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Experimental Investigation of Gaseous Reaction Products from Na-CO_2 Reaction in Na/CO_2 Heat Exchanger leakage scenario

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1. Introduction

Sodium-cooled Fast Reactor (SFRs) is one of the most promising candidates for a fast neutron reactor. The SFRs have operated with the steam Rankine cycle as a power conversion system. However, the potential sodium-water reaction (SWR) whose chemical reactivity is vigorous and instantaneous has been one of the major issues concerning the safety and integrity of the SFRs. In order to avoid SWR, supercritical CO_2(S-CO_2) Brayton cycles have been investigated recently. Compared to conventional steam Rankine cycles, S-CO_2 Brayton cycle features higher thermal efficiency and potential compactness of its required equipment. In spite of the superiority of S-CO_2 Brayton cycle, there is a potential reactive process between sodium and CO_2 if the pressure boundary fails in the sodium-CO_2 heat exchanger. The leakage scenario which could lead to mechanical and thermal problems should be evaluated.

Previous studies have reported the following major reaction formulas [2]. Each reaction occurs competitively.

$$4Na(l) + CO_2 \rightarrow 2Na_2O(s) + C(s) + \Delta H° \quad \Delta H° = -442.3kJ/mol \quad (1)$$

$$4Na(l) + 3CO_2 \rightarrow 2Na_2CO_3(s) + C(s) + \Delta H° \quad \Delta H° = -1081.1kJ/mol \quad (2)$$

$$2Na(l) + 2CO_2 \rightarrow 2Na_2CO_3(s) + CO(g) + \Delta H° \quad \Delta H° = -454.5kJ/mol \quad (3)$$

$$4Na(l) + 4CO_2(g) \rightarrow Na_2C_2O_4(s) + CO(g) + Na_2CO_3(s) + \Delta H° \quad \Delta H° = -980.1kJ/mol \quad (4)$$

where (s), (l) and (g) denote the solid, liquid and gas phases, respectively. All reactions are exothermic with the negative value of the standard enthalpy change ($\Delta H°$). In these reactions, unreacted CO_2 and generated CO are gathered in the cover gas space and affect its pressure. It threatens the integrity of the system. Also carbon monoxide (CO) is a poisonous gas so it requires attention.

Previous studies regarding Na-CO_2 reaction were performed in KAERI (Korea Atomic Energy Research Institute), JAEA(Japan Atomic Energy Agency), and CEA(Commissariat à l'Energie Atomique). KAERI and JAEA conducted the studies on thermodynamic and kinetic aspect of Na-CO_2 [1, 2]. In CEA, the results from the experimental and numerical studies were compared for the case of under-expanded gas-into-liquid jet [3].

These studies are fundamental for modeling a leakage scenario in Na-CO_2 heat exchanger of SFR. However, there is still insufficient information to fully understand the CO_2 leak mechanism and its consequences. Thus, this experiment is planned to obtain more information about the effect of mixture of unreacted CO_2 and gas reaction products (i.e. CO) by measuring the pressure variation and CO concentration in the system during the CO_2 leak.

2. Experiment

2.1 Experimental setup

The main objectives of the experiment are to obtain the trend of pressure variation in the system and CO concentration. The experimental loop consists of several parts: a main test section where the chemical reaction takes place, a gas supply vent system, instrumentation and gas sampling system. The schematic diagram of the experimental loop and a photo of the apparatus in glove box are shown in Figs. 1 and 2, respectively.

2.2 Experimental Conditions and Test Procedures

The experimental conditions are listed in Table I. The pressure of the system and concentration of CO/CO_2 will be measured under following flow rate and temperature conditions.

Table 1 : Experimental condition

Case number	Temperature of sodium and CO_2 (℃)	Flow rate of CO_2 (ml/min)
1-1	200	150
1-2		300
2-1	400	150
2-2		300
3-1	450	150
3-2		300
4-1	500	150
4-2		300

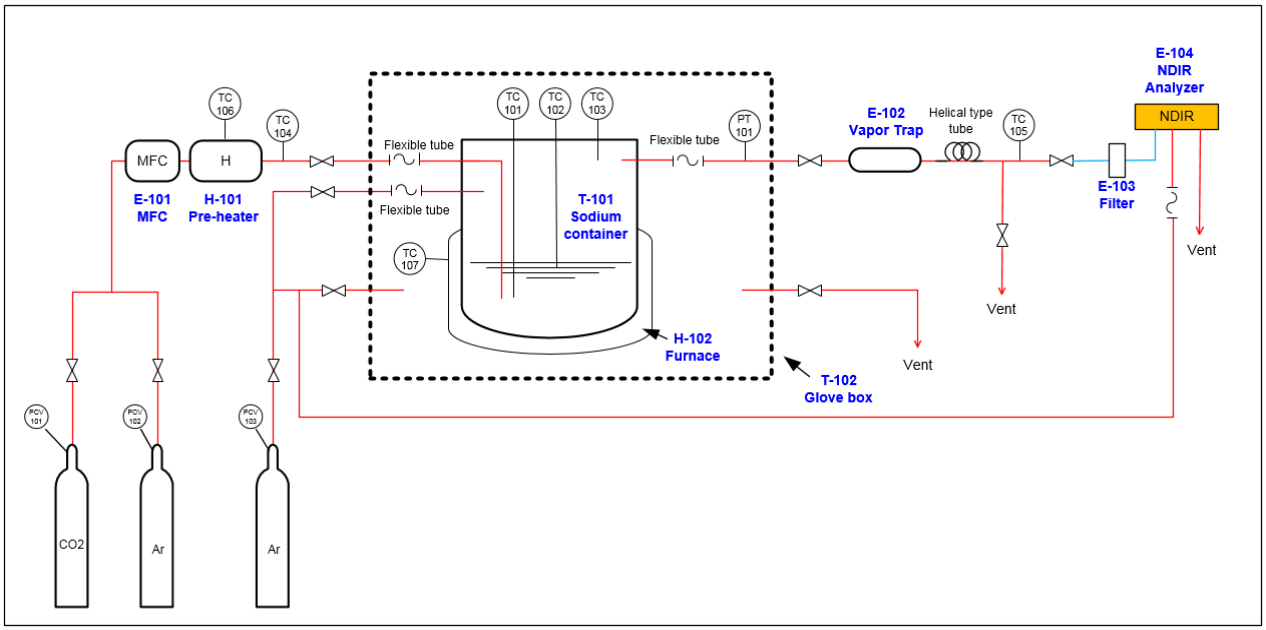

Figure 1. Schematic diagram of the experimental loop

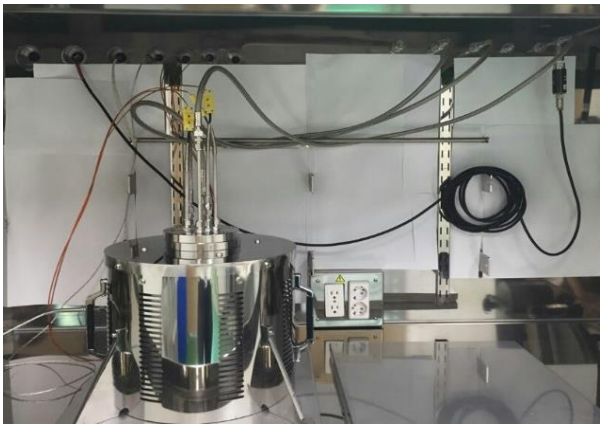

Figure 2. The photo of the apparatus in glove box

All valves are closed to block the inflow of outside gas. Sodium ingot will be put into the sodium container with purging argon gas into the test section continuously, and the sodium container is sealed. The temperature of furnace covering sodium container is set to 110℃ to dissolve sodium. If sodium is melted, the temperature of the furnace is set to 500℃ at atmospheric pressure as experimental condition. CO_2 gas is heated up to 500℃ by the preheater then will be injected into test section through a nozzle with 0.5mm in diameter. The emitted gas, CO/CO_2 mixture, is continuously sampled through the nondispersive infrared (DNIR) analyzers then the CO/CO_2 concentration data were recorded during the test. After finishing measurement and analysis, the experimental device is cooled down under argon gas atmosphere. In the end, the apparatus is dismantled and washed out.

3. Summary and Further works

In this paper, the experimental setup to observe the pressure variation and CO concentration in Na-CO_2 heat exchanger during the CO_2 leak is explained.

Before the experiment is carried out, water-CO_2 mock-up test will be performed. Based on the result of water-CO_2 mock-up test, more suitable experimental conditions will be set again.

Even though some research works on investigating Na-CO_2 interaction have been performed previously, the study on the analysis of pressure variation due to the mixture of unreacted CO_2 and CO has not been performed yet. Thus, in order to evaluate the leakage scenario in Na-CO_2 heat exchanger more accurately, this study will be important for guaranteeing the system of SFR coupled with S-CO_2 cycle.

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