Preliminary Plugging tests in Narrow Sodium Channels by Sodium and Carbon Dioxide reaction

Sun Hee Park*, Myung-Hwan Wi, and Jae Hong Min
Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, Korea
**Corresponding author: sunheepark@kaeri.re.kr*

1. Introduction

Printed circuit heat exchanger (PCHE) is considered for the supercritical CO_2 Brayton cycle power conversion system of sodium-cooled fast reactors (SFRs), which is known to have potential for reducing the volume occupied by the sodium-to-CO_2 exchangers compared to traditional shell-and-tube heat exchangers [1, 2]. This report is on the investigation of the physical/chemical phenomena that a slow loss of CO_2 inventory into sodium after the sodium-CO_2 boundary failure in PCHEs in realistic operating conditions. The first phenomenon is potential channel plugging inside the narrow PCHE channel. Unlike a conventional shell-and-tube type HXs, failures in a PCHE are expected to be small cracks. If the faulted channel is blocked, it may have a positive function for plant safety because the pressure boundary would automatically recover due to this self-plugging. The other one is damage propagation on pressure boundary, which is referred to as potential wastage with combined corrosion/erosion effect. Here, we report our preliminary experimental results of plugging tests.

2. Methods and Results

2.1 Experimental Facility

Plugging experiments were carried out in the facility as reported previously (Figure 1) [3].

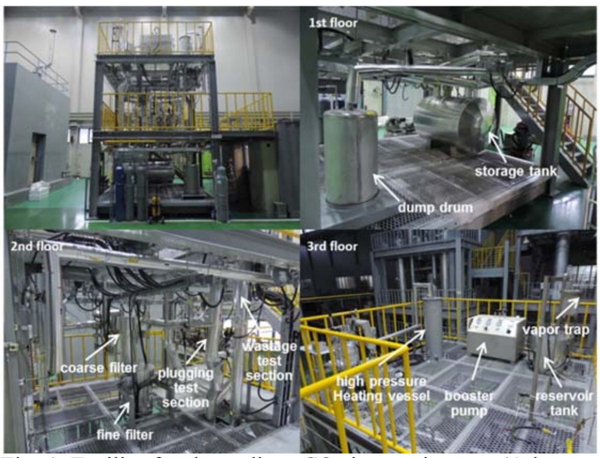

Fig. 1. Facility for the sodium-CO_2 interaction test (A booster pump and a high pressure heating vessel were added on 3rd floor recently).

2.2 Experimental Procedure

Plugging experiments for the reaction of sodium and CO_2 were carried out in the facility as reported previously (Figures 2 and 3) [3].

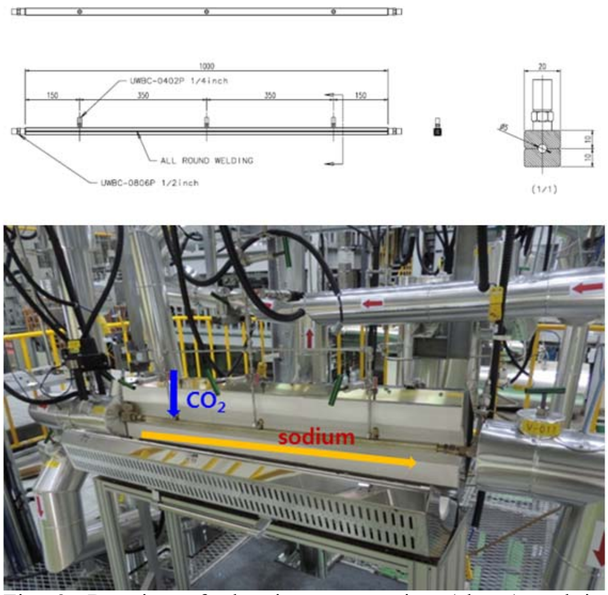

Fig. 2. Drawing of plugging test section (above) and its equipment in the facility (below [3]).

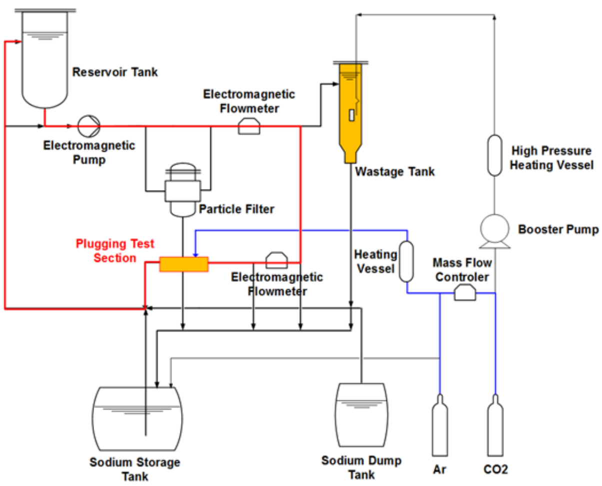

Fig. 3. Schematic diagram for the plugging experiment (red: sodium flow, blue: CO_2).

2.3 Experimental Results

Flow rates of sodium with CO_2 injection into the plugging test section (single sodium channel) in at 300–400 °C are shown Figure 4. Flow rates of sodium in both 3 and 5 mm (inner diameter) of single sodium channel were slower as CO_2 injection at 300−400 °C. Flow rates of sodium in 3 mm channels at 300−400 °C decreased earlier and faster compared to 5 mm channels. In 3 mm of sodium channels, flow rates of sodium decreased immediately as CO_2 injection and reached at 0 m/s at 300 and 350 °C. In 5 mm of sodium channels, flow rates of sodium decreased as CO_2 injection similar to those in 3 mm sodium channels. However, they reached at 0 m/s for 33, 350 and 75 min at 300, 350, and 400 °C, respectively. In both 3 and 5 mm of sodium channels, temperatures of sodium at inlet and outlet of the test section decreased when flow rates of sodium decreased at 300−400 °C. These results are not consistent with previous studies about reaction of sodium and CO_2, in which temperature of sodium increased by exothermic reaction of sodium and CO_2 [4, 5]. Analysis of these results is of interest in this study.

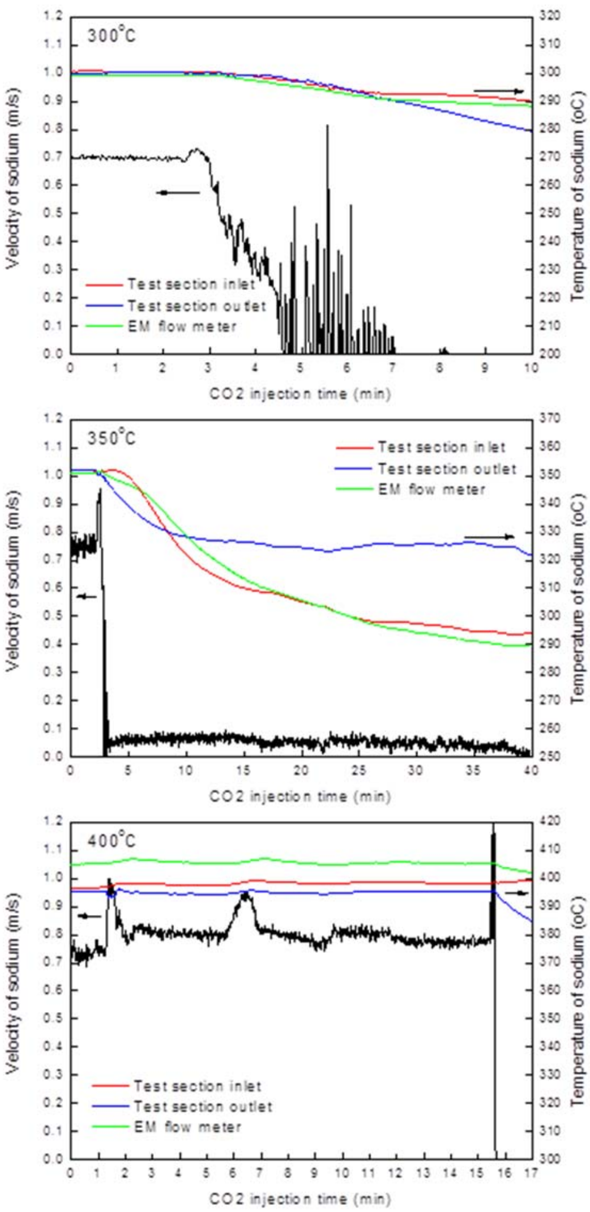

Figure 4. Flow rates of sodium in 3 mm channel with CO_2 injection into the plugging test section.

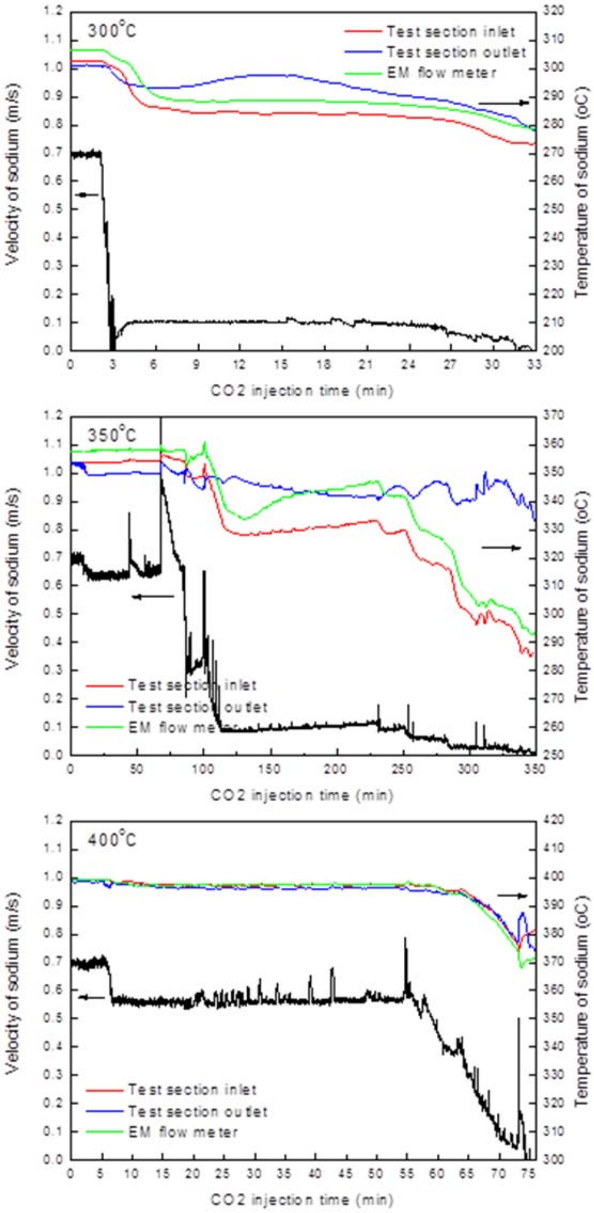

Figure 5. Flow rates of sodium in 5 mm channel with CO_2 injection into the plugging test section.

It is known that reaction products such as sodium carbonate (Na_2CO_3) and amorphous carbon which are hardly soluble in sodium plug sodium channels. Proposed mechanism for reaction sodium and CO_2 is as follows [6]:

$2Na(s, l) + CO_2(g) \rightarrow Na_2O(s, l) + CO(g)$
$Na_2O(s, l) + CO_2(g) \rightarrow Na_2CO_3(s, l)$
$2Na(s, l) + CO(g) \rightarrow Na_2O(s, l) + C(s)$
$4Na(s, l) + 3CO_2(g) \rightarrow 2Na_2CO_3(s, l) + C(s)$
$4Na(s, l) + CO_2(g) \rightarrow 2Na_2O(s, l) + C(s)$
$2Na(s, l) + 2CO_2(g) \rightarrow Na_2CO_3(s, l) + CO(g)$
$C(s) + CO_2(g) \rightarrow 2CO(g)$

Above 400 °C, 100 μm of nozzle completely shrank by thermal expansion of the test section (stainless steel 316). During sodium is heated to the temperature of the experimental condition, Ar gas was fed into the test section through the nozzle to prevent the nozzle from plugging. Ar gas was ordinarily supplied up to ~410 °C, whereas Ar gas hardly injected and then stopped when the temperature of the test section at ~410 °C. These results imply that micro cracks (< 100 μm) at pressure boundary of sodium-CO_2 might be automatically clogged above 410 °C.

3. Conclusions

Physical/chemical phenomena that a slow loss of CO_2 inventory into sodium after the sodium-CO_2 boundary failure in printed circuit heat exchangers (PCHEs) were investigated. Our preliminary experimental results of plugging show that sodium flow immediately stopped as CO_2 was injected through the nozzle at 300−400 °C in 3 mm sodium channels, whereas sodium flow stopped about 60 min after CO_2 injection in 5 mm sodium channels. These results imply that if pressure boundary of sodium-CO_2 fails in a narrow sodium channel (≤ 3 mm) would be plugged by reaction products in a short time whereas a relatively wider sodium channel (≥ 5 mm) would be plugged with higher concentration of reaction products.

REFERENCES

[1] Vaclav Dostal, Pavel Hejzlar, and Michael J. Driscoll, High-performance supercritical carbon dioxide cycle for next-generation nuclear reactors, Nuclear Technology, Vol. 154, p. 265, 2006.
[2] Yoichi Momozaki, Dae H. Cho, James J. Sienicki, and Anton Moisseytsev, Experimental investigations on sodium plugging in narrow flow channels, Nuclear Technology, Vol. 171, p. 153, 2010.
[3] Sun Hee Park, Myung-Hwan Wi, Jae Hong Min, and Tae-joon Kim, Investigation of Plugging of Narrow Sodium Channels by Sodium and Carbon Dioxide Interaction, Transactions of the Korean Nuclear Society Spring Meeting Jeju, Korea, May 7-8, 2015.
[4] Shinya Miyahara, Hiroyasu Ishikawa, and Yoshio Yoshizawa, Experimental investigation of reaction behavior between carbon dioxide and liquid sodium, Nuclear Engineering and Design 241 (2011) 1319.
[5] C. Latgé and N. Simon, Investigation of sodium-carbon dioxide interactions; potential consequences on reactor operation, Proceeding of Global 2007, Boise, Idaho, September 9-13, 2007.
[6] Daniele Vivaldi, Frédéric Gruy, Nicole Simon, and Christophe Perrais, Modeling of a CO2-gas jet into liquid-sodium following a heat exchanger leakage scenario in Sodium Fast Reactors, Chemical Engineering Research and Design 91 (2013) 640.