Effects of the Outside Tube Length on Nucleate Pool Boiling Heat Transfer of Saturated Water in an Annulus with Closed Bottoms

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1. Introduction

The mechanism of pool boiling heat transfer has been studied extensively since it is closely related with the thermal design of more efficient heat exchangers. It is very important if the space for heat exchanger installation is very limited like advanced light water reactors [1, 2]. One of the effective means to increase heat transfer is to consider a confined geometry.

The confined boiling can result in heat transfer improvement up to 300%-800% at low heat fluxes, as compared with unconfined boiling[3, 4]. Once the flow inlet at the tube bottom is closed, a very rapid change in the heat transfer coefficient is observed [5]. As the outer tube is shorter than the heated tube the deterioration point of heat transfer moves up to the higher heat fluxes and the possibility of CHF creation is prevented [5].

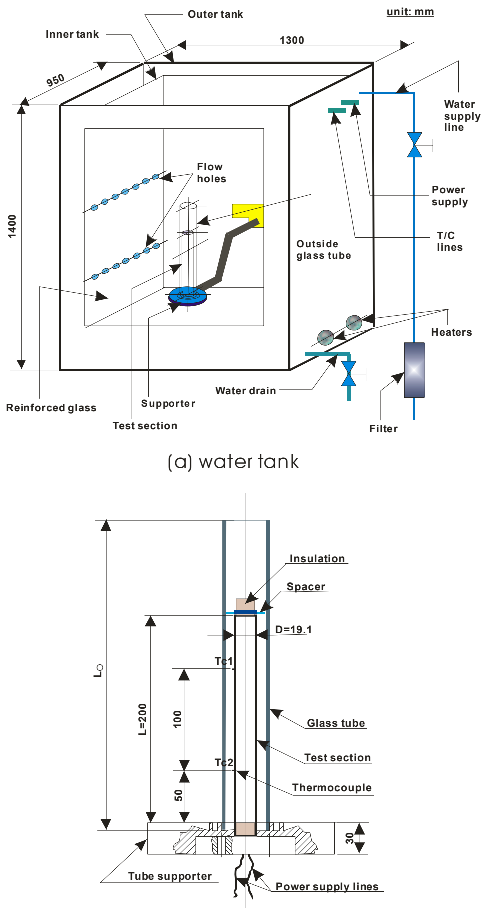
Summarizing the previous results, the length of the outer tube is a very important parameter to improve pool boiling heat transfer in an annulus with closed bottoms. Therefore, the present study is aimed at the investigation of the outer tube length on heat transfer in the annulus with closed bottoms through changing the length of the outer tube longer than the heated tube. Up to the author's knowledge, no previous results concerning to this effect have been published yet.

2. Experiments and Results

A schematic view of the present experimental apparatus and an assembled test section is shown in Fig. 1. The sizes of the inner tank were 800×1000×1100 mm (depth×width×height). The heat exchanging tube was simulated by a resistance heater (Fig. 1b) made of a very smooth stainless steel tube. To make the annular condition several transparent glass tubes were used. Electric power of 220 V AC was supplied through the bottom of the tube.

After the tank is filled with water until the initial water level is reached at 1.1 m, the water is then heated at atmospheric pressure until the water gets saturated. The temperatures of the tube surface are measured with two T-type sheathed thermocouples when they are at steady state while controlling the heat flux on the tube surface. Through the tests combinations of two gap sizes (s=3.5 and 15.5 mm) and four outside tube lengths (L_o =0.3, 0.4, 0.5, and 0.6 m) were used.

The uncertainties of the experimental data were calculated from the law of error propagation [6]. The 95 percent confidence uncertainty of the measured temperature had the value of ±0.11 °C. The uncertainty in the heat flux was estimated to be ±0.7% and the uncertainty of the heat transfer coefficient was determined to be ±6%.



(a) water tank

(b) assembled test section

Fig. 1. Schematic of experimental apparatus.

Figure 2 shows variations in heat transfer as the length of the outer tube changes. At $q'' \leq 60$ kW/m², much difference is observed in ΔT_{sat} between the results of the annulus and the single unrestricted tube. This tendency is similar to the results of Kang [5]. For the single tube a steeper curve slope of q'' versus ΔT_{sat} is observed. Some results for the annulus show deterioration in heat transfer comparing to the single tube as the heat flux is increased more than 100 kW/m². The changes in heat transfer due to the variation of the outer tube length depend on the annular gap size. The increase in L_o results in ΔT_{sat} decrease for s =3.5 mm whereas the increase in L_o results in ΔT_{sat} increase for s =15.5 mm. At q'' =100 kW/m² and s =3.5 mm the increase of L_o from 0.3 m to 0.6 m results in more than 11.2% (from 11.6 to 10.2 ℃) decrease in ΔT_{sat}. For the same heat flux and s =15.5 mm the increase of L_o from 0.3 m to 0.6 m results in more than 12.1% (from 9.9 to 11.1 ℃) increase in ΔT_{sat}. The tendency suggests that the major heat transfer mechanisms for the annuli are different from each other.

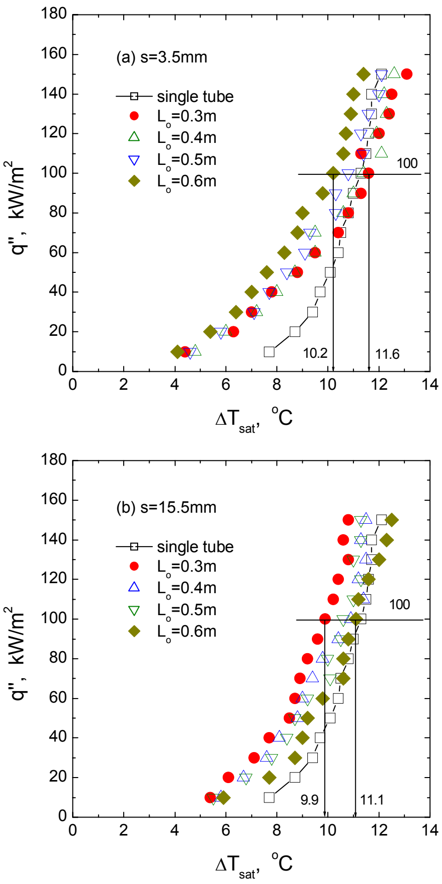


Fig. 2. Plots of q'' versus ΔT_{sat} data.

When the gap size is 3.5 mm the bubbles departed from the annulus move upward through the inside of the plain tube. After the bubbles get out of the tube a rapid rush of liquid into the space is generated. Since much bigger size of bubble lumps are generated inside the longer outside tube the more active liquid agitation in the space is expected accordingly. Therefore, results of L_o=0.6 m shows enhanced heat transfer comparing to the results of L_o=0.3 m.

For s =15.5 mm, since there are much space active interference between the bubbles and the liquid are hardly observed in the plain tube region. As the outer tube length is increased the head loss gets increased and this, in turn, reduces the intensity of liquid agitation, too. Because of the reduced bubble velocity and loss of the active agitation, the effect of bubble coalescence on the tube surface gets increased and, as a result, heat transfer decrease is observed for the longer outside tube.

To develop a correlation to predict pool boiling heat transfer in annuli a total of 494 data points have been obtained using the present data and the published data. Throughout the literature review, several dimensionless parameters containing D, L, s, and q'' are selected as independent variables [1, 5, 7, 8]. The selected dimensionless parameters are Nusselt number (Nu), Reynolds number (Re), and Bond number (Bo) [12]. Two additional geometric parameters are $L_s = LD/s^2$ and $L_r = L_o/L$. The developed correlation predicts the data within ±17% error bound and has the form as follows:

$$\mathrm{Nu} = 0.244\,\mathrm{Re}^{0.609}\,\mathrm{Bo}^{1.622}\,L_s^{0.837}\,L_r^{0.197} \qquad (1)$$

3. Conclusions

An experimental study was carried out to identify effects of the outer tube length on pool boiling heat transfer in a vertical annulus with closed bottoms submerged in a pool of saturated water at atmospheric pressure. The change of the outside tube results in heat transfer characteristics. Two major causes affecting on pool boiling are explained as the difference in the intensity of liquid agitation and the reduced flow velocity due to head loss. To take account effects of the tube ratio and the gap size an empirical correlation has been obtained and the correlation predicts the present experimental data within ±17% error bound.

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