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Performance of overall heat transfer in multi-channel heat exchanger by alumina nanofluid

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ABSTRACT

This study employs a direct synthesis method to prepare alumina/water (Al_2O_3/water) nanofluid working fluid for a multi-channel heat exchanger (MCHE) experiment, and then simulates its application to electronic chip cooling system to evaluate the practicability of its actual performance. The experimental variables included nanofluids of different weight concentrations (0, 0.5, and 1.0 wt.%) and the inlet water temperature at different flow values. Results show that the overall heat transfer coefficient ratio was higher at higher nanoparticle concentrations. In other words, the overall heat transfer coefficient ratio was higher when the probability of collision between nanoparticles and the wall of the heat exchanger was increased under higher concentration, confirming that nanofluids have considerable potential for use in electronic chip cooling systems.

1. Introduction

Traditional working fluids have poor heat transfer performance compared to most solids. It was not until 1995, when Choi [1] first called fluid combined with nanoparticles as nanofluid, that studies on new working fluids were started. Nanofluids are engineered by suspending metallic or nonmetallic nanoparticles in traditional fluids, such as water, ethylene glycol, engine oil, alcohol, etc. Fundamental research on the heat convection of nanofluid discuss the effects of particle size, flow condition, cross-section shape, theoretical models, etc., in theoretical and experimental studies, obtaining many achievements [2–10].Research on the direct application of nanofluid to actual component or system also presents some interesting results. In 2003, Faulkner et al. [11] indicated that applying nanofluid to the cooling system of flow channel could achieve an obvious cooling effect. Tsai et al. [12] used Au aqueous nanofluid with particles of different sizes (2–35 and 15–75 nm) in a heat pipe in 2004. At different particle concentrations, the thermal resistance ranged from 0.17 to 0.215 K/W. In 2006, Kim et al. [13] applied Cu, CuO, and Al_2O_3 nanoparticles to a NH_3/H_2O absorption system. They showed that maximum effective absorption ratios occurred at 0.1 wt.% Cu nanoparticles and a NH_3 concentration of 18.7%, achieving an 3.21-fold absorption enhancement.

In 2007, Nguyen et al. [14] applied Al_2O_3 nanofluid to an electronic liquid cooling system. When the volume fraction was 6.8 vol.%, the convective heat transfer coefficient was enhanced by 40% maximum. They used particles of two different sizes: 36 and 47 nm. Their experimental results indicate that under the same volume fraction, smaller particles seem to have a higher heat transfer coefficient. Chein and Chuang [15] applied CuO/water nanofluid to a microchannel heat sink (MCHS) and found that CuO/water nanofluid with a nanoparticle concentration of 0.2–0.4 vol.% enhanced the thermal dissipation effect. At lower flow rates (10 and 15 ml/min), CuO/water nanofluid had lower thermal resistance, but at a higher flow rate of 20 ml/min., the nanofluid had higher thermal resistance. Therefore, flow rate is a very important factor affecting the heat convection of nanofluid. Pantzali et al. [16] applied 4% CuO nanofluid to a commercial herringbone-type PHE in 2009. Their study shows that the fluid viscosity also seems to be a crucial factor in the performance of a heat exchanger. These results imply that the substitution of conventional fluid by nanofluid is ill-suited to industrial heat exchangers.

This study uses a direct synthesis method to make Al_2O_3/water nanofluid, which served as coolant in a multi-channel heat exchanger (MCHE). Focusing on how different nanofluid weight fractions, flow rates, and heating powers affect the heat convection

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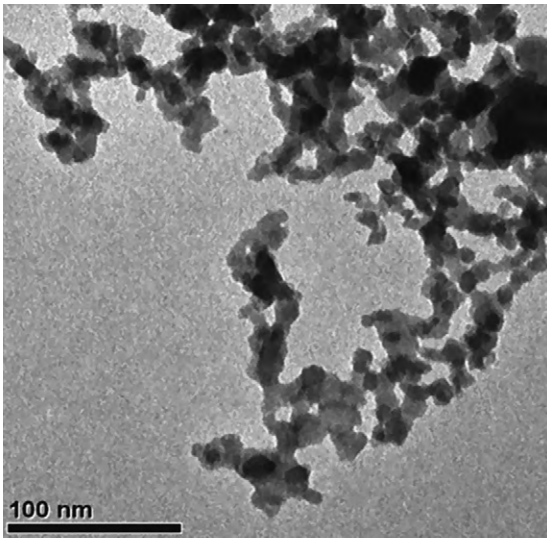

Fig. 1. TEM photograph of Al_2O_3 nanoparticles.

MCHE performance, this paper evaluates the feasibility of applying Al_2O_3/water nanofluid to electric chip cooling.

2. Experimental design and procedure

2.1. Nanofluid preparation

The Al_2O_3/water nanofluid used in this study was prepared by adding commercial nanoparticles (QF-Al-13P of Yong-Zhen Technomaterial Co., Ltd.) to deionized water. We prepared two nanofluids with different concentrations, 0.5 and 1.0 wt.%. The nanofluid was dispersed several times by ultrasonic dispersion and an electromagnetic stirrer. To achieve good suspension, the prepared Al_2O_3 nanofluid was combined with anionic surfactant (1.0 wt.% of sodium dodecyl benzene sulfonate, SDBS). All the completed experimental samples were stored statically for 3 weeks until a good suspension effect was achieved. Fig. 1 shows a TEM photograph of Al_2O_3 nanoparticles with particle sizes of approximately 20 nm.

2.2. Experimental setup and test procedure

This experiment used a thermostatic bath (Firsteck B403L) to stabilize the temperature of the working fluid until it reached the expected temperature of ±0.5 °C. The working fluid was pumped to the MCHE for circulation, with a flow meter (accuracy: 0.2%, uncertainty: ±0.01 L/min) monitoring the fixed flowing volume. This type of MCHE used in this study is usually applied to the cooling of electronic chips, like CPUs, etc. The MCHE was installed on a plate-type electric heater to act as a heat source and heated via constant electric power to simulate a controllable heat source. Then, data acquired by Fluke's 2625A and T-type thermocouple (accuracy at 0.1%, uncertainty at ±0.1 °C) was used to measure the temperature of the test point on the MCHE with different experimental parameters. Fig. 2 shows the equipment used in the heat exchange experiment.

The experiments in this study used water as the bulk liquid. Hence, to determine if the addition of nanoparticles has any effects on overall heat transfer performance, we must conduct a comparative experiment with water first. The control variables of the study were the mass flow rate, inlet water temperature, and heating power. Having completed the control experiment with water, we used nanofluids of different concentrations to carry out the same experiment. Finally, using the same control variables, we calculated the ratio of the overall heat transfer performance of nanofluid to the overall heat transfer performance of water, and then acquired the overall heat transfer coefficient ratios under different conditions. Based on the collected temperature data for different mass flow rates, electric input powers, and nanofluid concentrations, the overall heat transfer coefficient ratio (r_U) of the MCHE can be written as follows:

$$r_U = \frac{U_{nanofluid}}{U_{water}} = \frac{(T_{wall} - T_m)_{water}}{(T_{wall} - T_m)_{nanofluid}} \quad (1)$$

where T_{wall} is the mean temperature of the base plate given by readings from the junction thermocouple; T_m is the averaged temperature of liquid traversing the MCHE, $T_m = (T_{liq.in} + T_{liq.out})/2$.

3. Results and discussion

Figs. 3–5 show the effects of simulating different heating powers, inlet temperature, and mass flow rates on the overall heat transfer coefficient ratio. The results of this study show that nanofluid enhances the overall MCHE heat transfer coefficient ratio. This is primarily because the added nanoparticles improved the heat transfer performance of the fluid. The addition of nanoparticles revealed a triple heat transfer enhancement mechanism: (1) nanoparticles had higher thermal conductivity, so a higher concentration of nanoparticles resulted in a more obvious heat transfer enhancement. (2) Nanoparticles collided with the base fluid molecules and the wall of the heat exchanger, thus strengthening energy transmission. (3) The nanofluid increased friction between the fluid and the pipe wall, improving heat exchange. These collisions included the more strenuous movements of nanoparticles suspended in fluid under higher temperature and

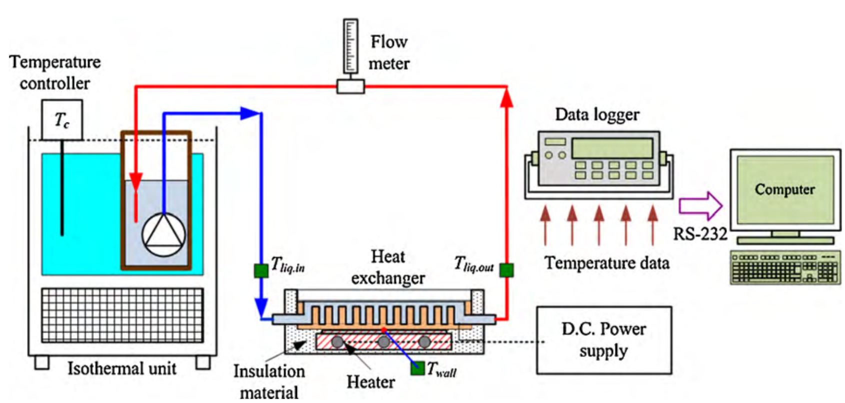

Fig. 2. Schematic diagram of experimental installation.

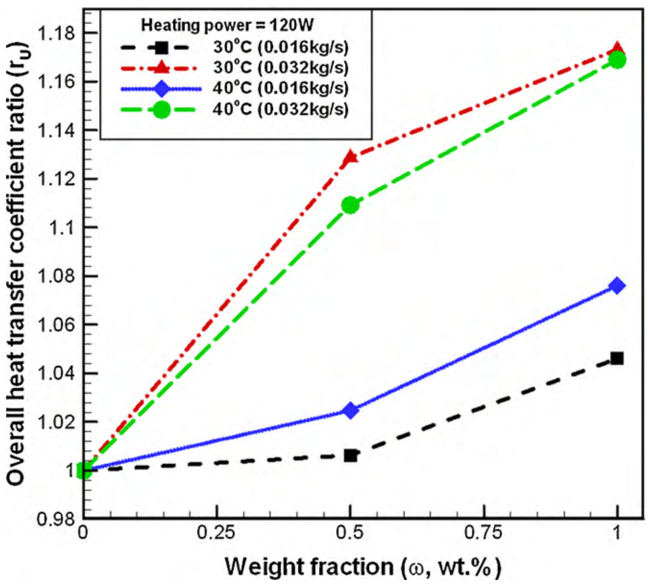

Fig. 3. Variations of overall heat transfer ratios of MCHE with different weight fractions of Al_2O_3/water nanofluid and different flow rates at 120 W.

the increased mass flow rate of fluid. Both strengthened the collision of nanoparticles with the wall of heat exchanger. Friction was determined by the nanofluid and the properties of the wall of heat exchanger. These effects influenced the functions of the heat exchanger.

The results of this study show that at a lower mass flow rate, a higher inlet water temperature and higher concentration produce a greater overall heat transfer coefficient ratio. Under optimal conditions, the inlet water temperature was 40 °C, being 3.3% higher than the time of 30 °C. However, at a higher mass flow rate, a lower inlet water temperature achieved better overall heat transfer coefficient ratio. This situation was caused by three main factors: (1) When the mass flow rate increased, the influence of nanoparticles on the wall surface primarily came from the increased mass flow rate, since the collision caused by temperature rise was relatively low. Therefore, the increased heat transfer capacity created by temperature is relatively small. (2) When the temperature rose,

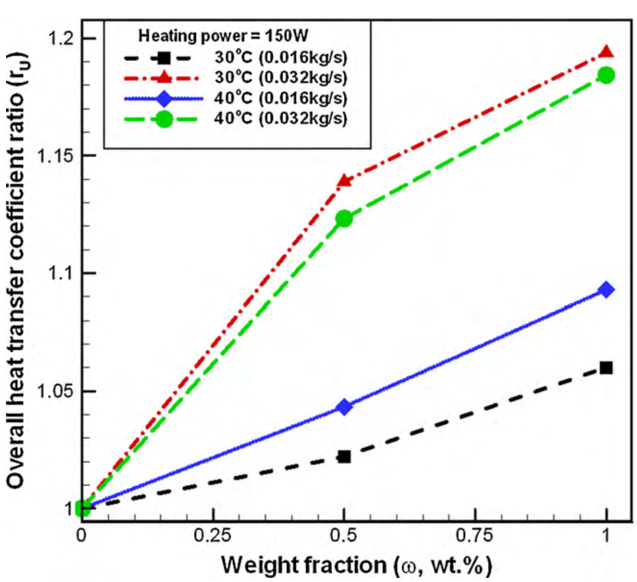

Fig. 4. Variations of overall heat transfer ratios of MCHE with different weight fractions of Al_2O_3/water nanofluid and different flow rates at 150 W.

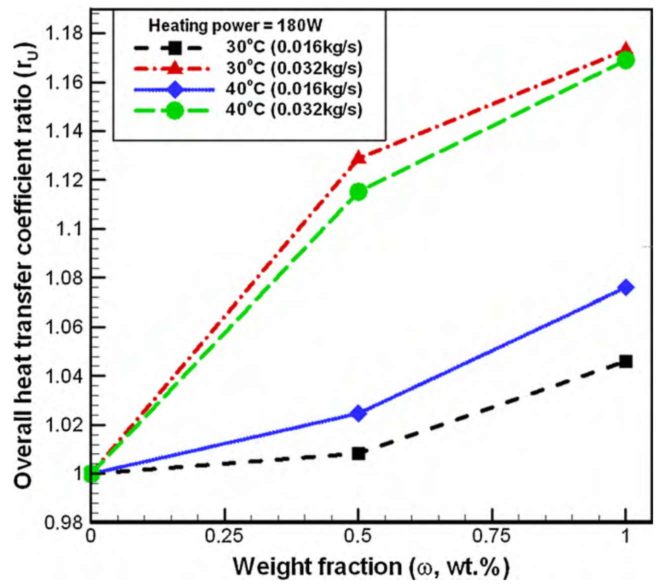

Fig. 5. Variations of overall heat transfer ratios of MCHE with different weight fractions of Al_2O_3/water nanofluid and different flow rates at 180 W.

the decreased nanofluid density was very low, and the falling rate of its viscosity was greater, leading to a higher Reynolds number in high-temperature nanofluid. Therefore, when the friction factor was smaller, the capacity of heat exchange acquired from friction was smaller. (3) At a slow flow speed, the surface properties of the heat exchanger had less influence on friction. Although high temperature increased the collision of suspended particles, it was rather low compared with the heat exchange enhancement caused by a faster flowing speed. Therefore, when the flowing speed was high, 30 °C produced a higher overall heat transfer coefficient ratio than 40 °C.

Nevertheless, when the concentration of nanofluid was 1.0 wt.% and the flowing speed was 0.032 kg/s, the experimental results of 30 and 40 °C were very close. This situation was caused not only by the abovementioned change of friction factor, but also by the fact that the concentration of added particles contributed much greater to heat transfer capacity than the effect produced by an increase in temperature. Therefore, at a high mass flow rate and high concentration of nanoparticles, the influence of temperature on the capacity of heat transfer was comparatively small.

4. Conclusion

This study analyzed the characteristics of Al_2O_3/water nanofluid to determine the feasibility of its application to an electronic chip cooling system. These results confirm that nanofluid offers higher overall heat transfer performance than water, and a higher concentration of nanoparticles provides even greater enhancement of the overall heat transfer coefficient ratio. However, when the mass flow rate was higher, a higher temperature does not provide greater enhancement of the overall heat transfer coefficient ratio. Therefore, in addition to the nanoparticle concentration, the temperature of the working fluid and its performance of suspension, which can affect the overall heat transfer performance of nanofluid, the surface and structure of the heat exchanger is an important factor to be taken into consideration.

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