Investigation of Na-CO_2 Reaction with Initial Reaction in Various Reacting Surface

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1. Introduction

The supercritical carbon dioxide (S-CO_2) Brayton cycle option for energy conversion in a Sodium-cooled Fast Reactor (SFR) has recently been focused on as it could eliminate the potential Sodium Water Reaction (SWR) in Rankine cycle. Nevertheless, when the pressure boundary tube between liquid sodium and CO_2 gas ruptures, potential risk of CO_2 interacting with liquid sodium still exists. If the Supercritical carbon dioxide (S-CO_2) in the heat transfer leaks into liquid sodium with temperature approximately 500 °C, then it generates the CO gas and Na_2CO_3 by Na-CO_2 reaction on the sodium surface. This reaction products that cause oxidation and erosion are threaten the heat transfer tubes so that it is necessary to investigate Na-CO_2 reaction according to various experimental parameter.

Unlike SWR, Na-CO_2 reaction is more complex to deal with reaction kinetics. Since a comprehensive understanding of Na-CO_2 reaction mechanism is crucial for the safety analysis, the reaction phenomenon under the various conditions was investigated. The current issue is to make a database for developing computational code for CO_2 gas leak situation because it is experimentally difficult to analyze the actual accident situation.

Most studies on Na-CO_2 interaction reports that chemical reaction is getting vigorous as temperature increased and reactivity is sensitive as temperature change [1] between 400 °C and 600 °C. Therefore, temperature range is determined based on the operating condition (450~500 °C) of KALIMER-600 [3] employed as supercritical CO_2 brayton cycle energy conversion system for Na-CO_2 heat exchanger. And next parameter is sodium surface area which contact between sodium and CO_2 when CO_2 is injected into sodium pool in the accident situation. So, the fundamental surface reaction is experimentally studied in the range of 8~12 cm^2. Additionally, it has been reported in recent years that CO_2 Flow rate affects reactivity less significantly and CO_2 flow rate is assumed that 5 SLPM (standard liter per minute) is suitable as a basis for a small leakage [4]. The finally selected control parameters is sodium temperature and reacting surface area with constant CO_2 flow rate.

2. Methods and Results

2.1 Experimental condition

Various sodium tray is manufactured according to the appropriate reacting area which is 8 cm^2 (20 mm x 40 mm), 10 cm^2 (20 mm x 50 mm) and 12 cm^2 (20 mm x 50 mm). The depth of all sodium filled in sodium tray is fixed at 15 mm. The Experimental conditions are summarized in Table.1.

Table I: Experimental condition

Parameters	Experimental range
Reacting surface area	8~12 cm^2
Reacting temperature	450~500 °C
CO_2 feeding flow rate	5 SLPM
Na purity	99.999 %
CO_2 gas purity	99.999 %

2.2 Experimental facility

To perform the actual surface reaction of liquid sodium and CO_2, the integrated facility with glove box and reactor is manufactured which is shown in Fig 1.

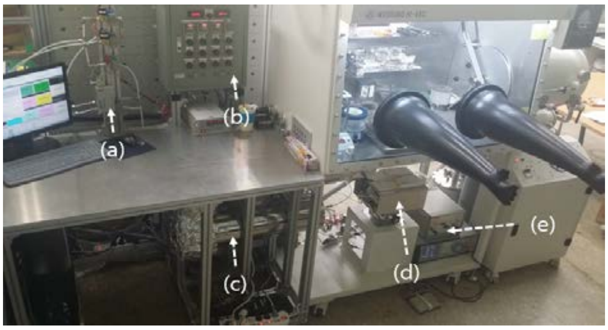

Fig. 1. Configuration of experimental facility: (a) Mass flow controller (MFC), (b) Control box, (c) Gas line heater, (d) Reactor and heater, (e) Non-dispersive infrared absorption (NDIR).

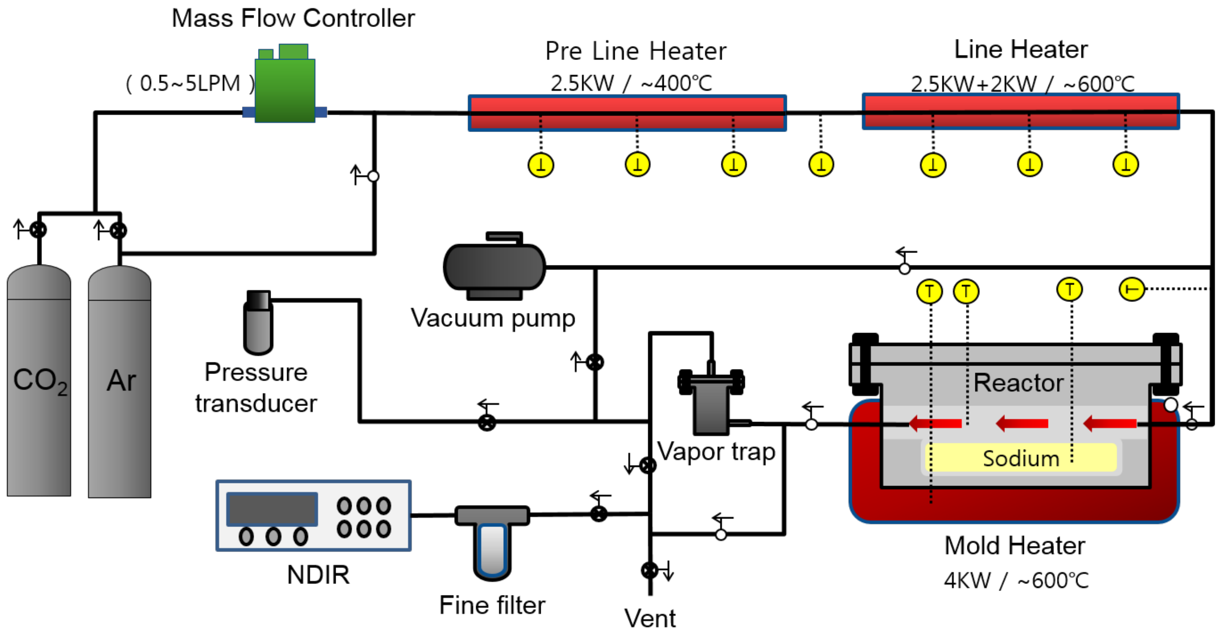

Fig. 2. Flow diagram of the experimental loop

The main experimental facility is divided by 2 parts; reactor and CO_2 heating line. Reactor (110mm x 40mm x 30mm) is attached at the bottom of the glove box (1200mm x 760mm x 840mm) and heated by 4kW ceramic mold type heater. CO_2 heating line consists of pre line heater which is coiled up the tube by 2.5kW cartridge heater and line heater which is coiled up the tube by 2.5kW + 2kW cartridge heater.

The flow diagram of the experimental loop is shown in Fig 2. The sodium is treated in the glove box to avoid contamination and sodium tray is installed at the reactor after filled with liquid sodium (< 10 g). And then, reaction test is prepared by separating the condition of glove box and reactor using cover. After test preparation, the reactor is heated up to target temperature with flowing the Ar gas controlled by MFC (Mass Flow Controller) at 5 SLPM. When the experimental condition is satisfied, CO_2 gas flows in the reactor and reacts with liquid sodium at Na-CO_2 interface. During the Na-CO_2 reaction, gas phase reaction products (CO) is analyzed in real time by Non-dispersive infrared absorption (NDIR).

2.3 Test results

Reactivity of Na-CO_2 is determined by measuring CO gas concentration over time (vppm/s) during the reaction. As shown in Fig. 3, the area under the CO concentration line in real time represents the amount of CO gas generated and slope (vppm/s) means reaction rate. Through this slope, the initial reaction rate of 12 cm^2 and 10 cm^2 is more vigorous than 8 cm^2 one. The peak point means reactivity and the area under the line is the consumption of sodium by reacting with CO_2. Therefore, the more reacting area is wider, the more reaction amount is large.

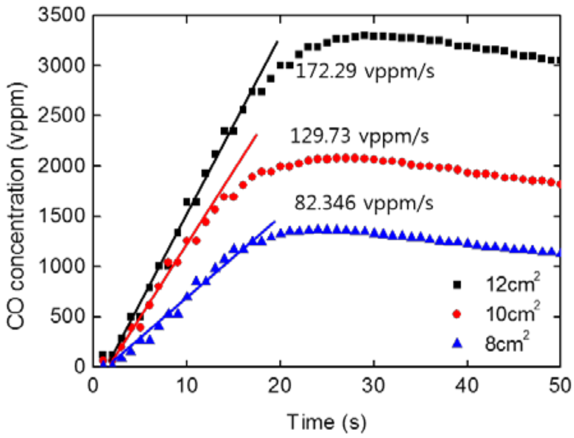

Fig. 3. CO concentration change during Na-CO_2 reaction at 450 °C with surface area variation.

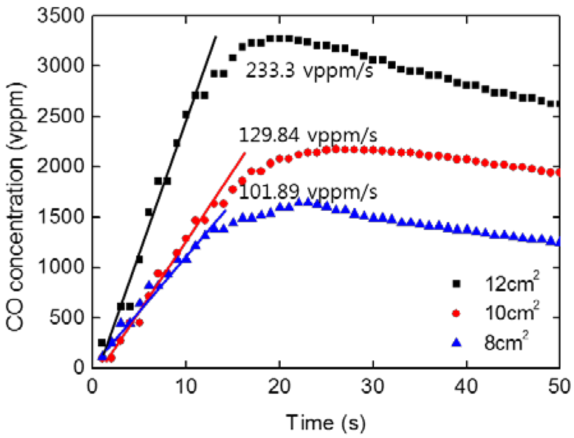

Fig. 4. CO concentration change during Na-CO_2 reaction at 500 °C with surface area variation.

Fig. 5. Sodium surfaces after reaction test at 500 °C; (a) 10 cm^2, (b) 12 cm^2

By comparing to Fig. 3 and Fig. 4 respectively, initial slopes are much higher in 500 °C case than 450 °C ones. This means that reaction rate is highly dependent of temperature. However, peak point is similar regardless of temperature increasing. This is mainly because solid phase reaction products are produced at the Na-CO_2 interfacial area and this reaction products prevents to contact with sodium and CO_2 as shown in Fig 5. Therefore, reaction takes place only by diffusion of CO_2 molecular. As a result, although generation of solid phase reaction products is getting higher, CO concentration is similar because the energy of CO molecular is high and diffusivity is getting better as temperature increased.

3. Conclusions

Na-CO_2 reaction test is performed for investigating risk of potential accident which contacts with liquid sodium and CO_2. The control parameters are temperature range of 450~500 °C and reacting area range of 8~12cm^2. As a result, as temperature goes up, initial reaction rate is getting higher and the production of solid phase reaction products is much larger. And the similar amount of sodium is participated in reaction rage of 450~500 °C region regardless of reacting area. Furthermore, amount of reaction is saturated as time passed because of kept a balance between production of solid phase reaction products and amount of diffusivity.

These results contribute to make a database for the SFR safety analysis and additional experiments are needed at high temperature in various reacting area.

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