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Pool Boiling Heat Transfer on the Inside Surface of an Inclined Tube

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1. Introduction

Pool boiling is closely related with the design of passive type heat exchangers, which have been investigated in nuclear power plants to achieve safety functions in case of no power supply [1]. Since the space for the installation of a heat exchanger is usually limited, developing more efficient heat exchangers is important. Several researchers have published results for the pool boiling on the outside surface [2-4].

Jung et al. [5] experimented boiling heat transfer in R-11 to investigate heat transfer mechanisms on the inside surface of a circular cylindrical tank. They simulated the surface by a flat plate. Somewhat detailed study on the inclination angle itself was previously done by Nishikawa et al. [6] by using the combination of a plate and water.

Jabardo and Filho [7] performed an experimental study of forced convective boiling of refrigerants in a 12.7 mm internal diameter tube to investigate effects of physical parameters over the variations in local surface temperature. However, mechanisms of pool boiling are much different from those of the forced convective boiling.

Kang[8] investigated pool boiling heat transfer of water on the inside surface of a horizontal tube at atmospheric pressure. Experiments were performed at four different azimuthal angles to investigate variations in local heat transfer coefficients along the tube periphery. The local coefficient changes much along the tube periphery and the minimum was observed at the tube bottom.

Summarizing the previous works, it is identified that the study for pool boiling heat transfer on the inside surface of a tube is very rare. Therefore, the present study is aimed at the determination of heat transfer characteristics on the inside surface of a tube while changing the inclination angle.

2. Experiments

For the tests, the assembled test section (Fig. 1) was located in a water tank which has a rectangular cross section (950×1300 mm) and a height of 1400 mm. The heat exchanging tube is a resistance heater made of a very smooth stainless steel tube. The inclination angle was regulated by rotating the assembled test section.

Several rows of resistance wires are arrayed uniformly around the outside surface of the heated tube (L =400 mm and D_i =16.2 mm). Then, the heating wires were covered with insulating material. The test section and the supporter were assembled with bolts.

Surface temperatures were measured with four T-type sheathed thermocouples (diameter is 1.6 mm). They were placed in holes made in wall thickness of the tube. The temperatures of the inside tube surface were calculated by the one dimensional conduction equation. The water temperatures were measured with six sheathed T-type thermocouples that placed vertically at a corner of the inside tank. All thermocouples were 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 were used. The temperatures of the tube surfaces were measured when they were at steady state while controlling the heat flux with input power.

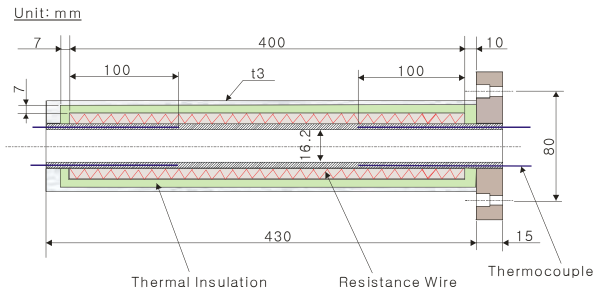

Fig. 1. Schematic diagram of the assembled test section.

The uncertainties of the experimental data were calculated from the law of error propagation [9]. The 95 percent confidence uncertainty of the measured temperature has the value of ±0.11 °C. The uncertainty of the heat flux is estimated to be ± 0.7%. After calculation and taking the mean of the uncertainties of the propagation errors the uncertainty of the heat transfer coefficient (h_b) can be decided as ± 6%.

3. Results

Figure 2 shows variations in heat transfer as the inclination angle increases from 15° to 90°. The general tendencies of q'' versus ΔT_{sat} curves are different from the results for pool boiling on the outside tube surface [10]. The curves have banana shape curvatures. The generated bubbles on the outside tube surface grow and depart from the surface after some movement along the surface. However, for the case, because of the tube the bubbles are restricted and flow along the inside space of the tube. Then the bubbles generate active liquid agitation and enhance heat transfer. Results for $30° \leq \theta \leq 90°$ are almost same. The result for θ=15° is different from the results for the other inclination angles. As the inclination angle decreases and becomes to be horizontal the buoyancy of bubbles gets decreasing. This results in the decrease in the intensity of liquid agitation. For example, ΔT_{sat} increases 12.6% (from 12.8 to 14.3ºC) when θ is decreased from 90° to 15° at q'' =60 kW/m^2.

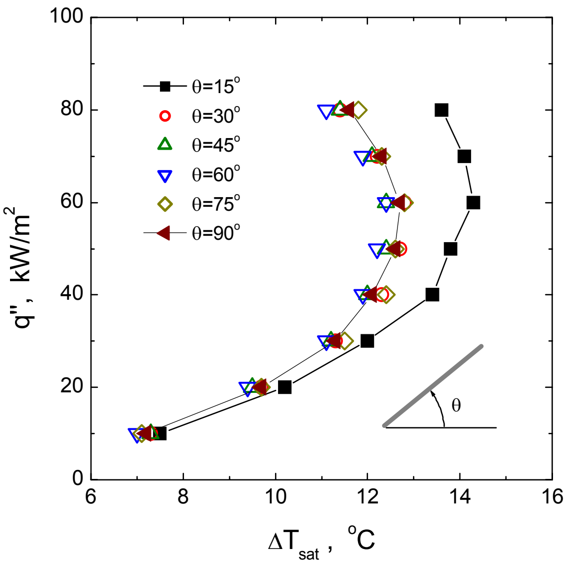

Fig. 2. Plots of q'' versus ΔT_{sat} .

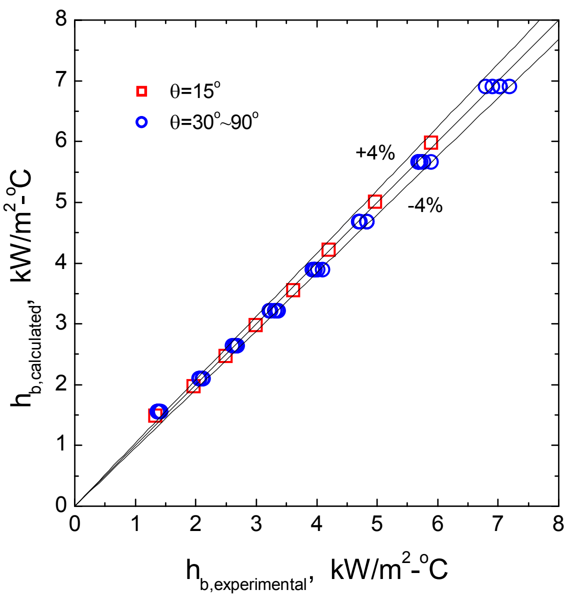

Fig. 3. Comparison of calculated values with experiments.

The heat transfer coefficients can be correlated as $h_b = 1/(A + B\ln q'')$. The dimensions for h_b and q'' are kW/m²-ºC and kW/m², respectively. The empirical constants A and B are listed in Table 1. Since the heat transfer coefficients are almost same for the inclination angles except θ=15° two different sets of parametric values are suggested. The developed correlation can predict the measured experimental data within ±4% error bound as shown in Fig. 3.

Table 1. Values of empirical constants

θ	A	B
15°	1.232	-0.243
30°~90°	1.192	-0.239

4. Conclusions

Changes in pool boiling heat transfer coefficients on the inside surface of a 16.2 mm internal diameter has been studied experimentally at atmospheric pressure. Experiments were performed at six different inclination angles to investigate variations in the heat transfer coefficients due to the inclination angle change. Results for $30° \leq \theta \leq 90°$ are almost same whereas the result for θ=15° is different from the other angles. To predict the heat transfer coefficients an empirical correlation has been developed as $h_b = 1/(A + B\ln q'')$. The developed correlation can predict the measured experimental data within ±4% error bound.

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