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Lab-Scale Experimental Apparatus to Study Plate-out Characteristics of Metallic Fission Products on the Flow Channel of VHTR Heat Exchanger

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1. Introduction

Plate-out of fission products (FP) is an important phenomenon during the transport process of FP under normal operating as well as accidental conditions of very high temperature reactor (VHTR) [1]. Metallic FP, such as silver (Ag), cesium (Cs), and strontium (Sr), can be released from fuel particles for the case of TRISO fueled reactors. These products may subsequently diffuse from the fuel, become plate-out on the internal walls of primary components and become stored either within carbon components of the reactor or in the carbon dust in the primary loop components as shown in Figure 1. This dust is highly mobile and potentially reaches the coolant circuit, leading to the introduction of radioactive impurities into many components of the reactor. It is therefore important to be able to quantify the plate-out FP on primary components.

Although FP interactions with primary components have been a subject of study for more than four decades, the prediction of FP interactions with alloy surfaces is empirical and still incomplete. It is usual to test the interaction of a specific FP on a specific material at different temperatures to generate data on interaction kinetics as a function of temperature. Each material and each FP and each of its compound forms have different kinetics and so, potentially, a very large number of experiments is necessary. It should be understood that the empirical knowledge of FP–alloy interactions makes no distinction between the different adsorption/ absorption/reaction mechanisms. KAERI had been prepared last year (2017) a lab-scale apparatus to study plate-out characteristics of metallic FP on the VHTR heat exchanger. The apparatus is an out-of-pile test device and is able to simulate VHTR core temperature at helium flow condition.

2. FP interactions with components wall

The interaction process is not the same for each FP: there is the initial heterogeneous interaction occurring at the alloy surface which is generally highly temperature dependent and reversible (Figure 2). This first step is governed by mass-transfer mechanisms and vapor-pressure driven or governed by absorptivity. The adsorption or condensation is followed, depending on the FP, by absorption into the bulk or diffusion and chemical reaction in the bulk. This subsequent interaction may be only partially reversible [2]. It is known, for example, that Cs interaction with alloys is stronger and less reversible the higher the temperature at which it occurs. In particular, a significant fraction of the Cs diffusing in steel alloys to form a silicate that is very stable and immobile below about 1000 ℃. In addition, silver has a significant solubility in nickel so it might be expected that Ag (110m) would accumulate in the IHX and/or the gas turbine; the expectation that the turbine will constitute a preferential site for Cs and Ag plate-out is well established [1].

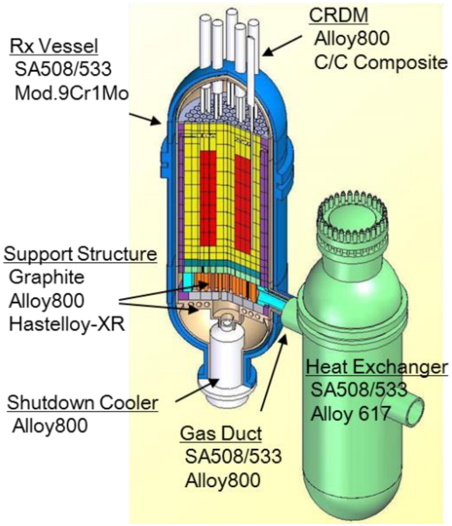

Fig. 1. Materials of VHTR primary components

The major parameter effect on plate-out is the temperature of both coolant and alloy surface. The vaporized FP can be either condensed down or continued on vaporized state by coolant temperature. We can imagine this fact more well if we see Figure 3 that represents the vapor pressure change to coolant temperature for the Cs, Sr and Ag. Surface temperature also allows either plate-out on their surface or not. The other parameters related on plate-out amount are alloy materials and surface oxidation condition as listed in Table 1. Generally, oxidized surface captures FP more.

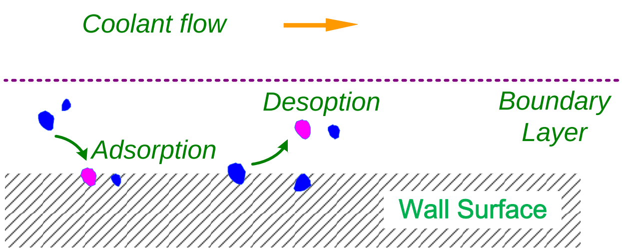

Fig. 2. Concept of FP interactions on the wall

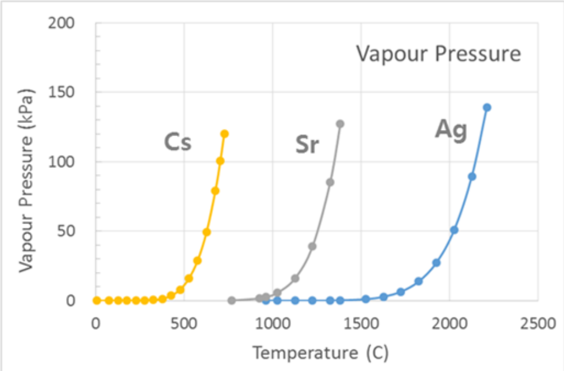

Fig. 3. Vapor pressures of FP metals [3]

Table 1. Test Matrix

FP Metal (3)	Coolant Temp. (℃)	Material (2)	Surface (2)
Strontium Silver Cesium	300, 400 500, 600 700, 800 950	Carbon Base (Alloy 800H SUS316) Nickel Base (Alloy 617 Hastelloy-XR)	Non-Oxide Oxide

3. Experimental Apparatus

3.1. Description of experimental apparatus

The experimental apparatus simulates the VHTR core temperature and reduced helium flow condition. The apparatus is an open loop that composed of a helium tank, a helium heater, a FP heater, a test section, an air cooler and a filter as shown in Figure 4. The operating condition of plate-out test apparatus is as follows;

- o Working Fluid Helium
- o FP Heater 2000 ℃
- o Helium Temperature ~ 950 ℃
- o Helium Flow ~ 65 liter/min
- o Operating Pressure 1~ 3 bar

3.2. Test Section

The test section is simulated single channel of the PCHE type VHTR intermediate heat exchanger. The half-circle of the PCHE flow channel is converted to equivalent full circle as 1/8 or 1/4 inch commercial tube. The test section is designed to dual tube heat exchanger type as shown in Figure 4. The inner tube is test tube and the outer tube has the function of surface temperature control. Normally the amount of plate-out are not depend on hydraulic diameter but hydraulic condition like coolant or surface temperature and Reynolds(Re) number. The range of Re number in PCHE channel are from 500 ~ 1500. In case of 1/8 inch (1.8mm of flow channel diameter) tube test section, the flow-rate equivalent of the Re number are 12~36 liter/min at atmospheric pressure.

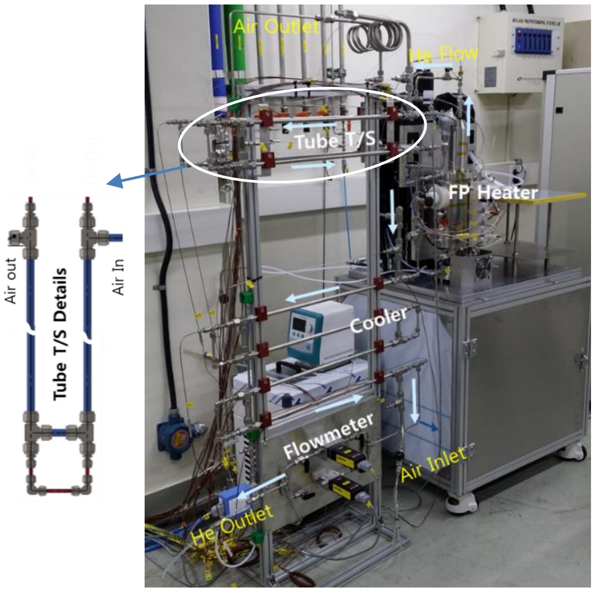

Fig. 4. Plate-out experimental apparatus in KAERI

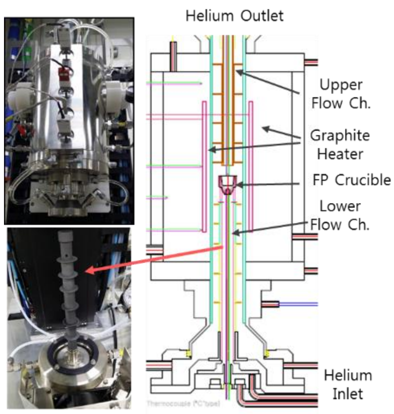

Fig. 5. Details of FP heater assembly

3.3. FP Heater

Figure 6 shows the details of FP heater and its major parts. The heater element is IG-11 graphite. Most parts of FP heater are used the IG-11 graphite like upper and lower flow channels, FP crucible and channel spacers. The FP filled in IG-11 crucible can be heated over 1500℃ by radiation emitted from the IG-11 heater which could be withstand over 2000℃ in an oxygen free environment. The body of the heater is designed to open and close automatically by a stepping motor. Helium comes from the bottom side of FP heater and is heated by high temperature channels and exit to top side. The body of the FP heater is water cooled and the inside of body filled with insulator to protect the vessel from the high-temperature helium gas.

4. Discussion

The experimental apparatus is assembled and it is now on-going various pre-test. The pre-test items are as follows;

- Test data on the loss of FP metal at the heating crucible by vaporization at a constant temperature and He flow
- Test data between the Furnace power and He exit temperature at constant flow rate and pressure
- Test data between the He exit temperature and flow rate at constant power and pressure
- Sensitivity test data on the external parameters such as room temperature, He inlet temperature, cooling water temperature and cooling water flow
- Test data on the furnace heat loss

Figure 7 shows one of pretest results for the He exit temperature change trend to the change of He flow rate. We can see the jump of He temperature as ramp raise of He flow rate from the graph.

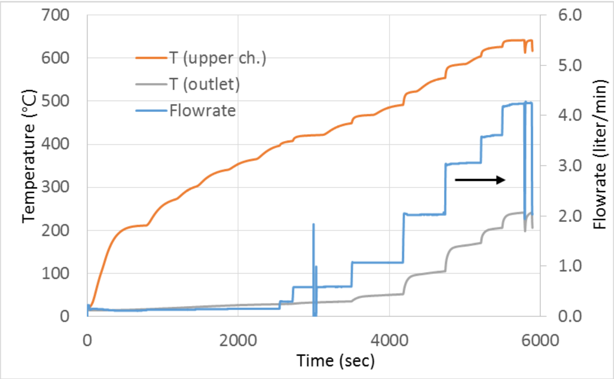

Fig. 7. He temperature vs. flow rate

5. Conclusion

KAERI has been prepared a lab-scale apparatus to study plate-out characteristics of metallic FP on the VHTR heat exchanger. The apparatus is an out-of-pile test device and is able to simulate VHTR core temperature at helium flow condition. Various pretests are now on-going and filing up the pretest data that would be used to obtain reliable plate-out experimental data at the end of this year.

ACKNOWLEDGEMENTS

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