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Numerical Study of Condensation Heat Exchanger Design in a Saturated Pool: Correlation Investigation

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1. Introduction

Generally the condensation heat exchanger has higher heat transfer coefficient compared to the single-phase heat exchanger, so has been widely applied to the cooling systems of fissile power plant. Recently vertical or horizontal type condensation heat exchangers are being studied for the application to secondary passive cooling system of nuclear plants.

To design vertical condensation heat exchanger in a saturated water pool, a thermal sizing program of condensation heat exchanger, TSCON(Thermal Sizing of CONdenser) was developed. 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).

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 Rohsenow (1952) pool boiling correlation [1] and natural convection correlation are adopted for saturated and single phase pool, respectively.

2.2 Existing condensation correlations

Shah [2] 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) and the improved Shah correlation (2009) [2].

2.3 Experimental data

From the decade, there have been a number of papers that study condensation heat exchanger design. Henderson *et. al.* [3] reviewed that most of these researches use forced convection for the heat removal with the presence of noncondensable gas. To investigate the existing condensation correlations in TSCON, the experimental data obtained at condensation heat exchanger without the presence of noncondensable gas in a saturated pool is needed. Currently, two data sets are only available: Henderson *et. al.* [3]. and Kim [4]. Henderson et. al. [3] provided 20 data points of local condensation heat transfer coefficient. Kim [4] provided 984 data points in Appendix B of the dissertation, but 63 data points are only appropriate to evaluate TSCON. Table I shows experimental conditions of the collected data.

3. Results

Figure 1 shows the prediction of the correlations of condensation heat transfer coefficient with the experimental data of Henderson *et. al.* [3]. Traviss' correlation is the best prediction of condensation heat transfer with 26% MAE(Mean Average Error).

Figures 2 and 3 are the prediction of the correlations of condensation heat transfer coefficient and condensation mass flow rate with the experimental data

Table I: Experimental conditions of Henderson *et. al.* [3] and Kim [4]

	System Pressure (MPa)	Steam mass flow rate (kg/s)	Pipe I.D./O.D (mm)	Pipe length (m)
Henderson [3]	0.225, 0.274	0.05	52.6/60.5	1.8
Kim [4]	1.071 ~ 7.155	0.0287 ~ 0.0891	46.2/50.8	1.8

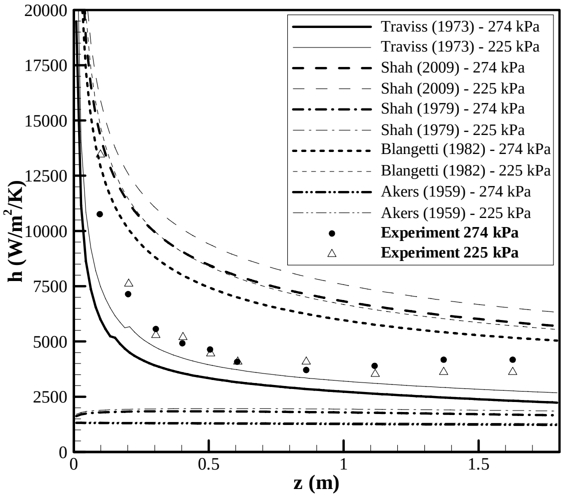

Fig. 1. The prediction of the correlations of condensation heat transfer coefficient with the experimental data of Henderson et. al. [3]

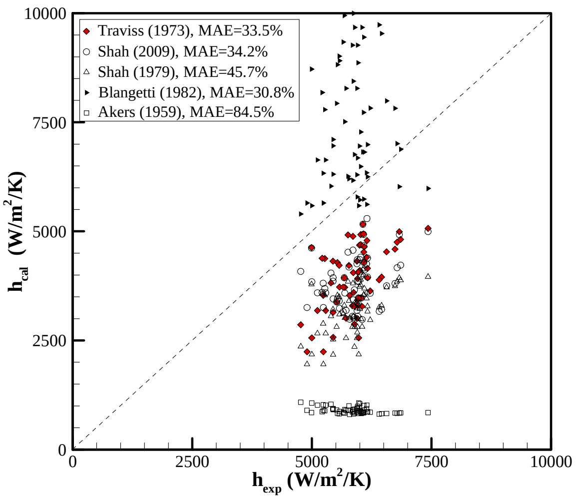

Fig. 2. The prediction of the correlations of condensation heat transfer coefficient with the experimental data of Kim [4]

of Kim [4], respectively. It appears that Traviss (1973), Blangetti (1982), and the improved Shah correlation (2009) can predict the condensation heat transfer within 35% MAE adequately in Fig. 2. However, Blangetti and the improved Shah's correlations show nonphysical heat transfer distribution in the vertical pipe. Therefore, these correlations cannot predict condensation mass flow rate well in Fig. 3. From the examination, it is found that Traviss' correlation is the best prediction for both condensation heat transfer and mass flow rate with 33.5% and 14.4% MAE, respectively.

Table II indicates MAE of condensation mass flow rate experimental data compared with the existing correlations. The improved Shah's correlation gives the best prediction of the condensation mass flow rate experimental data of Henderson *et. al.* [3]. However, it overpredicts the experimental condensation heat transfer in Fig. 1. Traviss' correlation predicts the condensation heat transfer well, but not condensation mass flow rate. The condensation mass flow rate errors from Traviss' correlation may come from the horizontal

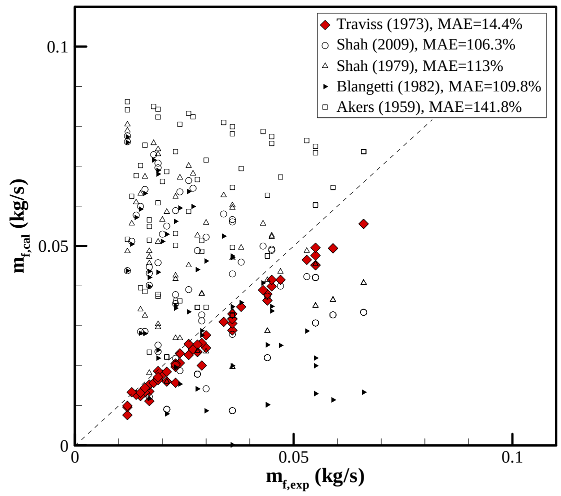

Fig. 3. The prediction of the condensation mass flow rate with the experimental data of Kim [4]

Table II: Mean average error (%) of condensation mass flow rate experimental data compared with the existing correlations

	Akers (1959)	Traviss (1973)	Shah (1979)	Blangetti (1982)	Shah (2009)
Henderson [3]	78.7	62.8	73.3	49.9	**48.0**
Kim [4]	141.8	**14.4**	113.0	109.8	106.3

based correlation, which could not consider gravitational effect on the film condensation.

4. Conclusions

From the investigation of the existing condensation heat transfer correlation to the existing experimental data, Traviss' correlation showed most satisfactory results for the heat transfer coefficient and mass flow rate in a saturated water pool without the presence of noncondensable gas, although Traviss's correlation was developed based on the horizontal tube.

Since Shah's correlation was stated to be only vertical tubes, accurate condensation correlation for the vertical condensation tube is required to develop.

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