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Heat Loss Evaluation of the SMART-ITL Primary System

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1. Introduction

Heat loss rate of a test facility for simulating the high temperature condition of a conventional nuclear reactor is an important factor for enhancing the quality of test data and to simulate it using safety analysis codes. It is considered that the heat loss rate is one of the critical factors affecting the transient behavior of an integral effect test facility [1, 2].

This paper presents the experimental results of the heat loss rate for the primary system of a SMART-ITL (System-Integrated Modular Advanced ReacTor-Integral Test Loop) facility including the pressurizer (PZR). To evaluate the heat loss rate of the primary system, two different approaches were pursued, i.e., integral and differential approaches. The integral approach is a constant temperature method which controls the core and PZR powers at a desired temperature condition and the differential approach is a natural cooling-down measurement method that lasts for a long period of time.

2. Heat loss evaluation

In this section, the test results of the heat loss rate acquired through two different approaches are suggested and compared.

2.1 Heat loss evaluation by integral method

The determination of the heat loss by the integral method was conducted based on data sets obtained during a steady-state conditions of 100°C, 200°C, 300°C, and 320 °C. When the whole system reaches a steady-state condition, the core and PZR powers supplied at that time can be regarded as a heat loss of the primary system. Figure 1 shows the experimental data and empirical correlation based on the test results. The uncertainty of the experimental data in Fig. 1 is determined using Eqs. (1) and (2) [3].

$$U_T = \sqrt{B^2 + (t_{v,95\%}P)^2} \tag{1}$$

$$t_{v,95\%}P = \frac{S}{\sqrt{n}} \tag{2}$$

where U_T is the total uncertainty, B is the bias uncertainty, $t_{v,95\%}P$ is the precision uncertainty, S is the standard deviation, and n is the number of data.

Generally, a heat loss rate can be determined through natural convection equations from immersed bodies. It is proportional to the temperature difference between the wall temperature T_w and ambient temperature T_{amb} with a power of 5/4 for a laminar flow and 4/3 for a turbulent flow as follows [4, 5].

$$Q_{loss} \propto (T_w - T_{amb})^{5/4} \quad \text{for } Ra_L < 10^9 \tag{3}$$

$$Q_{loss} \propto (T_w - T_{amb})^{4/3} \quad \text{for } 10^9 < Ra_L \tag{4}$$

$$Ra_L = \frac{g\beta(T_w - T_{amb})L^3}{\nu\alpha} \tag{5}$$

where Ra_L is the Rayleigh number, g is acceleration from gravity (m/s^2), β is the coefficient of expansion (K^{-1}), L is the characteristic length (m), ν is kinematic viscosity (m^2/s), and α is the thermal diffusivity (m^2/s).

Based on the test results for various temperatures, the following empirical correlation was obtained for the primary system. In the present case, a natural convection equation for a turbulent flow was used because the value of Ra_L is bigger than 10^9.

$$Q_{loss} = 0.0765(T_w - T_{amb})^{4/3} \tag{6}$$

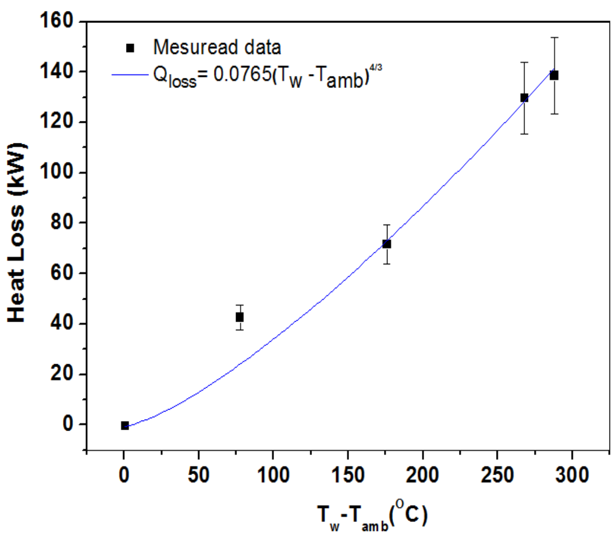

Fig. 1 Heat loss rate of the SMART-ITL primary system estimated using the integral method

2.2 Heat loss evaluation by differential method

To evaluate the heat loss rate using a differential method, the primary system including the PZR was divided into nine sub-regions, i.e., the PZR head, PZR supporting structure, upper downcomer, core support barrel, lower downcomer, upper guide structure, core, steam generator and water inventory, as shown in Table 1. The heat losses from the differential method were experimentally determined by measuring the cooling rates of nine sub-regions which lasted about 700,000 seconds.

Figure 2 shows the temperature variations over time at each location of the sub-regions, and Fig. 3 shows the heat loss rate calculated by Eqs. (7).

$$Q_{loss} = \sum V_i c_{p,i} \frac{T_1 - T_2}{t_1 - t_2} \quad (7)$$

where V_i is the i-th volume of the sub-regions, $c_{p,i}$ is the volumetric heat capacity, T_1-T_2 is the temperature difference, and t_1-t_2 is the time difference.

2.3 Comparison of two heat loss evaluation methods

Figure 4 shows the comparison of heat loss by two different approaches, integral and differential methods. The results obtained by the two approaches agree well within the uncertainty bound throughout the whole measured ranges. However, the integral approach shows milder variation against temperature difference than the differential approach.

Table 1 Sub-Regions of SMART-ITL primary system

No.	Sub-zone	Materials
1	PZR head	SUS304/Insulator
2	PZR supporting structure	SUS304/Insulator
3	UDC	SUS304
4	CSB	SUS304
5	LDC	SUS304
6	UGS	SUS304/Insulator
7	Core	SUS304/Al_2O_3/Nichrome /BN/Inconel600
8	SG	SUS304
9	Water Inventory	water

3. Conclusions

In the present work, the heat losses derived from integral and differential approaches were acquired for the primary system of the SMART-ITL. The results obtained by the two approaches were very similar. In addition, an empirical correlation with respect to the difference between the wall temperature and the ambient temperature was proposed to represent the heat loss characteristics of the SMART-ITL facility. The estimated heat losses could be used to estimate the heat loss during the tests and code simulations.

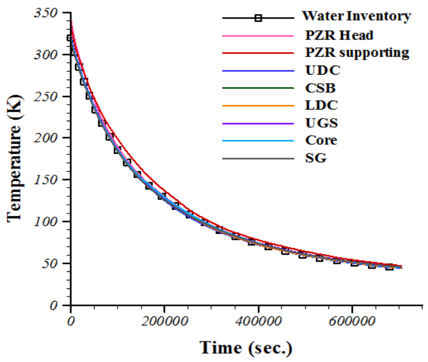

Fig. 2 Sub-regional temperature variations over time

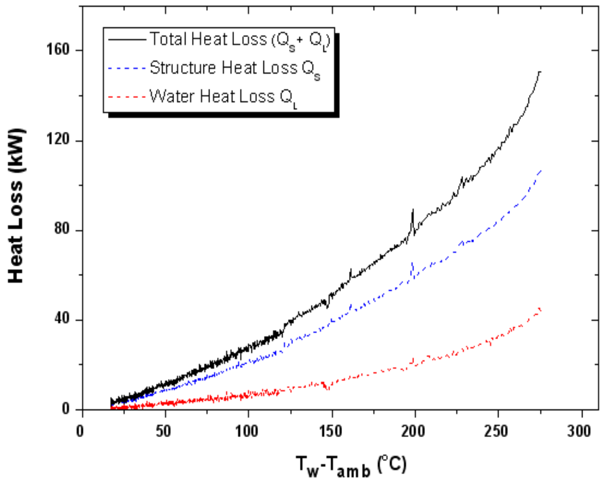

Fig. 3 Heat loss rates of the SMART-ITL primary system estimated using the differential method

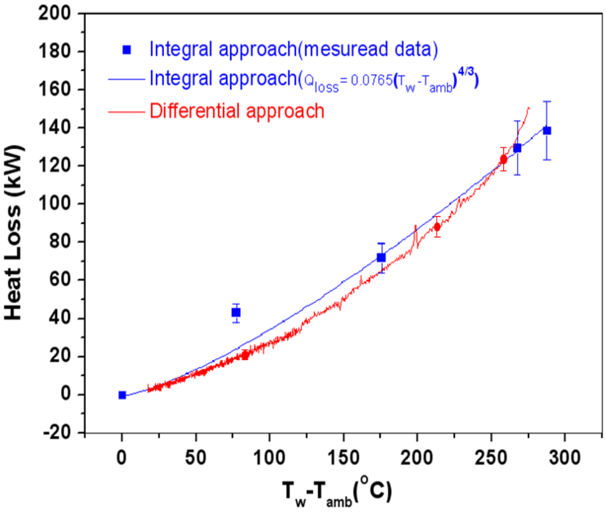

Fig.4 Comparison of heat loss rates acquired by two approaches(integral and differential methods)

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REFERENCES

[1] S. Cho, H. S. Park, K. Y. Choi, K. H. Kang, Y. S. Kim and W. P. Baek, "Heat Loss Evaluation of the ATLAS Facility," Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 22, 2009.

[2] S. P. Schollenberger et al., Determination of Heat Losses in the PKL Ⅲ Test Facility, NTT1-G/2006/en/0067, 2006.

[3] T. G. Beckwith, R. D. Marangoni and J. H. Lienhard, Mechanical Measurement, 5th ed. Addison Wesely, New York, 1993.

[4] J. H. Lienhard, On the Commonality of Equations for Natural Convection from Immersed Bodies, Int. J. Heat Mass Transfer, 16, p. 2121, 1973.

[5] F. P. Incropera and D. P. Dewitt, Introduction to Heat Transfer, 3rd ed. Wiley, 1996.