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Effects of the Location of Side Inflow Holes on Pool Boiling Heat Transfer in a Vertical Annulus

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1. Introduction

One of the effective ways to enhance heat transfer is considering a confined space around a heat exchanging part. Having higher heat transfer rate is very important if the space for heat exchanger installation is very limited or rapid heat removal is essential like passive type heat exchangers in advanced reactors. Major geometries studied for the crevices are annuli [1-4] and plates [5,6]. Some geometry has closed bottoms [1,3-5].

It is well known from the literature that the confined boiling can result in heat transfer improvements up to 300-800% at low heat fluxes, as compared with unconfined boiling. However, deterioration of heat transfer appears at higher heat fluxes for confined than for unrestricted boiling [1,3]. To apply the vertical annulus to the thermal design of a heat exchanger a solution to prevent the deterioration is needed in advance.

Since the major cause of the bigger bubble coalescence which results in the deterioration is partly because of the no inflow at the lower regions of the annulus, the present study is aimed at the investigation of the way to improve heat transfer in the annulus through changing the location of the inflow holes along the height of the annulus. Up to the author's knowledge, no previous results concerning the ways have been published yet.

2. Experiments

For the test a water storage tank made of stainless steel and has a rectangular cross section (950×1300 mm) and a height of 1400 mm and a resistance heater made of a very smooth stainless steel tube (L=0.5 m and D=34 mm) have been prepared. The surface of the tube was finished through a buffing process to have a smooth surface. Electric power of 220 V AC was supplied through the bottom side of the tube.

The tube outside was instrumented with five T-type sheathed thermocouples (diameter is 1.5 mm). The thermocouple tip (about 10 mm) was brazed on the tube wall. The water temperatures were measured with six sheathed T-type thermocouples brazed on a stainless steel tube that placed vertically at a corner of the inside tank. All thermocouples were calibrated at a saturation value (100 °C since all tests were done at atmospheric pressure). To measure and/or control the supplied voltage and current, two power supply systems were used. The capacity of each channel is 10 kW.

To make the annular condition, glass tubes (gap size=10.7 mm) of 55.4 mm inner diameter and 600 mm length were used. The inflow into the annular space was controlled by the location (L_h) of the inflow holes changing from 0.1 to 0.4 m. The diameter of the inflow hole is 15 mm and the number of the holes is four, which are located at every 90° along the circumference of the glass tube.

After the water storage tank is filled with water until the initial water level is reached at 1100 mm, the water is then heated using four pre-heaters at constant power. When the water temperature is reached at a saturation value, the water is then boiled for 30 minutes to remove the dissolved air. The temperatures of the tube surfaces are measured when they are at steady state while controlling the heat flux on the tube surface with input power.

The heat flux (q'') from the electrically heated tube surface is calculated from the measured values of the input power as follows:

$$q'' = \frac{VI}{\pi DL} = h_b \Delta T_{sat} = h_b (T_W - T_{sat}) \qquad (1)$$

where V and I are the supplied voltage (in volt) and current (in ampere), and D and L are the outside diameter and the length of the heated tube, respectively. T_W and T_{sat} represent the measured temperatures of the tube surface and the saturated water, respectively.

The uncertainty in the heat flux is estimated to be ± 1.0%. The total uncertainty of the measured temperatures is estimated as ±0.3 °C. The uncertainty in the heat transfer coefficient can be determined through the calculation of $q'' / \Delta T_{sat}$ and is within ± 10%.

3. Results and Discussion

Figure 1 shows variations in heat transfer as the location of the inflow holes changes. Results for the closed bottoms without side holes show deterioration of heat transfer comparing to the single unrestricted tube. At $q'' \geq 70$ kW/m² the tube wall superheat for the closed bottoms is higher than that of the single tube at the same heat fluxes. This means that the adoption of the bottom-closed annulus has no advantage in heat transfer enhancement at theses heat fluxes. Addition of the side inflow holes removes deterioration of heat transfer at higher heat fluxes and, moreover, still maintains higher heat transfer at low heat fluxes. The most attractive results are obtained for the annulus with inflow holes at L_h=0.3 m. As Kang [4] explained the major cause of the deterioration is the formation of large bubble slugs. Two cases should be coincided with each other to generate big bubbles. One is generation of enough bubbles at the lower region of the inflow location and the other one is liquid interference to reduce the velocity of the bubbles. The introduction of the side inflow holes effectively removes the possibility of the bigger bubble generation around the upper region of the tube since no enough bubbles are generated under the lower region of the inflow holes. The inlet liquid through the side inflow holes still interferes upward bubble movement at the lower regions of the tube. It generates pulsating flow to occur active liquid agitation in the annular space. This is the major cause of heat transfer enhancement at low heat fluxes.

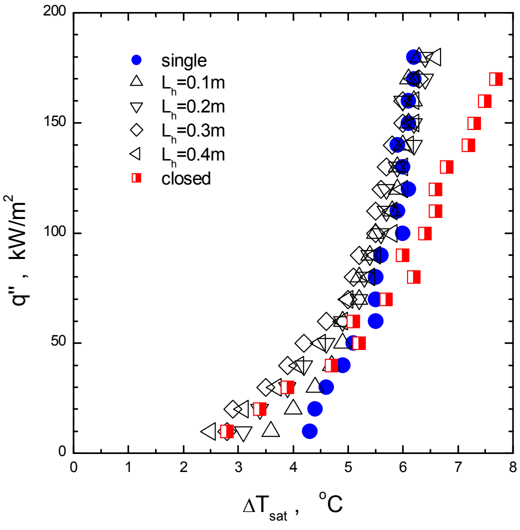

Figure 1. Plots of heat flux versus tube wall superheat.

Changes in the heat transfer coefficients versus the location of the inflow holes are shown in Fig. 2. Four different heat fluxes have been investigated to observe the tendencies. Among the cases, L_h=0.6 m at x-axis means the annulus without side holes. The heat transfer coefficients get increased at $L_h \le 0.3$ m, and then get decreased at 0.3 m $< L_h$. Through the heat fluxes, the heat transfer coefficients for L_h=0.3 m have the highest values comparing to the other cases. To identify the enhancement two heat transfer coefficients for the annuli with inflow holes at L_h=0.3 m and without the holes have been compared each other at q'' =160 kW/m². The heat transfer coefficients increased 26.9% (from 21.2 to 26.9 kW/m²-°C) in case of the inflow holes are applied.

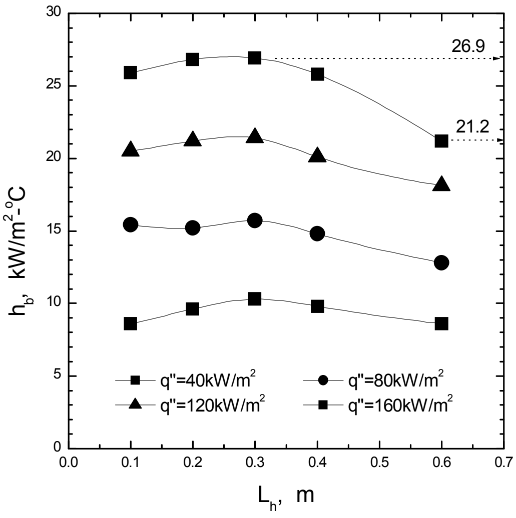

Figure 2. Variations in heat transfer coefficients as location of side inflow holes changes.

4. Conclusion

To identify effects of the location of the side inflow holes on pool boiling heat transfer in a vertical annulus (gap size=10.7 mm), a heated tube of 34 mm diameter and water at atmospheric pressure has been tested. The change in the location of the holes results in much variations in heat transfer coefficients at low heat fluxes less than 100 kW/m². Moreover, the side inflow holes could remove the deterioration of heat transfer in the vertical annulus without side inflow holes. Locating the inflow holes at 0.3 m from the bottom of the tube results in the best results for the heat fluxes tested. Therefore, the annulus with side inflow holes could be recommended as a useful way to improve pool boiling heat transfer.

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