Performance Tests of a Mechanical Pump in Sodium Environment

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1. Introduction

As contrasted with PWR (Pressurized light Water Reactor) using water as a coolant, sodium is used as a coolant in SFR (Sodium-cooled Fast Reactor) because of its low melting temperature, high thermal conductivity, the high boiling temperature allowing the reactors to operate at ambient pressure, and low neutron absorption cross section which is required to achieve a high neutron flux.

But, sodium is violently reactive with water or oxygen like another alkali metal. So very strict requirements are demanded to design and fabricate of sodium experimental facilities. Furthermore, performance testing in high temperature sodium environments is more expensive and time consuming and need an extra precautions because operating and maintaining of sodium experimental facilities are very difficult.

For that reason, water is often selected as a surrogate test fluid because it is not only cheap, easily available and easy to handle but also its important hydraulic properties (density and kinematic viscosity) are very similar to that of the sodium.

Nevertheless, to ensure the performance, safety, and operability of major components before its installation in the SFR, a series of demonstration experiments of some components in sodium environment should be positively necessary.

So, SFR NSSS System Design Division of Korea Atomic Energy Research Institute (KAERI) built various sodium experimental facilities, especially STELLA-1[1] in 2012. STELLA-1 (***S***odium in***T***egral ***E***ffect test ***L***oop for safety simu***L***ation and ***A***ssessment) is a large-scale separated effect test facility for demonstrating the thermal-hydraulic performances of major components such as a Sodium-to-Sodium heat exchanger (DHX), Sodium-to-Air heat exchanger (AHX) of the decay heat removal system, and mechanical sodium pump of the primary heat transport system (PHTS).

In 2015, in order to estimate a hydraulic behavior of a mechanical pump, performance tests of a mechanical pump in water environment was carried out using the pump vender's experimental facility [2].

Also, to compare hydraulic characteristic of a mechanical pump operated in water and sodium, performance tests of mechanical pump in sodium environment were performed using STELLA-1.

The present paper delineates performance test results of a mechanical sodium pump in sodium environment.

2. A Mechanical Pump Experimental Apparatus

A mechanical pump was manufactured to preserve the major hydraulic phenomena according to the related similarity criteria using the corresponding prototype pump of the 600 MWe Demonstration SFR (DSFR).

The impeller outer diameter of the pump was scaled down a factor of 5.5 of that of the prototype pump while keeping the same specific speed. A mechanical pump had a rated flow rate of 510 m^3/h, a rated pressure head of 50.3 m, and a rated rotational speed of 2,140 rpm [3].

Major specifications of the mechanical pumps are follows.

Table 1 Major specifications of the mechanical pump

Item	Specification
Specific speed	330.3 rpm·m^3/min·m
Rated flow rate	510.3 m^3/h
Rated head	50.31 m
Efficiency	71.8 %
Impeller Out Diameter	320 mm
Rated Rotation speed	2,140 RPM
Rated power of Motor	110 kW

Fig. 1. A mechanical pump

Add to this, to accommodate non-uniform thermal expansion and to secure the operability and the safety, the gap size between suction cover of pump and impeller, and impeller and diffuser were increased from 0.5 mm to 5 mm and from 1 mm to 6 mm, respectively.

Although the pump's total head and pump efficiency at the rated operational point tend to lower than design value because of the pressure leak according to gap size increasing, sufficient data to compare hydraulic characteristic of a mechanical pump in sodium environment were collected throughout the pump performance test in water using the pump vender's experimental facility [2].

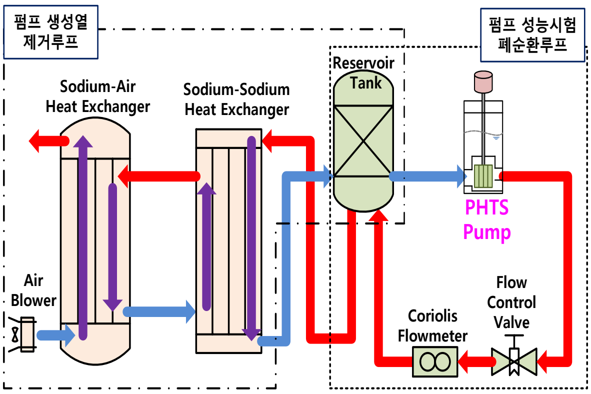

Fig. 2. The schematic diagram of pump performance test part of STELLA-1

Fig. 2 shows the schematic diagram of a mechanical pump experimental apparatus installed in STELLA-1. The main parts of closed pump performance test loop was consist of mechanical pump, coriolis flow meter, reservoir, three of glove valves, eighteen of elbow 90˚, two of elbow 45˚, one of tee, and two of 6 inch to 10 inch pipe enlarger. The closed main test loop was connected with 10 inch diameter and 6 inch diameter pipes made of STS316 and total length of test loop was 43.5 m. Reservoir and mechanical sodium pump was equipped with pressure control system using Ar gas.

Fig. 3. Photograph of closed pump performance test loop installed in STELLA-1

A heat tracing system with numerous type-K thermocouples were equipped with the test loop and components to control the temperature of experimental facility. Also, differential pressure gauges were equipped with the front of pump inlet and the back of pump outlet to measure the pump pressure head.

3. The Performance Test of Mechanical Pump

Two kinds of performance tests, one was the pump pressure head vs flow rate test, and the other was a coast-down test, were performed.

The pump pressure head vs flow rate test was performed at the lower RPM (749 RPM, 35% of rated RPM), middle RPM (1391 RPM, 65% of rated RPM), and the rated RPM (2,140 RPM) with variable flow rate from 15% to 120% of rated flow rate. Operational temperature and pressure of test loop were 300℃ and 80kPa, respectively. It was also performed at 250℃, the rated RPM, to see how temperature difference has an effect on the pump pressure head.

Table 2 shows the test matrix of the pump pressure head vs flow rate test.

Table 2 The test matrix of the pump pressure head vs flow rate test

N/N_R Q/Q_R	35% (749RPM)	45% (963RPM)	55% (1,177RPM)	65% (1,391RPM)	100% (2,140RPM)
15%	◎				
20%		◎			
25%			◎	◎	
30%	◎	◎			
35%			◎	◎	
40%	◎	◎			◎
45%			◎	◎	
50%	◎	◎			◎
55%			◎	◎	
60%		◎			◎
65%		◎	◎	◎	
70%					◎
75%			◎	◎	
80%			◎		◎
85%				◎	
90%					◎
95%				◎	
100%					◎
105%					
110%					◎
115%					
120%					◎

Differential pressure of pump, flow rate, rotational speed of motor, temperature of inlet sodium, and torque of pump shaft were measured at one-second intervals over one minute. Steady state of performance test had to be continued for more than one minute and criteria of steady state of pump performance test are follows.

- Flow rate variation: less then ± 2% of the assigned flow rate

- Inlet sodium temperature: less then ± 5℃ of the operational temperature

Coast-down tests were performed using the two kinds of fly-wheel.

The halving time, how long does it take the pump discharge flow rate to be reduced to half after pump seize-up while operating the pump, and pump discharge flow rate according to the time variation were measured through the coast-down tests at 250℃. Table 3 shows the specification of flywheels.

Table 3 Specifications of flywheels.

Fly-wheel No	Maximum outer diameter (mm)	Height of maximum diameter part(mm)	Weight (kg)	GD^2 (kg-m²)
CM-45C-0005	Φ 524	76	157.3	21.6
CM-45C-0002		200	356.1	48.9

The pump pressure head vs flow rate test and coast-down test were repeated three times to confirm the reproducibility of the experiment.

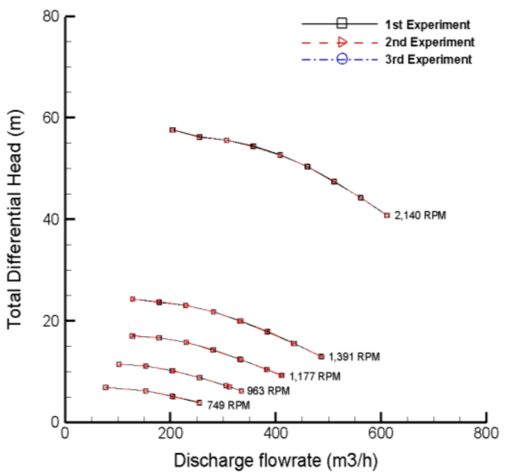

Fig. 4. The Performance curve of the mechanical pump in sodium environment at 300℃

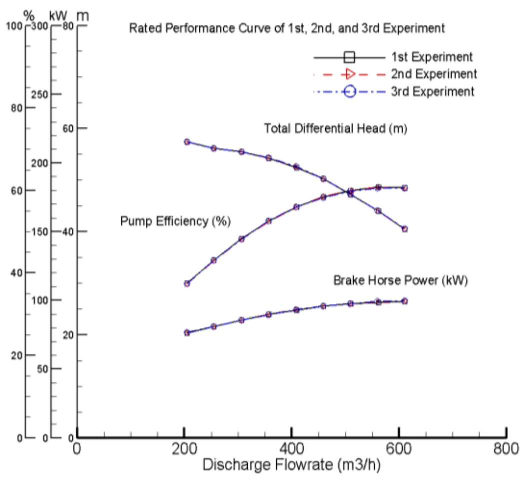

Fig. 5. The Performance curve of the mechanical pump in sodium environment at 250℃, rated RPM

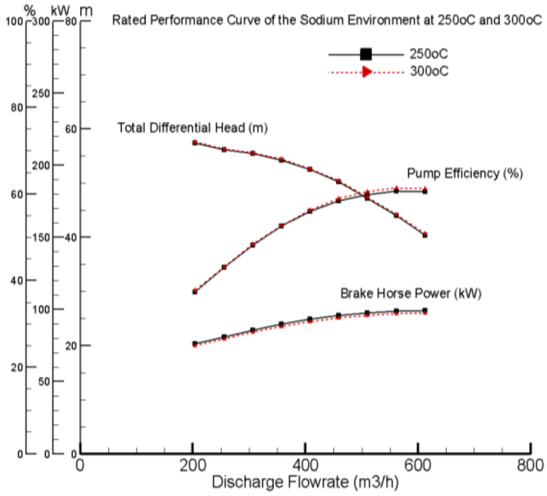

Fig. 6. The comparison of performance curve of the mechanical pump in sodium environment at 250℃ and 300℃, rated RPM.

Table 4 The halving time with flywheel variation

Flywheel No.	Valve open rate	Q(kg/s)	RPM	Halving time (sec)			Ave. (sec)
				1st	2nd	3rd	
CM-45C-0005	Full opening	62.371	742	10	10	11	10.3
		124.741	1461	8	8	9	8.3
	Rated opening	62.371	1089	9	9	9	9.0
		124.741	2140	6	6	7	6.3
CM-45C-0002	Full opening	62.371	742	15	15	16	15.3
		124.741	1461	12	12	12	12.0
	Rated opening	62.371	1089	13	13	13	13.0
		124.741	2140	10	10	10	10.0

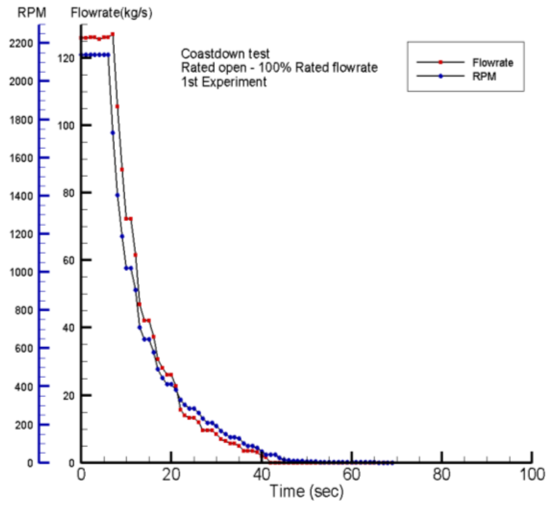

Fig. 7. Pump discharge flow rate and rotational speed of pump with time variation after pump seize-up (CM-45C-0005, rated opening, rated flow rate, 1st test)

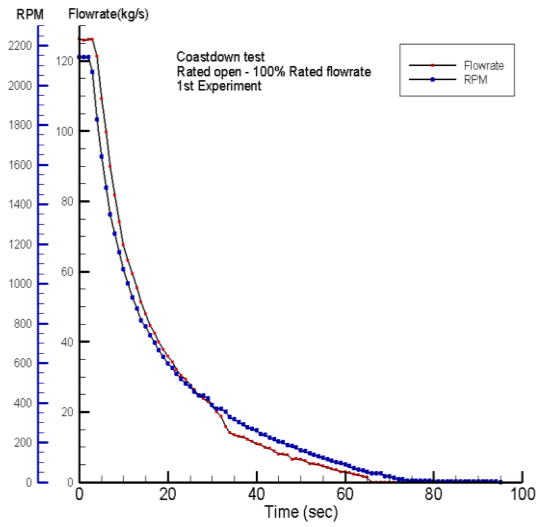

Fig. 8. Pump discharge flow rate and rotational speed of pump with time variation after pump seize-up (CM-45C-0002, rated opening, rated flow rate, 1st test)

4. Conclusion

There was no experience of operating of mechanical pump with sodium environment in domesticity. So, there were many trial and errors for the mechanical pump in-sodium performance test.

The mechanical pump in-sodium performance test was successfully performed with good reproducibility of the experiment and data to compare hydraulic characteristic of a mechanical pump in-water was collected.

In effect of temperature variation on the pump pressure head, reduction of pump pressure head at 250℃ by 0.57% of that of 300℃ maybe the result of an increase in sodium viscosity by 13.6% according to operating temperature decrease by 50℃.

Also, we confirmed that the more flywheel weight, the longer halving time and the more initial flow rate when the pump seized, the shorter halving time.

The results of the mechanical pump performance test data in sodium environment will be used to compare with that of the in water environment after the evaluation of measurement uncertainty for tests

And then the comparison result will be used to be shown that performance test data in-water for mechanical pump of Prototype Gen IV SFR can be used instead of in-sodium experimental data, obviously.

5. Acknowledgement

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