Development of Printed Circuit Heat Exchanger and Experimental Test Loop For Liquid Sodium - Supercritical Carbon Dioxide Heat Exchange

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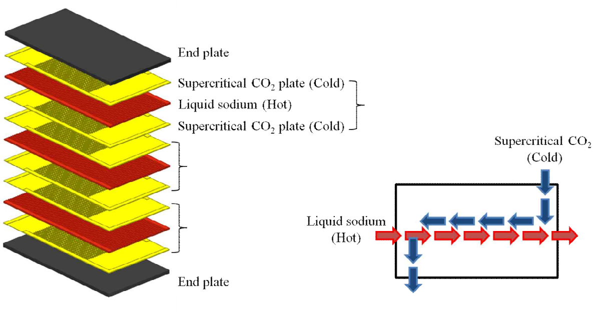
1. Introduction

Sodium-cooled Fast Reactor (SFR) has many advantages with its fundamental design, for example, high temperature operation in low pressure and feature of spent nuclear fuel combustion. Nevertheless, public rejection on the possibility of sodium-water reaction accident and higher construction cost than light-water reactors delay the commercialization of SFR. Recently, as part of the study on the next generation nuclear reactor, researches on high efficiency energy cycles have been conducted, and Brayton cycle with supercritical carbon dioxide(S-CO_2) began to emerge as a strong alternative to the Rankine cycle with steam. [1] Supercritical carbon dioxide Brayton cycle system inherently excludes the sodium-water accident by using S-CO_2 instead of steam. Also, adoption of Brayton cycle concept makes it possible to minimize the size of the overall system and reduce the compression work. Currently we are conducting an optimization of heat exchanger design for Na-CO_2. In this article, configuration of a heat exchanger and the experimental loop for the purpose of heat exchanger verification will be introduced.

2. Heat Exchanger

In S-CO_2 Brayton cycle, liquid sodium - supercritical CO_2 heat exchanger is the largest volume portion of the system. An integrated heat exchanger design is essential to reduce the entire volume. PCHE type heat exchanger shows high compactness, high temperature and pressure durability, and anti-leak robustness.



(a) Stack layer (Double bank type) (b) Flow pattern (Counter flow)

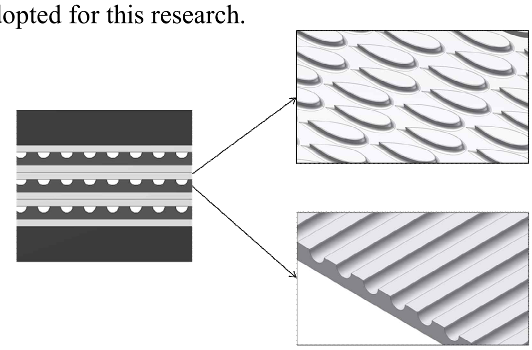
Fig. 1. Configuration of the PCHE and flow pattern

2.1 PCHE Type Heat Exchanger

Figure 1 (a) shows the configuration of heat exchanger design. As is shown above, liquid sodium (hot side) plate is wrapped on top and bottom with S-CO_2 (cold side) plate which makes double bank type stack method. The stacked three plates (S-CO_2 / Sodium/ S-CO_2) constitute one basic unit, and the three basic units are stacked in a row. Finally, the end plates are wrapped on the top and bottom side of the entire stack. Figure 1 (b) shows the flow pattern of heat exchanger. Liquid sodium and S-CO_2 exchanges heat by moving in counter flow. Flow path of liquid sodium was made straight in order to drain liquid sodium completely.

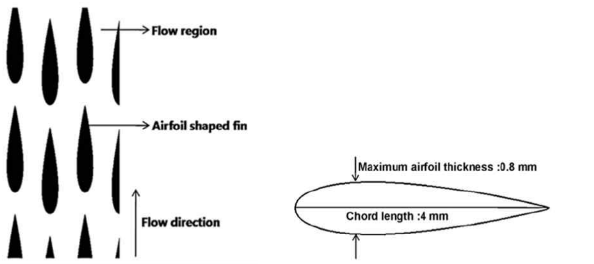
2.2 Flow Channel Configuration of PCHE Plates

Figure 2 shows the shape of the flow channels where the working fluids are passing through. On the cold side plate, a number of airfoil shaped fins are arranged as is shown on the figure 2 (b)-(up). S-CO_2 exchange heat by moving between the arranged fins. Airfoil fin type was chosen for cold side channel configuration, because it performs better in heat transfer and dramatically reduces pressure drop in comparison to other channel shapes.[2] Figure 3 shows the details about the patterns which we adopted for this research.



(a) Cross section of PCHE (b) Channel shape of each plate: (up) supercritical CO2 side, (down) liquid sodium

Fig. 2. Flow channel of each PCHE plate



(a) Airfoil fin PCHE plate for supercritical CO_2 side [2] (b) Airfoil shape (NACA 0020); Generated by DesignFOIL R6, Expert Demo 6.223 DreeseCODE Soft [2]

Fig. 3. Airfoil fin shape PCHE plate for cold side

Table I: Heat exchanger specification

Parameters	Hot side	Cold side
Design pressure	6 bar	100 bar
Design temperature	400'C	400'C
Flow area	114.5 mm^2	144.9 mm^2
Number of plates	3	6
Number of channels	90	-
Hydraulic Diameter	1.10 mm	-
Plate thickness	1.5 mm	1 mm
Channel height	0.9 mm	0.5 mm
Capacity	0.024 liters	-
Nozzle size	1" pipe	3/8" tube
Dimension (H x W x L)	30.5 x 110.5 x 210	
Material	Stainless Steel 316L	

For the hot side plate, because of superior thermal conductivity of liquid metal, the most simple channel shape was chosen by considering cost of manufacture and maintenance.

3. Experimental Loop

Figure 4 shows the schematic diagram of the experimental loop for liquid sodium – supercritical CO_2 heat exchanger. It has liquid sodium loop and S-CO_2 loop, separately and respectively.

In the sodium loop, 5~6 liters of liquid sodium flows in the loop and 2~3 liters of it is contained in expansion tank. The total volume of liquid sodium is 8~9 liters and initially contained in storage tank. For measurement of flow rate, Coriolis mass flow-meter (RHEONIK, RHM 04) is used. For control of flow rate, electromagnetic pump and bellows typed regulating valve is used. To compensate the heat loss and maintain the experimental condition, wire heaters are installed on the outside of pipes and components. As a heat source, emersion typed electric heater is installed inside of the expansion tank. In the S-CO_2 loop, mass flow rate is controlled by using magnetic drive gear pump (Micropump GLHH25, Lesson SCR rated DC Motor) and is measured by using Coriolis mass flow meter (RHEONIK, RHM 03 a1). S-CO_2 is heated to the experimental temperature condition by using pre-heater (Watlow Cast X-2000, 6kW). As a heat sink, shell and tube typed heat exchanger is installed on the loop, which is connected to the outside constant temperature tank unit. Table 2 shows the standard operating condition of the current experimental loop design.

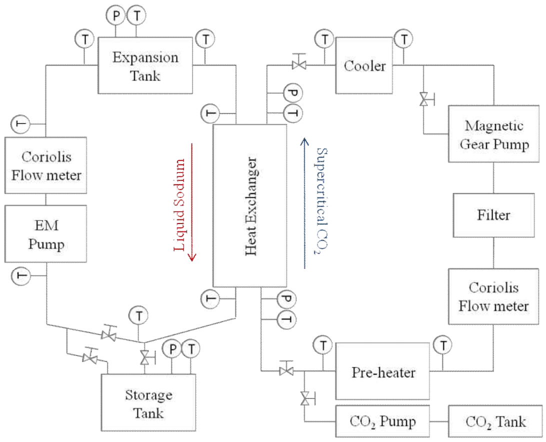


Fig. 4. Schematic diagram of experimental loop

Table 2: Operating condition of the experimental loop

Parameters	Hot side	Cold side
Flow rate	1~2 kg/m	0.5~1.5 kg/m
Heat transfer rate	1~3 kW	
Temperature range	180~240'C	130~240'C
Pressure	1 bar	80~90 bar

4. Following Works

As soon as the setup of the experimental loop and safety test are completed, verification test for the designed PCHE typed heat exchanger for liquid sodium -supercritical carbon dioxide will be conducted successively.

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