Investigation of a Wastage Effect by a Potential CO_2 Ingress in a Supercritical CO_2 Power Conversion System of an SFR

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1. Introduction

The supercritical CO_2 Brayton cycle option has been considered as a promising alternative for the power conversion system of an advanced sodium-cooled fast reactor (SFR). One of the most important benefits of this option is that plant safety can be remarkably improved due to its highly reliable design features that make it essentially free from risk of a sodium-water reaction.

In spite of this superiority, the potential pressure boundary failure should be assessed to cope with the consequential sodium-CO_2 intermixing event. The major design issues affecting the likelihood of a CO_2 ingress accident into liquid sodium are i) a wastage phenomenon in regard to structural damage adjacent to the leaking position, and ii) potential channel-plugging due to the formation of a particulate reaction product.

In order to understand the factors affecting the occurrence of these issues, the potential wastage effect tests were carried out and the specific consequences of the sodium-CO_2 interaction were compared to those of a sodium-water reaction.

2. Methods and Results

The experimental work for the wastage effect test was executed in order to verify the possibility of a combined corrosion/erosion effect on the structure surface due to the impingement of the reaction products of the sodium-CO_2 interaction. Detailed descriptions are provided in the following sections.

2.1 Experimental setup and test conditions

The experimental loop for the wastage test consists of the main reaction vessel where the chemical reaction takes place and associated components including a gas supply system, sodium feed/drain systems, a sodium storage tank, a dump drum, vapor traps, instrumentation, and gas sampling systems. The flow diagram of the test facility is depicted in **Figure 1**.

The defect of the pressure boundary rupture in the wastage test was simulated by a small nozzle diameter of 300 micrometers, and modified 9Cr-1Mo tube was used as the target wall with a 12-mm pitch length of the reference design [1]. The CO_2 injection nozzle and target wall were integrated as shown in **Figure 2**, and the target assemblies were immersed into the sodium pool through the top flange of the reaction vessel.

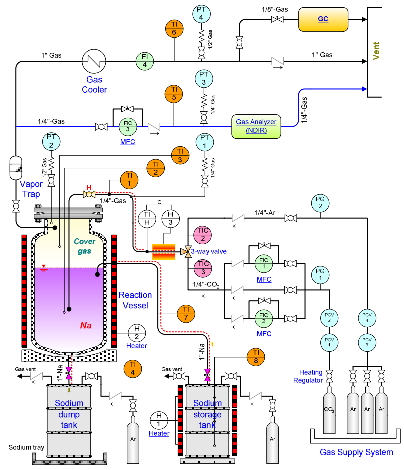

Fig.1 Flow diagram of the wastage tests

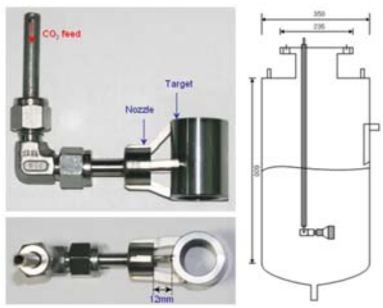

Fig.2 Target assembly of the wastage test

In order to simulate practical accident conditions, all experimental conditions were chosen to reasonably represent the normal operating conditions and realistic design parameters of the reference plant[1]. The CO_2 injection flow rates were not measured in this test since the major parameter affecting the wastage phenomenon is the upstream gas pressure. The major values set as experimental conditions are listed in **Table 1**.

Table 1. Experimental conditions for the wastage test

Parameters	Set value	Remarks
Sodium volume	~ 40 liters	Cylindrical vessel
Initial *Na* temp.	350 ~ 550°C	Normal operation
Nozzle diameter	0.3 mm	Fixed
CO_2 pre-heating	~ 400°C	Lower bound temp.
CO_2 pressure	~ 55 bar	Gas bottle pressure
CO_2 supplying time	120 sec	Mod. design basis
Test vessel pressure	< 1 bar	Practical condition
Sodium purity	99.999 %	Oxygen : < 10 vppm
Gas purity(CO_2, *Ar*)	99.999 %	Moisture : < 3 vppm

2.2 Results and discussion

Since the chemical reaction between liquid sodium and CO_2 gas are totally dependent on the reaction temperature [2], the combined corrosion/erosion effect on the structure surface was investigated with respect to the sodium temperatures. On the basis of wastage test results, it was observed that a large amount of solid reaction products was accumulated and curdled around the target assembly during the sodium-CO_2 interaction.

Figure 3 shows the post-test views of the target surfaces after cleaning of each target specimen. Post-test examinations of the target tubes were made to provide quantitative data regarding the damaged area and the depth of the wastage-affected zone. The results of the surface examinations are provided as the sequence of the initial sodium temperatures.

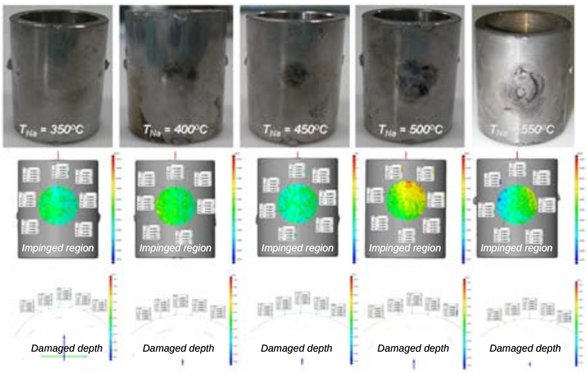

Fig.3 Post-test examination of the target tubes

Since a large amount of reaction heat was allocated to the impinged area, the target surface experienced a kind of thermal damage. Hence, the region directly impinged by the CO_2 jet became dark as the initial sodium temperature increased, as shown in **Figure 3**. In spite of the apparent damage, little mechanical degradation was observed on the target surface. The damaged depth was far less than 10 micrometers, which was not much different from the manufacturing roughness of the tube material. Hence, a combined corrosion/erosion effect was not observed, even in higher temperature tests.

In order to compare this feature with the SWR case, the results of high-pressure steam injection tests [3] were cited in this study. The tests were carried out in the same manner as the CO_2 injection test, and the modified 9Cr-1Mo steel was also chosen for the test specimen. The pressure and temperature of the injected steam were 150 bar and 350°C, respectively. The steam injection time was 30sec, and the initial sodium temperatures were selected as 400°C and 450°C for the mean temperatures of the reference steam generator design [1]. **Figure 4** shows the results of the steam wastage effect tests[3].

The post-test view of the target assembly of the SWR case is significantly different from the result of the sodium-CO_2 interaction. There were few solid reaction products on the target surface in the SWR case because the melting temperature of sodium hydroxide (NaOH), one of the major by-products of an SWR, is 328°C [4]. For this reason, most reaction products were melted and removed with liquid sodium after the test.

On the other hand, the target surface was apparently damaged to a depth of 1.4~2.4 mm depending on the test conditions [3]. Hence, the surface degradation rate of the SWR case was determined to be approximately 4 mm/min on average, while that of the sodium-CO_2 interaction was less than 0.005mm/min.

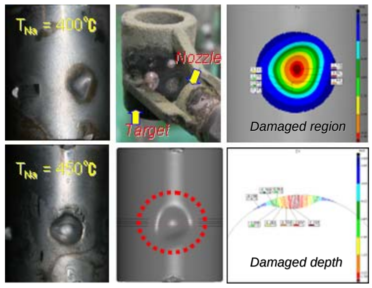

Fig.4 Wastage effect on a sodium-water reaction [3]

This is very different feature between a sodium-CO_2 interaction and a SWR, and this comparison confirms that the potential surface degradation resulting from CO_2 impingement could be negligible for normal sodium operating temperatures. Hence, the wastage scenario including additional damage propagation does not need to be considered.

3. Conclusions

The potential wastage scenario during the sodium-CO_2 interaction was investigated, and the absence of the combined corrosion/erosion effect on the target surface was observed. Finally, the potential for the wastage scenario including additional damage propagation would not be expected at normal operating temperatures of the SFR power conversion system.

ACKNOWLEDGEMENT

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