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Experimental Facility Design for a Gap Heat Transfer in a Double Wall Tube

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1. Introduction

A reliable steam generator design is one of the most critical issues in developing a sodium-cooled fast reactor (SFR), and various efforts to avoid potential sodium-water reaction (SWR) have been made. For this reason, SFR steam generators have been developed to improve its reliability using a double-wall tube (DWT), which has two barriers between the sodium and water [1]. Most steam generators for SFRs are the shell-and-tube type. Steam at high pressure and low temperature flows inside the inner tubes, which are heated by the shell-side sodium at low pressure and high temperature, as shown in Fig.1.

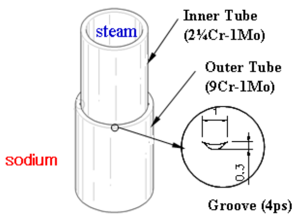

Fig. 1 Double-wall tube with the different materials

Since the inner and outer tubes of conventional DWTs are made of identical materials, the degree of thermal expansion is somewhat different between the two concentric tubes owing to their temperature difference. Therefore, a greater temperature difference results in less contact pressures between the inner and outer tubes. This feature results in a deterioration of the heat transfer capability of DWTs. Current developments are focused on an improvement of heat transfer capability by investigating the gap conductance between the two concentric tubes.

To improve the heat transfer capability of DWTs, it is preferable to use different tube materials (Fig. 1). It is recommended to choose the inner tube material whose thermal expansion coefficient is greater than that of the outer tube by 10 to 15% [2-3].

2. Setup of the Experimental Facility

2.1 Estimation of the experimental error

A facility was designed to verify the feasibility of the DWT, three types of which were fabricated. The heat transfer capability through the gap is the most important issue in this work because it varies by the temperature difference between the two concentric tubes. It was estimated that the contact pressure of the DWT under normal operating conditions at which the temperature difference was about 55℃ was similar to that at room temperature. When the tube side was empty and the sodium temperature was 550℃ under an abnormal condition, the heat transfer was enhanced, but the stress was estimated to be about 12 MPa in a computational analysis. Although the estimated stress was lower than the yield stress of the used materials, its mechanical integrity should be confirmed during the experiment.

The annular-type test section was oriented vertically with an annulus-and-tube heat exchanger employing a sodium-sodium counter flow. The DWT was installed concentrically at the center, and its outer and inner diameters were 30 mm and 22 mm, respectively. Heat balance in the test section based on the gap diameter (d_g) and gap heat transfer coefficient (h_g) is

$$\frac{1}{h_g d_g} = \frac{\pi L(T_{out} - T_{in})}{mCp(T_o - T_i)} - \frac{1}{h_i d_i} - \frac{\ln(d_g/d_i)}{2k_i} - \frac{\ln(d_o/d_g)}{2k_o} - \frac{1}{h_o d_o}, \quad (1)$$

where d is the diameter, h is the heat transfer coefficient, k is the thermal conductivity, T is the temperature, and L is the effective test section length. The subscripts i, o, and g stand for the tube side, annular side, and gap, respectively. The sodium mass flow rates (m) are equal on both sides because of a recirculation flow.

The gap heat transfer coefficient (h_g) and sodium heat transfer coefficients (h_i and h_o) have the same order of magnitude. Compared with them, the measured parameter $1/h_g d_g$ is small, thus causing a large error due to the error propagation as in Eq. (1). Table 1 shows the minimum errors estimated under several geometrical conditions.

Table 1 Minimum error according to the conditions

Case	Ref. test section	Length (m)	Flows	Error (%)	Remark
1	X	5	Na/H_2O	83	0.7MPa
2	O	2	Na/Na	47	-
3	X	5	Na/Na	33	-
4	O	5	Na/Na	26	$h_{dwt} = h_{swt}$
5	X	5	Na/Na	27	dT error ±0.5℃
6	O	5	Na/Na	9	dT error ±0.5℃

The following errors were assumed for the calculation: the error in the sodium flow rate is 3%, the error in the water flow rate is 1%, the absolute errors in measuring the temperature are 1.1℃, and the errors in measuring the diameter and length are 0.2 mm, 2 mm, respectively. The errors of the correlations used in the calculation are assumed as 5%, and those of the physical properties are assumed as 1%.

2.2 Design of experimental facility

An experimental facility was designed to minimize errors under practical conditions. Three types of 6-meter long DWTs were fabricated to compare their heat transfer capabilities, and the inner, gap, and outer diameters were 22 mm, 26 mm and 30 mm, respectively. The two concentric tubes of the first type were made of the same material with a groove. Those of the second type were made of different materials with a groove. Those of the third type were made of different materials without a groove. The reference test section employed a single wall tube made of 9Cr-1Mo-V steel.

Fig. 2 shows the flow diagram of the facility. A cold trap loop was operated separately with the experimental procedure. The cold sodium was injected into the inside of the reference test section by an electromagnetic pump, and heated up by the sodium flow in the annulus. The sodium reheated by heater-1 was sequentially injected into the annulus of the test section, cooler-2, inside of the test section, heater-2, the annulus of the reference test section, and cooler-1. Consequently, a circulation loop was achieved by the facility.

The temperatures at 17 points in the test section were measured. The 3-D layout is shown in Fig. 3. The dimension is 3.5×4.6×11.8 m. Coolers with a 160 kW capacity were designed as a helical heat exchanger cooled by air.

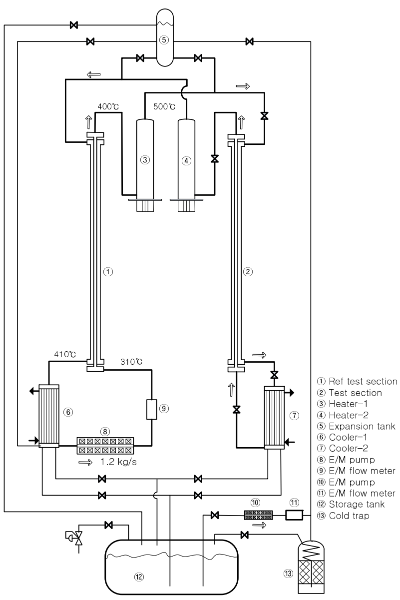

Fig. 2 Flow diagram of the facility

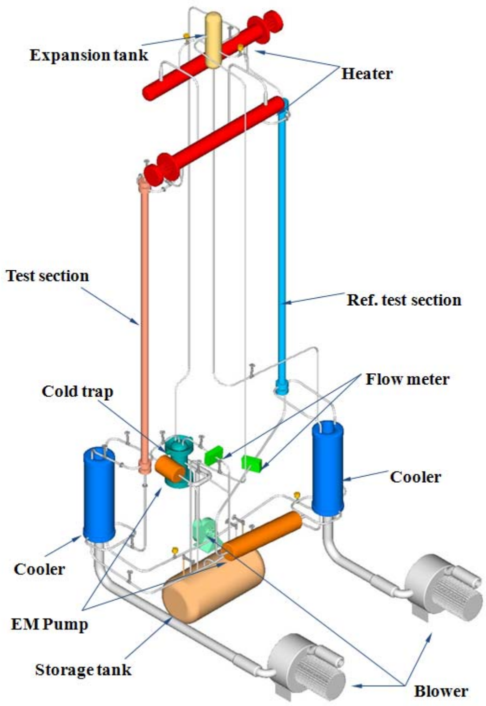

Fig. 3 3-D Layout of the facility

3. Conclusions

A method was developed to improve the heat transfer capability of a double wall tube. Three kinds of newly-proposed DWTs were fabricated, and an experimental facility was designed to verify the feasibility of the new concept. In this work, the major measured parameter was the heat transfer coefficient at the gap between the two concentric tubes of the DWT. A reference test section with a single wall tube was required to reduce the experimental error. A minimum error was estimated to be about 9% in measuring the gap heat transfer coefficient when the thermocouples were calibrated within a ±0.5℃ error for the temperature difference (dT) concerned with the data reduction.

Acknowledgement

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