Experimental Investigatation of Pool Boiling for Single and Double Heaters Using Printed Circuit Board

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1. Introduction

Over the past several decades, a considerable number of studies have been conducted on boiling heat transfer in pool boiling. Boiling heat transfer is used in a variety of cooling applications, such as heat exchangers, high powered electronics, and nuclear reactors. Nucleate boiling is one of the most efficient heat transfer mechanisms in boiling regime, but it is imperative that the critical heat flux(CHF) should not be exceeded. CHF phenomenon leads to a dramatic rise in wall temperature, decreased heat transfer, and material failure. Although numerous attempts have been made by researchers to demonstrate the CHF, there is little agreement with the CHF mechanism.[1,2]

In recent years, many researchers have been focusing on surface condition using nanoparticles and surface enhancements, such as a micro structure and artificial cavities, due to enhancement of the CHF point. Cooke and Kandlikar[3] used chips etched with microchannels to prove that these structure has the most enhancement effect. They found that the most efficient boiling surface is with a larger channel size and deep etch.

The purpose of this paper is to evaluate the heat transfer and CHF of double heaters on printed circuit board(PCB) in pool boiling. In addition, bubble dynamics of nucleate boiling were observed with high speed observation on single and double heaters using PCB heater.

2. Experimental Apparatus and Methods

A schematic of the experimental facility is shown in Fig. 1. It consists of a boiling pool, test heater, power supply, and data acquisition system. Here, a glass test cell is double-walled with thermally treated glass and equipped with two small internal heaters to preheat the test pool up to the saturated temperature of de-ionized water before experiment. In addition, a reflux condenser on top of the glass test cell prevents fluid loss due to evaporation. Schematics of present heater configuration and drawing are shown in Fig. 2. The heater was made of copper strap wire plated with nickel. The temperature of the heater can be calculated using the following equation:

$$R(T) = R_o(1+\alpha(T_{wall} - T_{sat})) \quad (1)$$

where T is the heater temperature, R is the electrical resistance, and α is the temperature coefficient of resistance. T_{sat} and R_0 are the initial values of the temperature and resistance of the heater, respectively. The error for the temperature measurement is estimated to be below 3%. Single heaters have width(w) of 0.635, 1, 2mm, respectively, and double heaters have width(w) of 0.635 mm and gap(δ) of 0.3175, 0.635, 6.35mm, respectively.

Power is supplied to the heater via a programmable DC power supply(20V × 330A), Power Ten P60-203309, AMETEK. In series with the heater is a shunt

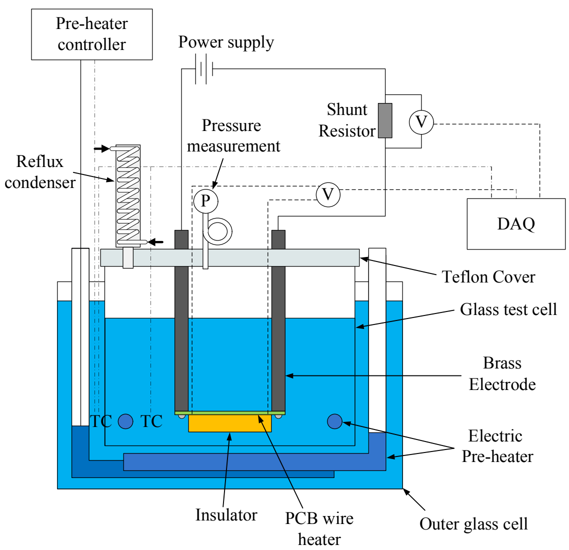


Fig. 1 Schematics diagram of pool boiling experimental apparatus.

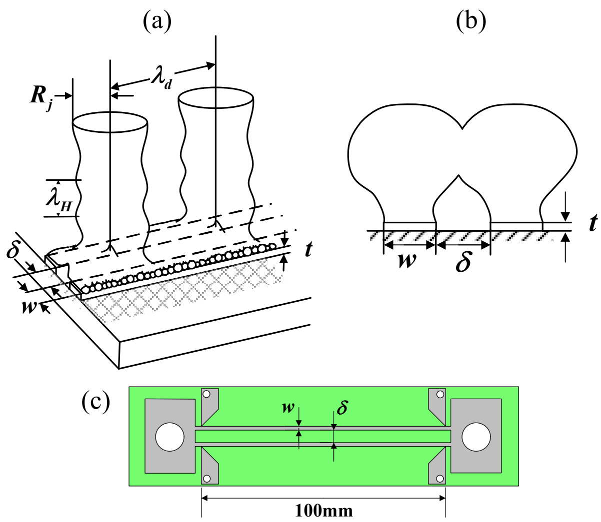


Fig. 2 Schematics diagram of (a) vapor structure (b) cross-dimension (c) drawing of PCB heater

resistor(50mV, 500A) which measures dc current in this system. The accuracy of the shunt resistor is ± 0.25% over the entire range in this study. The two pairs of voltage measure the voltages across the heater and the shunt resistor. Two K-type thermocouples are used to measure the temperature of water in the glass test cell and outer glass cell. An Agilent 34970A data acquisition system was used to measure and store the voltage and temperature signals. The heat flux can be calculated using equation below.

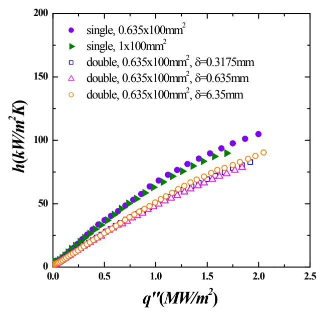
$$q'' = \frac{IV}{A} \qquad (2)$$

Here I and V are the current and the voltage across the heater, respectively. A is the heat transfer test area of the heater. The error of heat flux is estimated to be 10%.

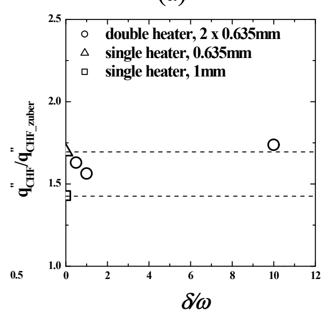
3. Results and Discussion

Heat transfer coefficient and CHF points of single and double heaters are shown in Fig. 3. Fig. 3(a) shows representative heat transfer coefficient. Heat transfer coefficient of single heater is higher than coefficient of double heaters when two kinds of heater have the same heat flux, but at the CHF point, single heater of 1mm width and double heaters are similar to heat transfer coefficient.

As for the CHF, the double heater has strong dependency with the gap between heaters as shown in Fig. 3(b). For the heater with small gap, the CHF approaches to the CHF of wide width (to 1mm heater) but for the large gap, as expected the double heater approaches thinner heater (to 0.635 mm). At this moment it is not clear to define the critical gap size, which requires more experimental work.



(a)



(b)

Fig. 3 CHF data and Heat transfer coefficient of single and double heaters

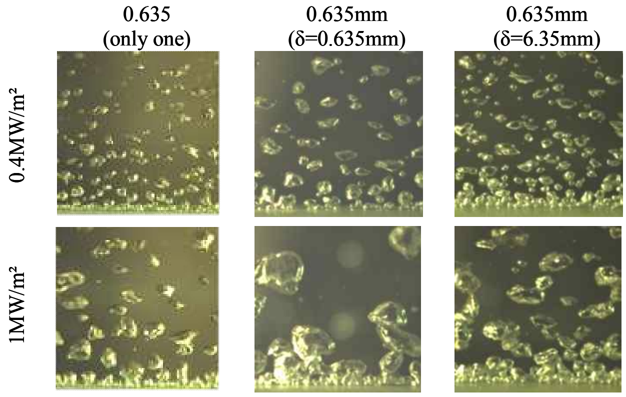


Fig. 4 Pictures of bubble formation on single and double heaters at 0.4MW/m² and 1MW/m²

As seen in Fig. 4 for pictures of bubble formation, we observed that size and quantity of bubble are certainly different with single and double heaters. At the same heat flux, double heaters with narrow gap have bulky bubble rather than single heater. On the other hands, double heaters with wide gap have larger number of bubbles than the single heater. It means that each heater has its own cooling mechanism independently unlike Fig. 2(b).

4. Conclusions

The present study is to investigate how to use the CHF enhancement capability of the thin flat heater as noted by Lienhard and Dhir[4]. We provided the same thin heaters parallel to see if its CHF is higher than the heater of twice width. Experimental data clearly shows that in any gap difference, CHF of the parallel double heaters are close to the CHF of single heater. Interestingly, the size of gap which forms water channel for the boiling is less than 0.3175mm. Determination of the critical gap size needs further experiments.

Acknowledgment

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