STUDY ON MICRO-LAYER THICKNESS IN A MICRO-CHANNEL VAPORIZER

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ABSTRACT

It has become an important issue to improve the heat transfer characteristics in a micro-channel vaporizer because a more compact unit is required for use on fuel cell vehicles. This study concerns the micro-layer thickness that affects the heat transfer characteristics. The micro-layer thickness was measured with a laser absorption method, and the process of bubble growth was recorded with a high-speed camera.

Key words : Boiling, Micro-channel, Evaporation states, Heat transfer characteristics, Micro-layer thickness, Laser absorption method

INTRODUCTION

Against a backdrop of growing demands for a cleaner global environment, there is a need for automotive powertrains that can provide higher efficiency and contribute to lower CO_2 emissions. From these viewpoints, fuel cell vehicles are expected to gain a share of the automotive market in the 21st century.

The reformer fuel cell vehicle requires high heat exchange efficiency and low heat capacity to fulfill the powertrain requirements for quick response and compactness. The use of a micro-channel type of vapor generator for the reformer is one possible way of meeting these requirements.

However, as reported in previous studies(1), (2), (3), the characteristics of evaporation in the micro channel are completely different from those of pool boiling. The bulk liquid, the superheated thin liquid layer (micro-layer) and the bubbles in the micro channel affect the boiling characteristics in complex ways. For example, although a decrease of the heat transfer coefficient has been reported for an extremely small gap, the mechanism involved has not been analyzed yet. Elucidating the mechanism of these phenomena is an important factor in specifying measures for satisfying the above-mentioned requirements.

In recent years, attempts have been made to unravel the micro-scale heat and mass transfer phenomena in evaporating thin films by mathematical description(4), (5). It is important to compare the results of calculations with experimental findings for various types of evaporating thin liquid films.

In this study, the micro-layer thickness in the micro channel was measured with a laser absorption method, while the boiling states were simultaneously recorded with a high-speed camera.

EXPERIMENTAL APPARATUS AND PROCEDURE

An outline of the experimental apparatus used is shown in Fig. 1. The micro-channel test rig and the details of the quartz glass plates are shown in Figs. 2 and 3.

A laser ray having a diameter of 3 mm and a wavelength of 3.39 μm was launched from a He-Ne laser through the micro channel via a chopper and a convex lens, one side of which was flat, and introduced into a Pb-Se infrared detector (optical conducting element).

A water reservoir and a heating tank were placed upstream in the micro-channel test rig. The cross-sectional area of the water reservoir was large enough to maintain a constant water level in the micro channel. The water supplied to the micro-channel test rig was boiled in the heating tank that was open to the atmosphere. The micro channel was formed between two quartz glasses. The passages for high temperature gas that supplied heat to the micro channel were located at the back and the front of the micro channel. Two thermocouples were embedded in the quartz glass to measure the heat through this component. The process of bubble growth was recorded with a high-speed camera in front of the micro channel, in synchronization with the laser signal. An image processor was used to analyze the pictures.

The micro-layer thickness was found by applying Lambert's law (1) shown below to the measured laser signal.

$e^{-A\delta} = I/I_0$ - - - (1)

A : Absorption coefficient (5.42×10^4 for H_2O)

δ : Micro-layer thickness

I_0: Standard of light intensity

I : Intensity of transmitted light

I_0 and I indicate the light intensity at the detector under the condition that the micro channel is empty and the micro channel is filled with the bulk liquid and bubble, respectively, as shown Fig. 4.

An example of consecutive measurements (a→e) for the process of bubble growth and the laser signal is shown in Fig. 5. The laser signal fluctuated according to the micro-layer thickness at the moment a bubble grew at the point irradiated by the laser beam, and it was recorded in a personal computer.

EXPERIMENTAL RESULTS

Measurements were made for a micro channel with a 0.5 mm gap size. The relationship between the micro-layer thickness and the velocity of the bubble interface at the measuring point is shown in Fig. 6. The relationship between the micro-layer thickness and the distance from the incipient bubble point is shown in Fig. 7.

Below a velocity of around 2 m/s, the micro-channel thickness increased with increasing velocity. At higher velocities, on the other hand, the micro-layer thickness remained in a range of around 20 to 30 μm. Moreover, the micro channel thickness tended to increase with a longer distance from the incipient bubble point.

CONCLUSION

Under the experimental conditions used in this study, it was confirmed that the velocity of bubble growth and the distance from the incipient bubble point affected the micro-layer thickness in the micro channel.

REFERENCES

1. Katto, Y. and Yokoya, S., Experimental Study of Nucleate Pool Boiling in the Case of Making an Interference-Plate Approach the Heating Surface, *Proc. 3rd Int. Heat Transf. Conf.*, Vol. 3, (1966), p. 219.

2. Fujita, Y., Ohta, H. and Uchida, S., Heat Transfer in Nucleate Boiling within a Vertical Narrow Space, *JSMA International Journal* Series II, Vol. 31, No. 3, (1988), p. 513.

3. Cooper, M. G. and Lloyd, A. J. P., The Microlayer in Nucleate Pool Boiling, Int. J. Heat Mass Transfer, Vol. 12, (1969), p. 895.

4. Stephan, P., Micro scale evaporative heat transfer: modeling and experimental validation, *Proc. 12th Int. Heat Transfer Conf.* (2002).

5. Wayner, Peter C., Jr., Intermolecular Forces in Phase-Change Heat Transfer: 1998 *Kern Award Review,* AIChE Journal.

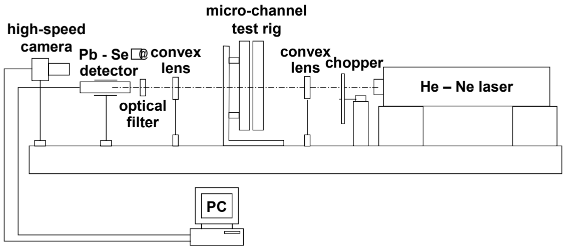

Fig. 1 Outline of experimental apparatus

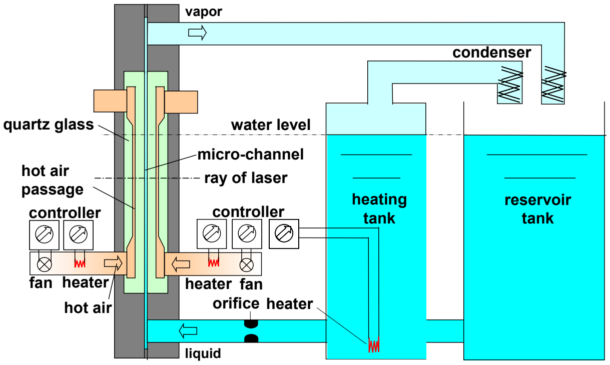

Fig. 2 Micro-channel test rig

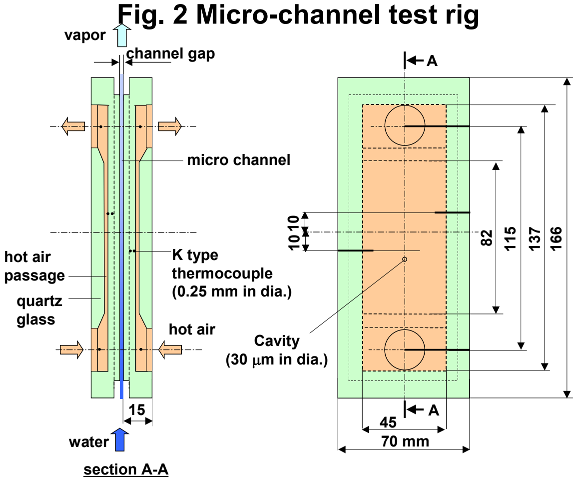

Fig. 3 Quartz glass plates of micro-channel

Lambert's Law

$$e^{-A\delta} = \frac{I}{I_0}$$

A : Absorption coefficient (5.42×10^4 for H_2O)
δ : Micro-layer thickness
I_0 : Standard of light intensity
I : Intensity of transmitted light

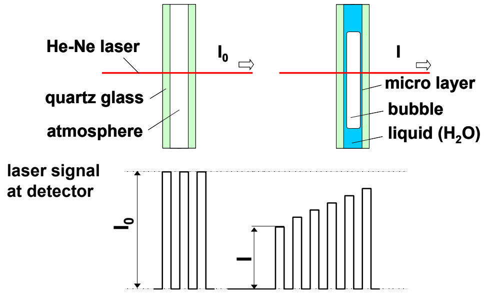

Fig. 4 Light intensity value used for Lambert's Law

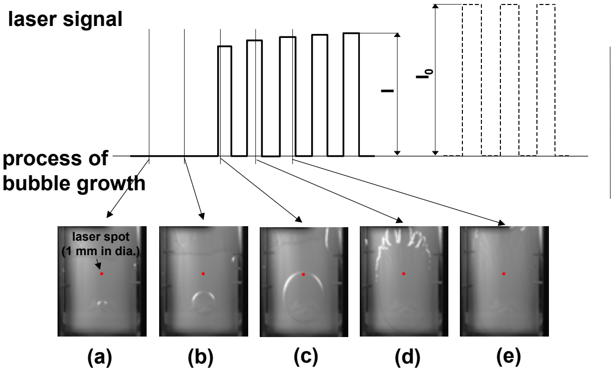

Fig. 5 Example of measurement

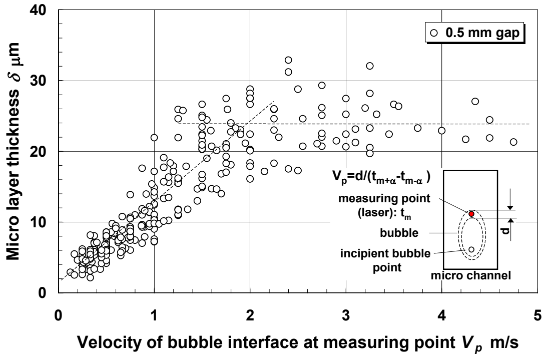

Fig. 6 Relationship between micro-layer thickness and velocity of bubble interface at measuring point

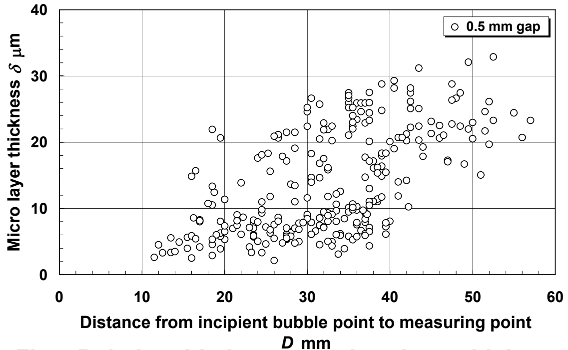

Fig.7 Relationship between micro-layer thickness and distance from incipient bubble point