Design and Manufacture of Fouling Simulation Test Apparatus for a Printed Circuit Steam Generator

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1. Introduction

A printed circuit heat exchanger (PCHE) is a plate type of heat exchanger in which micro flow channels are alternately stacked to form a block as shown in Fig. 1. [1]. Recently, a new type of PCHE called printed circuit steam generator (PCSG) has been developing in the Korea Atomic Research Energy Institute (KAERI) to improve safety and economics of steam generators for nuclear power plants (NPPs) [2].

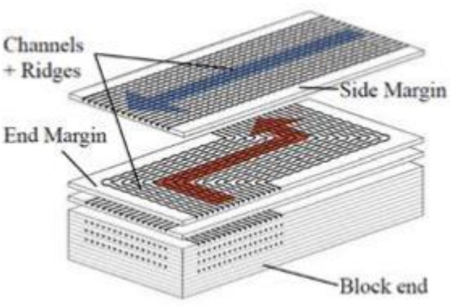

Fig. 1. Schematic diagram of a PCHE [1].

However, as the flow channels are small and narrow, the most fatal drawback of PCSG is that the flow channels are more susceptible to clogging by corrosion products. This clogging phenomenon calls fouling [3, 4]. In the secondary coolant system in NPPs, the major corrosion product is magnetite (Fe_3O_4) [5, 6]. In other word, the source of fouling is magnetite which is corroded and dissolved from the surface of carbon steel pipe. And then, it is transported by feedwater and accumulated within steam generators [7]. If this fouling phenomenon occurs continuously, impurities are concentrated within the porous corrosion products and this behavior can accelerate corrosion-related degradation such as stress corrosion cracking (SCC), intergranular corrosion attack (IGA), and pitting [8-10], etc. In addition, fouling inside the PCSG increases the blockage of waterway and shorten the life of the PCSG.

In order to commercialize the PCSG, it is essential to evaluate and mitigate the fouling phenomenon within micro-channels, but it has not been studied until now.

Therefore, the objective of this research is to briefly describe the test apparatus to simulate fouling behavior in the secondary coolant system of a PCSG. Furthermore, future experiment plans for simulation and evaluation of the fouling phenomenon were also described.

2. Preparation of fouling test apparatus

To simulate the fouling behavior occurring within the micro-channels of a PCSG, a realistic cooling water circulation system must be built to satisfy a high pressure and high temperature operating condition. In addition, water chemistry conditions similar to the actual secondary coolant system of the NPP should be satisfied. A circulation loop system for PCSG fouling tests was manufactured and the schematic diagram of the fouling test system is shown in Fig. 2.

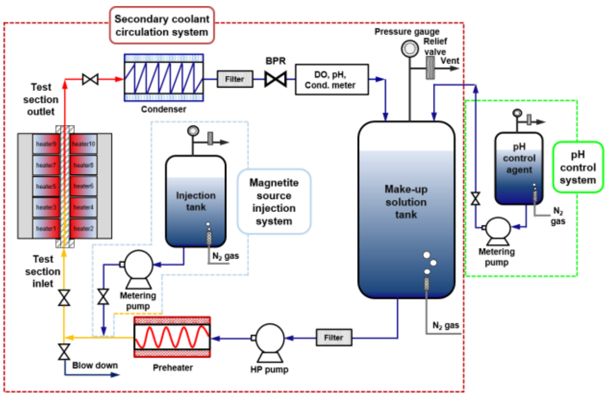

Fig. 2. Schematic diagram of the PCSG fouling test loop system.

The PCSG fouling test loop system can be divided into three types of system such as secondary coolant circulation system, pH control system, and magnetite source injection system as shown in Fig. 2.

2.1. Secondary coolant circulation system

As a system in which the secondary coolant is circulated, it is a system that circulates by simulating the similar water chemistry conditions as the actual NPPs. The single-phase coolant stored inside the make-up tank enters pre-heater through a high pressure pump and the coolant heated through a pre-heater enters into the micro-channels. And then, the coolant is heated inside the micro-channels by heater to turn into superheated steam of the single-phase and effused through the outlet of PCSG. Finally, the superheated steam is passed through a condenser and phase transformations back into single-phase of liquid and enters the make-up tank. As these phase transformation was repeated, the secondary coolant can be circulated by the loop system while simulating all phase transformations that occur in an actual steam generator.

Fig. 3. shows the dimension and image of the condenser which is an important component in the secondary water circulation system. The condenser was made of STS 304 and had an operating pressure of 25 MPa and a heat removal capacity of 40,000 kcal/h.

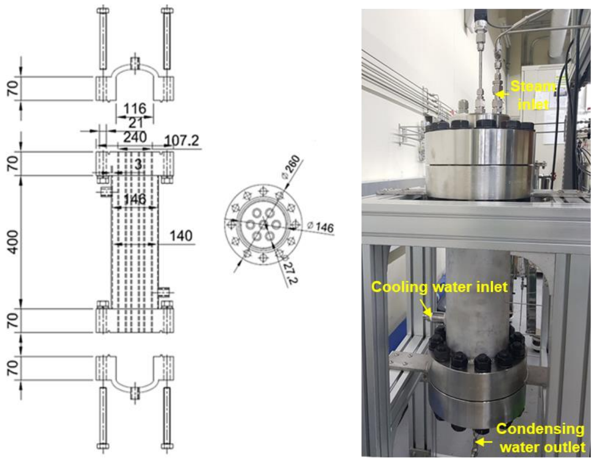

Fig. 3. Dimension and image of the condenser.

2.2. pH control system

The coolant adjusted to $pH_{25°C}$ 9.0 ~ 10.0 using ammonia is pyrolyzed at high temperatures, resulting in low pH. Therefore, a system that monitors and maintains the pH of circulating coolant in real time is essential. The function of monitoring pH in real time and automatically injecting ammonia and adjusting pH was implemented.

Furthermore, it is also possible to change the various pH control agents such as ethanolamine or morpholine instead of ammonia to assess the fouling behavior inside the micro-channels of PCSG.

2.3. Magnetite source injection system

The magnetite source injection system is a system that artificially injects fouling source into the secondary system cooling water. As mentioned in the introduction, because the typical corrosion product generated in the secondary coolant system is magnetite, Fe ions which is fouling source are quantitatively injected, causing the fouling phenomenon inside the micro-channels. Fe ions will be continuously injected at the bottom of the test section through a micro-metering pump. Therefore, it will be mixed with the secondary coolant and flowed inside the micro-channels of PCSG.

3. Future experiments

The image of PCSG fouling simulation apparatus is shown in Fig. 4.

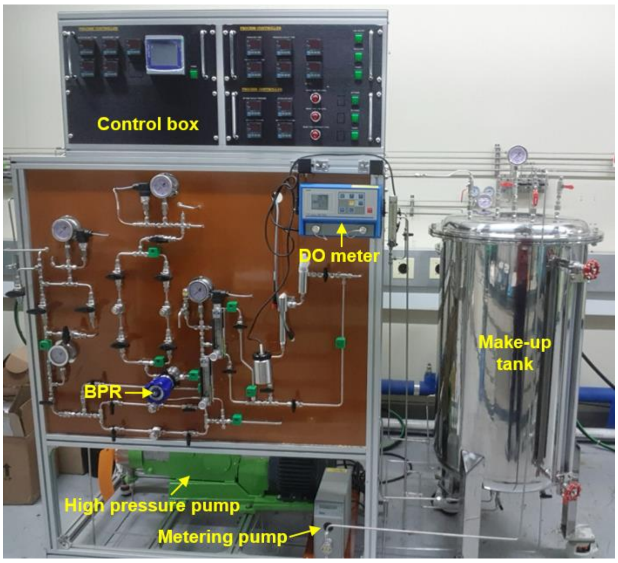

Fig. 4. Image of PCSG fouling simulation apparatus.

Using the fouling test loop, various fouling simulation experiments and mitigation techniques will be studied in the future as follows.

(1) Simulation of phase transformation from secondary system coolant to superheated steam within micro-channels.
(2) Simulation of fouling behavior by pH variation.
(3) Evaluation of fouling behavior by various types of pH control agents such as ammonia, ethanolamine, and morpholine.
(4) Water chemistry development for fouling mitigation.

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