Experimental investigation of steam condensation on helically-coiled tube for SMART

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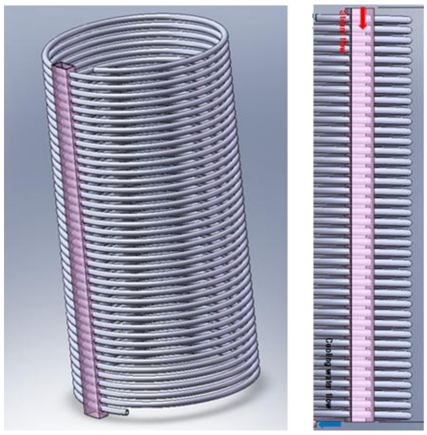
1. Introduction

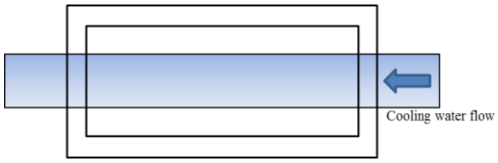
SMART (System-integrated Modular Advanced ReacTor), which is a 330 MWt advanced integral PWR (pressurized water reactor) was developed by the Korea Atomic Energy Research Institute for electricity generation and seawater desalination (KAERI, 2010). Different with other loop-type commercial reactors, SMART is designed to contain most of its reactor coolant system (RCS) components in a compact reactor vessel, such as core, reactor coolant pumps (RCPs), steam generators (SGs), and a pressurizer (PZR)[1]. The heat transfer characteristics of steam generators (SGs) are the essential parts of the overall SMART performance and safety. Therefore, experimental research must be conducted for the verification and development on analytical methodology for heat transfer performance and safety. There are eight SG cassettes in SMART and each cassette consists of many helically-coiled tubes. However, the primary side is designed to operate with subcooled liquid in normal operation, the primary side can be exposed to steam in SBLOCA, and condensation may occur outside of the SG tube. The experiment shown in this work is focused to see the characteristics of condensate heat transfer on the outside of a helically-coiled tube.

2. Steam generator test facility

The test facility was designed to see the characteristics of condensate heat transfer outside of the SGs when the primary side is filled with steam. As shown in Fig. 1, the steam generator test facility is designed to simulate part of the full-scale steam generator. The circular part of the steam generator is reduced to simulate the condensate heat transfer of a single helical tube, as depicted in Fig. 1 (a). The tubes in this experiment are changed from a series of helices to straight tubes for ease of manufacturing. Consequently, the test facility is made as parallel straight tubes with a long rectangular duct (hereafter, called a shell) but the other configuration parameters are exactly the same as the SGs used in SMART. Through the SG shell, the steam flows downward, and the coolant filled in the tubes flows from the bottom to the top. Condensation then occurs inside the shell, and the pressures and temperatures are measured for shell and tube to find condensate heat transfer coefficients (HTCs). The test is performed with different steam pressures and steam flow rates with



(a) Schematics of test facility



(b) Cross section

Figure 1: Steam generator test facility.

steam pressures of 15, 20, 40 and 60 bar and 0.02, 0.04 and 0.06 kg/s for the steam flow rate. In each case, the coolant temperature and flow rate are fixed.

3. Characteristics of heat transfer on helical tube

Condensation HTCs at a steam pressure of 15 bar are shown in Fig. 2. The values are normalized by the inlet value at a pressure of 15 bar and a flow rate of 0.02 kg/s. Only the values before the full condensation, where the negative quality appears, occurs are shown in this work. Near the inlet, the HTCs are especially higher than the others but this is considered an inlet effect. As the steam flow proceeds, the HTCs are high when the flow rate is high. When the system pressure increased as shown in Fig. 3, the HTCs are decreased compared with low pressure. The density of saturated steam increases with pressure and make the steam velocity slow. Thus, the shear stress between steam and saturated liquid film decreases. In addition, the thermal conductivity of saturated liquid is decreased with increasing pressure. Thus, these may induce low HTCs in high pressure.
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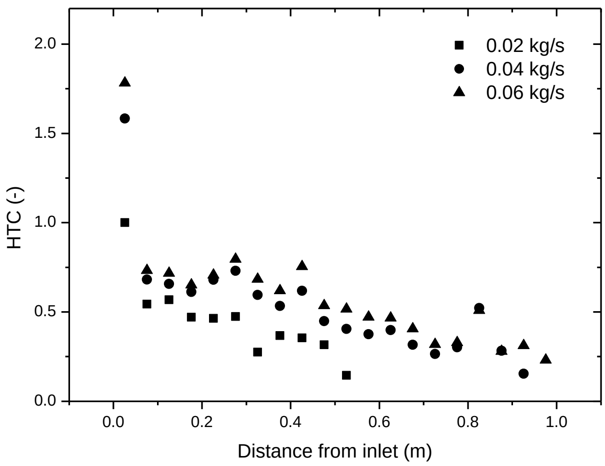

Figure 2: Condensation HTCs at pressure of 15 bar.

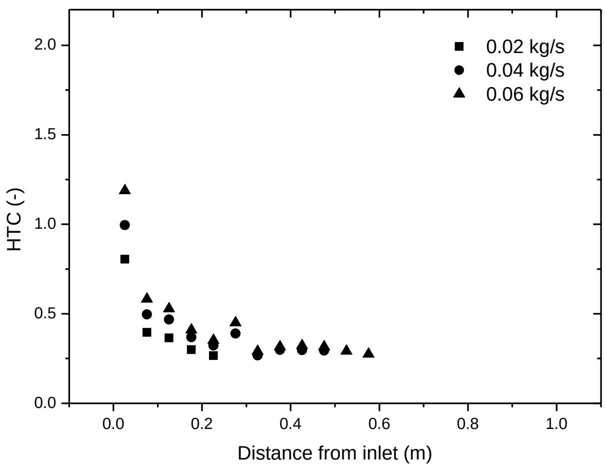

Figure 3: Condensation HTCs at pressure of 60 bar.

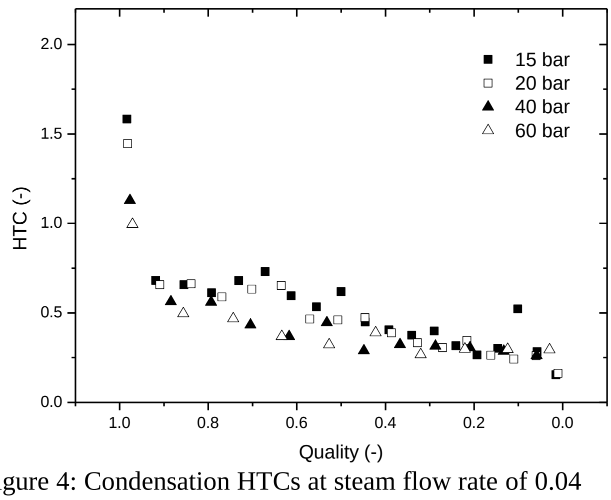

Figure 4: Condensation HTCs at steam flow rate of 0.04 kg/s.

high. When the system pressure increased as shown in Fig. 3, the HTCs are decreased compared with low pressure. The density of saturated steam increases with pressure and make the steam velocity slow. Thus, the shear stress between steam and saturated liquid film decreases. In addition, the thermal conductivity of saturated liquid is decreased with increasing pressure. Thus, these may induce low HTCs in high pressure.

When the steam pressure changes, all physical properties of steam will be changed, including the shear stress on the condensation liquid film. As shown in Fig. 4, the HTCs are decreased with increasing system pressure. Under high pressure condition, the density of saturated steam is high and the shear stress between steam and compensated liquid film is decreased by a low steam velocity. Also, the heat conductivity of the liquid is decreased with an increasing system pressure. These may induce the decreasing HTCs at a high pressure.

4. Conclusions

The experimental validations of a two-phase heat transfer for a condensate heat transfer for helically-coiled tubes were performed to confirm the capability of the SMART design. The shell side experiment on the steam generator in the reduced test section was conducted in a quantitative analysis on the condensation heat transfer process. To obtain the condensation heat transfer coefficient, the coolant temperature inside a tube, the outer wall temperature of the tube, and the fluid temperature outside the tube were measured. The HTCs are increased with increasing steam flow rate but decreased with increasing pressure.

REFERENCES

[1] Y. J. Chung, H. J. Kim, B. D. Chung, W. J. Lee and M. H. Kim, Thermo-hydraulic characteristics of the helically coiled tube and the condensate heat exchanger for SMART, Annals of Nucelar Energy, Vol. 55, p. 49, 2013.