# Effects of Outer Tube Length on Saturated Pool Boiling Heat Transfer in a Vertical Annulus with Closed Bottoms

Myeong-Gie Kang
*Department of Mechanical Engineering Education, Andong National University*
*388 Songchun-dong, Andong-city, Kyungbuk 760-749, Korea*
*mgkang@andong.ac.kr*

## 1. Introduction

The mechanism of pool boiling heat transfer has been studied extensively in the past since it is closely related with the thermal design of more efficient heat exchangers [1]. One of the effective means to increase heat transfer is to consider annuli [2-5]. Some geometry has closed bottoms [2,4,5].

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, a deterioration of heat transfer appears at higher heat fluxes for confined than for unrestricted boiling [3,4]. The cause for the deterioration was suggested as bubble coalescence at the upper regions of the annulus [4]. To apply the vertical annulus with closed bottoms to the thermal design of a heat exchanger investigation of any possible ways to prevent the deterioration is needed in advance.

Up to the author's knowledge, no previous results concerning the ways have been published yet. Therefore, the present study is aimed at the investigation of the way to improve heat transfer in the annulus with closed bottoms through changing the length of the outer tube.

## 2. Experiments

A schematic view of the present experimental apparatus is shown in Figure 1. The water storage tank is made of stainless steel and has a rectangular cross section (950×1300 mm) and a height of 1400 mm. Four auxiliary heaters (5 kW/heater) were installed at the space between the inside and the outside tank bottoms. The heat exchanger tubes are simulated by a resistance heater made of a very smooth stainless steel tube ($L$=0.54 m and $D$=19.1 mm). The surface of the tube was finished through buffing process to have 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 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. To measure and/or control the supplied voltage and current two power supply systems were used.

To make the annular condition, a glass tube (gap size=6.35 mm) of different axial length (i.e., $L_o$=0.2, 0.4, and 0.6 m) was used. For the tests, the heat exchanging tube is assembled vertically at the supporter and an auxiliary supporter is used to fix a glass tube.

After the tank is filled with water until the initial water level is 1100 mm, the water is then heated using four pre-heaters. When the water temperature is reached at a saturation value (i.e., $T_{sat}$=100 °C since all the tests are run at atmospheric pressure condition), the water is then boiled for 30 minutes to remove the dissolved air. The temperatures of the tube surfaces ($T_W$) are measured when they are at steady state while controlling the heat flux on the tube surface with input power.

The uncertainty in the heat flux is estimated to be ±1.0%. The uncertainty of the measured temperatures is estimated as ±0.3 K.

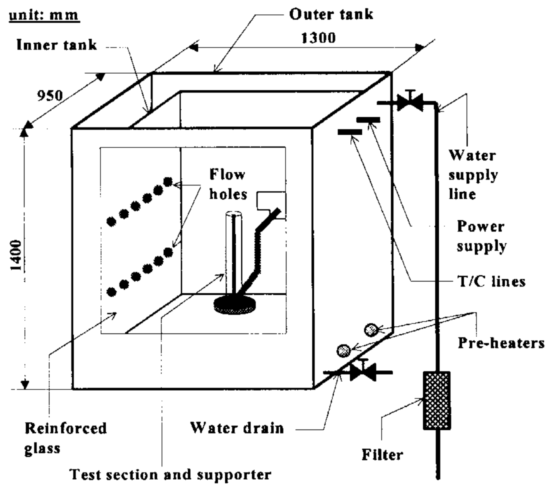


Figure 1. Schematic of the experimental apparatus.

## 3. Results and Discussion

Figure 2 shows variations in heat transfer as the length of the outer tube changes. Experimental data for $L_o$=0.2, 0.4, and 0.6 m are shown in the figure and are compared with the single unrestricted tube (i.e., $L_o$=0.0 m). At $q'' \leq$ 60 kW/m², changes in $\Delta T_{sat}$ for the annulus are different from the single unrestricted tube. For the annulus, the heat flux is almost a linear function of the superheat and increases gradually as the wall superheat increases from 2 K to 6 K. For the single tube a steeper curve slope of $q''$ versus $\Delta T_{sat}$ is observed and small changes in $\Delta T_{sat}$ result in much changes in $q''$. As the length of the outer tube gets shorten the slope of $q''$ versus $\Delta T_{sat}$ curve approaches to the single tube at $q'' > 60$ kW/m². As $L_o$ >0.2 m the slopes of $q''$ versus $\Delta T_{sat}$ curves are smooth and the slope of $h_b$ versus $q''$ curves are deteriorated. At $q'' > 60$ kW/m² the gradients of $h_b$ versus $q''$ curves for $L_o$ =0.4, and 0.6 m get decreased and at $q'' \geq 70$ kW/m² $h_b$ for the annulus is less than the single tube. At $q''$ < 70 kW/m² heat transfer coefficients for the annulus is higher than the single tube. The major mechanisms affecting on the heat transfer changes from liquid agitation to bubble coalescence for the annulus [4]. At lower heat fluxes less than 60 kW/m² active liquid agitation in the annular space increases heat transfer. As the heat flux increases the incoming liquid interrupts bubbles escaping through the exit. Therefore, bubbles are coalescing in the space. However, as the outer tube length gets shorten (for the present $L_o$ =0.2 m) active bubble coalescence is not observed and the heat transfer coefficient is not deteriorated. Therefore, the heat transfer coefficients for the annulus with $L_o$ =0.2 m is larger than the single tube because of active liquid agitation at $q'' \leq$ 60 kW/m and the slope of $h_b$ versus $q''$ is still maintaining at higher heat fluxes because active bubble coalescence is not observed.

### 4. Conclusions

To identify effects of the outer tube length on pool boiling heat transfer in a vertical annulus (gap size=6.35 mm) with closed bottoms, a heated tube of 19.1 mm diameter and water at atmospheric pressure has been studied experimentally. The change in the length results in much variation in heat transfer coefficients. As the length is 0.2 m a deterioration in heat transfer at higher heat fluxes is not observed while the coefficients is still much higher than the unrestricted single tube at lower heat fluxes. Therefore, the annulus with closed bottoms and a short outer tube length could be recommended as a very useful way to improve pool boiling heat transfer.

### REFERENCES


[1] M. H. Chun, M. G. Kang, Effects of heat exchanger tube parameters on nucleate pool boiling heat transfer, ASME J. Heat Transfer 120 (1998) 468-476.

[2] S. C. Yao, Y. Chang, Pool boiling heat transfer in a confined space, Int. J. Heat Mass Transfer 26 (1983) 841-848.

[3] Y. H. Hung, S. C. Yao, Pool boiling heat transfer in narrow horizontal annular crevices, ASME J. Heat Transfer 107 (1985) 656-662.

[4] M.G. Kang, Pool boiling heat transfer in vertical annular crevices, Int. J. Heat Mass Transfer 45 (15) (2002) 3245-3249.

[5] M.G. Kang, Y.H. Han, Effects of annular crevices on pool boiling heat transfer, Nuclear Engineering and Design 213(2-3) (2002) 259-271.


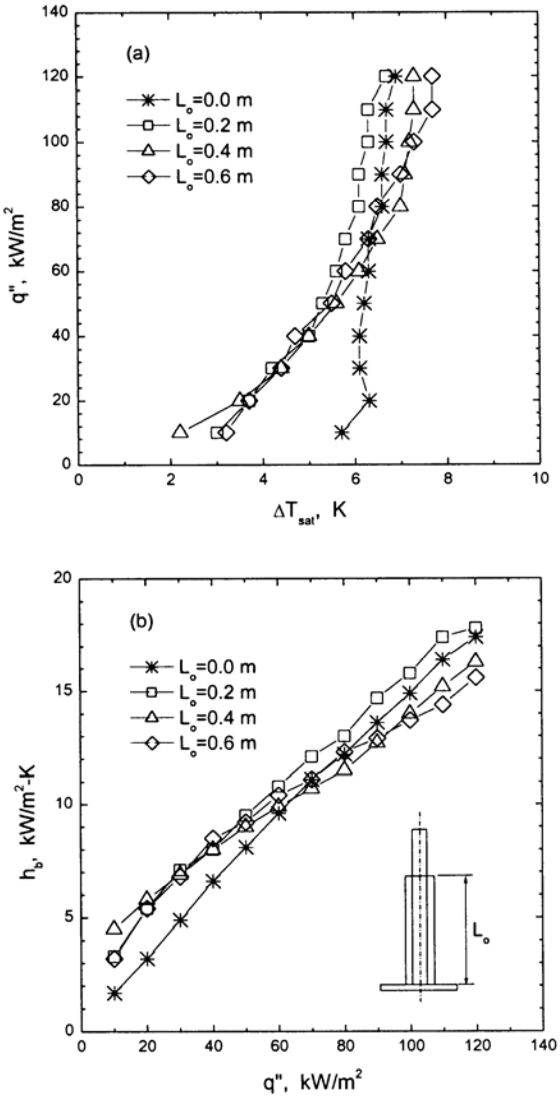


Figure 2. Plots of experimental data as $L_o$ changes.