Study on the Experimental Conditions for the Control of High DH Concentration in the Simulated Primary Water Loop

Ju-Eun Park [a,b], Dong-Jin Kim [a], Dong-Bok Lee [b], Min-Jae Choi [a]*

[a] Materials Safety Technology Development Division, Korea Atomic Energy Research Institute (KAERI)
[b] Department of advanced Material Science & Engineering, Sungkyunkwan University
Corresponding author: mjchoi@kaeri.re.kr

1. Introduction

The main role of reactor internals in the PWR is to maintain the geometric integrity of the reactor core and to support the fuel rod. In case of internal structures in nuclear power plant cooling system, the corrosion characteristics of materials are very important because the internal materials are always exposed to high temperature, high radiation and water chemistry environment during operation. Irradiation Assisted Stress Corrosion Cracking (IASCC) is one of the most important degradation mechanisms of internal materials, there are many researches to identify and clarify the IASCC initiation and propagation. The dissolved hydrogen concentration is one of the water chemistry environment factors to influence the IASCC initiation, however, the studies about the effect of high hydrogen concentration on the IASCC of austenitic stainless steels are insufficient. In this study, we tried to set up optimal experimental conditions to control high dissolved hydrogen concentration in the simulated primary water loop.

2. Experiments and Results

2.1 Loop modifications

A high hydrogen pressure was required approximately gauge pressure of 5.3 bar to simulate a primary water system with high DH concentration of 100 cc/kg·H_2O. Therefore, the loop was designed to be able to control water chemistry in high pressure environment of about 10 bar level. The column for purging hydrogen gas and the chamber for ion exchanging were changed to type 316 stainless steel to withstand high pressure. Dissolved oxygen sensor, feed pump and every pressure gauges were also changed for high pressure. Fig 1 shows the photos of the replaced ion exchanger chamber and the loop.

Fig. 1. Primary water loop and Ion exchanger

2.2 Experimental conditions

The simulated primary water conditions were 1200 ppm of B, 2 ppm of Li, 6.3 ~ 6.5 of pH and under 5 ppb of dissolved oxygen in room temperature and phase pressure. The conditions with the dissolved hydrogen (DH) were 25, 50 and 100 cc/kg·H_2O.

The hydrogen concentration at the inlet and outlet were compared. These were compared with the results of measured values according to the sensor type which are electrochemical (EC) sensor and thermal conductivity (TC) sensor. After comparing EC and TC values, additional experiments were conducted to determine the reliability of each sensor. The dissolved hydrogen concentration was set in the loop system to measure the EC and TC sensor values equally at 25 cc/kg·H_2O. After that, all the conditions of the loop were setting as same and the error of each value measured when the hydrogen concentration was changed to 50 and 100 cc/kg·H_2O.

2.3 Loop monitoring

Various water chemistry factors were measured according to time. DO was decreased to 5 ppb. The conductivity showed an initial value of 21.75 uS/cm and it increased to 23 ~ 26 uS/cm. However, the actual experiment time is about 100 hours, so the changing conductivity values were not serious. The pH was maintained between 6.35 ~ 6.4. Every conditions were simulated as theoretical primary water system.
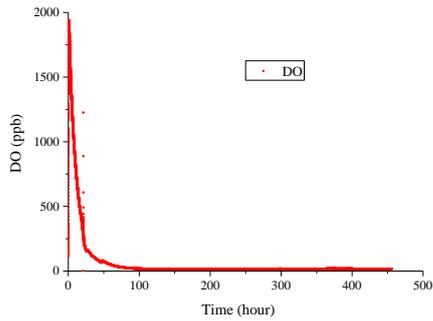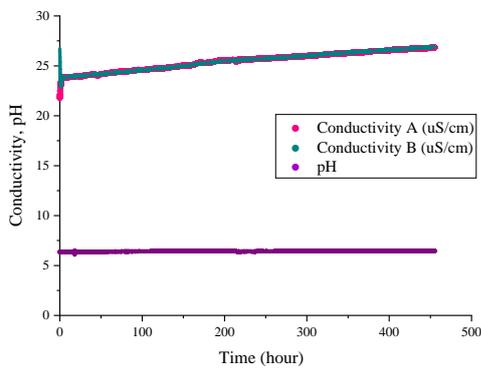
Fig. 2. DO change over time

Fig. 3. Conductivity and pH change over time

2.4 Flow rate

The experiments were conducted under several conditions to find a suitable flow rate for the dissolved hydrogen sensors. Each of these sensors has a recommended flow rate. EC sensor have to use less than 50 cc per minute. The flow rate had been fluctuated even though it was used on the proper range. On the other hand, the flow rate of TC sensor have to be guaranteed above 200 cc per minute to use. The results of DH concentration with different flow rate conditions is shown in Fig 4 and Table 1. Table 1 shows the flow rate conditions about section (a), (b) and (c) of Fig 4.
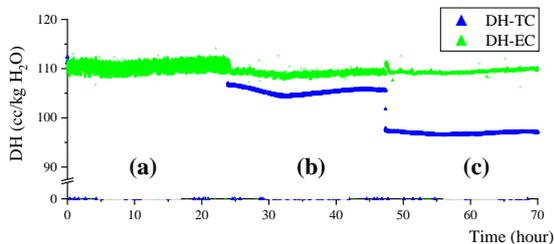

Fig. 4. DH with different flow rates

Table 1. Flow rates

	(a)	(b)	(c)
EC(outlet)	40	20	10
TC(inlet)	200	100	50

2.5 Dissolved hydrogen concentration monitoring – in room temperature and phase pressure

As the results of installing different types of hydrogen sensor in the inlet and the outlet of the loop, there was no significant difference in the measured values of EC and TC sensor. When DH concentration was increased from 25 to 50 and 100 cc/kg·H_2O, the value of the EC sensor fluctuated at the beginning. However, it was stabilized over time, then DH of the two sensor types chowed similar values. It means that the values of inlet and outlet are not significantly different.

2.6 Dissolved hydrogen concentration monitoring – high temperature and high pressure through autoclave

The loop was operated through the autoclave in high temperature and high pressure. The experiment was conducted in the same method that the DH concentration conditions were the same, but the temperature was maintained at 325℃ and the pressure 2400 psi. DH values of TC and EC sensors were measured as similar way such as the results at the room temperature and phase pressure. These two values were also stabilized over time.

3. Conclusions

Hydrogen sensors and flowmeters were installed in the inlet and outlet of the simulated primary water loop. By controlling the flow rate under various conditions, the suitable flow rates for the high hydrogen concentration was 10 cc/min in EC type sensor and 200 cc/min in TC type sensor.

The difference of the values between inlet and outlet was measured by the TC and EC sensors, and there was no significant change in the values. Similar values were measured when the temperature and pressure changed. The values was saturated over the time even the water through the autoclave.

A loop system of high pressure and high dissolved hydrogen concentration environment was constructed. The system will be used to study for the effects of proton-irradiated stainless steel in high hydrogen concentration environments.

References

[1] Z. Jiao, G.S. Was, J. Nucl. Mater 382 (2008) 203-209

[2] Kale J. Stephenson, Gary S. Was, J. Nucl. Mater 481 (2016) 214-225

[3] P.L. ANDRESEN, "Stress corrosion cracking (SCC) of austenitic stainless steels in high temperature light water reactor (LWR) environments", 2010