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Numerical Study of Condensation Heat Exchanger Design in a Cooling jacket: Correlation Investigation

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1. Introduction

Lee *et al.* [1,2] reported the improved Shah correlation [3] gave us the best predictor for the condensation heat transfer data of Kim and Henderson in a subcooled and saturated water pool. They suggested the improved Shah correlation should be adopted as condensation heat transfer module in TSCON(Thermal Sizing of CONdenser) to design condensation heat exchanger in secondary passive cooling system of nuclear plant.

In this study, condensing heat transfer correlation of TSCON is evaluated with the existing experimental data set to design condensation heat exchanger without noncondensable gas effect (pure steam condensation) in a cooling jacket.

2. Numerical study

2.1 TSCON program

TSCON solves one-dimensional steady continuity, momentum and energy equations together by nodalizing a pipe. After assuming initial local heat load, condensation part of the pipe length and mass flow rate are decided. Total pressure is assumed to be constant through the pipe. Inner wall temperature of the pipe at each node is calculated by the given condensation heat transfer coefficient. Outer wall temperature of the pipe is calculated by one dimensional pipe conduction equation. Calculated pipe length by the outside pool boiling heat transfer coefficient is compared to the original. If it was not same, the inner wall temperature would be iterated. The original heat load up to satisfy overall heat transfer rate is also iterated. Then, the same procedure applies to single phase part of the pipe. Inside the pipe heat transfer coefficient, the existing condensation correlation, discussed in next subsection, is used for condensation section and the Dittus-Boelter for single phase. Outside the pipe, the heat transfer coefficient from experimental data was used.

2.2 Existing condensation correlations

Shah [3] reviewed the existing condensation heat transfer correlation. Since most correlations proposed for horizontal tubes, none of well-validated correlations for vertical tubes was found. Shah's correlation (1979) was stated to be only vertical tubes. Gravitational liquid film effect cannot be negligible, so that a condensation correlation in a vertical tube is appropriate to be selected. However, five existing condensation correlations were chosen to validate TSCON: Akers (1959), Traviss (1973), Shah (1979), Blangetti (1982), Kim (2000) and the improved Shah correlation (2009) [3].

2.3 Experimental data

From the decade, there have been a number of papers that study condensation heat exchanger design. Cooling jacket with a large number of experimental data exist from heat sink. Recently, Khun [4] and Lee [5] study condensation heat transfer characteristics when pure steam condensation. To investigate the existing condensation correlations in TSCON, the experimental data obtained at condensation heat exchanger in a cooling jacket is needed. We collected 315 and 408 experimental data points of Khun [4] for laminar and turbulent film condensation, respectively. In addition, 71 experimental data of Lee [5] was used to select the best accurate condensation correlation for TSCON. Table I shows experimental conditions of the collected data.

3. Results

Figures 1 and 2 are the prediction of the correlations of condensation heat transfer coefficient with the experimental data of Khun [4] for laminar and turbulent liquid film condensation. Blangetti and the improved Shah's correlations tend to under-predict condensation heat transfer for laminar liquid film with 17.5% and 14.5% error, respectively. Similarly, the prediction trend is similar to the turbulent liquid film condensation with 33.1% and 35.4% error, respectively. In case of Blangetti's correlation, some of experimental data have included the prediction results of single phase heat transfer, so that the error of condensation heat transfer only is much greater than current error. Moreover, Blangetti's correlation cannot predict the experimental data for the condition of interfacial shear stress more than 40. As a result, the improved Shah's correlation

Table I: Experimental conditions of Khun [4] and Lee [5]

	System Pressure (MPa)	Steam mass flow rate (kg/s)	Pipe I.D./O.D (mm)	Pipe length (m)
Khun [4]	0.1 ~ 0.5	0.0078 ~ 0.054	47.5/50.8	2.4
Lee [5]	0.1 ~ 0.11	0.0018 ~ 0.00784	13/18	2.8

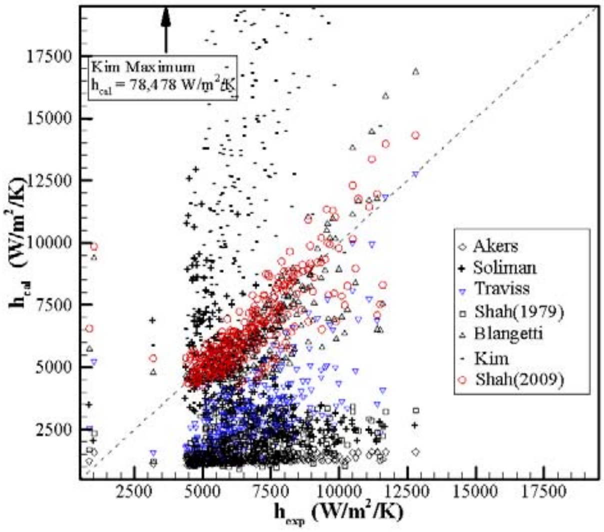

Fig. 1. The prediction of the correlations of condensation heat transfer coefficient with the experimental data of Khun(Laminar)

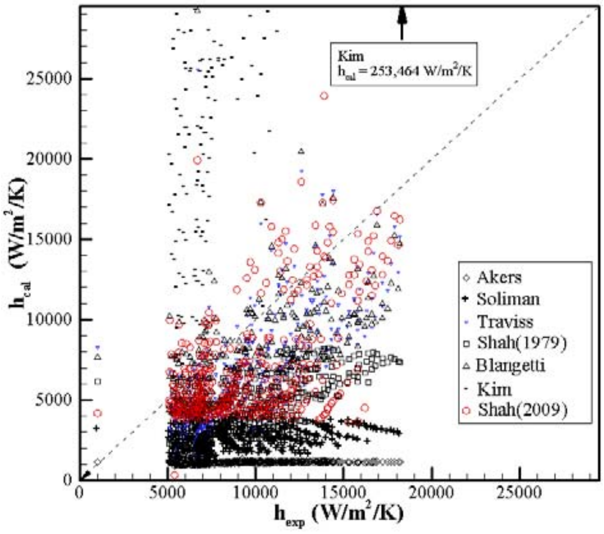

Fig. 2. The prediction of the correlations of condensation heat transfer coefficient with the experimental data of Khun(Turbulent)

gives the best prediction of the condensation heat transfer coefficient with experimental data of Khun with overall 26.2% error.

Figure 3 show the prediction of the correlations of condensation heat transfer coefficient with the experimental data of Lee [5]. Shah's correlation gives the best prediction of the condensation heat transfer with 43.9% error. Blangetti's correlation cannot apply to Lee's experimental data due to the limitation of the interfacial shear stress.

4. Conclusions

From the investigation of the existing condensation heat transfer correlation to the existing experimental data, the improved Shah's correlation showed most satisfactory result for the condensation heat transfer

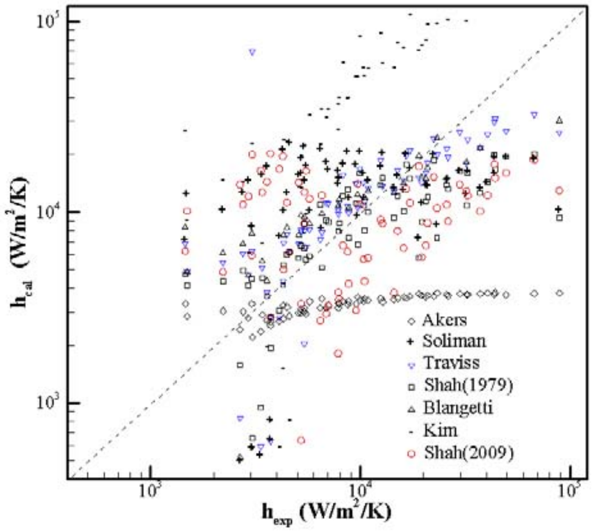

Fig. 3. The prediction of the correlations of condensation heat transfer coefficient with the experimental data of Lee

Table II: Mean average error (MAE) (%) of condensation heat transfer coefficient experimental data compared with the existing correlations (cooling jacket)

Correlation	Khun (Laminar)	Khun (Turbulent)	Lee
Akers	79.7%	87.2%	63%
Soliman	50.3%	69.5%	133%
Travss	55.8%	39.5%	80.3%
Shah	70.8%	58.3%	43.9%
Blangetti	17.5%	33.1%	-
Kim	158.7%	421.5%	367.1%
Shah (2009)	14.5%	35.4%	121.4%

coefficient with experimental data of Khun [4] in a cooling jacket, whereas the Shah's correlation with experimental data of Lee [5].

REFERENCES

[1] H. J. Lee and T. –H. Lee, Numerical Study of Condensation Heat Exchanger Design in a Saturated Pool: Correlation Investigation, Proceedings of the Korean Nuclear Society Autumn Meeting, Oct.26-28, 2011, Gyeongju, Korea.

[2] H. J. Lee, Y. J. Ju, H. –O. Kang, T. –H. Lee and C. –T Park, Numerical Study of Condensation Heat Exchanger Design in a Subcooled Pool: Correlation Investigation, Proceedings of the Korean Nuclear Society Spring Meeting, May.16-18, 2012, Jeju, Korea.

[3] M. M. Shah, An Improved and Extended General Correlationfor Heat Transfer During Condensation in Plain Tubes, HVAC&R RESEARCH, Vol.15, p.889, 2009.

[4] S. Z. Khun, Investigation of Heat Transfer from Condensation Steam-gas Mixtures and Turbulent Film Flowing Downward inside a Vertical Tube, Ph.D. Dissertation, University of California, Berkeley, 1995.

[5] K. –Y. Lee, The Effects of Noncondensable Gas on Steam Condensation in a Vertical Tube of Passive Residual Heat Removal System, Ph.D. Dissertation, Pohang University of Science and Technology, 2008.