Analysis study of the condensation heat transfer coefficient in the presence of noncondensable on PCCS vertical condenser tube using MARS-KS

Dong jae Choi[a], Yeong jun Jang[a], Sin Kim[b] and Yeon-Gun Lee[a]
[a]*Department of Nuclear and Energy Engineering, Jeju National University, #66 Jejudaehakno, Jeju-si, Jeju, KOREA*
[b]*School of Energy Systems Engineering, Chung-Ang University, Seoul 156-756, KOREA*
yeongun2@jejunu.ac.kr

1. Introduction

The Passive Containment Cooling System (PCCS) is a new safety system to preserve the structural integrity of the containment. The PCCS to be introduced in advanced LWRs removes released energy to an external heat sink by a naturally driven flow. Containment through the condensation heat transfer phenomenon in the event of the loss of coolant accident (LOCA) or main steam line break (MSLB). As the released steam pressurizes the containment, the PCCS will activate to transport the decay heat

In this study, a numerical analysis of the condensation heat transfer coefficients on the PCCS condenser tube is conducted using the MARS-KS code. The condensation heat transfer coefficients are obtained from JNU condensation tests performed on a 1000 long and 40 mm O.D. tube.[1] The experimental results, Dehbi's [2] and Uchida's [3] correlations are compared with the analysis results from MARS-KS code. The analysis condition covers 2 and 4 bar for the air mass fraction ranging from 0.1 to 0.8

2. JNU condensation test

2.1 Experimental facility

Fig. 1 shows the schematic diagram of the JNU condensation experimental facility. This facility consists of two sections: condensation section and cooling section. The condensation section includes test tank with the condensing tube, the steam generator, the condensate storage tank and the recirculation pump. The cooling section has the coolant storage tank and the pump.

The diameter of test tank is 609 mm and the height is 1950 mm. A condensing tube with 40 mm in outer diameter, 5 mm in thickness and 1000 mm in length is vertically installed inside of the test tank.

2.2 Heat transfer coefficient

Generally the design pressure of the containment is about 4 bar. Therefore, the JNU condensation experiments were performed 2, 3, 4 and 5 bar.

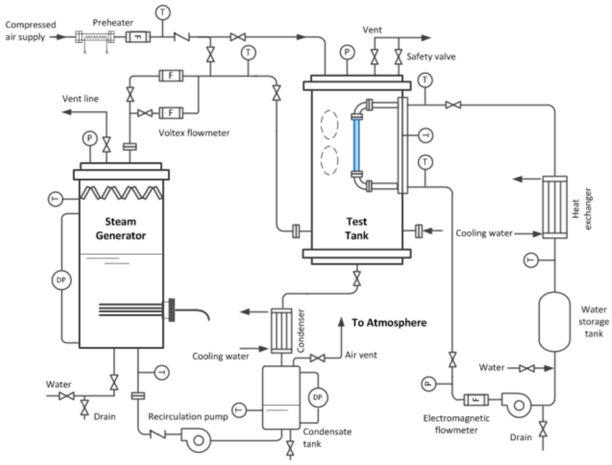

Fig. 1. Condensation experiment facility

To evaluate the effect of a noncondensable gas, the air mass fraction ranged from 0.1 to 0.8. The condensation heat transfer coefficient is obtained using the heat removal rate through the tubs as:

$$Q = \dot{m} c_p (T_o - T_i) \tag{1}$$

where $\dot{m}$, c_P, T_o and T_i represent mass flow rate of coolant, specific heat, outlet and inlet temperature of coolant, respectively. Utilizing the Newton's cooling low, Eq. (1) can be used to express the average condensation heat transfer coefficient on the condensing surface as:

$$\bar{h} = \frac{\dot{m} c_p (T_o - T_i)}{A(T_b - T_w)} \tag{2}$$

where, A, T_b, T_w represent total heat transfer area, temperature of steam and noncondensable mixtures and temperature of outer surface of tube, respectively. The uncertainty of the condensation heat transfer coefficient was 14 %.

3. MARS-KS Analysis

3.1 MARS-KS Nodalization

MARS-KS nodalization of the experimental facility is presented in Fig. 2. The test tank is modeled as a single-volume since the distribution of the gas mixture was almost uniform in the experiments. The inlet and outlet of steam-air mixture and coolant are described by time-dependent volumes. The condensing tube is modeled as a pipe component containing 10 volumes to figure out the temperature vriations along the condenser's height. The heat structures are provided between the single-volume for the test tank and the pipe component.

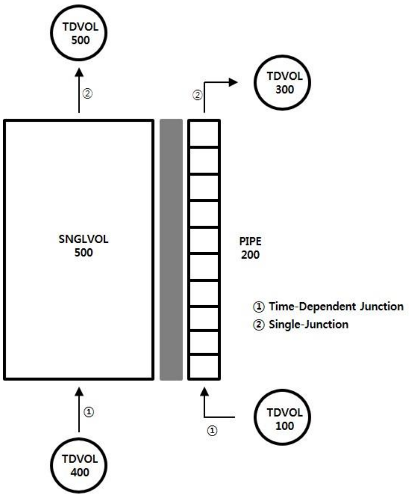

Fig. 2. Test tank Nodalization for MARS-KS

3.2 Existing correlations

The condensation heat transfer coefficients obtained from the experiment and MARS-KS are compared to existing correlations by Dehbi and Uchida. The experiment of Dehbi is performed to investigate the pressure behavior in the containment. The Uchida's correlation is well known to investigate the condensation phenomenon in the containment. The Dehbi's correlation considers various physical parameters including total pressure, tube length, air mass fraction and wall subooling. Correlations are as following:

$$\bar{h}_U = 379\left(\frac{W}{1-W}\right)^{-0.707} \qquad (3)$$

where, W is air mass fraction.

$$\bar{h}_D = 1.25\frac{L^{0.05}\left[(3.7+28.7P)-(2438+458.3P)\log W\right]}{(T_b - T_w)^{0.25}} \qquad (4)$$

Where, P and L is total pressure and condensing tube length, respectively.

3.3 Simulation results

Fig. 3-4 show that comparison between the heat transfer coefficients from the experiments, the analysis using MARS-KS, Dehbi's and Uchida's correlations..

The predicted condensation heat transfer coefficient is higher than experimental result when air mass fraction is between 0.1~0.3. If air mass fraction exceeds 0.4, the predicted condensation heat transfer coefficient is a little lower. These differences come from the definition of the wall subcooling. In the experiment, the wall subcooling is obtained the temperature difference between the bulk and wall. However, in the MARS-KS, the wall subcooling is calculated using the interface and wall temperature based on the Fahri[4]. An average relative error is 18.8% and 15% at 2 and 4 bar, respectively.

Dehbi's experimental facility diameter is 450 mm and the height is 4500 mm. The ratio of the height-to-diameter is very large. It caused strong natural driven flow. Consequently, heat transfer coefficient correlation may be affected. Therefore, Dehbi's correlation is very higher than JNU experimental results and MARS-KS results.

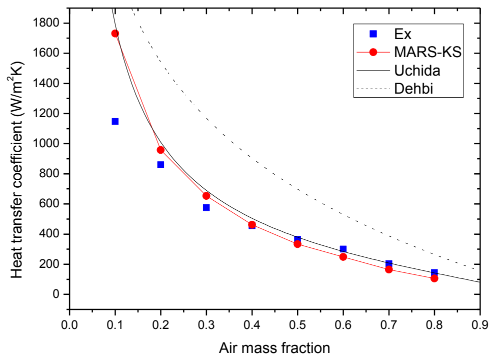

Fig. 3. Comparison result at 2 bar

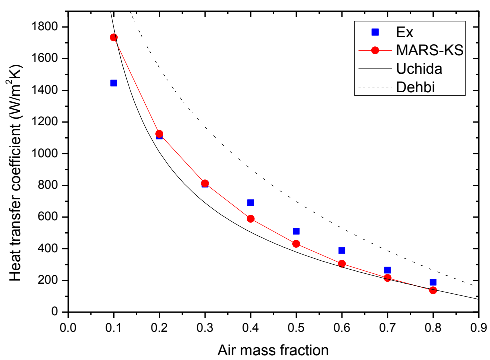

Fig. 4. Comparison result at 4 bar

4. Conclusion

The JNU single vertical condensation experimental results, Uchida's and Dehbi's correlation compared with the MARS-KS code's results at 2 and 4 bar. Experimental results and MARS-KS predicted heat transfer coefficient is different from the thermal resistances and Wall subcooling. An average relative error is 18.8% and 15% at 2 and 4 bar, respectively. Uchida's correlation is considered the noncondensable gas mass fraction only. Therefore, that is lower than MARS-KS results at 4 bar. Dehbi's correlation affected by ratio of the height-to-diameter, so its results are higher condensation heat transfer coefficient than MARS-KS predicted results.

More analysis of pressure condition 3 and 5 bar in MARS-KS code will be followed in the near future. The heat transfer coefficient will be compared with experimental results similar method used in this study.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2012M2A8A4055548, NRF-2010-0020077).

REFERENCES

[1] Yeong-Jun Jang, Dong-Jae Choi, Sin Kim, Dong-Wook Jerng, Yeon-Gun Lee, Experimental study of condensation heat transfer in the presence of noncondensable gas on the vertical tube, NURETH-16, 2015.
[2] A.A. Dehbi, The effects of Noncondensable Gases on Steam Condensation under Turbulent Natural Convection Conditions, Ph. D thesis, MIT, USA, 1991.
[3] H. Uchida, A. Oyama, Y. Togo, Evaluation of Post-incident Cooling Systems of Light-water Power Reactors, Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, August 31 – September 9, 1964.
[4] Fahri Aglar, An assessment of RELAP5/Mod3.3 condensation model for high Reynolds number flows, Progress in Nuclear Energy, Vol. 52, Issue 8, pp. 759-766.