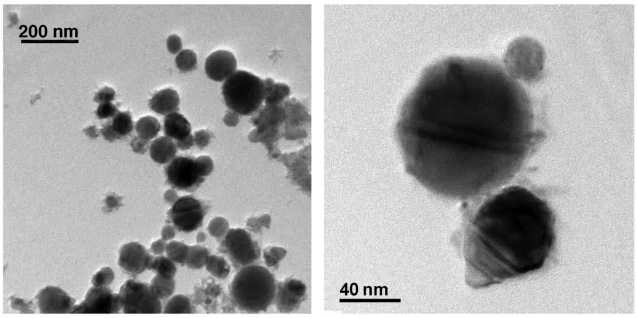

Fig. 2 Micrographs of CuNi nanometer particles.

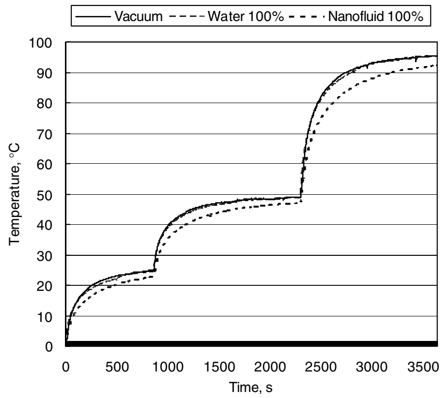

Fig. 3 Experimental data of transient temperature differences between the evaporating section and condensing section without oscillating motions at power inputs of 5, 10, and 20 W.

heat pipe were constant at 20 ± 0.5°C, which was controlled by the cooling bath. When the desired steady-state condition was obtained, the input power was increased in small increments. The test indicated that a time of approximately 30 min was necessary to reach steady state. During the tests, the thermal power and the temperature data were simultaneously recorded using a data acquisition system controlled by a personal computer.

III. Results and Discussion

To study the nanofluid effect on the heat transport capability in the OHP, the heat pipe was tested in two situations: 1) without oscillating motions and 2) with oscillating motions.

A. Nonoscillating Motions

No oscillating motions were achieved by 1) absolutely no working fluid at a vacuum condition; 2) charging with HPLC-grade water at a filling ratio of 100%; and 3) charging with nanofluid at a filling ratio of 100%. Figure 3 illustrates the experimental results of input power

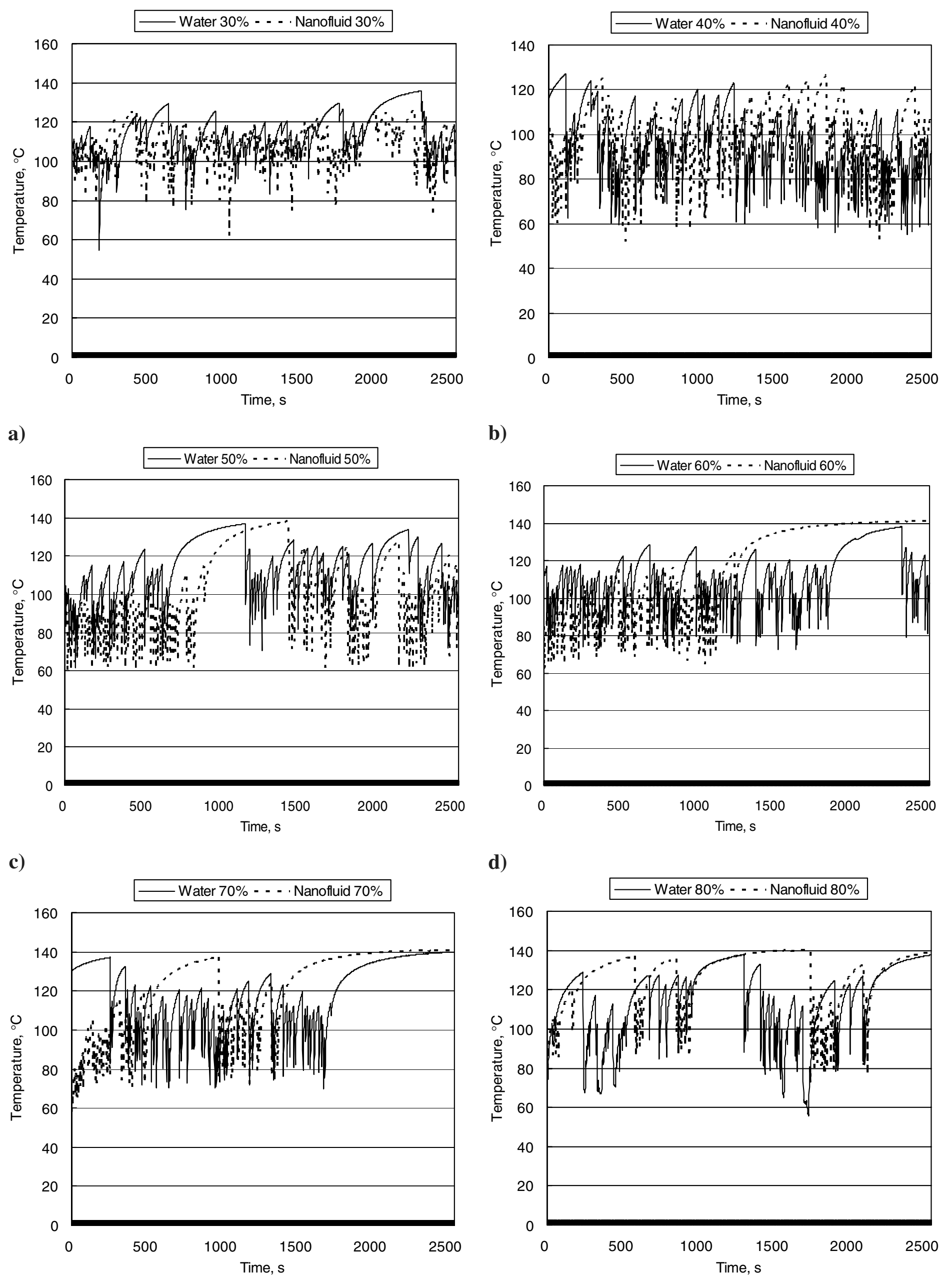

Fig. 4 Comparison of temperature differences at filling ratios of a) 30%, b) 40%, c) 50%, d) 60%, e) 70%, and f) 80% (power input is 30.0 W).

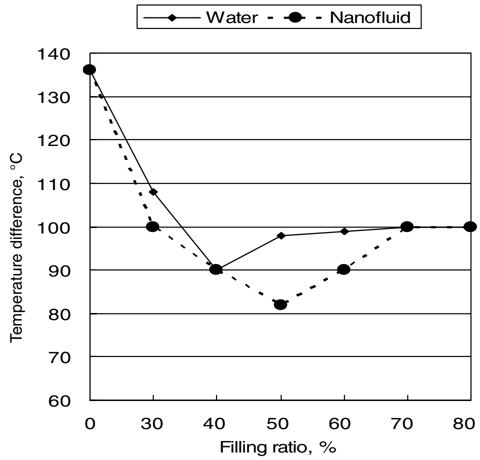

Fig. 5 Nanofluid effect on the temperature difference.

effect on the temperature difference between the evaporating section and the condensing section for all three cases. When the input power was increased from 0 to 20 W, as shown in Fig. 3, the temperature difference increased quickly for all three cases. For each of the power inputs, the OHP charged with nanofluids always has the lowest temperature difference among three cases. When the input power was set to 5 W, for example, the temperature difference from the evaporating section to the condensing section was 24.85°C for the vacuum condition, which was a little higher than 24.37°C with pure water. When the heat pipe was charged with nanofluid, the temperature difference was reduced to 22.79°C. When no oscillating motion existed in the OHP, heat was transferred from the evaporating section to the condensing section, basically by conduction and free convection. The conduction heat transfer was through the tube wall and water. Because the thermal conductivity of copper tubing is much higher than water, most of the heat was transferred through the tube wall by heat conduction from the evaporating section to the condensing section. Therefore, when the heat pipe was charged with a filling ratio of 100% of pure water, the temperature difference was improved only from 24.85 to 24.37°C at a power input of 5.0 W. In this way, the heat transfer enhancement of nanofluid can be easily detected. When the OHP was charged with the nanofluid at a filling ratio of 100%, the temperature difference shown in Fig. 3 could be improved to 22.79°C at the same power input of 5.0 W. Although the heat transfer performance has been improved, the heat transfer enhancement of nanofluid is not significant. The primary reason for this is that the CuNi nanoparticles in the HPLC-grade water were settled, because oscillating motion did not exist, which directly reduces the thermal conductivity of nanofluid.

B. Oscillating Motions

When heat is added to the evaporating section, liquid vaporizes, causing the vapor volume expansion. On the other hand, when the heat is removed from the condensing section, vapor condenses into liquid, causing the vapor volume contraction. The contraction and expansion produce the oscillating motion in an OHP, which depends on the heat pipe design and filling ratio. Figure 4 shows a comparison of temperature differences occurring in both the heat pipes charged with the HPLC-grade water and nanofluids at filling ratios of 30%, 40%, 50%, 60%, 70%, and 80%. As shown, the oscillating motions occurring in the heat pipe were very irregular, which are very different from those seen typically in unbalanced OHPs [3–5,9]. It indirectly shows that the unbalanced heat pipes can easily generate oscillating motions. When the oscillating motion existed, the temperature difference would oscillate at 100°C for an input power of 30 W at a filling ratio of 30%, as shown in Fig. 4. When the oscillating motion stopped, the temperature increased up to 125°C. Clearly, the oscillating motion occurring in the OHP enhances heat transfer, resulting in a decrease of the temperature difference between the evaporating section and the condensing section, which increases the effective thermal conductivity. One interesting result is that when the filling ratio was from 40 to 60%, the oscillating motion was stronger, resulting in a lower temperature difference between the evaporator and the condenser. In other words, the filling ratio significantly affects the heat transfer performance in a balanced nanofluid OHP.

The temperature difference between the evaporator and the condenser oscillated from 90 to 120°C for the OHP charged with the HPLC-grade water at a filling ratio of 30% and a power input of 30 W. When the OHP was charged with the nanofluid at the same filling ratio, the temperature difference was reduced and oscillated between 80 and 110°C. The oscillating motion was much stronger than the OHP charged with the HPLC-grade water. And when the filling ratio was equal to 50%, the oscillating motion for the nanofluid OHP was the strongest, resulting in the lowest temperature difference between the evaporator and the condenser, as shown in Fig. 5. When the filling ratio was higher than 60%, the oscillating motion stopped frequently, the time period for nonoscillating motions became longer, and the nanofluid would not make any difference, as shown in Fig. 5.

IV. Conclusions

A well-balanced oscillating heat pipe with no turns was fabricated and tested. Oscillating motions occurring in the well-balanced heat pipe are very irregular, which is very different from those occurring in unbalanced OHPs. In other words, the unbalanced heat pipes can easily generate the regular oscillating motions. The nanofluid can significantly enhance heat transfer in an OHP when the oscillating motions exist. The effect of the nanofluid on heat transport capability depends on the filling ratio. When the heat pipe was charged at a filling ratio of 50% of nanofluid in the current study, the heat pipe had its best heat transfer performance.

Acknowledgments

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