Variations in CO concentration based on the control parameters during Na-CO_2 reaction

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1. Introduction

One of the energy conversion system options in Sodium-cooled Fast Reactor (SFR) is a supercritical CO_2 Brayton cycle that enables to exclude the sodium-water reaction (SWR) when SFR employs a conventional Rankine cycle. Besides the advantages, the pressure boundary of 20 MPa at the tubes in the heat exchanger where the high-pressure CO_2 gas flows inside the tube surrounded by the liquid sodium at the atmospheric pressure provides a potential risk of the Na-CO_2 interaction. Therefore it is necessary to understand the chemical reaction between a CO_2 gas and the liquid sodium. It has been known that the Na-CO_2 reaction is relatively less energetic than SWR. However, for the design of the S-CO_2 based SFR, quantitative assessment of Na-CO_2 reaction is required.

In general, sodium reacts with CO_2 gas above 300 ℃ and chemical reaction is getting vigorous as the reacting temperature increases [1]. Additionally, chemical reaction would likely produce CO gas and sodium carbonate during Na-CO_2 reaction test [2]. Recently, a two-zone reaction model was reported with a threshold temperature around 460 ℃ accompanied with a rapid change in the activation energy [3].

As a part of the computational code development of Na-CO_2 reaction, this study aims to gain a fundamental understanding of the Na-CO_2 reaction. Therefore, it analyzes the effect of the experimental parameters which is expected to take part in the chemical reaction. The experimental parameters to be considered are reacting area, temperature and CO_2 flow rate.

For the practical application of SSFR, the CO concentration were investigated based on the experimental parameters in order to determine the reactivity.

2. Experimental arrangement

2.1 Experimental conditions

An experimental temperature range is determined based on the operating temperature of KALIMER-600 which is a sodium-cooled fast reactor designed by KAERI [4]. Next parameter is reacting area where liquid sodium and CO_2 gas contact. The CO_2 flow rate (5 ~ 15 SLPM) is determined by considering sensitivity of the velocity of CO_2 flowing over the gas-liquid reacting interface.

For a various reacting area, different size of sodium tray is manufactured based on the reacting area which is 8 cm^2 (20 mm Ｘ 40 mm) and 12 cm^2 (20 mm Ｘ 60 mm) with the depth of 15 mm. The summarized experimental conditions are following Table. 1.

Table 1: Experimental conditions

Parameters	Set value	Remarks
Reaction area	8–12 cm^2	2cm×(4cm & 6cm)
Temperature	350–500℃	±3℃ for set value
CO_2 flow rate	5–15 SLPM	Micro-leak
Test time	15–30 min	Stabilization time
CO_2 purity	99.999 %	Moisture <3 vppm
Ar purity	99.999 %	Moisture <3 vppm

2.2 Experimental facility

The experimental facility is designed to enable the Na-CO_2 reaction test with consideration of various parameters and characteristics of sodium as shown in Fig 1. The feature of this facility is a reactor attached to the bottom of a glove box (1200 × 760 × 740 mm^3) to avoid contamination of the sodium surface.

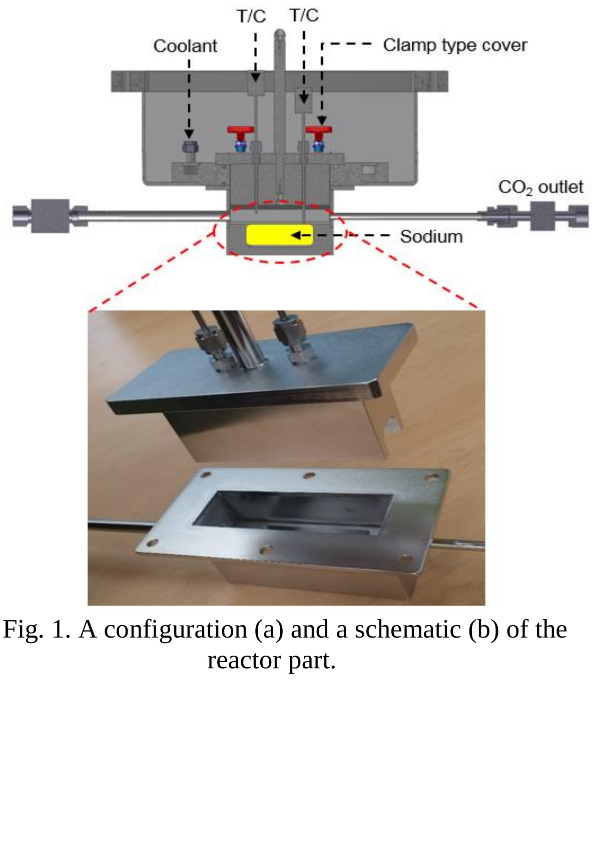

Fig. 1. A configuration (a) and a schematic (b) of the reactor part.

The upper part of this facility takes a role of glove box and allows the transport and loading of sodium. The lower part is used as a test section and analyzer.

The reactor, which played a key role in the Na-CO_2 reaction test, is fabricated of stainless steel (SST316). The reactor is rectangular in shape and the size of the reactor is 150 mm in length, 80 mm in width and 60 mm in height as shown in Fig. 1. Additionally, this reactor is used with a toggle clamp to separate the environment between the glove box and the reactor during the Na-CO_2 reaction test. The toggle clamp can tighten the channel-type cover, which is designed to eliminate any gas stuck in the reactor corner.

The heaters for heating the liquid sodium and CO_2 gas up to target temperature are insulated with Cerakwool (KCC, Korea) and finally wrapped in a stainless steel cover and aluminum foil. Additionally, K-type thermocouples with a 1/16-inch outer-diameter sheath is inserted at every 200 mm to improve the accuracy of target temperature. When the experimental condition is satisfied, CO_2 gas flows in the reactor and reaction is started on the sodium surface. During the Na-CO_2 reaction, gas phase reaction product (CO gas) is analyzed in a real time by non-dispersive infrared (NDIR) analyzer.

3. Results

3.1 Effects of the reacting surface area

Experimental results are analyzed at the same temperature under the same flow rate to investigate the effect of the reacting surface area. The wider the reacting area is, the higher CO concentration is measured as shown in Fig. 2. Especially, converting CO concentration per unit area, the maximum error is less than 1.1 vppm. From this result, the reacting area is not involved in the chemical reaction and this result can be used as data to ensure the reliability of experimental facility and the validity of all experimental results.

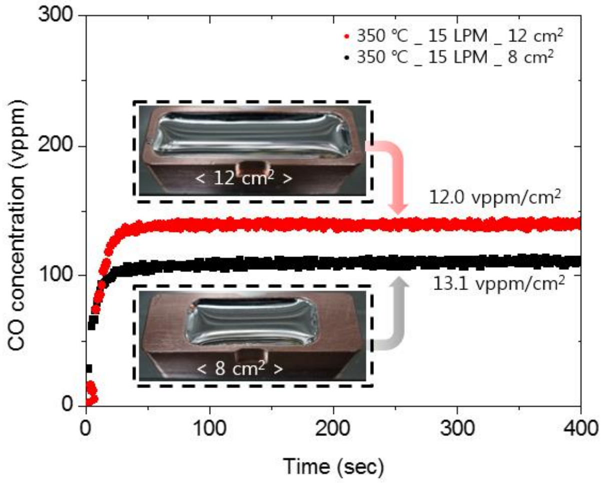

Fig. 2. Variations in CO concentration based on A_{Na}.

3.2 Effects of the reaction temperature.

As previous experiments and theoretical studies have reported, the CO concentration depends highly on reaction temperature. This result also shows a significant difference in the CO concentration between the high-temperature region, i.e. above 450 ℃, and the low-temperature region. Particularly, considering all of the results for each pivot temperature, the CO concentration is not much different in the low-temperature region. Therefore, it can be expected that the Na-CO_2 reaction rarely occurs below 450 ℃.

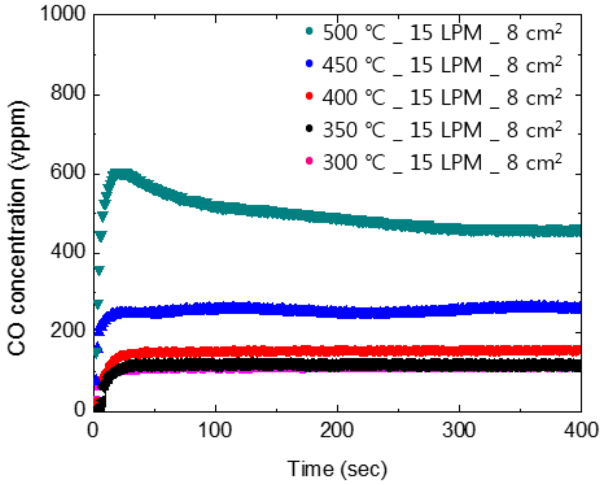

Fig. 3. Variations in CO concentration based on T_{Na}.

3.3 Effects of the CO_2 flow rate

The CO concentration measured at 5 SLPM is higher than at 12 SLPM in all of the experimental results as shown in Fig. 4. This result shows a decrease in the CO/CO_2 conversion rate, although a large amount of CO_2 gas is supplied. The reason is that large amount of CO_2 gas bypasses without reaction with sodium in the reactor. Additionally, CO gas is vented continuously together with the bypassed CO_2 gas at the high flow rate. Thus, CO gas flows into the gas analyzer at a high flow rate and that results in low concentration. However, at the low flow rate, CO gas flows into the gas analyzer with a high concentration due to the small amount of CO_2 gas. Therefore, it is found that the concentration per unit volume of the CO gas is measured to become low in the NDIR analyzer.

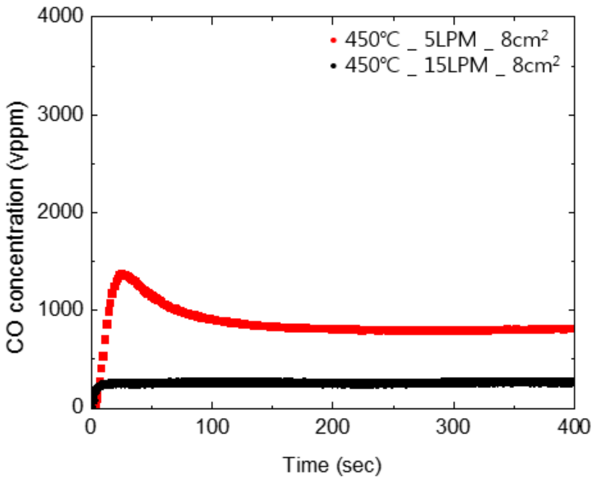

Fig. 4. Variations in CO concentration based on $\dot{m}_{CO_2}$

4. Conclusion

In the basic step for understanding of Na-CO_2 reaction, which is a potential accident situation of sodium-cooled fast reactor, the chemical reaction between liquid sodium and CO_2 is investigated through various surface reaction test with well-controlled test parameters. The reactivity of Na-CO_2 reaction is determined by analyzing the nominal concentration of the CO gas in the venting gas.

Based on the experimental results, it is confirmed that Na-CO_2 reaction over the sodium temperature range of 300 ℃ to 500 ℃ heavily depends on the temperature. Actually, it is found that the reactivity is influenced by velocity of CO_2 flowing over the gas-liquid reacting interface as well as sodium temperature in this study.

These results will be contributed to validate a computational code of Na-CO_2 reaction for the SFR safety analysis under development in POSTECH.

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