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Visual observation of the effect of magnetic field on moving air and vapor bubbles in a magnetic fluid

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Abstract

Theoretical prediction suggests that magnetic fluid (MF) as working liquid in heat pipe could enhance and control the heat transfer under the application of magnetic field. However, heat pipe experiments using ionic MF showed only marginal gain and demands investigation. As an initial step, visualization of air and vapor bubbles behavior under zero and applied magnetic field has been carried out using X-ray. The observations can be summarized as follows; applied magnetic field (a) reduces the size and deforms the shape of the bubble that secede from the heating surface or air supply tube, and (b) accelerates the movement of the bubble in the liquid. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Magnetic fluids; X-ray microfocus; Air bubbles; Vapor bubbles; Heat pipes

1. Introduction

Magnetic levitation on nonmagnetic bodies in a magnetic fluid (MF) has been applied to the separation of materials of different densities [1], development of a new energy conversion system using gas–liquid two-phase magnetic flows [2] and MF heat pipes [3]. In the case of heat pipe, the magnetic levitation force acts on vapor bubbles evolved during boiling of the MF and believed to enhance the heat transfer properties. However, heat pipe experiments using MFs demonstrated only marginal gain and demanded detail investigation. As an initial step towards finding the answer, visualization of air or vapor bubbles in MF had been attempted using X-rays. Though there has been attempts using X-rays [4], ultrasonic echo [5] and proton rays [6] no detailed information is available. In this paper, we report the real time visual observation of the effect of nonuniform magnetic field on air and vapor bubbles moving in a static and boiling MF using the microfocus X-ray generating equipment.

2. Experimental

A microfocus X-ray generating equipment (Fig. 1) was used to irradiate the cell ($30 \times 20 \times 200$ mm)

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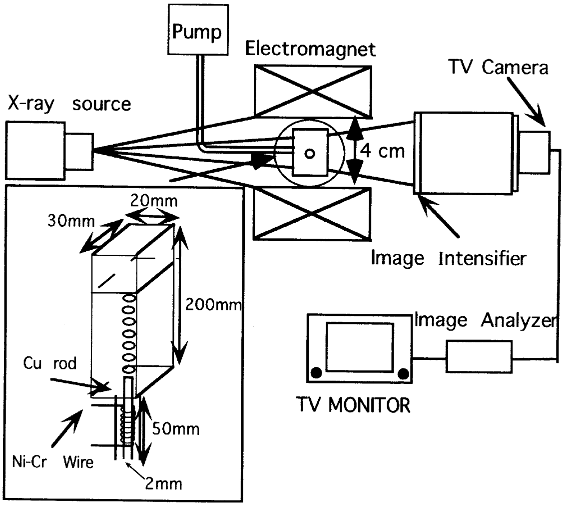

Fig. 1. The experimental setup.

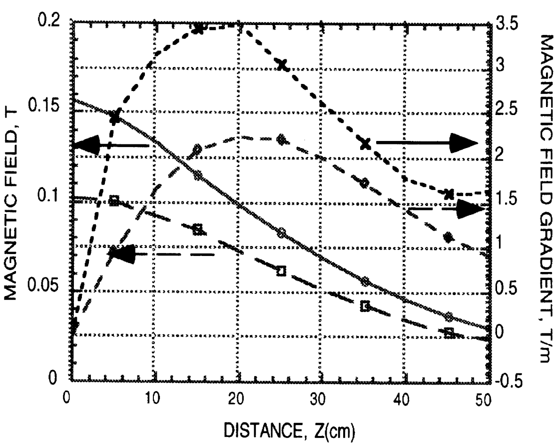

Fig. 2. Magnetic field and magnetic field gradient distribution in the Z (vertical) direction.

that contained MF. Air bubble was introduced from a point 2 cm (z-direction) above the bottom of the cell and a nonuniform magnetic field (Fig. 2) was applied perpendicular to the movement of the air bubble. In the case of a boiling MF experiment, a copper rod of 2 mm diameter was used as the source of heat. The experimental set up and detail description of the cell is given in Fig. 1. X-rays were transmitted through the MF column and received by the fluorescent plate. The image on the fluorescent plate is created by the difference in the intensity of the transmitted rays. The brightness of the fluorescent plate was electronically amplified and projected onto the secondary fluorescent plate and the image was developed by a TV camera and visualized using a TV monitor.

3. Results

The levitation force is generated when a nonmagnetic body is immersed in MF placed in a nonuniform magnetic field. The forces acting on a nonmagnetic body moving in a static magnetic field are (a) gravitational force $V\rho_b g$, (b) levitation force $V\rho_f g$ and (c) magnetic levitation force $\mu_0 M\nabla H$ and can be given by the following equation:

$$F/V = (\rho_f - \rho_b)g - \mu_0 M\nabla H.$$

Solid substances immersed in MF experience the magnetic levitation but do not undergo any change in their size or shape. However, in the case of air or vapor bubbles, the magnetic field is expected to bring about changes in their shape, size and movement within the fluid.

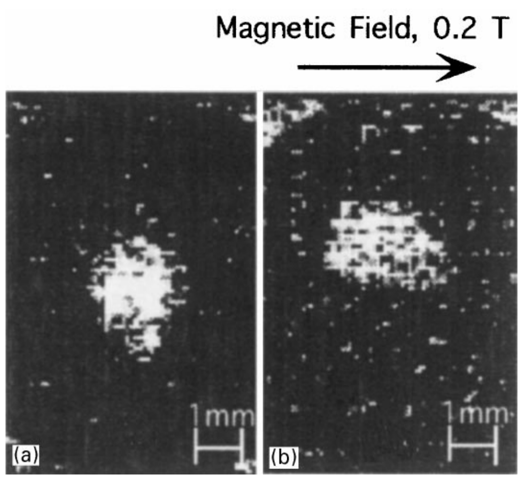

Fig. 3. The analyzed images of air bubble released from a tube from the bottom of the cell, at a constant rate under applied magnetic field strengths of (a) 0, and (b) 0.2 T in water-based MF of 51.2 wt%.

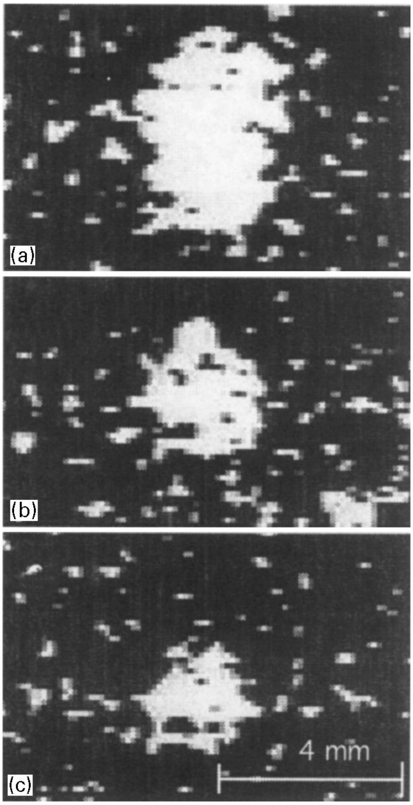

Fig. 4. The analyzed images of air bubble released from a tube from the bottom of the cell, at a constant rate under applied magnetic field strengths of (a) 0, (b) 0.075 T and (c) 0.15 T in ionic MF of 22.7%.

3.1. *Effect of magnetic field on the movement of air bubble*

The Fig. 3a shows the movement of the air bubble under 0 and 0.2 T in a water-based MF of 51.2 wt%. It was observed that the bubble deformed in the direction of the magnetic field as shown in Fig. 3b. The degree of deformation depended on the strength of magnetic field and solid concentration of the MF. Fig. 4a shows the effect of magnetic field strength on the size of the bubble released from a tube of 1 mm diameter at a constant flow rate in ionic MF of 22.7 wt%. The size of the air bubble released becomes smaller for increasing magnetic field strength. Furthermore, for higher magnetic field strengths the movement of the bubbles within the fluid got accelerated. When the magnetization of the fluid is high the effect of magnetic field is large. Here, the bubble size is reduced and lift off speed is increased so much that it is quite difficult to obtain the image with the present resolution.

3.2. *Effect of magnetic field on the vapor bubble in boiling MF*

The boiling experiments were carried out using ionic and water-based MFs. All phenomena reported in the above section were confirmed in boiling ionic MF under external magnetic field. Furthermore, the enhancement of heat transfer characteristic under applied field was observed by a decrease in temperature of the surface of heat source. When a field of 0.2 T was applied, the ionic MF (22.7 wt%) reduced the temperature of the heat source by about 20°C, where as only 8°C of reduction was attained in the case of water-based MF (24.6 wt%), all other factors being the same. The boiling characteristics of ionic and water-based MFs were different and work is in progress to identify the cause for the same.

Table 1
Summary of experimental observation. Note: O clearly observed, Δ not so clearly observed

	Observed phenomena	Ionic MF	Water-based MF
Air bubble	Size	O	Δ
	Shape	Δ	O
	The state of seceding bubble	O	O
Vapor bubbles in boiling MF	Size	O	Δ
	Shape	Δ	Δ
	The state of seceding bubble	O	O

4. Conclusions

We succeeded in visualizing the effect of magnetic field on air and vapor bubbles in MF. The observations made using X-ray microfocus equipment for air bubble and boiling MF are summarized in Table 1. Furthermore, ionic MF showed better heat transfer characteristics than water-based MF. However, further quantitative analysis has to be carried out to conclude on the right MF for heat transfer applications.

References

[1] J. Shimoiizaka et al., J. Mining, Metall. Inst. Japan 199 (1979).
[2] S. Kamiyama, S. Inoue, Trans. Jpn. Soc. Mech. Eng. 54 (1988) 80 (in Japanese).
[3] K. Nakatsuka, J. Magn. Magn. Mater. (1992).
[4] O. Takahashi et al., Meeting (Fall) of Japan Nuclear Energy Association, 1993, p. 22.
[5] J. Ishimoto et al., JSME 61 (1995) 581, 157.
[6] O. Takahashi et al., Meeting of Japan Magnetic Fluid Association, 1994, p. 48.