Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Experimental Study on the Condensation Heat Transfer with Non-condensable Gas at High Pressure

Hyoung-Kyoun Ahn, Yeon-Gun Lee, Jong-Won Kim and Goon-Cherl Park
Department of Nuclear Engineering, Seoul National University, San 56-1, Shillim-dong, Kwanak-Gu, Seoul, 151-742, South Korea

1. Introduction

A new concept of energy supply system for nuclear district heating and electricity generation with dispersed power grid by small and medium nuclear power reactor is introduced. A regional energy reactor adopts the steam-gas pressurizer, which introduces the passive safety concept, in order to enhance the safety. The thermal-hydraulic phenomena in steam-gas pressurizer are very complex. Especially, the condensation mechanism with non-condensable gas under the natural convection is important to evaluate the pressurizer behavior. There haven't been many investigations on the condensation heat transfer in the presence of non-condensable gas at high pressure. In this study, the experimental work is performed to obtain the condensation heat transfer coefficients at high pressure with mass fraction of non-condensable gas and total pressure. The experiment is conducted at 4, 7, 12 bar with the non-condensable gas mass fraction of 10, 30, and 70 % respectively. The condensation heat transfer coefficients are acquired and new correlation is developed.

2. Condensation Heat Transfer Experiment at High Pressure with Nitrogen Gas

The heat transfer rate on the high pressure condition should be obtained for analysis of thermal-hydraulic behavior in the steam-gas pressurizer. The cylindrical chamber is designed to estimate the condensation heat transfer.

2.1. Experimental Facility

Figure 1 shows the design of the autoclave chamber for condensation experiment. The copper pipe, which is 0.04 m in diameter and 0.6 m in length, is set up at the center of the autoclave chamber. The heater with the maximum heating power 20 kW is installed to evaporate the water at the bottom of the autoclave chamber, resulting in the mixture of steam and nitrogen gas. To measure the amount of water condensate, the condensate gauge is installed out of autoclave chamber.

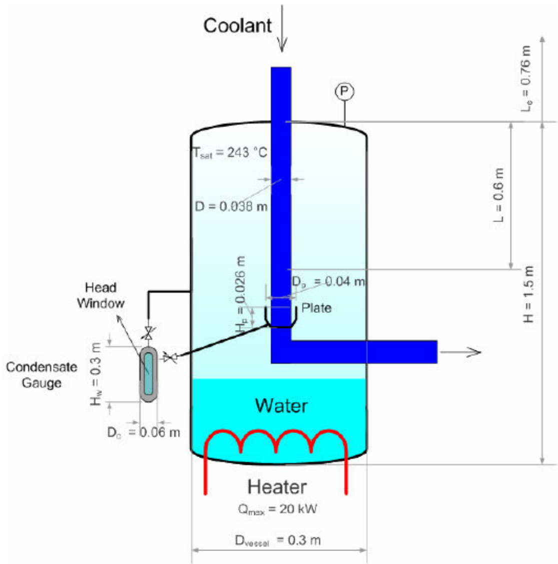

Figure 1. Design of the autoclave chamber

The K-type thermocouples are used to measure the temperature of the inner wall, coolant water and mixture gas. On the top of the autoclave chamber, the coolant water flows from the chiller. After cooling the copper pipe, the coolant water flows out to the chiller.

2.2. Experimental procedure

At first, the air in the autoclave chamber has to be removed to inject required amount of nitrogen gas. In order to remove the air, the water is heated by heater in the autoclave chamber. Up to 1.5 bar, the chamber is closed. When the total pressure reaches 1.5 bar, the gas drain valve is opened to discharge the air and steam mixture gas. After some minutes, the gas drain valve is closed and the total pressure decreases. Until the temperature of the steam is equal to the saturation temperature, this procedure is repeated. When the steam saturation temperature and pressure are satisfied, the nitrogen gas is injected up to required mass fraction. The amount of injection is determined based on partial pressure of nitrogen, calculated from following equation.

$$W_{N_2} = \frac{m_{N_2} P_{N_2}}{m_{N_2} P_{N_2} + m_{stm} P_{stm}} \tag{1}$$

Steady state is achieved by controlling the heating power of heater. The temperature is measured at steady state.

3. Results and Discussion

Figure 2 shows average condensation heat transfer coefficients obtained from experimental data. From this experiment, the condensate rate is also measured, as in Figure 3.

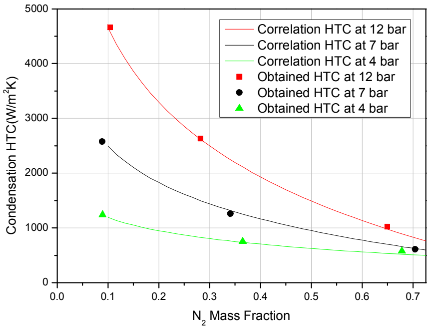

Figure 2. Obtained condensation HTC and developed correlation

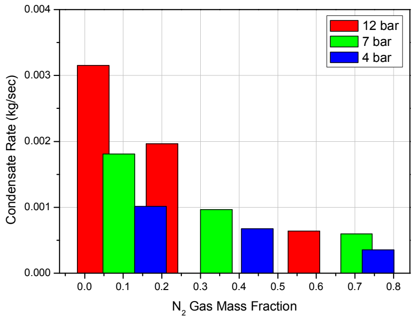

Figure 3. Condensate rate at different pressure

The condensation heat transfer coefficient decreases as mass fraction of nitrogen gas increases. Moreover, the condensation heat transfer coefficient increases as total pressure increases. The new correlation of condensation heat transfer coefficients at high pressure is developed based on these experimental data, and it is plotted in Figure 2. The maximum deviation of the correlation of the condensation heat transfer coefficient is 9.7%.

$$h = \frac{(1381.3 - 85.3P_{tot}) + (2850.3 - 1264.2P_{tot})\log_{10}(W_{N2})}{(T_{mix} - T_{w,in})^{0.25}}$$

$$\text{where } \begin{cases} 4\text{ bar} < P_{tot} < 12\text{ bar} \\ 10\ \% < W_{N2} < 70\ \% \\ 50\ ^\circ\text{C} < T_{mix} - T_{w,in} < 60\ ^\circ\text{C} \end{cases} \qquad (2)$$

The conventional correlations of condensation heat transfer coefficient by Uchida and Tagami are compared with developed condition. At high pressure, the conventional correlations underestimate condensation heat transfer coefficient, since they do not consider the pressure effect. As mass fraction of nitrogen gas decreases, the condensation heat transfer coefficient increases rapidly compared with conventional correlations.

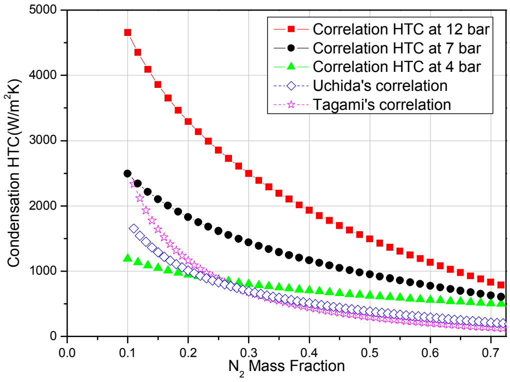

Figure 4. Comparison of condensation HTC correlations

4. Conclusion

The high pressure condensation experiments with nitrogen gas are performed to investigate the characteristics of condensation heat transfer at high pressure. The experiments are conducted at 4, 7, 12 bar with several mass fraction of nitrogen gas. The condensation heat transfer coefficients and condensate rates under different conditions are acquired. The new correlation of condensation heat transfer coefficient is also developed, and compared with conventional correlations. The condensation heat transfer is enhanced by decreasing mass fraction of nitrogen gas or increasing total pressure.

In near future, additional condensation experiments will be performed at higher pressure, and the correlation of condensation heat transfer coefficients will be updated. These research results are expected to contribute to thermo-hydraulic analysis and behavior evaluation of steam-gas pressurizer.

REFERENCES

[1] H. Uchida, A. Oyama and Y. Togo, "Evaluation of post-incident cooling systems of light-water power reactors", Proc. Int. Conf. Peaceful Uses of Atomic Energy, Vol. 13, p. 93-104, 1965

[2] Tagami, "Interim Report on Safety Assessment and Facilities Establishment Project for June 1965," No. 1, Unpublished work, 1965.

[3] H. K. Al-Diwany, J. W. Rose, "Free Convection Film Condensation of Steam in the Presence of Non-condensing Gases", Vol. 16, p. 1359-1369, Journal of Heat and Mass Transfer,1972

[4] A. A. Dehbi, "The Effects of Noncondensable Gases on Steam Condensation under Turbulent Natural Convection Conditions", Ph. D. Thesis, MIT, 1991

[5] H. Araki, Y. Kataoka, M. Murase, "Measurement of Condensation Heat Transfer Coefficient inside a Vertical Tube in the Presence of Noncondensable Gas", Vol. 6, p.

517-526, International Journal of Nuclear Science and Technology, 1995