Performance Test of Electromagnetic Flow Meter in Sodium thermal hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger (SELFA)

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1. Introduction

Prototype Gen-IV Sodium-cooled fast reactor (PGSFR) is being developed at Korea Atomic Research Institute (KAERI). A forced-draft sodium-to-air heat exchanger (FHX) is a part of decay heat removal system (DHRS) in PGSFR [1]. Sodium thermal hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger (SELFA) is a test facility for verification and validation of the design code for FHX [2]. There exist an electromagnetic flow meter and a Coriolis flow meter in SELFA to measure sodium flow rate of main loop as shown in Fig. 1. Each flow meter can be simultaneously used or independently used by manipulating valves in the main loop. In this paper, we have investigated performance of the electromagnetic flow meter in comparison with the Coriolis flow meter in the main loop of SELFA.

2. Performance Test of Electromagnetic Flow Meter

2.1 Setup of Performance Test

The flow path for electromagnetic flow meter performance test is shown in Fig. 2. As shown in Fig. 2, the electromagnetic flow meter and the Coriolis mass flow meter are serially connected in the main loop, so that they can measure sodium flow rate provided by electromagnetic pump. The temperature of sodium is controlled by loop heater. The performance test has been performed for various sodium flow rates and temperatures given by performance test matrix as shown in Table I. We have performed test for nine flow rate conditions (from 0.55 kg/s to 4.80 kg/s) and three temperature conditions (150℃, 200℃, and 240℃).

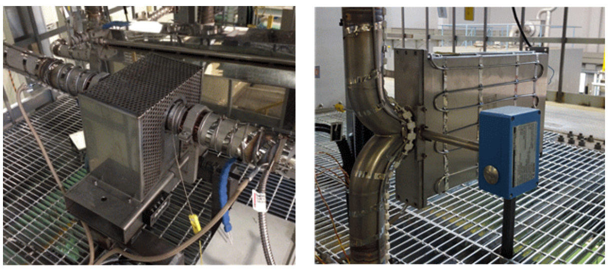

Fig. 1. Electromagnetic flow meter (left) and Coriolis flow meter (right) in the main loop of SELFA

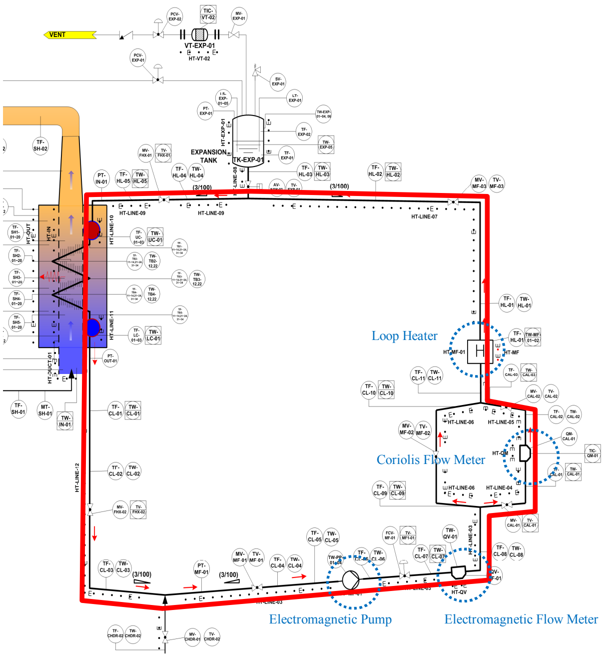

Fig. 2. Flow path for performance test of electromagnetic flow meter

Table I: Performance Test Matrix

Flow rate (kg/s) / Temp. (℃)	0.55	1.10	1.65	2.20	2.75	3.30	3.85	4.40	4.80
150	O	O	O	O	O	O	O	O	O
200	O	O	O	O	O	O	O	O	O
240	O	O	O	O	O	O	O	O	O

2.2 Calibration Function of Electromagnetic Flow Meter

For the performance test of electromagnetic flow meter, it is required to investigate flow rate calibration function of the electromagnetic flow meter based on flow rate of the Coriolis flow meter. The Coriolis flow meter measures mass flow rate, on the other hand the electromagnetic flow meter measures volume flow rate. Thus, first, it is required to convert the mass flow rate from the Coriolis flow meter into volume flow rate considering density of sodium in the test temperature condition. Let $\rho(T)$ be the density of sodium at temperature T, then the density of sodium is given as follows [3]:

$$\rho(T) = 0.9501 - 2.2976 \times 10^{-4} T - 1.46 \times 10^{-8} T^2 + 5.368 \times 10^{-12} T^3 \tag{1}$$

Then, we obtain mass flow rate Q_m from volume flow rate Q_v as follows:

$$Q_m = Q_v \rho(T) \tag{2}$$

Volume flow rate from the electromagnetic flow meter can be represented as follows:

$$Q_v = f_{k_v}(V) \tag{3}$$

where V is output voltage from the electromagnetic flow meter and $f_{k_v}(V)$ is first-order linear equation, which is called volume flow rate calibration function. By substituting eq. (3) into eq. (2), we obtain mass flow rate as follows:

$$Q_m = f_{k_m}(\rho(T), V) = \rho(T) f_{k_v}(V) \tag{4}$$

where $f_{k_m}(\rho(T), V)$ is mass flow rate calibration function. Volume flow rates obtained from eq. (2) and output voltages from the electromagnetic flow meter at different three temperatures are shown in Fig. 3 ~ Fig. 5.

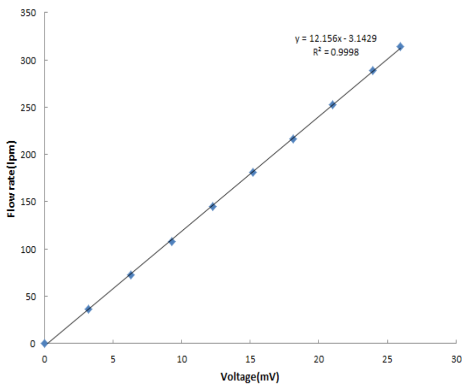

Fig. 3. Volume flow rate versus output voltage from electromagnetic flow meter at 150℃

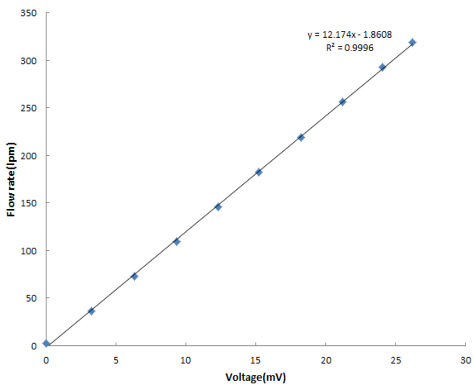

Fig. 4. Volume flow rate versus output voltage from electromagnetic flow meter at 200℃

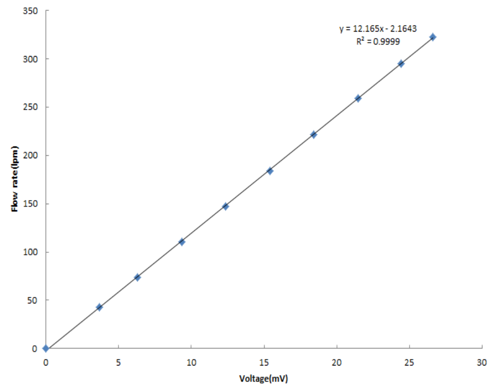

Fig. 5. Volume flow rate versus output voltage from electromagnetic flow meter at 240℃

Then, the volume flow rate calibration function can be estimated by averaging three different first-order linear equations representing volume flow rate versus output voltage of the electromagnetic flow meter as follows:

$$f_{k_v}(V) = 12.165V - 2.3893 \tag{5}$$

Thus, the mass flow rate calibration function is given as follows:

$$f_{k_m}(\rho(T), V) = \rho(T)(12.165V - 2.3893) \tag{6}$$

Then, performance of electromagnetic flow meter versus Coriolis flow meter can be investigated by obtaining mass flow rate from eq. (4) and eq. (6).

2.3 Performance Test Results

The performance of electromagnetic flow meter can be represented by accuracy. There exist two types of accuracy for flow meter. The first one is percentage of reading (RD) accuracy and the second one is percentage of full scale (FS) accuracy. The percentage of reading accuracy is given by

$$\%\text{ of reading} = \frac{\pm\text{ Measurement error}}{\text{Instantaneous measurement}} \times 100 \tag{7}$$

and the percentage of full scale accuracy is given by

$$\%\text{ of full scale} = \frac{\pm\text{ Measurement error}}{\text{Full scale measurement range}} \times 100 \tag{8}$$

Thus, the performance of electromagnetic flow meter can be evaluated by either the percentage of reading accuracy or the percentage of full scale accuracy. First, the performance of electromagnetic flow meter versus Coriolis flow meter based on percentage of reading at different three temperatures is shown in Fig. 6 ~ Fig. 8. Thus, the percentage of reading accuracy is given by $\pm 2.594\%$. On the other hand, the percentage of full scale accuracy with full scale measurement range 4.8kg/s is given by $\pm 0.866\%$ since the maximum measurement error is 0.042 kg/s.

Then, it is important to determine which accuracy is more appropriate for performance evaluation. Measure

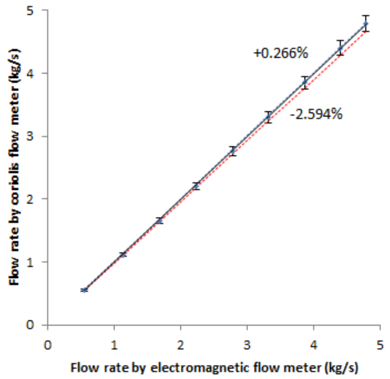

Fig. 6. The percentage of reading accuracy of electromagnetic flow meter versus Coriolis flow meter at 150℃

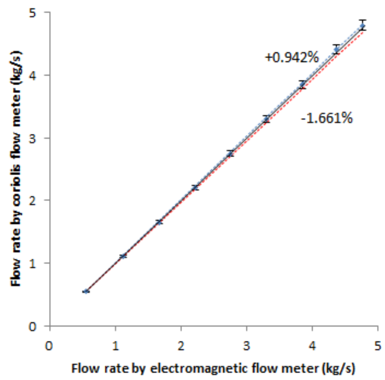

Fig. 7. The percentage of reading accuracy of electromagnetic flow meter versus Coriolis flow meter at 200℃

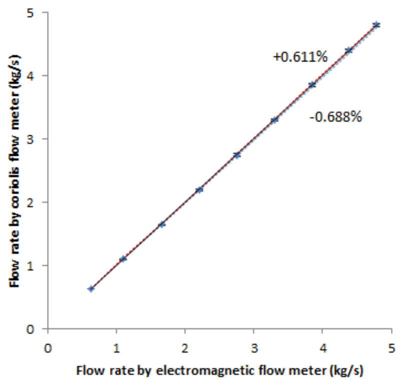

Fig. 8. The percentage of reading accuracy of electromagnetic flow meter versus Coriolis flow meter at 240℃

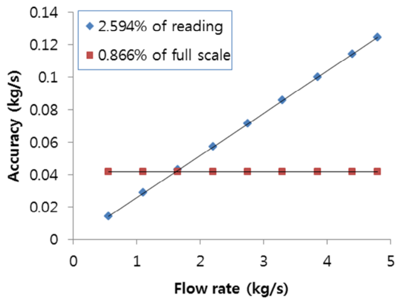

Fig. 9. Two accuracy measures versus flow rate

Table II: Performance of Electromagnetic Flow Meter

Range	Accuracy
~ 1.65kg/s	±2.594% of RD
1.65kg/s ~ 4.8kg/s	±0.866% of FS

of performance evaluation can be determined by comparing two accuracies versus flow rate. As shown in Fig. 9, the percentage of reading accuracy is smaller than the percentage of full scale accuracy below 1.65kg/s. On the other hand, the percentage of full scale accuracy is smaller than the percentage of reading accuracy above 1.65kg/s. Thus, appropriate accuracy according to flow rate is required to be chosen for the performance evaluation of electromagnetic flow meter. Then, the performance of electromagnetic flow meter can be represented by different measure of accuracy according to flow rate as shown in Table II.

3. Conclusions

Performance test results of electromagnetic flow meter in comparison with Coriolis flow meter in main loop of Sodium thermal hydraulic Experiment Loop for Finned-tube sodium-to-Air heat exchanger (SELFA) have been provided in this paper. We have investigated the performance of the electromagnetic flow meter for nine flow rate conditions (from 0.55kg/s to 4.8kg/s) and three temperature conditions (150℃, 200℃, and 240℃). The electromagnetic flow meter has ± 2.594% of reading accuracy below 1.65kg/s and ± 0.866% of full scale accuracy from 1.65kg/s to 4.8kg/s. Thus, it has been shown that the electromagnetic flow meter has sufficient accuracy since the maximum measurement error is 0.042kg/s which is sufficiently small compared to required flow measurement range.

ACKNOWLEDGEMENT

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