Development of Experimental System for Material Compatibility Test for Ultra-long Cycle Fast Reactor (UCFR)

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1. Introduction

Sodium is a candidate for fast reactor coolants that has been believed to have favorable compatibility with structural materials. However, recent studies showed results which need for a more careful attention at this previous belief [1, 2]. For prolonging the service life time of cladding and structural materials in contact with liquid sodium, more detail analysis methods are needed to examine this material compatibility issue with sodium.

As a candidate of liquid metals coolants of Ultra-long Cycle Fast Reactor (UCFR), the compatibility of sodium with cladding materials has to be investigated in detail with long term exposure time.

It is known that sodium promotes corrosion in two ways. One is corrosion produced by dissolution of alloy elements into sodium and the other is corrosion produced through a chemical reaction with impurities in sodium (especially, dissolved oxygen) [3].

The use of the technique of impedance spectroscopy to measure the electrical impedance response of any oxide layers may be a good experimental tool to this monitoring system [4].

The motivation of current study is to investigate the relationship between the electrochemical behaviors of oxide scales on martensitic and austenitic steels and their corrosion rates in liquid sodium.

2. Experimental system set-up

Mainly three parts of experimental systems are under development. It consists of corrosion cell line (with mini-loop), coolant path line and purification line as shown in Fig. 1.

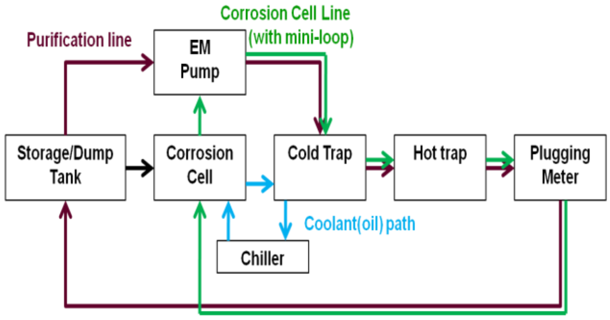


Fig. 1. The design concept of experimental system

2.1 Corrosion cell design

The corrosion cell consists of mainly parts with electrodes, molybdenum crucible, and thermal well. First, the electrodes are with reference electrode, counter electrode, and working electrode. In detail, the material of reference electrode is cerium oxide that is stable in liquid sodium at high temperature, the material of counter electrode is molybdenum that has low solubility in liquid sodium such as inert material, and the material of rotating working electrode is ferritic/martensitic steel that is insulated by stable ceramic from liquid sodium.

As reference electrode material, YSZ (Yttria Stabilized Zirconia) tube is widely used for electrolyte but the zirconia (ZrO_2) reacts with liquid sodium and make a compound such as Na_2ZrO_3 as shown Fig. 2. (a). However, Ceria (CeO_2) is stable in liquid sodium at high temperature as shown in Fig. 2. (b). So, Ceria is chosen as reference electrode electrolyte that oxygen ions easily move through wall. For strengthening the oxygen ion conductivity of ceria, gadolinia and samarium are usually doped and their ion conductivity values are shown in Table I.

And cerium oxide tube (as reference electrode) is extended with SS430 tube that has the same thermal expansion coefficient due to its length limit from manufacturing process.

Table I. Basic property of ceramic materials [7, 8]

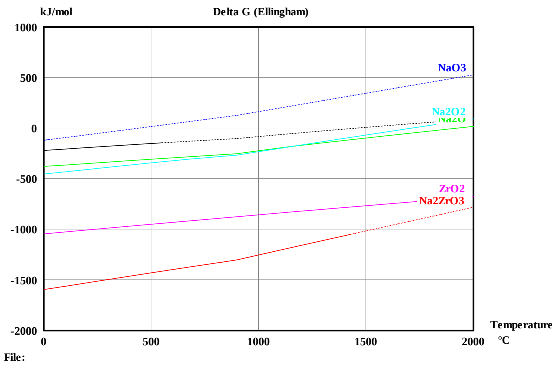
	CTE (ppm/℃)	IC (S/cm)
GDC-10	13.4	-1.2
SDC-15	12.7	-1.3
YDC-10	14.5	-3.7
YSZ-10	10.8	-2.25

*CTE: Coefficient of Thermal Expansion
*IC: Ion Conductivity at 700℃
*GDC: Gadolinia Doped Ceria
*SDC: Samaria Doped Ceria
*YDC: Yttria Doped Ceria
*YSZ: Yttria Stabilized Zirconia

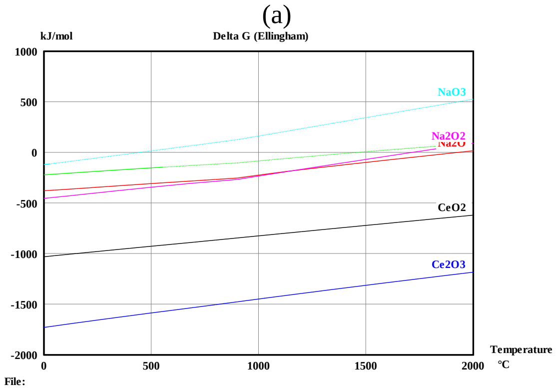
2.2 Experimental approach

As mentioned earlier, the motivation of this work is to measure the corrosion rate of specimens by electrochemical analysis.

In liquid sodium environment, the rotating disk electrode (RDE) is one of few convective electrode systems for which the hydrodynamic equations and the convective-diffusion equation have been solved rigorously for the steady state. This electrode is rather simple to construct and consists of a disk of the electrode material imbedded in a rod of an insulating material.



(a)



(b)

Fig. 2. Gibbs free energy changes of (a) Na-Zr-O system and (b) Na-Ce-O system (by HSC 6.0)

The general convective-diffusion equation is below:

$$\frac{\partial C_j}{\partial t} = D_j \nabla^2 C_j - v \cdot \nabla C_j \qquad (2)$$

The convective-diffusion equation, for the rotating disk electrode, written in convenient coordinates and with appropriate boundary conditions, can be solved.

2.3 Purification system

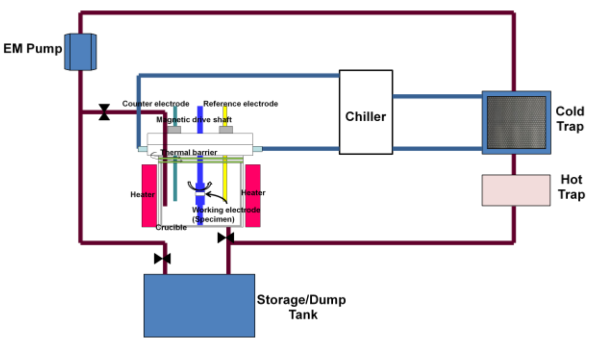


Fig. 3. The schematic of experimental system

As mentioned earlier, the corrosion process is dependent on the chemical reaction with dissolved oxygen in sodium [3]. The oxygen is controlled at a concentration as low as reasonably achievable to minimize the corrosion kinetics of the materials [5].

The technique used is to provide a circulation of liquid sodium in a cold trap. The cold trap is the most widely used of several liquid sodium purification methods. Impurity removal by precipitation utilizes the difference in solubility of impurities in sodium at difference temperature.

3. Summary

Electrochemical system to monitor the corrosion rate of specimens under liquid sodium environment at high temperature is under development. In liquid metal at high temperature, electrochemical analysis based on rotating disk electrode will be performed to evaluate the long term corrosion behaviors of candidate cladding and structural materials for the application to Ultra-long Cycle Fast Reactor .

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