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Technical Note

Effects of the upper inflow area on pool boiling heat transfer in a vertical annulus

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ABSTRACT

The upper inflow area has been changed to identify the effects of it on pool boiling heat transfer in a vertical annulus. Both bottom inflow conditions of the open and the closed are considered for the study. For the test, a heated tube of 25.4 mm diameter and the water at atmospheric pressure have been used. The ratios of the gaps have been varied from 0.18 to 1. Effects of the inflow area on heat transfer become evident as the heat flux increases and the gap ratio decreases. If the gap ratio is smaller than 0.51 and the heat flux is higher than 60 kW/m^2, a noticeable decrease in heat transfer is observed. The major cause for the tendency is attributed to the formation of a lumped bubble around the upper regions of the annulus.

1. Introduction

The mechanism of pool boiling heat transfer has been studied extensively for the several decades [1]. Although many workers have investigated effects of heater geometries on boiling heat transfer, knowledge on the confined spaces on pool boiling heat transfer is still limited. Studies on the crevices can be divided into two categories. One of them is about annuli [2–5] and the other one is about plates [6–8]. In addition to the geometric conditions, flow to the crevices can be controlled. Some geometry has a closed bottom [2,5,6].

It is well known from the literature that the confined boiling is an effective technique to enhance heat transfer. It can result in heat transfer improvements up to 300–800% at low heat fluxes, as compared with unconfined boiling [2,6]. However, a sudden deterioration of heat transfer appears at high heat fluxes for confined boiling [6,8]. The boiling heat transfer coefficient usually increases when the gap size decreases at low heat fluxes whereas it decreases at higher heat fluxes. However, in general, the heat transfer coefficient increases when the gap size decreases to a certain value [2–4,7] at low heat fluxes. Further decrease in the gap size results in a sudden decrease of the heat transfer coefficient. One of the possible reasons of the deterioration is a formation of big bubbles followed after active bubble coalescence at the upper regions of the annulus [4].

Around the upper region of the annulus with a closed bottom the downward liquid flow interferes with the upward bubble flow. Thereafter, bubbles are coalescing to a big lump while fluctuating up and down in the annular gap. Kang [5] published effective results of moving the deterioration point, where a sudden decrease in heat transfer was observed comparing to the unrestricted single tube, to the higher heat flux and of preventing the occurrence of the critical heat flux. To remove the coalescence of the big bubbles around the upper region of the annulus Kang [5] controlled the length of the outer tube of the annulus. The major cause of the big bubble formation which results in the deterioration is partly because of the no inflow through the lower regions of the annulus. Kang [9] identifies that the inflow area at the bottom regions of an annulus changes heat transfer coefficients much and moves the deterioration point of the heat transfer coefficients to the higher heat fluxes.

Summarizing the previous works about the pool boiling heat transfer in an annulus, it can be stated that heat transfer coefficients are highly dependent on the geometry and the confinement condition. One of the interesting and important geometric parameters in pool boiling heat transfer is the inflow area at the upside region of the annulus. The variation of the upper inflow area changes the outward velocity of the bubbles from the annulus. This kind of geometry is found in an in-pile test section that is important to identify nuclear fuel irradiation behavior at the operating condition of a commercial power plant. Up to the author's knowledge, no previous results concerning to this effect have been published yet. Therefore, the results of this study could provide a clue to the thermal design of those facilities.

2. Experiments

A schematic view of the present experimental apparatus and a test section is shown in Fig. 1. The water tank (Fig. 1(a)) is made

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Nomenclature

A_T	data acquisition error, °C	q''	heat flux, W/m^2
D	diameter of the heating tube, m	s	gap size (= $(D_i - D)/2$), m
D_i	inside diameter of the glass tube, m	s_d	gap size around the flow interrupter (= $(D_i - d)/2$), m
d	diameter of the flow interrupter, m	s_r	ratio of the gaps (= s_d/s)
h_b	boiling heat transfer coefficient, W/m^2-°C	T_{sat}	saturation temperature, °C
I	supplied current, A	T_W	tube wall temperature, °C
L	heated tube length, m	V	supplied voltage, V
P_T	precision limit, °C	ΔT_{sat}	tube wall superheat (= $T_W - T_{sat}$), °C

of stainless steel and has a rectangular cross section (950 × 1300 mm) and a height of 1400 mm. The sizes of the inner tank are 800 × 1000 × 1100 mm (depth × width × height). Four auxiliary heaters (5 kW/heater) are installed at the space between the inside and the outside tank bottoms. The heat exchanging tube is a resistance heater (Fig. 1(b)) made of a very smooth stainless steel tube (L = 0.5 m and D = 25.4 mm). The surface of the tube is finished through a buffing process to have a smooth surface. Electric power of 220 V AC is supplied through the bottom side of the tube.

The tube outside is instrumented with five T-type sheathed thermocouples (diameter is 1.5 mm). The thermocouple tip (about 10 mm) is brazed on the tube wall. The brazing metal is a kind of brass and the averaged brazing thickness is less than 0.1 mm. The temperature decrease along the brazing metal is calibrated by the one dimensional conduction equation. The water temperatures are 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 are calibrated at a saturation value (100 °C since all tests are done at atmospheric pressure). To measure and/or control the supplied voltage and current, two power supply systems are used.

For the tests, the heat exchanging tube is assembled vertically at the supporter (Fig. 1(a)) and an auxiliary supporter is used to fix a glass tube (Fig. 1(b)). To make the annular condition, a glass tube of 55.4 mm inner diameter (D_i) and 600 mm length are situated around the heated tube. The gap size ($s = (D_i - D)/2$) of the main body of the annulus is 15 mm. A glass tube without the bottom inflow holes is used for the test of the bottom closed annulus. To maintain the gap size between the heated tube and the glass tube a spacer (Fig. 2(b)) has been installed at the upper region of the test section. The upper inflow into the annular space is controlled by the flow interrupters (Fig. 2(c)) that having the outside diameters (d) of 40, 45, and 50 mm, respectively. After installing the flow interrupter around the test section the spacer is screwed down on the test section tightly. Because of the flow interrupter the gap size around the interrupter ($s_d = (D_i - d)/2$) is different from the gap of the main body. The ratio of the gaps ($s_r = s_d/s$) varies from 0.18 to 1 as shown in Table 1. Among the values s_r = 1 represents the annulus without the flow interrupter.

After the water tank is filled with water until the initial water level gets 1100 mm, the water is then heated using four pre-heaters at constant power. When the water temperature is reached at the saturation value, the water is then boiled for 30 minutes to

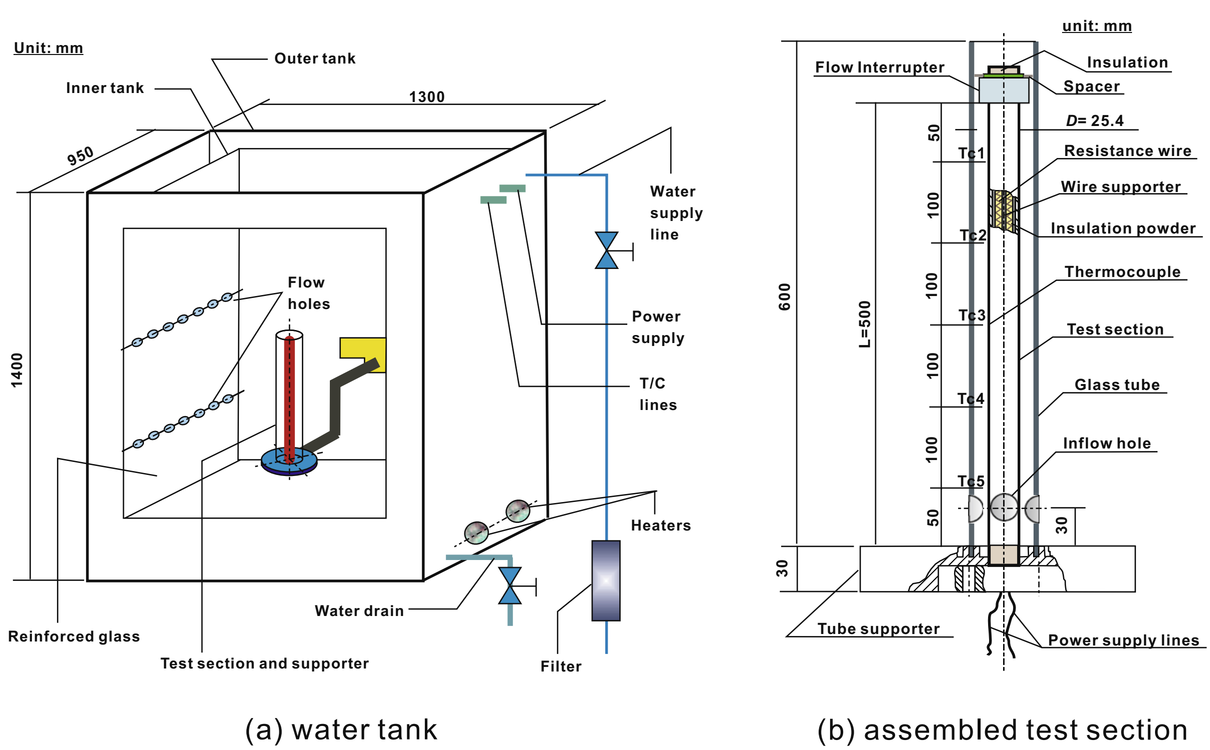

Fig. 1. Schematic of the experimental apparatus.