Investigation of Plugging of Narrow Sodium Channels by Sodium and Carbon Dioxide Interaction

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1. Introduction

The supercritical CO_2 Brayton cycle system is known to be a promising power conversion system for improving the efficiency and preventing the sodium-water reaction (SWR) of the current SFR concept using a Rankine steam cycle [1–3]. Among the various types of heat exchangers, printed circuit heat exchangers (PCHEs) are considered for the supercritical CO_2 Brayton cycle. PCHEs are known to have potential for reducing the volume occupied by the sodium-to-CO_2 exchangers as well as the heat exchanger mass relative to traditional shell-and-tube heat exchangers [4, 5].

Here, we report a study on a plugging test by the interaction of sodium and CO_2 to investigate design parameters of sodium channels in the realistic operating conditions.

2. Methods and Results

2.1 Experimental Facility

A plugging experiment was carried out in the facility whose size is 3.5 m by 3.5 m by 6.0 m for its width, depth, and height, respectively (Figures 1 and 2). The facility consists of mechanical components (sodium storage tank (~300 L of sodium inventory), sodium reservoir tank, sodium coarse filter, sodium fine filter, plugging test section, wastage test section, sodium dump drum, sodium catch tray, and CO_2 heating storage, gas collector) and electrical control/measurement components (sodium electromagnetic pump (EMP), sodium electromagnetic flow meter (EMFM), CO_2 mass flow controller (MFC), CO_2 mass flow meter (MFM), pressure transducer (PT), electrical heating coil, and electrical heating furnace). On the 1st floor, a storage tank, dump drum, catch tray, gas cylinders, air compressor, MFC, and MFM are placed. On the 2nd floor, an EMP, filters, an EMFM, and a plugging test section are placed. On the 3rd floor, a reservoir tank, wastage test section, gas cooler, and gas collector are placed. All components are connected with each other by welded pipes for sodium or by fitted tubes for gases, which are fixed with brackets at the H-beam frame and wrapped with electrical heating coils and insulators. The EMP, EMFM, MFC, electrical heating coil, and electrical heating furnace are electrically controlled with control systems.

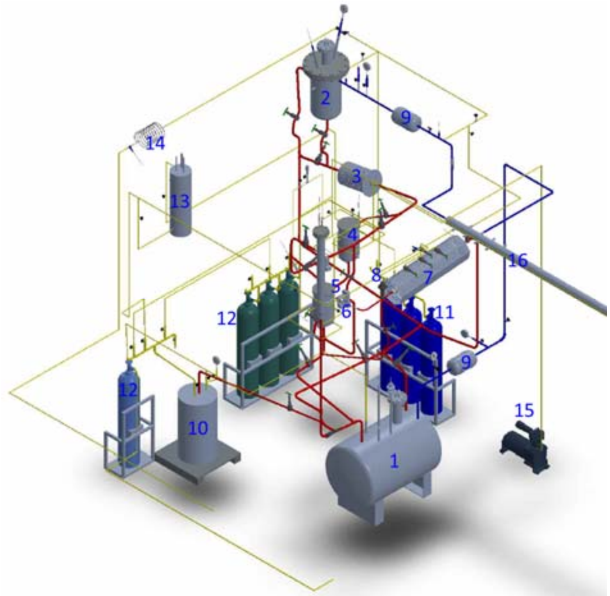

Fig. 1. 3-dimension drawing of the facility (catch tray, electrical heating coils, and insulators are omitted): 1, storage tank; 2, reservoir tank; 3, EMP; 4, coarse filter; 5, fine filter; 6, EMFM; 7, plugging test section; 8, MFC; 9, vapor trap; 10, dump tank; 11, CO_2 cylinder; 12, Ar cylinder; 13, gas heating storage; 14, gas cooler; 15, air compressor; 16, gas collector.

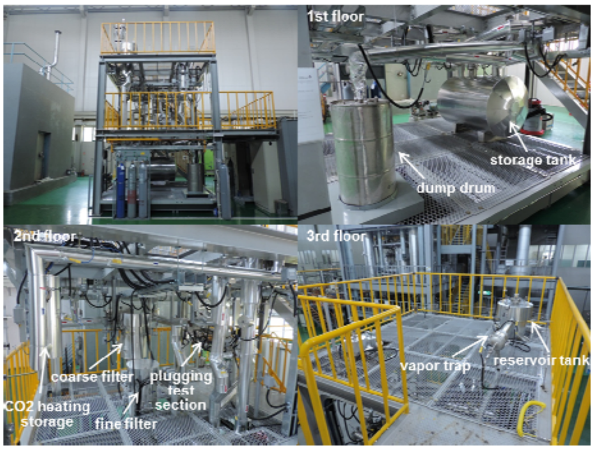

Fig. 2. Facility for the sodium-CO_2 interaction test.

2.2 Plugging Experiments

A plugging experiment for the interaction of sodium and CO_2 was carried out in the facility. Electrical heating coils and a furnace were used to heat the facility. The operation procedure for the plugging experiment is as follows. The specimen was equipped in the facility, whose inner diameter (ID) and length were 3–5 mm and

700 mm, respectively, and whose one side had a hole of 100 μm ID to be injected with CO_2 (Figure 3).The facility was heated at 200 °C, and purged with Ar for 60 min to eliminate any effects of O_2. The reservoir tank was charged with sodium (4.9 L) from the storage tank pressurized by Ar at 0.1–0.5 bar. The whole facility was heated up to the experimental temperature (300–500 °C). Sodium was circulated by the EMP in the facility. The flow rate of the sodium and temperatures reached a steady state. CO_2 heated at the experiment temperature in the heating storage was injected into the test specimen. When the flow rate of sodium decreased down at 0 L/min, the injection of CO_2 was stopped and the experiment was finished. The sodium used was drained into the dump drum, and the facility was flushed with Ar for ~30 min.

Fig. 3. Equipped plugging specimen for the sodium-CO_2 interaction test.

2.3 Experimental Results

The flow rates of sodium with 3 and 5 mm ID specimens at 300 °C for 12 min of CO_2 injection are shown in Figure 4. The flow rates of sodium started to decrease at 3 min and reached 0 mL/min at 8 min with the 3 mm ID specimen, whereas it started to decrease at 8 min and reached 0 mL/min at 13 min with the 5 mm ID specimen. Thus, at 300 °C, the flow rate of sodium was greatly slowed with a smaller diameter of the sodium channel.

After the flow rate of sodium started to decrease, it reached 0 L/min within 2 min (from 3 to 5min) and 5 min (from 8 to 13 min) with 3 and 5 mm ID, respectively, where the decreases in the flow rates of sodium were 0.35 L/min^2 and 0.12 L/min^2, respectively. Thus, the decrease in the flow rate of sodium with 3 mm ID was higher than that with 5mm ID. It has been known that products such as sodium carbonate or amorphous carbon cause this plugging phenomenon [1–3]. Plugging experiments for the interaction of sodium and CO_2 at 400–500 °C are going to be conducted.

3. Conclusions

We investigated a plugging test by an interaction of sodium and CO_2 with different cross sectional areas of the sodium channels. It was found that the flow rate of sodium decreased earlier and faster with a narrower cross sectional area compared to a wider one. Our experimental results are expected to be used for determining the sodium channel areas of PCHEs.

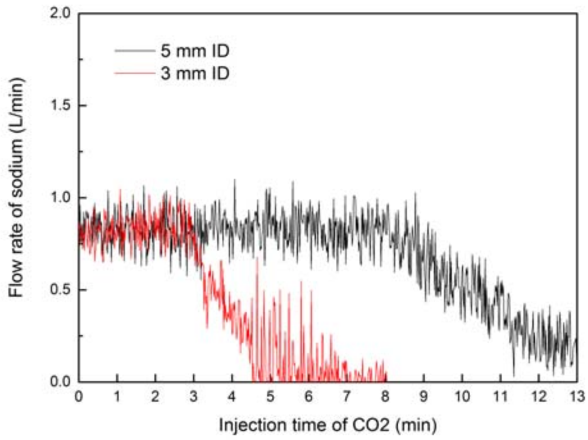

Fig. 4. Flow rates of sodium with 3 and 5 mm ID of sodium channels at 300 °C.

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