Experimental Evaluation of the Performance of Heat Pipes with Nanoparticle Layer

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Abstract: In order to enhance the heat transfer performance, the inside wall of a cylindrical heat pipe and/or a screen mesh were coated with a nanoparticle layer. The materials of heat pipe and screen mesh were copper and brass, respectively, and the material of nanoparticles was silicone-dioxide. When the screen mesh was coated with the nanoparticle layer, the thermal resistance increased 2-8% in comparison with the ordinary heat pipe without nanoparticle layer. Clogging of screen mesh with nanoparticles was considered as the main reason of the deterioration of heat transfer performance. On the other hand, when the inside wall of the heat pipe was coated, the thermal resistance was reduced up to 32%. Similar heat transfer performance was achieved even when the screen mesh was removed. This indicates that the nanoparticle layer coated on the inside wall of heat pipe worked as a high performance wick. Since the nanoparticle layer is thin, it may effectively be applied particularly to small heat pipes for small electronic devices.

Key-Words: Heat pipe, Nanoparticle layer, Wick, Heat transfer enhancement

1 Introduction

Heat pipe is a simple and efficient heat transfer device that uses continuous evaporation and condensation of working fluid [1]. Recently, Sureshkumar et al. [2], Alawi et al. [3] Gupta et al. [4] and Ghanbarpour et al. [5] experimentally showed that the heat transfer performance of heat pipe can be enhanced if nanometer-sized particles are dispersed in working fluid. A main reason of the heat transfer enhancement is considered that nanoparticles were deposited on the inner wall of the heat pipe to act as a high-performance wick. Separately, Umehara et al. [6] showed that nanoparticle layer can easily be formed on the surface if a high-temperature body is immersed in nanofluid that is the liquid containing colloidal dispersion of nanoparticles. The nanoparticle layer is thin, cheap and exhibits strong capillarity. It is therefore expected that the nanoparticle layer is pre-coated on the inner wall of the heat pipe and/or wick device, the heat transfer performance can be enhanced and it can be used as a high-performance heat transfer device for small-sized electronic devices such as smartphones and mobile terminals. In view of this, the nanoparticle-layer pre-coated heat pipe is fabricated and its heat transfer performance is experimentally explored in this work.

2 Description of the Experiments

2.1 Nanoparticle layer formation on the screen mesh

A screen mesh made of brass was heated to 800 ºC in a constant temperature reservoir and then it was immersed into distilled water-silica nanofluid. The particle concentration was set to 0.4 kg/m^3. To form nanoparticle layer on whole surface, this process was repeated three times. The screen mesh was placed on the inner surface of the copper tube of 8 mm in outer diameter, 0.5 mm in wall thickness, and 100 mm in length. After supplying the working fluid in the tube, the two ends were closed to construct a heat pipe.

2.2 Nanoparticle formation on the inner wall of heat pipe

First, the copper tube was covered with polyimide tape. Then, nichrome wire was wrapped around the tube and it was finally covered with fluorine tape. The polyimide tape was used for electric insulation between the copper tube and the nichrome wire, and the fluorine tape for thermal insulation between the nichrome wire and the nanofluid. After immersing the device in the same distilled water-silica nanofluid, alternating current was supplied to the nichrome wire to cause nucleate boiling on the inner surface of the copper tube. Through these experimental procedures, a nanoparticle layer was formed on the inner surface of the copper tube. The mass of deposited nanoparticles was measured about 1.5-2 g/m^2.

2.3 Measurement of heat transfer rate

An experimental apparatus used to measure the heat transfer rate is shown schematically in Fig. 1. In the figure, the left-hand-side of the heat pipe is the evaporation section and the right-hand-side the condensation section. Heating and cooling were carried out using a nichrome wire heater and a fan, respectively. The heating section was thermally insulated as shown in the figure. To enhance the cooling performance by the fan, copper fins were set on the cooling section. The heat pipe and fins were thermally connected using grease of high thermal conductivity. The temperature measurements were conducted using the 9 type-K thermal couples spot welded on the outer surface of the heat pipe. The temperature measurement positions were 5, 15, 25, 40, 50, 60, 75, 85 and 95 mm from the left end of the heat pipe. The electric power applied to the nichrome wire Q was set within 3-25 W. The thermal resistance of the heat pipe R was defined by

$$R = \frac{T_e - T_c}{Q} \quad (1)$$

where T_e and T_c are the temperatures measured at the evaporation and condensation sections, respectively.

3 Experimental Results

The values of thermal resistance R measured for the five heat pipes are plotted against Q in Fig. 3. Here, the three successive alphabets denote the type of heat pipe as follows.

- 1st (inner surface of heat pipe): B→Bare, N→Nanoparticle layer pre-coated
- 2nd (screen mesh): B→Bare, N→Nanoparticle layer pre-coated, X→Not used
- 3rd (working fluid): W→Water, N→Nanofluid

First, BBN shows generally better heat transfer performance than BBW. This confirms that nanofluid can be a high-performance working fluid as discussed in the previous studies [2-5]. Next, the values of R for BNW is larger than those for BBW. This indicates that the nanoparticle layer pre-coating on the screen mesh had negative effect on the heat transfer performance. Clogging of the mesh with nanoparticles was considered a main reason of the heat transfer deterioration. On the other hand, the value of R for NBW is larger in low power condition whilst smaller in high power condition in comparison with BBW. This result can be interpreted that the nanoparticle layer pre-coated on the inner surface of heat pipe acted as a thermal insulation material at low power but a high-performance wick at high power. It is interesting to note that NXW shows similar performance with NBW. This indicates that the wire mesh can be eliminated if the nanoparticle layer is pre-coated on the inner surface of the heat pipe. This is considered a preferable feature from the viewpoint of space-saving particularly for the cooling of small electronic devices since the nanoparticle layer is very thin.

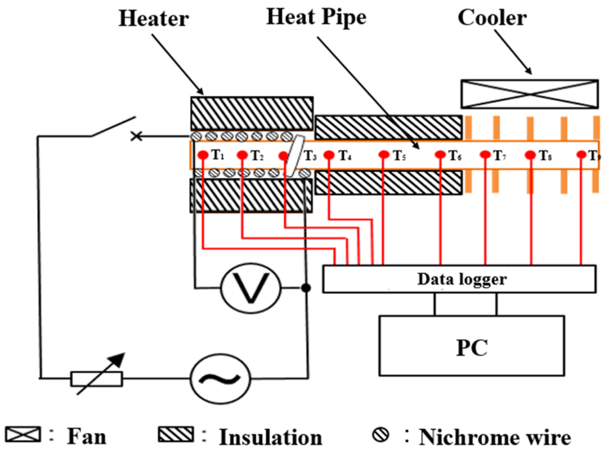

Fig. 1 Experimental apparatus.

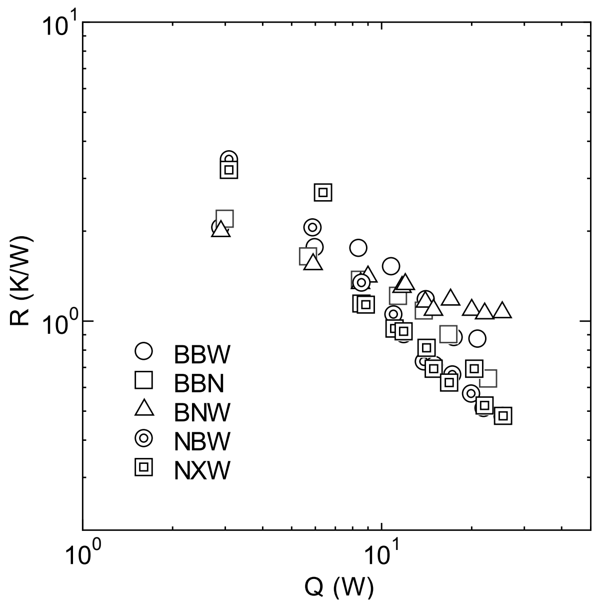

Fig. 2 Experimental results of thermal resistance.

4 Conclusion

The heat transfer performance of nanoparticle layer pre-coating on the inner surface of heat pipe and screen mesh was investigated experimentally. The coating on the screen mesh deteriorated the heat transfer mainly due to clogging but the coating on the heat pipe inner wall enhanced the heat transfer in the high power condition. This indicates that the nanoparticle layer pre-coated on the inner surface of heat pipe acted as a high-performance wick. Since the nanoparticle layer is thin and cheap, it is expected that the method proposed in this work can effectively be used particularly for cooling of small electronic devices such as smartphone and portable digital assistants.

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