Paper No. 45

Proceeding of the
1st International Forum on Heat Transfer
November 24-26, 2004, Kyoto, Japan

Visualization of convective boiling in a micro tube with simultaneous measurement of local heat transfer

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***Keywords**: Convective boiling, Visualization, Microtube*

ABSTRACT

Visualization of convective boiling flow modes in a 0.3 mm ID glass tube is made with simultaneous measurement of local heat transfer coefficient. In order to form a transparent electrode for direct joule heating ITO/Ag is sputtered onto the outer surface of the microtube. A high-speed CMOS camera is used to record transient flow patterns. The liquid superheat phenomena discovered in our previous measurement in metal tubes are observed in the present glass microtube. It is found that the explosive boiling from the highly superheated liquid has a very high nucleation frequency of 4kHz. Under the saturated boiling condition, a complex quasi-periodic flow pattern is observed. Both the liquid superheat and the heat transfer coefficient are strongly related to the bubble nucleation, which depends on the surface roughness of the microtube. This can be explained by the bubble growth rate restricted due to a limited space in the microtube.

1. INTRODUCTION

Highly efficient heat exchangers have become even more important because of the rapid increase of heat dissipation rate in high-end electronic devices. Therefore, the heat transfer research on both single and multi-phase flows in micro conduits has attracted much attention (Mehendale et al., 2000).

Because of the lack of experimental data and systematic research in microtubes/microchannels and the necessary to understand the overall heat transfer of convective boiling in microtubes or microchannels, the present study aims at carrying out visualization of liquid superheat and convective boiling with the simultaneous measurement of the local heat transfer coefficient and pressure loss.

2. EXPERIMENTAL APPARATUS

Figures 1 shows the test section used in the present experiment. HCFC123 was employed as a working fluid. A Pyrex glass tube was 0.3 mm in inner diameter and 0.5 mm in outer diameter. The tolerance of the inner and outer diameters was $\pm 20 \mu m$ and $\pm 15 \mu m$, respectively. In order to heat the tube, the mixture of ITO (Indium Tin Oxide) and silver was evenly sputtered on the outer surface of the tube. The sputtered film thickness was about 100nm. The total resistance of the sputtered glass tube was about 1000 Ω. Twelve K-type thermocouples of 25 μm OD, calibrated with the accuracy of ± 0.05 K, were glued on the tube outer surface with thermally conductive silicon.

A high-speed CMOS camera (Vision Research, Phantom v7) was employed for the flow visualization inside the microtube. The images having 800x100 pixels were taken at 20000 frames/sec.

3. EXPERIMENTAL RESULTS

3.1 Onset of boiling

A high degree of liquid superheat prior to the onset of boiling was observed. Figure 2 shows the distribution of outer surface temperature of the 0.3 mm Pyrex glass tube. The solid line represents the saturation temperature. Station #7 represents the seventh thermocouple from the inlet. Figure 3 shows the high-speed camera image near station #7, where the field of view in the streamwise direction is about 1 cm. The explosive boiling starts between the sixth and seventh thermocouples, and its nucleation frequency are observed as fast as 4kHz.

3.2 Simultaneous visualization and measurement of local heat transfer coefficient

At higher heat fluxes, the liquid superheat phenomenon disappears and the convective boiling occurs (Yen et al., 2003). According to the visualization at a fixed streamwise position of the test section, the flow field varies dramatically in time, and exhibits some quasi-periodic variation of flow patterns, including bubbly, plug, slug, annular and capillary flows, as shown in Fig. 4. The period of such flow pattern variation is about 0.2 sec. Figure 5 shows the local heat transfer coefficient in the same experimental run as in Fig. 4. The local heat transfer coefficient decreases at $\chi<0.3$. When $\chi>0.3$, the heat transfer coefficient becomes almost independent of the vapor quality. Figure 6 shows the time history of each flow pattern observed in the same experimental run. The time history moves forward along the direction of the arrow of y-axis in fig. 6 and it is found that, at lower vapor quality ($\chi<0.3$), the bubbly flow pattern appears and has about 30% time history of the total period. It is conjectured that the relatively large heat transfer coefficient at low χ corresponds to the existence of the bubble nucleation. On the other hand, the ratio between the plug, slug and annular flow patterns remains unchanged along the test section, so that the heat transfer coefficient is almost constant at $\chi>0.3$.

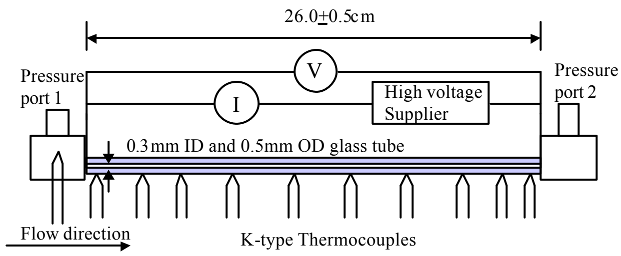

Fig. 1 Test section

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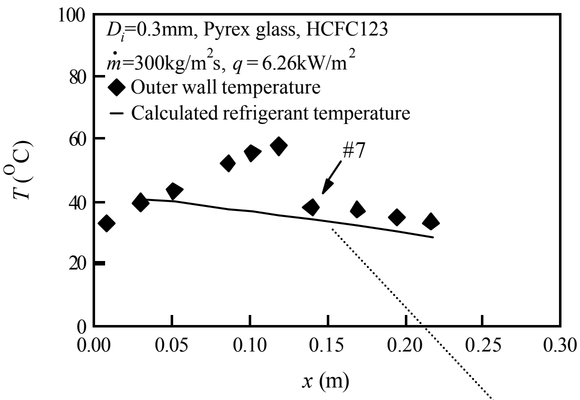

Fig. 2 Wall temperature distribution at a low heat flux of q=5.85 kW/ m^{2}s.

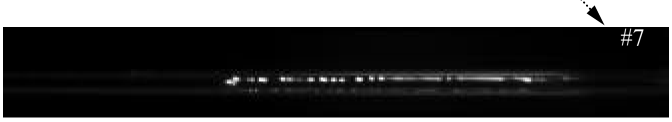

Fig. 3 Explosive boiling from the superheated liquid near the seventh thermocouple (same experimental run as in Fig. 2).

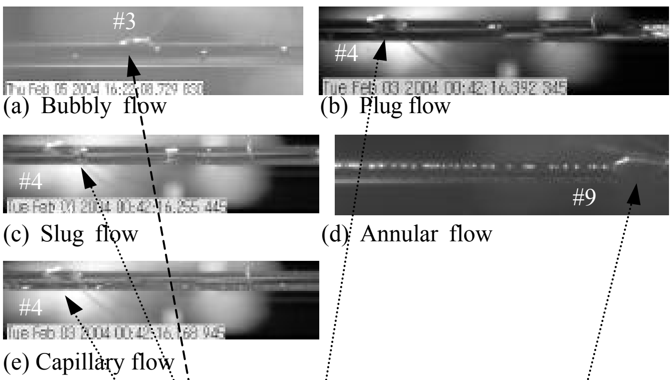

Fig. 4 Different flow patterns discovered in the microtube. D_i=0.3 mm, Pyrex glass tube at $\dot{m}$=300 kg/m^{2}s and q=20.33 kW/ m^{2}s.

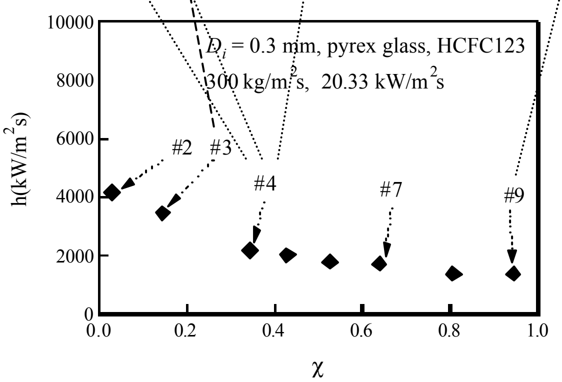

Fig. 5 Local heat transfer coefficient versus vapor quality (same experimental run as in Fig. 4).

CONCLUSIONS

Visualization of convective boiling flow modes in a microtube with the simultaneous measurement of local heat transfer coefficients was carried out. The quasi-periodic variation of the flow pattern was observed. It is conjectured that the heat transfer characteristics in microtubes depend on the time history of each

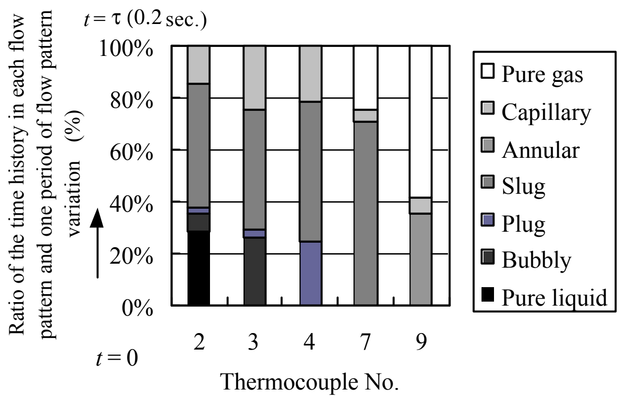

Fig. 6 Distribution of the flow patterns under one period at different visualization points of the test section of the same experimental run as fig.5. pyrex glass tube D_i =0.3 mm, $\dot{m}$ =300 k g/m^{2}s and q=20.33 kW/ m^{2}s.

flow pattern Therefore, a time-dependent model should be developed for predicting the peculiar heat transfer characteristics in microtubes.

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NOMENCLATURE

D_i: inner diameter of the test section h: heat transfer coefficient., $\dot{m}$: mass flux, q : heat flux, T: outer wall temperature. t: time, χ: vapor quality. τ: period of flow pattern variation.

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