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Technical Status of the Sodium/Material Compatibility Facility for the Sodium-cooled Fast Reactor

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1. Introduction

It has been reported that compatibility between the structural material and the sodium coolant has been concerned as one of the issues in developing new materials as well as designing core components for the Sodium-cooled Fast Reactor (SFR). The objectives of the paper are to summarize the past status of the developed facility regarding sodium/material compatibility and to propose the material compatibility facility that is suitable for the development of the SFR fuel.

2. Status of material compatibility test facility

2.1. Static test

Static test is characterized by immersing the specimen into the stagnant liquid sodium where the change of the specimen weight is periodically measured by the gravimetric method. Although the static test has the merit in that the test facility and the procedure are relatively simple, it has a drawback not to control the dissolved impurities with ease. Dissolved impurities soon saturated within the reactor in a few days, resulting in the alteration of the corrosion mechanisms as well as sodium chemistry. To overcome controlling impurities like dissolved oxygen, it was tried that sodium was encapsulated by the vanadium foil and exposed 500^{o}C for 24hr before the test [1]. However, static test is now hardly used except for the screening test of the candidate alloys.

2.2. Recirculating test

Recirculating test is characterized that liquid sodium is forcibly moved by the electromagnetic (EM) pump. Recirculating facility basically consists of the hot temperature (above 500^{o}C) region to perform material compatibility test and the low temperature (below 200^{o}C) region to control impurity contents [2, 3]. Economizer, electromagnetic flowmeter, cold trap, sodium bypass line to sample the sodium chemistry and expansion tank to compensate the volume change of the sodium are installed at the recirculating test facility. Additional vacuum glove box is needed to pull out the corroded specimen during the loop operation. Regarding the sodium/material compatibility test, ASTM G68 has been established which provides the design of the standard test facility, the specification of the reagent and the materials, the safety precautions, the test procedure, the sampling, and the weight change measurement after the test [4].

2.3. Quasi-dynamic test

Although the recirculating test has the much merit in performing reliable compatibility test, it needs a lot of auxiliary components which make it difficult to operate as well as maintain. To overcome such a difficulty, quasi-dynamic device was developed to simulate the flow field in a single reactor. Bubble flow [5], natural convection caused by the temperature difference [6], and the combination of both the bubble flow and the temperature gradient [7] were developed to simulate the flow dynamic in the liquid metal compatibility test.

3. Measurement and control of dissolved impurities

It is generally reported that impurities which are dissolved inside the liquid sodium have a great influence on the sodium-material compatibility. For example, dissolved oxygen affects the corrosion rate of the structural material by controlling dissolution kinetics of the iron, the nickel, and the chromium [8, 9], whereas dissolved carbon affects the carburization / de-carburization phenomenon at the material surface [10]. In order to construct efficient material compatibility device, one should bear in mind that measurement as well as control of the dissolved impurities should be considered.

3.1. Cold trap

Cold trap is the device which purifies sodium by the solubility difference according to the temperature differences. When the hot liquid sodium is cooled, excess oxygen will be precipitated as a sodium oxide and it will be filtered when it goes through the wire mesh. The oxygen solubility with the sodium temperature is shown as follows [4];

$$\log C_o(ppm) = 7.0058 - 2820 / T(K) \qquad (1)$$

According to the relationships, oxygen content in the liquid sodium amounts about 5800ppm at 650^{o}C, while it reduces to the value of 1.5ppm at 110°C. When the hot sodium is passed through the cold trap at 110°C, its oxygen level is lowered at around 1.5ppm. Since the cold trap was based on the solubility difference, it is expected that not only the oxygen but also the carbon can be purified through the cold trap device.

3.2. Vanadium Wire Equilibrium Technique

Vanadium wire equilibrium technique (abbreviated as VWET) is the technique where it indirectly measures the oxygen content in the liquid sodium through the vanadium wire exposed to the liquid sodium [11]. When the electro-polished vanadium wire is exposed to the liquid sodium environment up to the certain time, oxygen diffuses into the vanadium wire so that it reaches oxygen equilibrium in both the liquid sodium and the vanadium wire. Oxygen-contained vanadium wire then sampled and its oxygen content was analyzed. The relationships between oxygen content in the vanadium wire and the liquid sodium was well-established from the thermodynamic calculation. Fig. 1 shows the theoretical relationship of oxygen content between the vanadium wire and liquid sodium. VWET is the well-established technology in measuring dissolved oxygen in the liquid sodium so that ASTM C997 has provided VWET as the standard method in measuring oxygen [12]. VWET is designated as the reference method so that the calibration of oxygen sensor should be performed by comparing the value obtained from VWET.

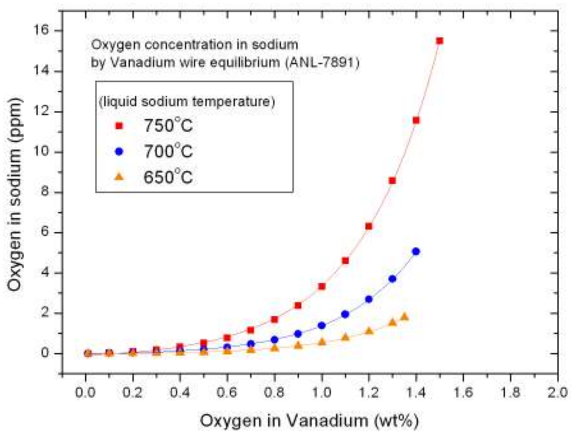

Fig. 1 Relationships between the oxygen content inside the vanadium wire and the liquid sodium by VWET [11].

4. Proposed sodium/material compatibility facility

This paper summarizes the past status of the material compatibility test for the liquid sodium environment and proposes the material compatibility facility which is going to be installed in this year. The main design principles are as follows. First, the compatibility test facility should be constructed as the recirculating type. Natural convection caused by the temperature difference will be preferentially considered, then the full-scale loop will be expanded based on the natural convection loop. Second, the dissolved impurities, especially dissolved oxygen and carbon will be measured and controlled. VWET and the cold trap concept will be considered at the constructed loop.

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REFERENCES

[1] V. Ganesan and V. Ganesan, J. of Nuclear Materials, 256, pp. 69, 1998.
[2] H. U. Borgstedt, G. Frees and H. Schneider, Nucl. Tech. 34, pp. 290, 1977.
[3] R. S. Reid, J. J. Martin and G. L. Schmidt, NASA/TM-2005-213902, pp. 58, 2005.
[4] ASTM G68-80, Standard Practice for Liquid Sodium Corrosion Testing of Metals and Alloys, pp.383, 1980.
[5] K. Hata, K. Hara and M. Takahashi, Progress in Nucl. Ener., 47, 1-4, pp.596, 2005.
[6] H. S. Khatak and J. B. Gnanamoorthy, Material Behavior and Physical Chemistry in Liquid Metal Systems, pp. 229, 1981
[7] E. P. Lowen, Progress in Nucl. Ener., 47, 1-4, pp.561, 2005.
[8] A. W. Thorley, Material Behavior and Physical Chemistry in Liquid Metal Systems, pp. 19, 1981
[9] W. F. Brehm, Materials Compatibility in Liquid Sodium, CONF-781071-2, 1978.
[10] O. K. Chopra, K. Natesan and T. F. Kassner, J. of Nuclear Materials, 96, pp. 269, 1981
[11] D. L. Smith and R. H. Lee, Characterization of the Vanadium-wire Equilibration Method for Measurement of Oxygen Activity in Liquid Sodium, ANL-7891, 1972.
[12] ASTM C997-83, Standard Methods for Chemical and Instrumental Analysis of Nuclear-grade Sodium and Cover Gas, 1983.