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Subcooled Pool Boiling on 3-Degree Inclined Tube Surface

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1. Introduction

Mechanisms of pool boiling heat transfer have been studied for a long time. Recently, it has been widely investigated in nuclear power plants for the purpose of acquiring inherent safety functions in case of no power supply [1]. To design more efficient heat exchangers, effects of several parameters on heat transfer must be studied in detail. One of the major issues is the variation in the local heat transfer coefficients on a tube.

Lance and Myers [2] reported that the type of boiling liquid can change the trend of local heat transfer coefficients along the tube periphery. Lance and Myers said that as the liquid is methanol the maximum local heat transfer coefficient was observed at the tube bottom while the maximum was at the tube sides as the boiling liquid was n-hexane. Cornwell and Einarsson [3] reported that the maximum local heat transfer coefficient was observed at the tube bottom, as the boiling liquid was R113. Cornwell and Houston [4] explained the reason of the difference in local heat transfer coefficients along the tube circumference with introducing effects of sliding bubbles on heat transfer.

According to Gupta et al. [5], the maximum and the minimum local heat transfer coefficients were observed at the bottom and top regions of the tube circumference, respectively, using a tube bundle and water. Kang [6] also reported the similar results using a single horizontal tube and water [6]. However, the maximum heat transfer coefficient was observed at the angle of 45 deg. Sateesh et al. [7] investigated variations in local heat transfer coefficients along a tube periphery as the inclination angle was changed.

Summarizing the published results, some parts are still remaining to be investigated in detail. Although pool boiling analysis on a nearly horizontal tube is necessary for the design of the advanced power reactor plus [8], no previous results are published yet. Therefore, the present study is aimed to study variations in the characteristics of pool boiling heat transfer for a 3-degree inclined tube submerged in subcooled or saturated water.

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 azimuthal angle (θ) was regulated by rotating the flange. The local values were determined at every 45 deg from the very bottom to the uppermost of the tube periphery.

The tube outside was instrumented with five T-type sheathed thermocouples. The thermocouple was brazed on the tube wall. The water temperatures (T_{wat}) 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 were done at atmospheric pressure). To measure and/or control the supplied voltage and current, power supply systems were used.

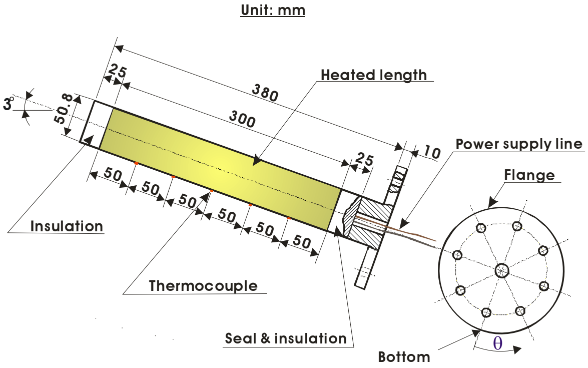

Fig. 1. Schematic diagram of the test section.

The temperatures of the tube surfaces (T_s) were measured when they were at steady state while controlling the heat flux on the tube surface with input power. 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 (q'') 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

The heat transfer coefficient is calculated by $h_b = q''/\Delta T_{tot}$. The ΔT_{tot} is determined as $T_s - T_{wat}$ and can be rewritten as $\Delta T_{sat} + \Delta T_{sub}$. The values of ΔT_{sat} and ΔT_{sub} represent the conditions of the tube surface and the water, respectively. The increase in ΔT_{sat} enhances the generation of bubbles whereas the increase in ΔT_{sub} suppresses the generation of bubbles.

Figure 2 shows the relation between the heat transfer coefficients and the temperature differences (ΔT). ΔT represents ΔT_{tot} , ΔT_{sat} , and ΔT_{sub} . For the given heat flux the decreases in ΔT_{tot} and ΔT_{sub} result in the increase in h_b . As the heat transfer coefficient is nearby 2kW/m^2°C a slight increase in h_b results in a sudden increase in ΔT_{sat} . When the heat transfer coefficient gets increasing more than 2kW/m^2°C ΔT_{sat} decreases slightly and converges to 10°C.

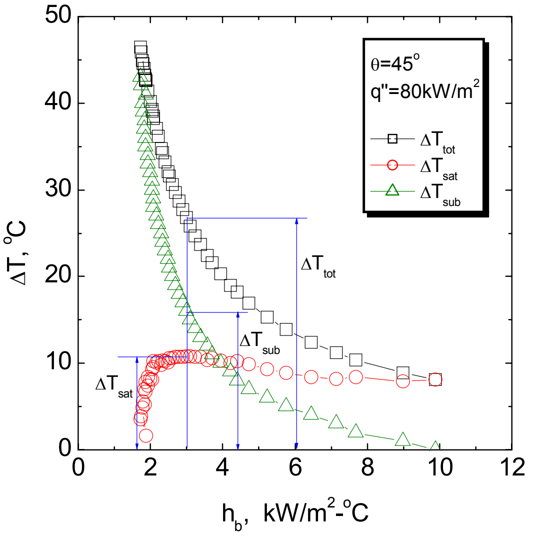

Fig. 2. Plots of ΔT versus h_b .

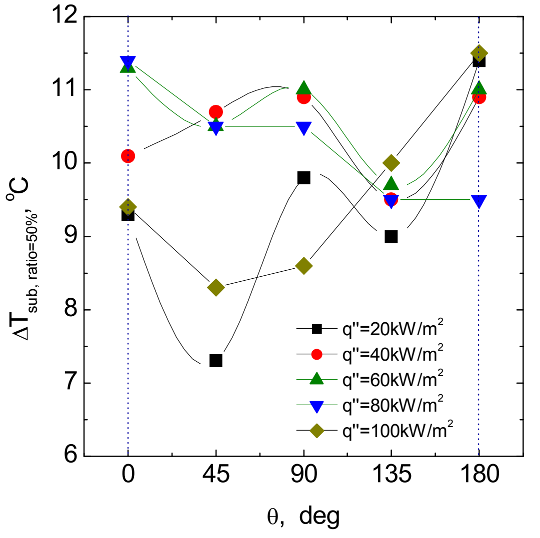

Fig. 3. Plots of $\Delta T_{sub,ratio=50\%}$ versus θ .

At the regions of high ΔT_{sub} and low h_b the major heat transfer mechanism changes from the natural convection to the latent heat due to phase change. As the degree of ΔT_{sub} is decreasing the effects of bubble movement and coalescence on heat transfer becomes dominant. When the heat transfer coefficient is 3kW/m^2°C, the ratio of $\Delta T_{sat} / \Delta T_{tot}$ is 40.6%. Since the gradual increase in h_b results in the decrease in ΔT_{sub} , the portion of ΔT_{sat} gets increasing.

Figure 3 shows the variations in ΔT_{sub} for the ratio of $\Delta T_{sub} / \Delta T_{tot}$ is 50% as the heat flux and the azimuthal angle changes. Lots of changes are observed in ΔT_{sub} when the heat flux is the highest or the lowest for the azimuthal angle variation. As the azimuthal angle is 180° the value of ΔT_{sub} is the highest. Throughout the heat fluxes tested the value of ΔT_{sub} for $\Delta T_{sub} / \Delta T_{tot}$ is 50% ranges from 7.3 to 11.5°C. The average is 10.1°C. When the degree of ΔT_{sub} is lower than this value the generation of bubbles is enhanced and, as a result, the heat transfer coefficient gets increased.

4. Conclusions

Both effects of a tube wall superheat and a degree of liquid subcooling on pool boiling heat transfer have been studied experimentally. For the study, results for the combination of a smooth stainless tube and water at atmospheric pressure are analyzed. The increase in the superheat enhances the generation of bubbles whereas the increase in liquid subcooling suppresses the generation of bubbles. It is identified that the ratio of superheat over subcooling is dependent on the heat flux and the azimuthal angle.

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