MARS code Improvement of selection criteria on determining condensation heat transfer coefficient in vertical tube

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1. Introduction

Several experiments and theoretical researches have been performed to calculate condensation heat transfer and many correlations have been suggested. Generally, correlations are largely divided into two groups: applicable to laminar flow or turbulent flow. That is because, depending on whether flow is laminar or turbulent, flow characteristics and phenomena which play major role in heat transfer process are greatly different. Film Reynolds number is widely used to determine whether flow is laminar or turbulent.

As shown in Fig.1, MARS code uses two condensation heat transfer coefficient(HTC) correlations: Nusselt's correlation for laminar flow and Shah's for turbulent. Condensation HTCs are calculated by using both correlations and the larger one is taken, that is, Film Reynolds number is not used to determine flow condition and select HTC correlation. This means that a correlation may be able to be incorrectly used just because its HTC is larger, though a correlation is not in an applicable range.

In this paper, simulation results of two condensation experiments using MARS code are discussed. It is shown that, though flow condition is similar, different correlation can be used and how much calculated results are differentiated from experimental data.

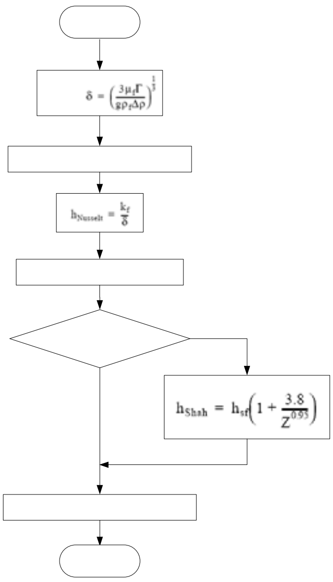

Fig. 1. Schematic procedure of calculating condensation heat transfer coefficient

2. Condensation Experiments Simulation Using MARS code with original criteria

Two condensation experiments have been simulated by using MARS code : Lee's condensation experiment[1] and Park's[2]. Except condensing tube diameter, both experiments are similar. A schematic of the experimental apparatus is shown in Fig 2. The steam/nitrogen mixture injected into top of the condensing tube is cooled down by cooling water which flows upward outside of the condensing tube. Fig. 3 shows the MARS code nodalization of condensation experiments.

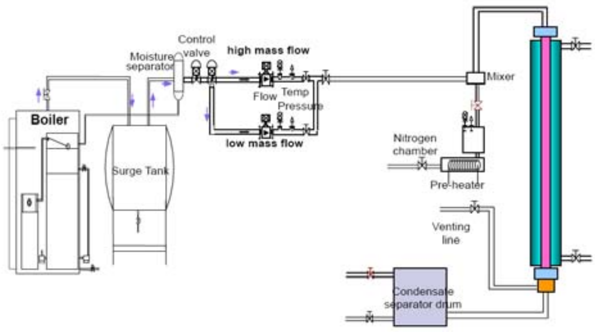

Fig. 2. Schematic diagram of the experimental apparatus.

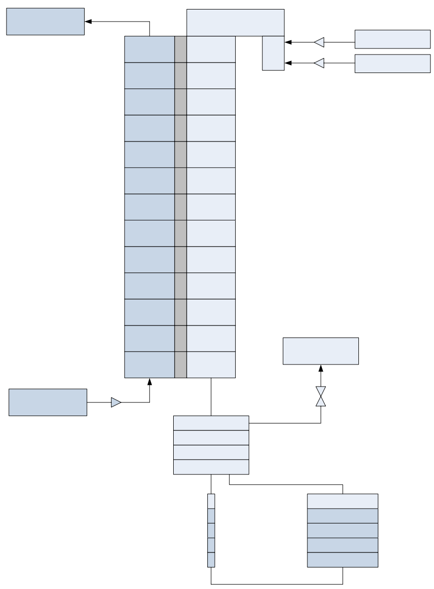

Fig. 3. Nodalization scheme of MARS code for the condensation experimental facility

In Fig. 4 and Fig. 5, comparisons between experimental data and calculated results of two experiments are presented and following two differences are found : 1) MARS code overestimates HTC and 2) applied correlation is different. When it comes to HTC overestimating, it is considered as main reason that enhanced turbulent by injecting air bubble to flatten the temperature gradient results in heat transfer increasing. The proper way to model turbulent mixing should be considered in MARS code, however, this is not the topic of this paper.

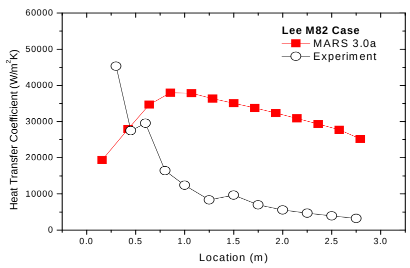

Fig. 4. Comparison of heat transfer coefficients calculated by MARS to Lee's experimental data

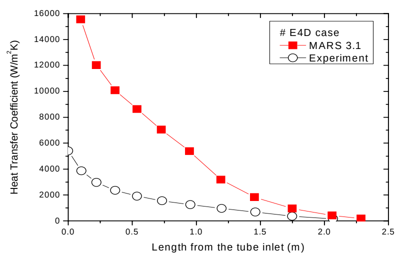

Fig. 5. Comparison of heat transfer coefficients calculated by MARS to Park's experimental data

Second, it is found that, though both have similar Re_l and flow rate, MARS code uses different correlation to calculate HTC : Shah's correlation to Lee's experiment while Nusselt's to Park's. It means that flow conditions of both experiments are same, but Lee's experimental condition is considered as turbulent flow while Park's is considered as laminar flow. Considering transition criteria, as flow conditions in both experiment are laminar, current MARS prediction of Lee's experiment is not correct. This results from current MARS criteria which is taking larger one between HTCs calculated by Nusselt's and Shah's correlation. That is, though Re_l are same, Shah's correlation differently calculates HTC according to hydraulic diameter, a certain flow might be considered as different type. In Lee's experiment, even though actual flow is laminar, due to small diameter, HTC by Shah's correlation is larger than that of Nusselt's and MARS considers it as turbulent flow.

$$h_{Shah} = 0.023\left(\frac{k_l}{D_h}\right)\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}\left[(1-x)^{0.8} + \frac{3.8x^{0.8}}{P_{red}^{\ 0.4}}\right]$$

Table 1. Comparison of Experiment conditions

	Correlation	D_h (mm)	Mass flow rate (kg/sec)	Re_l
Lee(M82)	Shah	47.5	8.3499E-3	64-1300
Park(E4D)	Nusselt	13	1.0147E-2	0-995

3. Modified Correlation Selection Criteria

In order to remove this problem, current MARS criteria should be modified. According to Nusselt's suggestion, 1,800 film Reynolds number is the critical value for transition from laminar to turbulent flow, so it can be used as criteria. Followings are suggested selection criteria.

- $\mathrm{Re}_l < 1{,}800$: laminar flow, Nusselt's correlation
- $\mathrm{Re}_l > 1{,}800$: turbulent flow, Shah's correlation

In case of applying new criteria to Lee's experiment, as shown in Fig. 6, better results are obtained.

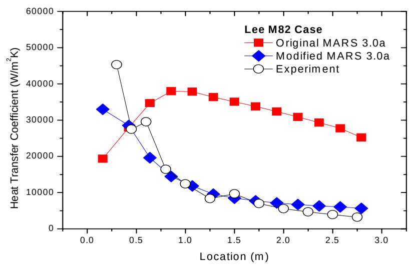

Fig. 6. Comparison of heat transfer coefficients calculated by new criteria and original criteria

4. Conclusions

Current MARS condensation HTC correlation selection method, just taking large HTC, may be able to cause misapplying correlation, so selection methodology should be modified. For consistency with Nusselt's correlation in MARS code, critical film Reynolds number by Nusselt would be reasonable. Authors suggest to use different correlations depending on flow type and a critical film Reynolds number to determine flow type. Applying new criteria leads to improved results.

REFERENCES

[1] K. Y. Kee, The Effect Noncondensable Gas on Steam Condensation in a Vertical Tube of Passive Residual Heat Removal System(Ph.D thesis), POSTECH, 2008.
[2] H. S. Park, Steam Condensation Heat transfer in the Presence of Noncondensables in a Vertical Tube of Passive Containment Cooling System(PhD thesis), KAIST, 1999
[3] M.M.Shah, A general correlation for heat transfer during film condensation inside pipe, Int.J.Heat Mass Transfer, vol.22, pp.547-556, 1978.