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Journal of Magnetism and Magnetic Materials 252 (2002) 360–362

Journal of magnetism and magnetic materials

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The magnetic fluid for heat transfer applications

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Abstract

Real-time visual observation of boiling water-based and ionic magnetic fluids (MFs) and heat transfer characteristics in heat pipe using ionic MF stabilized by citrate ions (JC-1) as working liquid are reported. Irrespective of the presence or absence of magnetic field water-based MF degraded during boiling. However, the degradation of JC-1 was avoided by heating the fluid in magnetic field. Furthermore, the heat transfer capacity of JC-1 heat pipe under applied magnetic field was enhanced over the no field case.

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Keywords: Heat transfer; Heat pipe; Real-time visual observation; Ionic magnetic fluid

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1. Introduction

Water-based magnetic fluid is preferred for heat transfer applications due to its higher latent heat over hydrocarbon liquids. Nevertheless, heat transfer characteristics of heat pipes using conventional water-based and tetramethyl ammonium (TMA) ion stabilized ionic magnetic fluids (MFs) have failed to show any improvements over pure water case and also the performance has been found to fluctuate from experiment to experiment [1]. The authors have been investigating the boiling characteristics of MFs in applied magnetic field using visual techniques [2]. The boiling heat transfer characteristic of ionic MF was more promising than the water-based MF. However, particle agglomeration during MF boiling, and the decomposition of the TMA to produce trimethyl hydroxyl amine has been considered detrimental for the use of the same in heat pipes. Here, we report the results of the studies conducted to determine the applicability of MF stabilized by citrate ions in heat transfer devices.

2. Experiment

(a) *Cell for visual observation*: A cell shown in Fig. 1 was constructed to observe the boiling MFs using the X-ray micro-focus. The heating surface area exposed to the fluid was minimized to facilitate distinct observation of the vapor bubbles. The setup used for X-ray microscopic measurements are given elsewhere [2].

(b) *Measurement of transferred heat*: Experimental setup used to measure the transferred heat from platinum wire surface to magnetic fluid is given in Ref. [3].

(c) *Samples*: W40 (water-based) and HC50 (kerosene-based) are products of Taiho Co. Ltd., Japan and ionic MF stabilized by citrate ions (JC-1) was supplied by Massart's laboratory, University of Paris, France [4]. Inhomogeneous DC magnetic field up to maximum 0.1 T was applied using an electromagnet. Magnetic field and field gradients are given in Ref. [2].

3. Results

3.1. Real-time observation of boiling MF

The experiment using X-ray micro-focus visualization technique confirmed degradation of water-based and

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PII: S0304-8853(02)00683-2

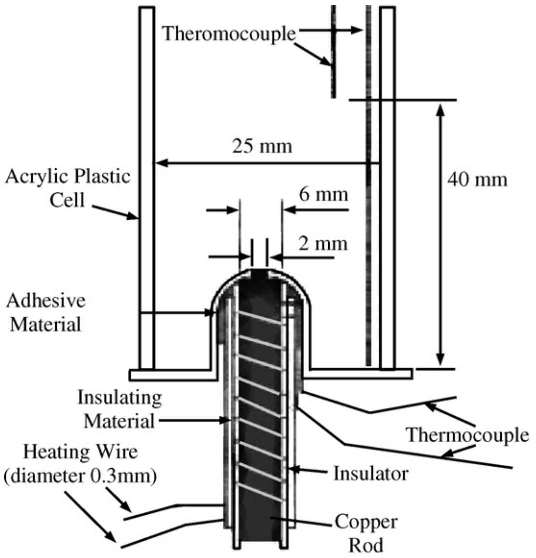

Fig. 1. The cell used to observe MF boiling using X-ray microfocus device.

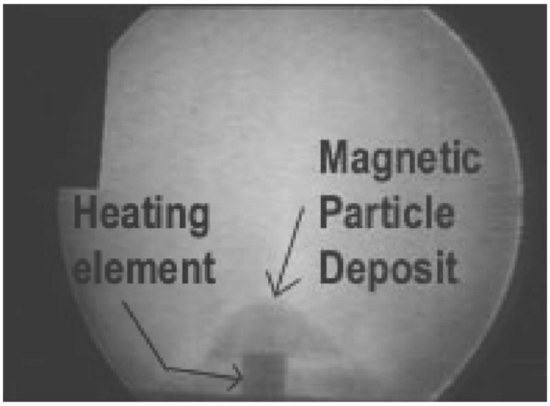

Fig. 2. Visual image of the heating element during boiling JC-1 in the absence of magnetic field.

JC-1 MFs boiled in the absence of magnetic field. In the case of JC-1, the magnetic particles were deposited on the heating surface as shown in Fig. 2. The deposition started when the temperature of heating surface was around 323 K and continued to grow in amount with time and temperature. Similar behavior was observed even in the case of water-based MF. However, due to the presence of the surfactant that controls the formation of aggregates, the visual image was not as marked as in the case of JC-1. The degradation of JC-1 was not observed when heated under an external magnetic field of 1000 G, which was not the case for water-based MF. It was believed that the magnetic convection induced the flow of the MF in the vicinity of the heating surface and prevented stagnation of the particles in a high temperature environment for a prolonged period of time. Therefore, if JC-1 is kept in magnetic field during heating cycles, the degradation could be minimized and the heat transfer characteristics could be enhanced.

3.2. Heat transfer from Pt wire in MFs

The heat transferred from the platinum wire of 20 mm length and 0.1 mm diameter to 50 ml of MF was measured. The magnetic field and field gradient at the Pt wire set perpendicular to the magnetic flux lines were 460 and 120 Oe/cm, respectively. The solid concentration of ionic (JC1), water- and oil-based MFs was 29 wt%.

Under zero applied magnetic field, the transferred heat increased with the rise in temperature and then the heat flux remained almost constant for a specific range of temperatures, which corresponded to the beginning of nucleation boiling. At higher temperatures, the presence of gas phase, with lower thermal conductivity, retarded the transfer of heat. In the presence of external magnetic field, an increase in transferred heat could be anticipated due to magnetic convection. However, the increase in heat flux was observed, only for the case of JC-1. The differences in heat transfer characteristics between JC-1 and water-based MFs could be due to the viscosity and actual magnetic fraction in each system. Though the water-based MF had similar specific gravity as that of the JC-1, it was believed to contain lesser fraction of magnetic particles on one hand, and had higher viscosity on the other. Both these factors had negative contribution to magnetic heat convection. On the other hand, the poor performance of kerosene-based MF was considered due to the higher boiling point of the solvent.

3.3. Heat pipes study using JC-1

The heat pipe consisted of heating, adiabatic, and condenser sections. The experimental setup is as shown in Fig. 3. Temperatures at different sections were measured at the wall of the Cu pipe. The magnetic field was applied using a Nd–Fe–B permanent magnet. The JC-1 was used as the working fluid of siphon type heat pipe. Magnetization (298 K), solid concentration and viscosity (298 K) of the fluid were 16.4 emu/g, 33.6 wt% and 6.5 cp, respectively.

The heat transfer characteristics as a function of magnetic field strength were determined by manipulating the position of the heating section with respect to the center of the permanent magnet. Fig. 4 shows the relation between the transferred heat against time for the heat pipe operated in the absence of magnetic field and under a magnetic field strength that gave the highest enhancement in heat transfer. The heat pipe with JC-1 performed well and the reproducibility of the results was confirmed.

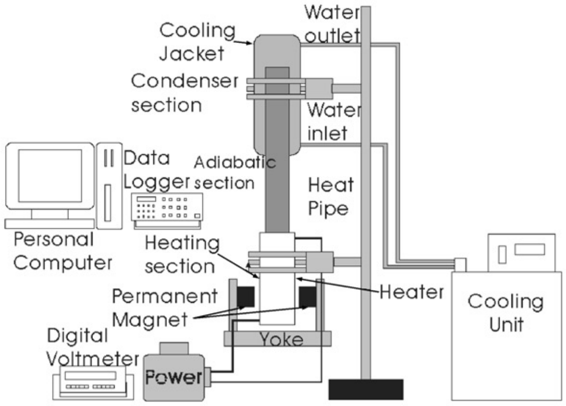

Fig. 3. The setup for the heat pipe experiment.

The application of the magnetic field improved the heat transfer characteristics by about 13%. Evidently, the experimental conditions such as optimum solid concentration of magnetic fluid, magnetic field intensity, etc. are yet to be optimized.

In summary, the MF stabilized by citrate ions was stable and free of any non-condensed gas at elevated temperatures and operated as expected. This type of magnetic fluid is considered as an attractive working liquid for heat transfer applications.

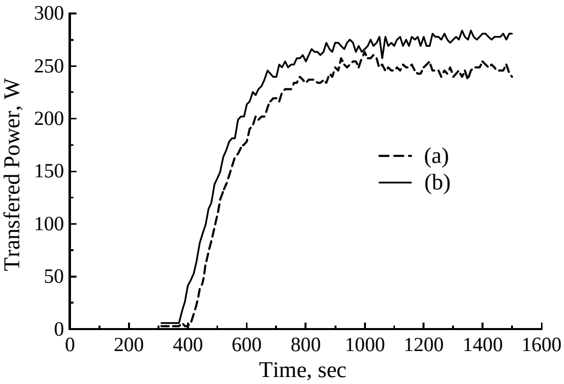

Fig. 4. Transferred power in MF heat pipe (a) in the absence and (b) presence of magnetic field.

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