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Heat Loss Evaluation of the ATLAS Facility

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1. Introduction

The heat loss rate of a test facility for simulating a high temperature condition of a conventional PWR is an important factor to enhance the value of experimental data for a computer code analysis, and it is also considered to be one of the critical factors affecting a transient behavior of the integral effect test facility, ATLAS.

This paper presents experimental results of a heat loss rate for the ATLAS facility including the primary system and the secondary side of the steam generator. To evaluate the heat loss rate of the primary system, a constant temperature method along with controlling the core power at a steady state was applied. On the other hand, for the heat losses of the secondary side, cool-down measurement method, which lasted about 15 hours, was used.

2. Heat loss evaluation for the primary system

Physically, a heat loss rate can be determined by a free convection equation for a given temperature difference between an outer surface temperature and a surrounding temperature. The heat loss rate due to a free convection for an arbitrary immersed geometry is proportional to a temperature difference with a power of 5/4 by Lienhard [1] as follows:

$$Q_{loss} \propto \Delta T^{5/4} \tag{1}$$

Separate effect tests were conducted to quantify a heat loss rate through the primary system boundary of the ATLAS for a specified wall temperature. The secondary side of the SG was filled with air at an atmospheric condition and the pressurizer was isolated from the primary system. As an integral approach, the primary system was heated up to a predetermined temperature and it was maintained at a constant temperature by controlling the core power. When the whole system reaches a steady state condition, the core power supplied at that time can be regarded as a heat loss of the primary system. Based on separate effect test results for various specified temperatures, the following empirical heat loss correlation was developed for the primary system.

$$Q_{loss} = 0.091 \cdot (T_w - T_{atm})^{5/4}, \tag{2}$$

where T_w and T_{atm} are a representative wall temperature and an atmospheric temperature (°C), respectively. During the transient, T_w and T_{atm} were obtained by averaging the measured outer surface temperatures of the downcomer wall of the RPV at three different locations and the atmospheric temperatures surrounding the ATLAS at four distributed locations, respectively. Based on the averaged T_w and T_{atm}, the heat loss rate to the surroundings was estimated by Eq. (2) and it was added to the core power. In particular, the estimated heat loss rate by Eq. (2) was partitioned into three groups, with the power factor of 1.0:1.353:1.47 for Group-1, 2, and 3, respectively, to make certain of a uniform heat flux distribution of the core power in a radial direction.

$$\begin{aligned} &\text{Group-1: } Q_{loss\_G1} = 0.26157 \times Q_{loss} \\ &\text{Group-2: } Q_{loss\_G2} = 0.35400 \times Q_{loss} \\ &\text{Group-3: } Q_{loss\_G3} = 0.38443 \times Q_{loss} \end{aligned} \tag{3}$$

Though this empirical correlation was obtained at a steady state condition, it was assumed that it can be applied to the present transient test to compensate for the heat loss to the surroundings [2]. Figure 1 shows the trend of Eq. (2) compared with the measured experimental data.

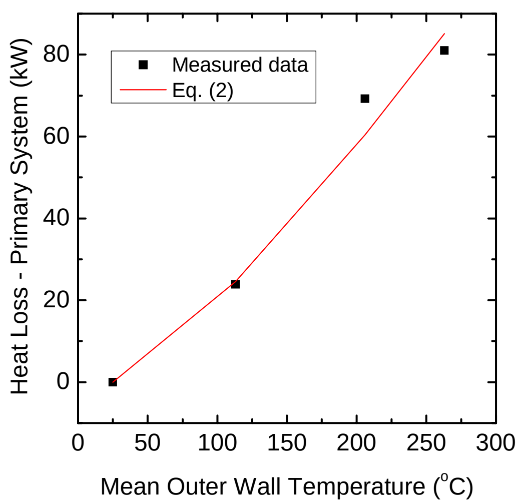

Fig. 1 Heat loss correlation of the primary loop and the measured experimental data

Table 1 Calculated geometric volume data of the ATLAS steam generator

Region	Material	Volume (m³)
Downcomer	SUS316	0.2344
Riser	SUS316	0.0632
Steam dome	SUS316	0.2413
Inlet & Outlet Plenum	SUS316	0.1156
U-tube	Inconel691	0.0734
Liquid Inventory	Water	0.6856

3. Heat loss evaluation for the secondary side of SG

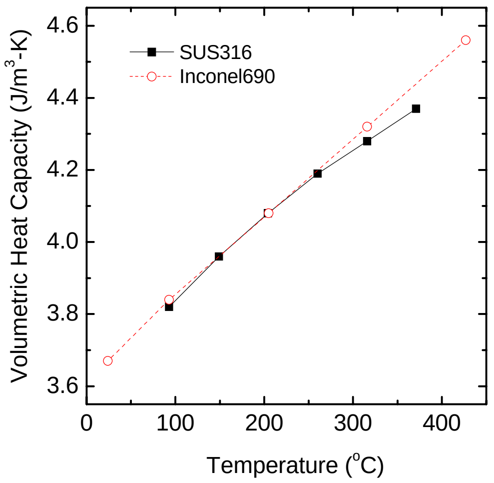

Fig. 2 Volumetric heat capacity of the steel structure of the steam generator

The secondary system of the ATLAS has no heat source. Therefore, the power-controlled constant temperature method could not be applied to evaluate the heat losses of the secondary side. The heat losses of the secondary side of the SG have been experimentally determined by measuring the cool-down of the SG, which lasted about 15 hours. From measured time-dependant temperature variations along with the geometric volume data and the related physical properties such as density (ρ) and specific heat capacity (C_p) of the steel structure and the fluid in the SG, a total heat capacity can be calculated. The heat loss rate is equal to the time variation of the total heat capacity as follows:

$$Q_{loss} = \frac{d}{dt}\left(\Sigma \rho_s V_s C_{ps}(T_s - T_{atm}) + \rho_l V_l C_{pl}(T_l - T_{atm})\right), \quad (4)$$

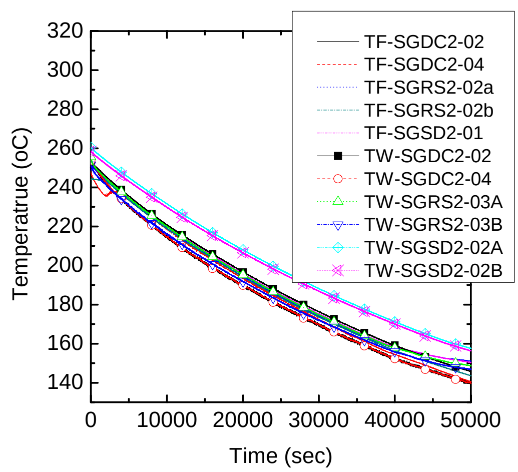

Fig. 3 Fluid and structure temperature variations with time at the downcomer, riser section, and steam dome

where V is the geometric volume (m^3) and the subscript s and l indicate steel structure and liquid inventory, respectively.

Table 1 presents the calculated geometric volume data of steel structure and the initial water inventory in the SG-2, and the value of the volumetric heat capacity with the variation of temperature can be seen in Fig. 2. Figure 3 shows the temperature variations with time at several locations. For the calculation of the heat capacity, the SG was divided into six characteristic regions such as the downcomer, riser, steam dome, inlet and outlet plenum region, U-tube, and water inventory region as indicated in Table 1. The total heat capacity was calculated from the six sub-regional heat capacities. Finally, the heat loss rate can be calculated by Eq. (4). Figure 4 shows the evaluated heat loss rate per 1 SG.

4. Conclusions

This paper describes the experimental results of the heat loss rate for the ATLAS facility. The core-power-controlled constant temperature method and the total heat capacity cool-down method have been used to evaluate the heat loss rate of the primary and secondary sides, respectively. A simple correlation with respect to the temperature difference between the mean wall temperature and the atmospheric temperature was proposed for the primary side heat loss rate. The estimated heat losses to the surroundings were added to the core power during the tests.

REFERENCES

[1] J. H. Lienhard, "On the Commonality of Equations for Natural Convection from Immersed Bodies," *Int. J. Heat Mass Transfer,* **16**, 2121 (1973).

[2] ATLAS operation group, "Test prospectus for the cold leg line small break test," Internal document of the ATLAS operation, 53211-TP-CLSB-01, (2008).

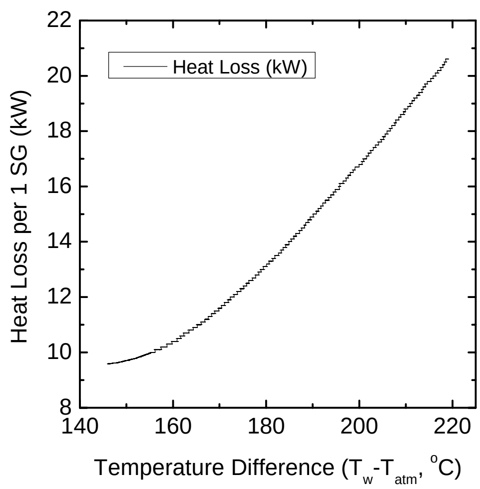

Fig. 4 Evaluated heat losses for the secondary side of one steam generator