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Comparative experiment of enhanced heat transfer performance between water-based magnetic fluid heat pipe and ordinary water heat pipe under magnetic field

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ABSTRACT

Based on the author’s previous related research and numerical simulation, in this paper the experimental study and theoretical analysis were conducted about the heat transfer characteristics of ordinary heat pipe and water-based magnetic fluid heat pipe under the DC magnetic field by combining the unique properties of magnetic fluid and magnetic field in heat transfer, to verify another new technology and improve the heat transfer enhancement of heat pipes. The comparative experimental results show that under the action of DC magnetic field, the heat transfer performance of the two pipes is directly proportional to the applied magnetic field strength; when the strength of the applied DC magnetic field is 150Gs, the heat transfer rate of the magnetic fluid heat pipe is increased by 15% more than that with no magnetic field; the heat transfer rate of the ordinary water heat pipe is increased by 9% more than that with no magnetic field.

1. INTRODUCTION

Adding magnetic particles to the water-based fluid shall generate one new type of enhanced heat transfer medium, which has greatly improved in heat transfer performance compared to the base fluid. Experimental studies have found that the addition of magnetic particles to the fluid significantly increases the thermal conductivity of the suspension. Shung, Barzi, Y.M, and Wen Kang [1-2] studied the effect of nanoparticle concentration and particle size (particle size 10nm and 35nm respectively) on the enhanced heat transfer performance of heat pipes. Then, it was found that the increase in the particle size of nanoparticles can effectively reduce the thermal resistance of heat pipes and enhance the heat transfer capacity. Meanwhile, it’s found that the heat transfer coefficient of water vapor condensation increases with the magnetic induction intensity [3-5], the magnetic field can also increase the heating rate of water and oil rapidly, and the water and oil magnetization time will not affect the water heating rate; when the applied magnetic field strength exceeds a certain value, the heat flux density will increase rapidly.

Now, the heat pipe, as the heat transfer element, has been developed maturely, but as an enhanced heat transfer technology, it is still in its infancy [6]. The heat transfer performance of enhanced heat pipe is the future research focus of heat pipe technology. Therefore, in this paper, the water-based magnetic fluid and applied magnet were applied to the heat pipe, and based on the previous related research and numerical simulation, a series of experimental research and theoretical analysis were carried out to verify the new technology in the heat transfer enhancement of heat pipes.

2. EXPERIMENTS

The experimental facility and measuring system mainly for the enhanced heat pipe with magnetic field include: heat pipe, thermostatic water device, heat exchange unit, magnetic coil, voltage regulator, rectifier, inspection instrument, thermocouple, HT201 portable digital Gauss meter, computer, and link water pipe, etc. Figure 1 shows the schematic diagram of experimental facility. The heat pipes used in the experiment were provided by the High-Efficiency Heat Exchange Laboratory of Hunan Province, Changsha University of Science and Technology. The heat pipe is a copper tube, with the outer diameter $D_{outside}$=16mm, the inner diameter D_{inside}=14mm, the wall thickness d=1mm, and the length L=1000mm, and then the total volume/capacity of heat pipe is V=3.14 (D_{inside}/2)2L=153.86ml.

The working mediums filled in the experimentally tested heat pipes were H_2O and Fe_3O_4-H_2O magnetic fluids (the diameter of the Fe_3O_4 solid particles was 5-8 microns). The magnetic fluid was prepared by the stirring method, and the mass fraction was 10%. The filling amount of the working fluid was 20% of the heat pipe volume [7], and taking the remaining amount of 5%, the actual filling amount of the working medium was 34ml. The optimal length ratio of the evaporation end to the condensation end in the vacuum heat pipe was calculated by the thermal efficiency factor F'_{HP} of the heat pipe flat-plate collector [8-10], with the length of the evaporation section Le=0.8m, that of the condensation section Lc=0.1m, and that of the adiabatic section La=0.1m.

When building the experimental bench, the evaporation end of the heat exchanger was placed in the magnetic coil, and the DC current is supplied to the magnetic coil by the DC device, thereby providing a DC magnetic field for the evaporation end of the heat pipe. Also, the voltage regulator was used to change the current and further adjust the magnetic field strength.

During the experiment, the 90°C hot water was supplied to the evaporation end of the heat pipe through the constant temperature water device (the starting temperature of the heat pipe was 65°C), to boil the working fluid in the heat pipe and start the phase change. By measuring the inlet and outlet temperatures t_1, t_2 and the flow rate q_1 of the circulating water at the evaporation end, the heat Q_1 absorbed by the heat pipe from the heat source was calculated according to the formula 1. At the condensation end of the heat pipe, the heat pipe was cooled by the circulating water, and the heat amount Q_2 of the circulating water recovery was calculated according to the formula (1-1) by measuring the temperature t_3, t_4 and the water flow rate q_2 of the inlet and outlet of the circulating water.

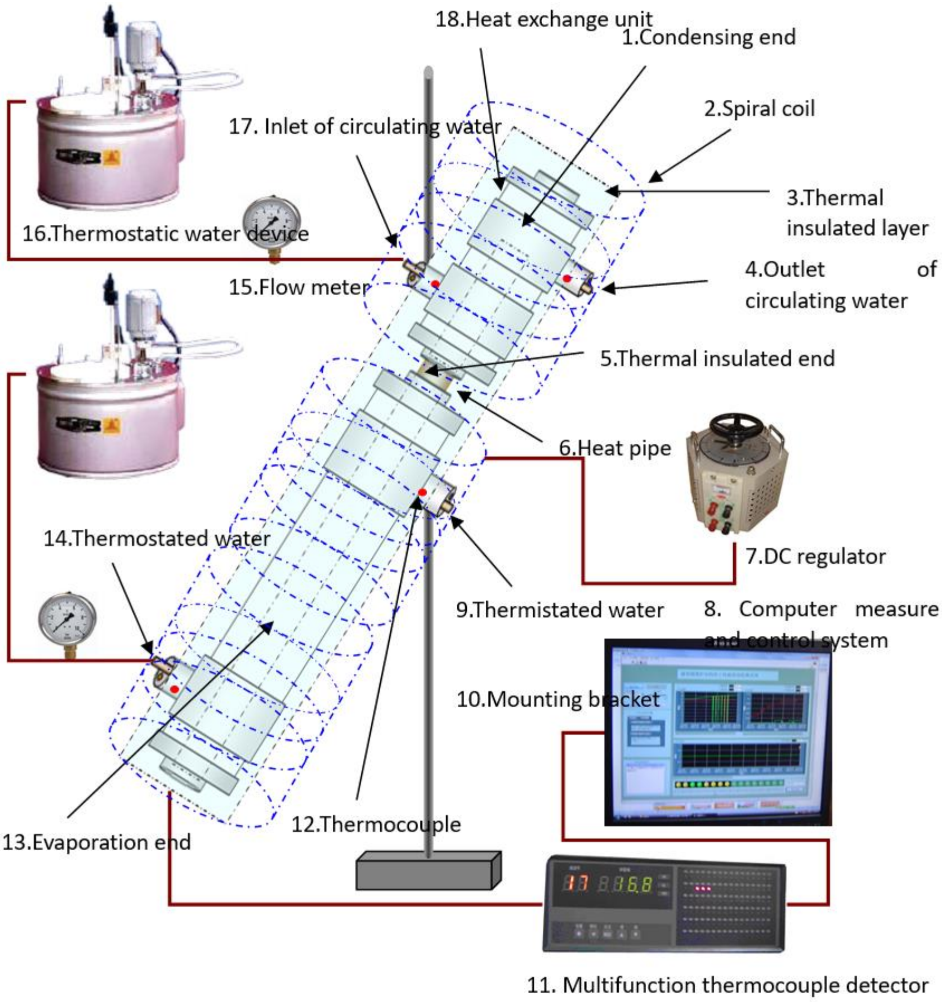

Figure 1. Schematic diagram of experimental facility

$$Q = q \cdot \Delta t \cdot c \cdot \rho \qquad (1)$$

where, c is the specific heat capacity of water, ρ is the water density, and Δt is the temperature difference of water temperature.

In industrial production, heat pipes are mainly used to recover heat and dissipate heat rapidly, that is, to use the heat released from the condensation section of the heat pipe. For better application, the heat quantity Q_2 emitted from the heat pipe condensation end was taken as the heat transfer rate of the heat pipe to judge its heat transfer performance in the experiment.

3. EXPERIMENTAL RESULTS AND ANALYSIS

Experiments were carried out on two heat pipes with magnetic field strengths of 0Gs.60Gs, 120Gs and 150Gs respectively. The experimental results are shown below.

(1) Applied magnetic field strength: 0Gs

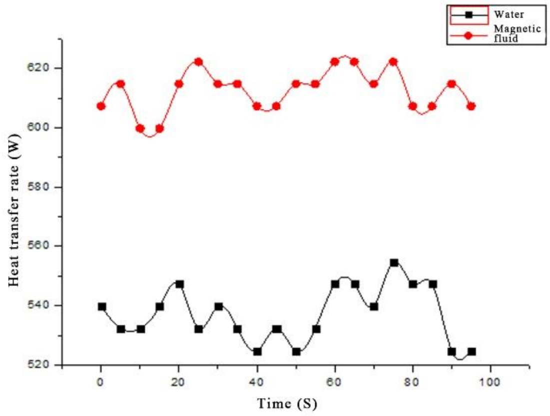

Figure 2. Heat transfer performance of two pipes with the applied magnetic field of 0

It can be seen from the experiments that, due to the thermal conductivity coefficient and surface tension, the average heat transfer rate of the magnetic fluid heat pipe is 13.9% higher than that of the water heat pipe with the applied magnetic field of 0 (Figure 2). The water-based magnetic fluid is a mixture of solid magnetic particles Fe_3O_4 and water. The thermal conductivity of the solid magnetic particles Fe_3O_4 themselves is much larger than the thermal conductivity of water, and the specific surface area of the magnetic particles Fe_3O_4 is large, which can accelerate the transfer of heat inside the base liquid and increase the thermal conductivity of the base liquid. According to the Maxwell model, Jung-Yeul Jun et al. [11], found that the greater the concentration of magnetic fluid, the greater the effective thermal conductivity. Solid magnetic particles can generate Brownian motion in the base fluid because of their small size, but not the prohibited state. Maziar Mohammadi measured the SiO_2 water-based suspension, finding that the surface tension of the liquid was reduced after the addition of the nanoparticles [12-13].

(2) Applied magnetic field strength: 60Gs

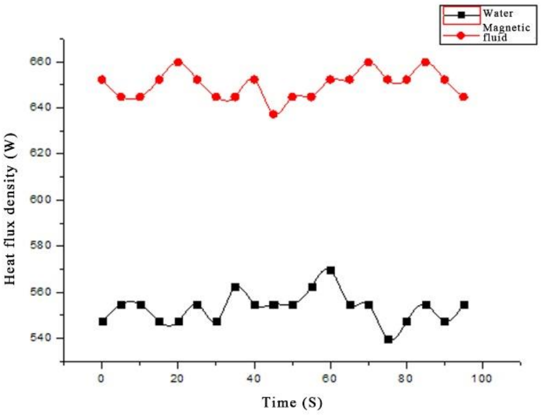

Figure 3. Heat transfer performance of two pipes with the applied magnetic field of 60Gs

The experimental results show that at the strength of the applied DC magnetic field 60Gs, the heat transfer rate of the magnetic fluid heat pipe is 650W, and the heat transfer rate is 6% higher than that under 0Gs magnetic field. The heat transfer rate of the water heat pipe is 553W, which is 3% higher than that 0Gs magnetic field.

(3) Applied magnetic field strength: 120Gs

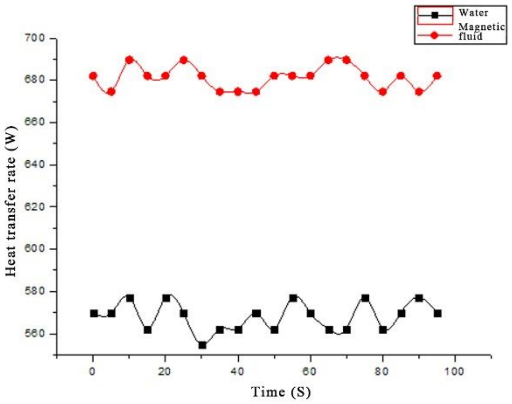

Figure 4. Heat transfer performance of two pipes with the applied magnetic field of 120Gs

The experimental results show that at the applied DC magnetic field strength of 120Gs, the heat transfer rate of the magnetic fluid heat pipe is 681W, 11% higher than that with 0Gs magnetic field. The heat transfer rate of the water quality heat pipe is 568W, which is 6% higher than that with 0Gs magnetic field.

(4) Applied magnetic field strength: 150Gs

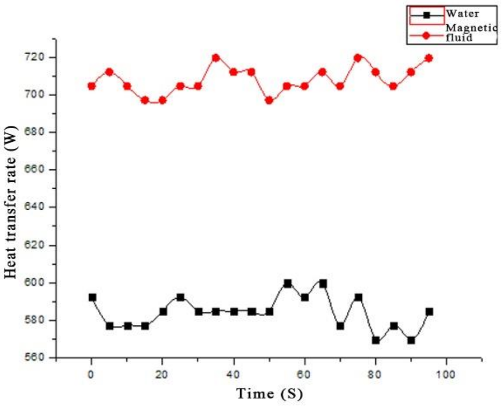

Figure 5. Heat transfer performance of two pipes with the applied magnetic field of 150Gs

The experimental results show that at the applied DC magnetic field strength of 150Gs, the heat transfer rate of the magnetic fluid heat pipe is 719W, 15% higher than that with 0Gs magnetic field. The heat transfer rate of the water quality heat pipe is 584w, which is 9% higher than that with 0Gs magnetic field.

In order to compare the influence of DC magnetic field on the heat transfer performance of two heat pipes more intuitively, the average heat transfer rate of heat pipe was used to compare and analyse the influence trend of DC magnetic field on two heat pipes. The results are shown in Fig 6

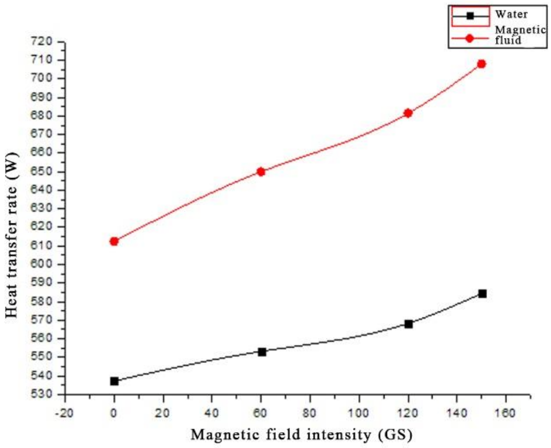

Figure 6. Comprehensive comparison of the effects of DC magnetic fields on the heat transfer between the two

The experimental results show that at the applied DC magnetic field strength of 150Gs, the heat transfer rate of the magnetic fluid heat pipe is 719W, 15% higher than that with 0Gs magnetic field. The heat transfer rate of the water quality heat pipe is 584w, which is 9% higher than that with 0Gs magnetic field.

4. RESULT ANALYSIS

4.1 Influence of magnetic field on water

Cao Jianguo [14] found in their experimental study that after certain magnetic field enhancement, the density of distilled water fluid medium in the heat pipe increased, and viscosity also decreased. As the magnetic induction intensity increases, the density of distilled water fluid medium increases and the viscosity gradually decreases. The magnetic field also affects the evaporation of water. No matter whether the magnetic field is applied or not, the evaporation of water increases with the temperature, but the evaporation rate of distilled water after applying the magnetic field is significantly higher than that without the magnetic field. The acceleration of the evaporation rate will inevitably lead to an increase in the heat transfer rate of the heat pipe.

4.2 Influence of applied magnetic field on enhanced heat transfer of magnetic fluid heat pipe

The viscosity of the water-based Fe_3O_4 magnetic media is greater than that of water. Under the action of the external magnetic field, the water viscosity shall be reduced, but the viscosity of the magnetic fluid is increased. Yin ShaoYou [15] found through experiments that the direction of the magnetic field applied in the experiment is parallel to the direction of the magnetic fluid flow; when the direction of the applied magnetic field is parallel to the flow direction of the magnetic fluid media, the concentration of the magnetic fluid first increases and then stabilizes,. Meanwhile, the concentration of the magnetic fluid is also affected by the temperature. When the temperature rises, the Brownian motion of the solid particles in the magnetic fluid media intensifies, the viscosity of the water-based magnetic fluid media decreases, and finally the viscosity of the media decreases. In this experiment, the constant water temperature of the heat source at the evaporation end was stabilized at 90°C, greatly reducing the viscosity of the magnetic fluid. The experimental results show that the heat transfer performance of the heat pipe is enhanced, indicating that the influence of temperature on the magnetic fluid is the same important as that of the magnetic field on the concentration of the magnetic fluid.

Thermomagnetic phase-change convection: The water-based magnetic fluid media is placed under a temperature field and a magnetic field. Due to the changes of the temperature difference, the magnetization of the magnetic fluid media varies, and thus the force of magnetic fluid phase change in the heat pipe is unbalanced. At low temperatures, the magnetic fluid has a large magnetization intensity and is subject to a large magnetic field. The magnetic fluid flows under the combined action of the magnetic field force and the floating force of the fluid. Thermomagnetic phase-change convection of magnetic fluid media is much more effective than natural convection. With the temperature characteristics, magnetocaloric effect, thermomagnetic convection and other properties of the magnetic fluid in the heat pipe, the magnetic fluid can significantly enhance the heat transfer under the action of the magnetic field. The magnetic fluid triples the heat transfer from the solid surface to the fluid, and the orientation of the magnetic field has a great influence on the heat transfer enhancement effect of natural convection and boiling phase-change heat transfer [16-17]. Thermomagnetic convection is the main factor for heat exchanger heat exchange rate enhancement

5. CONCLUSIONS

(1) The thermal conductivity of Fe_3O_4-H_2O water-based magnetic fluid heat pipe is greater than that of water-based heat pipe in terms of thermal conductivity. Addition of solid magnetic particles to the media of the heat pipe can enhance the thermal conductivity of the base fluid.
(2) The applied DC magnetic field strength can improve the heat transfer performance of the water-based heat pipe.
(3) The applied DC magnetic field can further enhance the heat transfer performance of the Fe_3O_4-H_2O magnetic fluid heat pipe.

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