Progress in the performance verification of PCHE type Na-CO_2 heat exchanger

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1. Introduction

Supercritical carbon dioxide(S-CO_2) Brayton cycle is attractive alternation for energy conversion system for SFR because it inherently excludes the sodium-water reaction. Also S-CO_2 Brayton cycle makes it possible to minimize the size of the overall system and reduce the compression work.

This study is about intermediate heat exchanger (IHX) for SFR with S-CO_2 Brayton cycle. To propose an advanced design concept for the Na-CO_2 heat exchanger, numerical simulations of six cases with different channel configurations and bank types at the sodium side were conducted. And an experimental test facility with liquid sodium loop and S-CO_2 loop was setup for verification of heat exchanger design. A PCHE type pilot heat exchanger was fabricated and trial run was conducted.

2. Numerical simulation

2.1 Objective function

Conventionally, a good heat exchanger is one that has a high volume-to-heat-transfer-rate ratio and a small pressure drop or pumping power within a specific operation condition. In this regard, the objective function in this research was defined as in equation (1). (Q : total heat transfer rate [W], V : volume [m^3], P_{sodium} : Pumping power [W])

$$f = \frac{Q}{V\,P_{sodium}} \tag{1}$$

2.2 Model development

Numerical simulation was conducted using the FLUENT software. Continuity equation, momentum equation and energy equation are used as governing equations in all the cases.

Pressure and velocity were coupled by SIMPLE method, pressure was discretized by PRESTO scheme, and momentum, turbulent kinetic energy, turbulent dissipation rate and energy was discretized by second order upwind scheme. In order to consider turbulent effect on numerical simulation, RNG k-epsilon model was used and enhanced wall treatment was used as near wall treatment.

2.3 Inlet / outlet conditions and boundary conditions

The inlet conditions in each cases are listed in Table I. The inlet mass flow rate and temperature was referred by [1]. The turbulence intensity in all cases was 2. Symmetric boundary conditions were used for each side in order to reduce the numerical cost.

Table I : Inlet conditions of each case

Case	$\dot{m}_{Na}$ [kg/s], T_{Na} [°C]	$\dot{m}_{Na}$ [kg/s], T_{Na} [°C]
1	0.00055766, 526	0.00060733, 354
2	0.00027883, 526	0.00030366, 354
3	0.00013942, 526	0.00030366, 354
4	0.00027883, 526	0.00060733, 354
5	0.00013942, 526	0.00030366, 354
6	0.00006971, 526	0.00030366, 354

2.4 Geometry modeling

The width of PCHEs for all cases were fixed to 1 m. At the sodium side, 150, 300 and 600 number of flow channel with rectangular shape were arranged and the pitch of channel was defined as 1.5 times bigger than the width of flow channel. And all the cases had the same geometry at the CO_2 side as with the airfoil-shaped channel proposed in previous research which showed superior performance in pressure drop at same heat load than conventional channel shapes (zig-zag, s-shape) [2].

2.5 Result

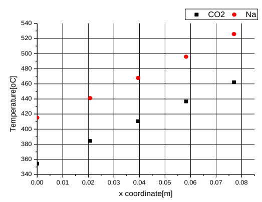

Fig. 1 Temperature distribution along the flow path of case3(600,single bank type)

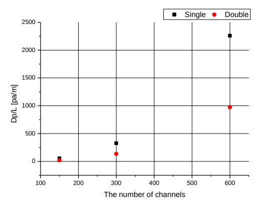

Fig. 2 DP/L at sodium side

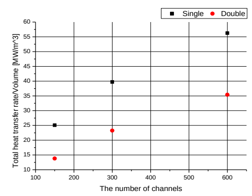

Fig. 3 Total heat transfer rate/volume of each case

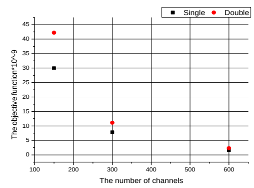

Fig. 4 The objective function of each case

3. Experimental study

3.1 Setup of experiment loop

For verification of heat transfer performance and pressure drop of the heat exchanger designs, an experiment loop was set up, which were composed of a liquid sodium loop and a S-CO_2 loop. Fig. 5 shows the schematic design of the experiment loop. Left side of the figure is liquid sodium loop and right side is the S-CO_2 loop. The PCHE heat exchanger placed between the loops.

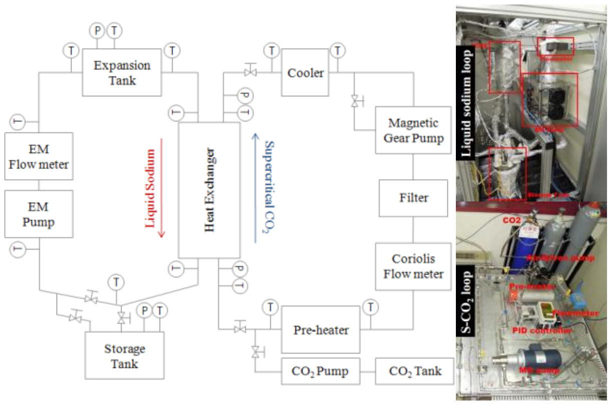

Fig. 5 Schematic diagram of test loop

3.2 Fabrication of a pilot heat exchanger

'Channel 600' with 'single bank' case was fabricated as a pilot heat exchanger because there are limitations in size (depth : width = 60 : 100, maximum depth = 1.2 mm) and shape (semi-circle or rectangular with round edge shape) with etching techniques. So the pilot heat exchanger has semi-circle shape straight channel with 1.8 mm diameter which is same hydraulic diameter with 'channel 600' case.

Table II : Design parameter of the pilot heat exchanger

	Hot side (Na)	Cold side (S-CO_2)
Max. Press. / Temp.	6 bar / 400'C	100 bar / 400'C
Number of plate	3	6
Channel number of 1 plate	30	-
Hydraulic diameter	1.10 mm	-
Height of channel	0.9 mm	0.5 mm
Plate thickness	1.5 mm	1.0 mm
Width × Length	110.5 × 210 (mm)	
Flow area	114.5 mm^2	114.9 mm^2
Material	SS316L	SS316L

3.3 Trial run

The trial run for the pilot heat exchanger model was conducted and Table III and IV shows the test conditions and results, respectively.

Table III : Test conditions of pilot heat exchanger

	Hot side (Na)	Cold side (S-CO_2)
Operating pressure	0.75 kPaG	92.5 bar
Mass flowrate (kg/min)	0.63 ~ 1.03	0.48
Inlet temperature	175'C	126'C
Reynolds number	214 ~ 354	1,945

Table IV. Test results of pilot heat exchanger

	Hot side (Na)	Cold side (S-CO_2)
Heat transfer rate	0.292 ~ 0.411 kW	
Overall HTC	316.2 ~ 347.3 W/m^2K	
Pressure drop	2.2 kPa	3.35 ~ 3.38 kPa
Nusselt number	-	0.00108~0.00118

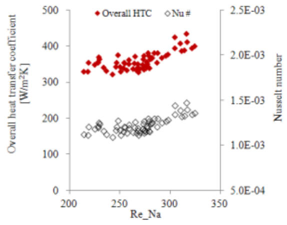

Fig. 6 Reynolds number vs. heat transfer coefficient and Nusselt number of liquid sodium

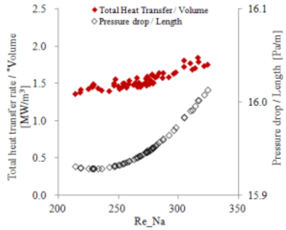

Fig. 7 Reynolds number of liquid sodium vs. pressure loss per unit length and heat transfer rate per unit volume

4. Conclusions

To suggest advanced design for IHX for SFR with S-CO_2 Brayton cycle, numerical simulation study and experimental study have been conducted.

In the numerical simulation study, the performance of 6 cases with different sodium channel shape with the different bank type were compared.

To verify and suggest an advanced design of Na-CO_2 heat exchanger, experiment loop was set up and trial run was conducted with pilot heat exchanger (channel 600, single bank case). The results of trial run showed the tendency to a reasonable.

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REFERENCES

[1] KAERI "Supercritical Carbon Dioxide Brayton Cycle Energy Conversion System", KAERI,RR-2973,2007

[2] D.E. Kim, M.H. Kim, J.E. Cha, S.O. Kim, "Numerical investigation on thermal-hydraulic performance of new printed circuit heat exchanger model", Nuclear Engineering and Design 238,2008