

Validation of Evaporation and Condensation Models in the Analysis Code for Reactor Building and Pool Cooling of Research Reactors

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1. Introduction

Evaluation of the cooling performance of the reactor building and pool during long term cooling in research reactors is needed since the radiological dose limits at the site boundaries are expected to be strengthened. Since the existing containment analysis code is compliant with the conditions of the nuclear power plant, a code that can be applied to the conditions of research reactor has been developed

The purpose of this paper is to validate the pool evaporation and wall condensation models implemented in the developed code.

2. Validation of Pool Evaporation

2.1 Database of Evaporation Experiment

Since the research reactor pool serves as a final heat sink, the temperature rises slowly and evaporation rate is very low. This phenomena is quite difference from the suppression pool in the nuclear power plant.

On the other hand, in the field of HVAC and civil engineering, a number of evaporation research have been carried out for the design of indoor swimming pool or cooling water pool in a power plant. The experiments performed in these studies are very similar to the phenomena for research reactor pool. Therefore, five experiments [1-5] in these field were selected as validation data for evaporation. The detailed condition of experiments are shown in Table 1. A total of 210 data were obtained from these experiments and they are shown in Fig. 1 as evaporation rate according to vapor pressure difference.

Table 1 Experimental Condition of Evaporation

Exp. name	Water temp.	Air temp.	Relative Humidity	Wind speed	# of data
Asdrubali [1]	20~30°C	22~32°C	50~70%	0m/s	30
Tibor[2]	19~70°C	19~50°C	20~60%	0~2.1 m/s	30
Boelter[3]	24~94°C	17~26°C	59~98%	0m/s	72
Jobat[4]	20~55°C	-	-	0.05~5m/s	42
Juan[5]	24~28°C	26~30°C	33~71%	0.08~0.55m/s	36

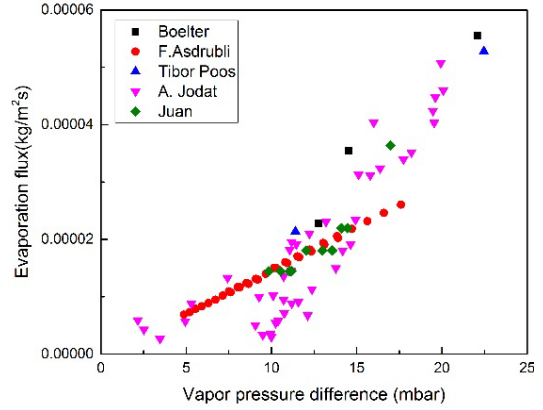


Fig. 1 Database of Evaporation Experiment

2.2 Validation Calculation

The evaporation prediction in the research reactor pool should be approached differently depending on the physical parameters related to the research reactor design. In terms of pool and core temperature, it is conservative approach to under-predict evaporation. But in terms of reactor building integrity and pool inventory, the over prediction is conservative. In order to meet this circumstance, four evaporation models were inserted in the developed code so that the user could use it according to the needs.

Two models (Eq. (1), (2)) are based on heat and mass transfer analogy and others (Eq. (3), (4)) are based on experiment using Dalton's equation.

$$\dot{m}_{evp} = K_{evp} A_p \frac{(W_{ip,v} - W_{b,v})}{1 - W_{ip,v}} \quad (1)$$

$$\dot{m}_{evp} = 35(\rho_{ip} - \rho_b)^{\frac{1}{3}} (W_{ip,v} - W_{b,v}) \quad (2)$$

$$q_{evp} = (6.9 + 0.49v^2)(e_s - e_a) \quad (3)$$

$$q_{evp} = (0.0887 + 0.07815v)(e_s - e_a) \quad (4)$$

Fig. 2 shows the comparison between the experimental data and the models implemented in the code. In the low evaporation region, all four models showed relatively accurate prediction performance. In the high evaporation region, heat and mass transfer analogy models tended to predict slightly higher, but generally show a similar trend to experimental results. In contrast, Dalton based correlations tended to predict lower than experimental results in overall region. Therefore, if the user uses the above option properly, it is confirmed that conservative

approach is possible depending on the parameters of pool water temperature, pool inventory, and reactor building pressure.

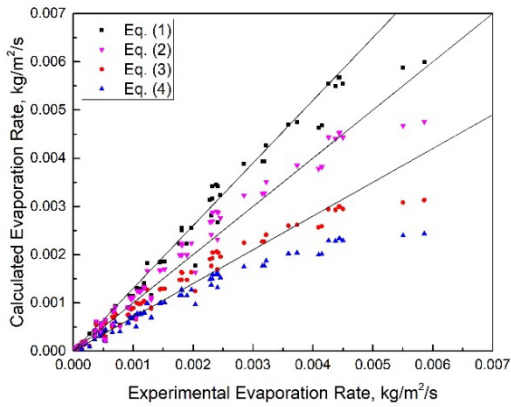


Fig. 2 Validation Results of Evaporation

3. Validation of Wall Condensation

3.1 Database of Condensation Experiment

Since the condensation on the containment wall is also critical issue in nuclear power plants, a number of research have been carried out. From the paper survey on wall condensation, eight condensation papers [6-13] were selected for validation calculation. The experimental conditions of these papers are shown in Table 2. The total numbers of 494 data were obtained from these experiments and they are shown in Fig. 3.

Table 2 Experimental Condition of Condensation

Exp. name	Pressure	Wall subcooling	Air mass fraction	# of data
Anderson	1~3bar	10~50K	0.37~0.88	72
Uchida	-	-	0.23~0.91	22
Su	2~6bar	13~69K	0.07~0.6	131
Lee	2~5bar	5~70K	0.1~0.8	43
Kataoka	1~1.5bar	-	0.5~0.9	37
Dehbi	1.5~4.5bar	9~47K	0.25~0.9	108
Liu	2.5~4.5bar	3~27K	0.18~0.71	26
Fan	2~5 bar	13~66K	0.2~0.7	146

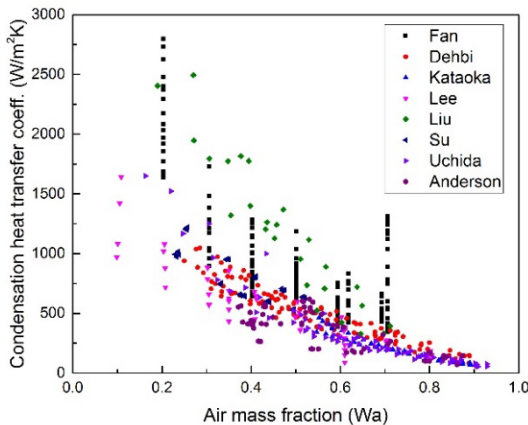


Fig. 3 Database of Condensation Experiment

3.2 Validation Calculation

Two condensation prediction models are inserted in the developed code. The first one is heat and mass transfer analogy (HMTA) model (Eq. (5)), the second one is Uchida model (Eq. (6)).

$$\dot{m}_{cond} = \frac{\ln(1+B)}{B} \cdot h_m \frac{W_{b,v} - W_{iw,v}}{1 - W_{iw,v}} \quad (5)$$

$$h_{cond} = 380 \left(\frac{W_s}{1 - W_s} \right)^{0.7} \quad (6)$$

Validation calculation results of entire region are shown in Fig. 4. The result depicted that both models predicted the condensation heat flux quite well in low condensation heat transfer region. However, in the high condensation heat flux region, both models tended to predict lower than the experimental results. Especially in this region, the Uchida model showed large error.

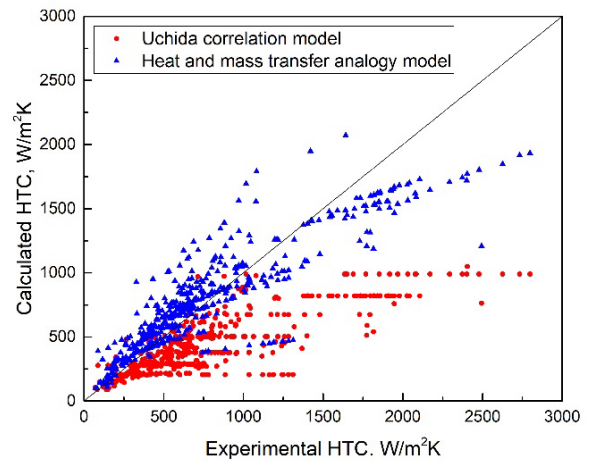


Fig. 4 Validation Results of Condensation

Fig. 5 shows only the comparison of the prediction and experimental data similar to the research reactor conditions in Fig.4. In this region, the HMTA model has good prediction performance because most of the calculation errors are within $\pm 30\%$. However, Uchida model showed the same tendency to predict lower than the experimental data. In particular, the errors are dramatically increased in the flat part of the graph, which is the data Obtained from different wall subcooling with other experimental variables fixed. This is because the Uchida model does not have a term to consider the effect of wall subcooling. All the take together, it is appropriate to use the HMTA model when an accurate prediction is needed. However, the Uchida model is recommended when a conservative approach is needed.

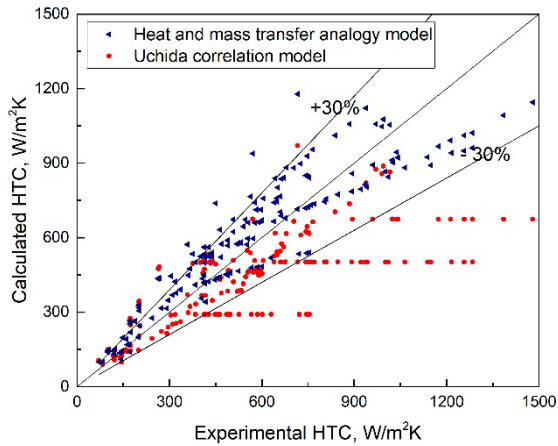


Fig. 5 Validation Results of Condensation in Low Condensation Region

4. Conclusions

In order to validate the analysis code for reactor building and pool cooling in research reactors, a series of comparisons between the models for evaporation and condensation and the experimental data has been carried out. From this study, it is concluded that:

- The heat and mass transfer analogy model predicts the evaporation and condensation very accurately.
- The Dalton model and the Uchida model based on the experiments predicts the evaporation and condensation lower than the experimental data.
- The various evaporation and condensation models in the developed code can be used by user's selection for conservative analysis.

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