Measurement and Prediction of the Average Heat Transfer Coefficient on a Tube

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

1. Introduction

Tubular heat exchangers have been widely accepted in pool boiling heat transfer. The detailed analyses on mechanisms of pool boiling become important in nuclear power plants for the purpose of acquiring inherent safety functions in case of no power supply [1, 2]. One of the major issues is to predict the average heat transfer coefficient along the periphery of a tube.

Previous studies on local heat transfer coefficients of the circular shape [3-12] are summarized in Table 1. Both pool and flow boiling are of concern in the various saturated liquids. Most results are for horizontal tubes of diameter ranging 7.6~51 mm. Only Sateesh et al. [12] studied variations in local heat transfer coefficients along the tube periphery while controlling the inclination angle.

The main result of the previous investigations is that there is a considerable difference among the local heat transfer coefficients along a tube periphery. This has been the major cause of the discrepancy among the results. It is very important to predict the exact heat transfer coefficient on a tube for the thermal design of tubular type heat exchangers. No results have been reported about the way to predict the average value on a tube except Kang [10] who suggested a method for the horizontal tube. The present study is aimed to find out a way of predicting the average heat transfer coefficient with considering the degree of subcooling and the inclination angle.

Author	Diameter	Liquid	Azimuthal angle, θ
Lance & Myers (1958)	31.75mm 50.8mm	Methanol n-hexane	0°~360°
Cornwell & Einarsson (1990)	27.1mm	R113	0°~360°
Gupta et al. (1995)	19.05mm	water	0°~360°
Luke & Golenflo (2000)	7.6mm 8mm	propane	0°~180°
Kang (2005)	51mm	water	0°~180°
Dominiczak & Clieslinski (2008)	8.15mm 13.52mm 23.60mm	water R141b	0°~360°
Sateesh et al. (2009)	21mm 26mm 33mm	water ethanol acetone	0°, 180°
Das (2010)	31.85mm	water methanol isopropanol	0°~270°

Table 1. Summary of the Previous Results

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 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).

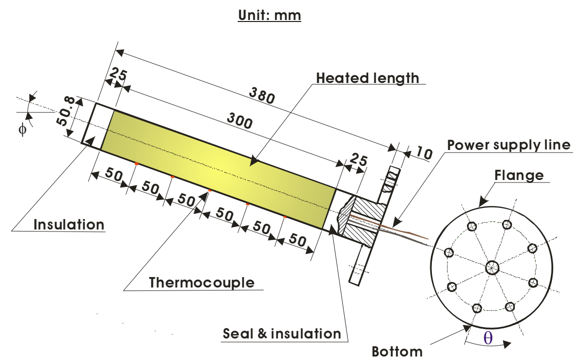

Fig. 1. Schematic diagram of the test section.

The uncertainties of the experimental data were calculated from the law of error propagation [13]. 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 are decided as ± 6%.

3. Results

Figure 2 shows the ratio of two heat transfer coefficients against the heat flux (q''). The average heat transfer coefficient ($h_{b,avg}$) was determined as the arithmetic average of the local values. In the figure $h_{b,\theta=90°}$ means the local heat transfer coefficient measured at θ=90°. Since Kang [10] suggested the local heat transfer coefficient measured at θ=90° to be the average heat transfer coefficient for a horizontal tube, similar approach was taken for the study. The local values measured at θ =90° for the different inclination angles (ϕ) are nearby the average heat transfer coefficient and the deviation from the average value is within ±5%. Therefore, the local heat transfer coefficient at θ=90° can be regarded as the average heat transfer coefficient for the near horizontal tubes.

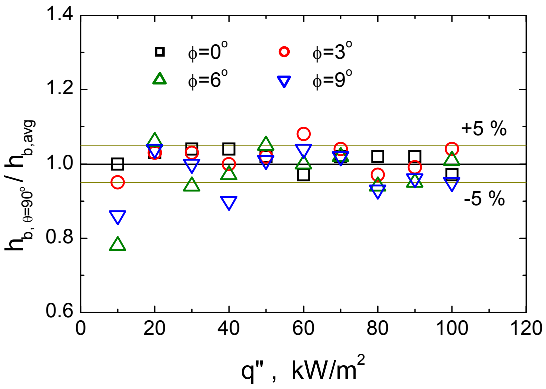

Fig. 2. Comparison of average heat transfer coefficients to local values at θ=90° as the water is saturated.

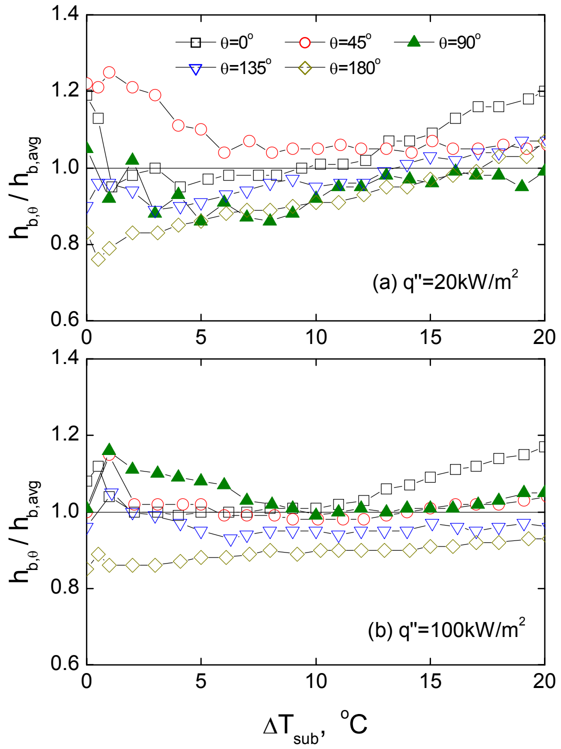

Fig. 3. Plots of $h_{b,\theta}$ against ΔT_{sub} for ϕ =3°.

Comparisons of the average heat transfer coefficient and the local heat transfer coefficients along the tube periphery against the degree of water subcooling (ΔT_{sub}) for ϕ=3° are shown in Fig. 2. When the liquid is subcooled the local heat transfer coefficient at θ=90° is different from the average heat transfer coefficient. The increase in the degree of subcooling decreases the intensity of liquid agitation. Moreover, the increase in heat flux increases bubble coalescence on the upper regions of the tube periphery. As a result, the local heat transfer coefficients at θ>90° become decreased and the location for the average heat transfer moves lower regions of the tube (i.e., θ=45°).

4. Conclusions

The average heat transfer coefficient was observed at θ=90° in the saturated water regardless of the tube inclination angle. However, as the water was subcooled the location for the average heat transfer coefficient moves to the lower region of the tube.

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