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Corrosion of Candidate Structural Materials in a Flowing NaCl-$MgCl_2$ Salt Environment

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1. Introduction

The Molten Salt Reactor (MSR) utilizes fluoride or chloride-based molten salt as a coolant for the system [1]. Notably, fuel materials are dissolved in the molten salt, making it possible for the coolant to also serve as a nuclear fuel. Despite the potential advantages of this technology, early-stage research and development programs of the MSR at Oak Ridge National Laboratory have uncovered a few challenges, including corrosion of structural materials and management of fission products. Thus, the development of a loop system for basic corrosion and fission product management experiments is vital. This study aims to address the design criteria of a high-temperature molten salt natural convection loop. Based on the identified criteria, a high-temperature molten salt natural convection loop for chloride-based salt is designed and manufactured, enabling further exploration and testing of this promising technology.

2. Experimental

In order to simulate the environment of the MSR system, a high-temperature natural convection loop has been designed and fabricated. The natural convection loop is equipped with a fill tank, top tank, and drain tank, which are installed using 1 inch SS316 tubes. A schematic of the natural convection loop is illustrated in Figure 1, which highlights the locations of temperature measurements (T1~T6) during the experiment. Figure 2 shows the completed system, including the heater-covered tubes and tanks. Table 1 provides a list of the names and powers of each heater that has been installed in the natural convection loop. Each tank is equipped with its own heater, and the total power of the loop is 5.43 kW.

Prepared chloride salt is introduced into the fill tank of the natural convection loop, along with corrosion coupons made of candidate structural materials for molten chloride salt reactor, including SS304, SS316, and Hastelloy-N. To generate flow in the natural convection loop, the hot leg temperature is set to 650 °C, while the cold leg temperature is set to 550 °C. Each heater in the loop has its own current sensor, which is used to calculate the flow rate of molten salt by measuring the heating power applied to the hot and cold legs of the loop. To maintain a degree of vacuum below 5 mTorr, a vacuum pump connected to the fill pot is operated during the experiment.

After a 500 h corrosion experiment, the salt is drained from the loop into the drain tank for analysis using inductively coupled plasma optical emission spectroscopy (ICP-OES) to investigate metal dissolution from structural materials to salt. The corroded candidate structural materials are analyzed with scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS).

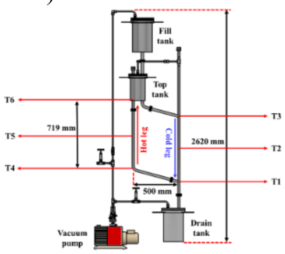

Figure 1. A schematic of molten salt natural circulation loop

Figure 2. A complete system for molten salt natural circulation loop

NaCl-$MgCl_2$ 57:43 mol% eutectic salt is prepared, with 99.5% purity sodium chloride (7647-14-5) from JUNSEI, and 99% purity magnesium chloride (7786-30-3) from Alfa Aesar. Total 8.6 kg of salt with 3.8 kg of NaCl and 4.7 kg of $MgCl_2$ are injected in the fill tank. Then, for removing remaining moisture in the salt, the eutectic salt in the fill tank is dried at 117, 185, 242, 304 and 350 °C. During whole drying process, -0.1 MPa vacuum is maintained to remove HCl and moisture from the salt.

3. Results and Discussion

Figure 3 displays the vacuum degree in the molten salt loop, while Figure 4 exhibits the temperature measurements in the molten salt loop at a vacuum condition of 5 mTorr. The hot leg and cold leg heaters are set to temperatures of 700 °C and 600 °C, respectively. Temperature data obtained during the test run without molten salt indicates that the hot leg temperature exceeds 650 °C, and the cold leg temperature is above 500 °C, thus satisfying the criteria for a natural convection loop. Currently, the corrosion experiment is being conducted using NaCl-$MgCl_2$ eutectic salt, and corrosion data, including weight loss, SEM, and EDS analyses for SS316, SS304, and Hastelloy-N samples, will be presented.

Table 1. Name of heaters and heater power

Heater Name	Heater Power (kW)
Fill Tank	1.8
Top Line	0.3
Top Tank	1.1
Hot Leg	0.8
Cold Leg Top Line	0.3
Cold Upper Leg	0.37
Cold Bottom Leg	0.46
Bottom Line	0.3
Sum	**5.43**

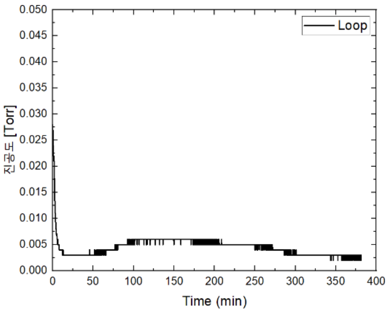

Figure 3. The degree of a vacuum in the molten salt loop

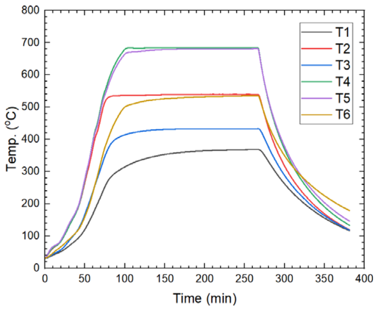

Figure 4. Temperature data during test-run

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[1] Gen IV International Forum 2007 annual report, Printed by the OECD Nuclear Energy Agency, 2007.