Effects of the Inclination Angle on Pool Boiling Heat Transfer in an Annulus

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1. Introduction

The mechanism of pool boiling heat transfer has been studied for a long time since it is closely related with the design of more efficient heat exchangers and heat removal systems [1]. Through the review on the published results it can be concluded that one of the efficient ways to increase the heat transfer rate can be suggested to utilize the inclination angle (θ) of the heated surface.

Stralen and Sluyter [2] performed a test to find out boiling curves for platinum wires in the horizontal and vertical position at atmospheric pressure. They concluded that the horizontal type was more effective than the vertical type. Githinji and Sabersky [3] changed the orientation from horizontally facing upward, to vertical, and to horizontally facing downward.

Nishikawa et al. [4] studied heat flux (q'') and wall superheat (ΔT_{sat}) on a flat plate oriented at an angle, that varied from a horizontal, upward-facing position to the near-vertical position in the water. One year later, Lienhard [5] explained the loss of orientation dependence at higher heat fluxes using the Moissis-Rerenson transition. Jung et al. [6] performed some experiments for inclined plates and R-11. Fujita et al. [7] studied the combined effects of inclination angle and gap size between two plates. El-Genk and Bostanci [9] studied effects of the inclination angle of a copper specimen shaped as a plate on pool boiling of HFE-7100 for application to the design of an electric chip.

Although many authors have studied effects of the inclination angle, no detailed studies have been performed for a tube until Chun and Kang [1]. Kang [10] carried out an experimental parametric study of a tubular heat exchanger to determine effects of the tube inclination angle on pool boiling heat transfer. Some more detailed study has performed by Kang [11] considering different tube diameters and inclination angles.

As Cornwell and Houston [12] suggested nucleate boiling on a tube differs considerably from that on a flat plate. The same is true for the wire. One of the important parameters in pool boiling is the gap size. As Fujita et al. [7] already observed the gap size can differentiate the tendency of heat transfer on an inclined surface. Therefore, the annular space in combination with the inclination angle can be a good design parameter to be investigated. Up to the author's knowledge, no previous results concerning to this effect have been published yet except the author's preliminary study [13]. As such, the present study is aimed at the determination of effects of the tube inclination angle on pool boiling heat transfer (1) to identify the combined effects of an annulus and (2) to investigate the potential areas for improvement of the thermal design of the heat exchangers.

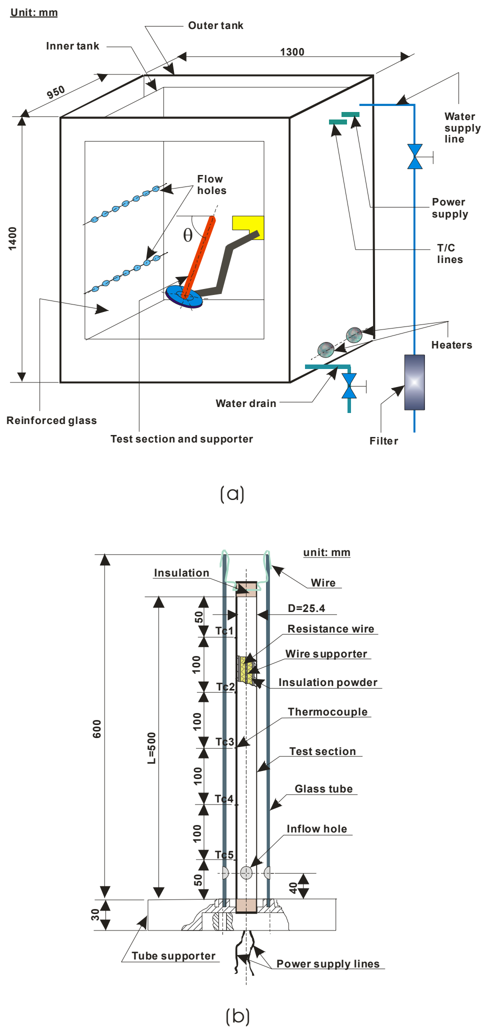

Fig. 1. Schematics of the experimental apparatus.

2. Experiments and Results

A schematic view of the present experimental apparatus and a test section is shown in Fig. 1. Four auxiliary heaters were installed at the space between the inside and 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). 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). 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, s =15 mm) of 55.4 mm inner diameter and 600 mm length were situated around the heated tube. 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 uncertainties of the experimental data are calculated from the law of error propagation. The uncertainty of the heat flux and the measured temperature are estimated to be ± 6% and ±0.11 °C, respectively.

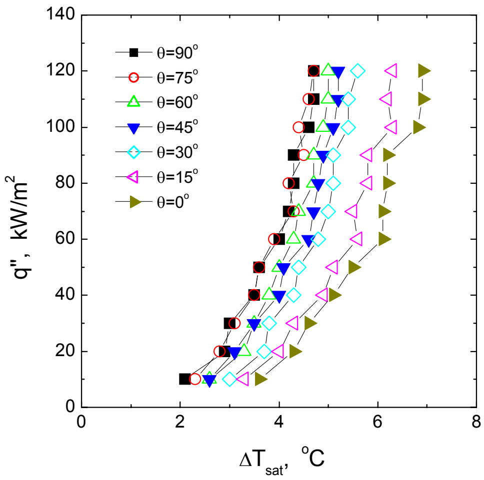

Fig. 2. Curves of the experimental data.

Figure 2 shows plots of q'' versus ΔT_{sat} data obtained from the experiments. In the figure the inclination angle θ denotes inclination from the horizontal. The inclination of the heated tube changes heat transfer characteristics. As the inclination angle increases the tube wall superheat decreases for the given heat flux. The change of θ from 0° to 90° results in 34.4% (from 6.1 to 4.0°C) decrease of ΔT_{sat} as the heat flux is 60kW/m².

The major cause for the tendency is considered as the difference in the intensity of liquid agitation. In nature, bubbles detached from the heated surface flows up to the free surface of water due to the buoyancy of the bubbles. For the vertical tube (i.e., θ =90º) bubbles generated at the bottom side of the tube length moves up along the tube surface. During the movement bubbles coalesce with the other bubbles. Thereafter, big size bubbles have been developed and, then, these result in active liquid agitation around the heated tube. For the annulus the bubbles detached from the heated surface do not move up to the free surface of water because the outer glass tube prevents the departure of bubbles from the annular space. The coalesced bubbles move up along the annulus space, and generate active liquid agitation around the tube surface. The intensity of the liquid agitation gradually increases as the inclination angle increases.

3. Conclusions

An experimental study has been carried out to identify effects of the inclination angle on pool boiling heat transfer. The inclination angle results in much change in heat transfer. The causes for the tendencies can be explained as the difference in the intensity of liquid agitation due to the enclosure by the outer tube.

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