Status of Manufacturing Experimental Apparatus to Investigate SWR Phenomenon in the PCSG

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1. Introduction

The Sodium-cooled Fast Reactor (SFR) is one of the most promising Generation-IV nuclear reactors. The SFR is liquid metal reactor using sodium as a coolant. Typically, two fluids (water and liquid sodium) exchange heat each other through heat transfer tube wall in a steam generator (SG). For this reason, the SFR has possibility of sodium-water reaction (SWR) inherently. If boundary between sodium and water, in case of steam generator tube, is ruptured by any reason, sodium and water will contact. Then vigorous exothermic chemical reaction will occur according to mainly the following chemical formula [1].

$$Na + H_2O \rightarrow NaOH + 1/2H_2 - 147.37\ kJ/mol$$

If SWR is happened, pressure and temperature in SG are increased because of highly exothermic reaction. And SG integrity is degraded by reaction product, NaOH, due to its corrosive property. In addition, hydrogen is generated by this chemical reaction. The SG integrity is severely threatened by the hydrogen explosion if venting of SG can’t be implemented. For these reasons, the SWR have always been a safety issue of the SFR. So, developing approaches to reduce probability of the SWR accident or limit the SWR consequence are very important. Until now, many researches [2~11] for prevention, detection, and mitigation of SWR have been performed to overcome this inherent risk. In point of design, two approached are suggested and studied to totally prevent the SWR. These methodologies are double walled SG tubes [12] and using a Brayton cycle [13] suggested in JSFR and ASTRID, respectively. However, some problems such as reduced heat transfer efficiency and increased fabrication coat exist in the double walled approach. Heat transfer efficiency problem also exists in the Brayton cycle. Using a PCSG (Printed Circuit Steam Generator) could be good approach to reduce probability of the SWR and to limit the SWR consequence.

The PCSG is a kind of PCHEs (Printed Circuit Heat Exchanger). The PCHE is manufactured by using diffusion bonding between chemically etched steel plates. Etching channels on steel board are shown in Figure 1. Schematic and cross-section of the PCHE are shown in Figure 2 [14].

Figure 1: PCHE platelet configuration

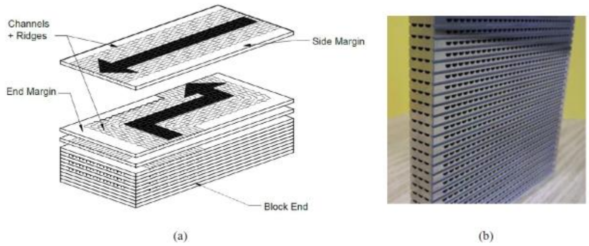

Figure 2: (a) plate stacking for diffusion bonding, (b) bonded printed circuit core

The PCSG is being considered as one of the candidated SGs to substitute the shell and tube SG in Korea due to safety and economic characteristics of the PCSG. The PCSG has much higher heat transfer surface area to volume ratio than the conventional shell and tube SG. It means the PCSG has high heat transfer efficiency. And size of the SG can be decreased considerably. Also manufacturing costs can be reduced. Although advantages of the PCSG comparing with the conventional SG are not only economics but also safety, integrity, performance, and reliability, only a safety feature of the PCSG against the SWR will be dealt with in this study. The PCSG could be expected to have strong points against the SWR accident comparing with shell and tube SGs. These expected advantages are as follows.

- Exclusion of damage propagation by impingement wastage
- Effective accident management by modularization of the PCSG

- Low background noise caused by laminarization of SG flow due to small size tubes can facilitate acoustic detection of SWR.

Among above advantages, exclusion of damage propagation by impingement wastage and acoustic detection will be demonstrated by the experimental study. In this paper, only concept and design of experimental apparatus and manufacturing status will be addressed.

2. Design of the Test Facility

Designed PCSG is shown in Figure 3, (a). Sodium flow directs from upper nozzle to lower nozzle of the PCSG (red arrows in Figure 3, (a)). Water flows into bottom side of the PCSG and steam is discharged from top side of the PCSG (blue arrows in Figure 3, (a)).

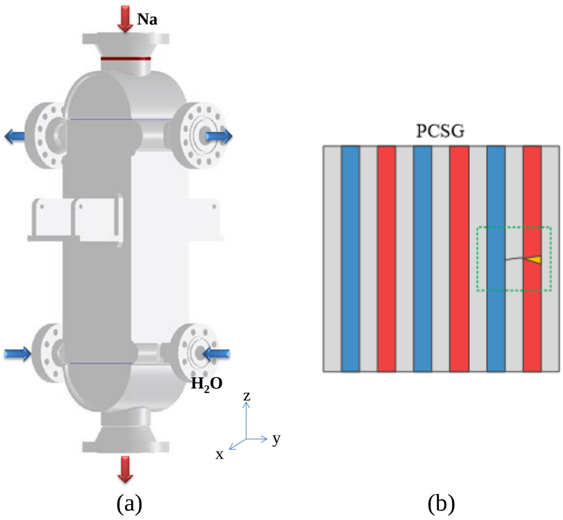

Figure 3: Designed PCSG (a), schematic of the SWR in the PCSG (b).

Figure 3, (b) represents cross-sectional area (y-z plane) of the PCSG and schematic of the SWR in the PCSG. Yellow indicates discharged steam. Water and sodium channels are expressed by blue and red respectively. Gray is body of the PCSG. Pressurized water can be discharged into the sodium tube when crack is generated between sodium side and water side. It is depicted in green dotted-line of Figure 3, (b).

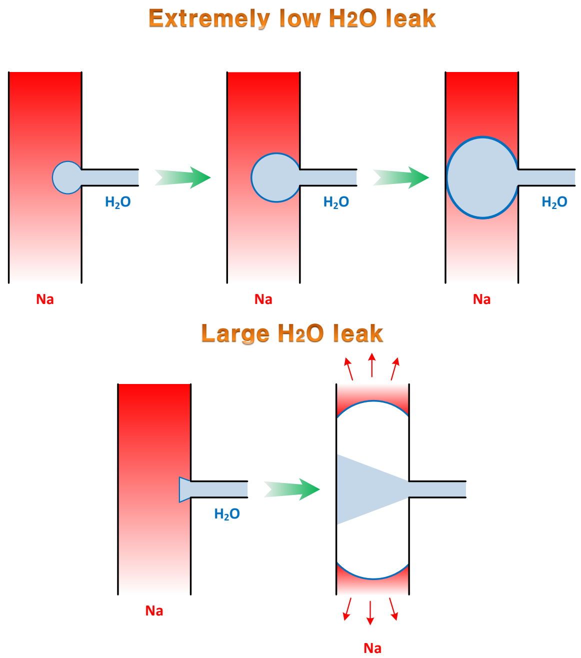

Figure 4: Expected two-phase (steam and liquid sodium) flow pattern forming by the SWR in the PCSG

If the SWR occurs, physical phenomenon in failed sodium channel depends on crack size dominantly. Expected physical phenomenon is described in Figure 4. If leak rate is extremely low, small size bubble (diameter < 4 mm) and slug could be formed in sodium tube. In this case, SWR can occur inside of the sodium tube. Corrosive reaction product, NaOH, might be generated near the sodium tube wall and crack tip. It causes impingement wastage and self-wastage. If larger crack is generated between sodium and water channel than previous case, high pressurized water can be discharged into the sodium channel. And sodium is expelled to both ends of the channel. In this case, SWR occurs in header of the PCSG, not inside of the sodium channel. Experimental apparatus is designed to identify these phenomena and to measure extent of wastage.

Design of the test section of the apparatus is shown in Figure 5. Vertical and horizontal pipe of the test section represent sodium and water channel, respectively. Rupture disc is mounted between sodium side and water side. If pressure higher than 10 bar is exerted on the rupture disc, it is partially torn. Then pressurized water is injected into the sodium channel through torn rupture disc and small hole.

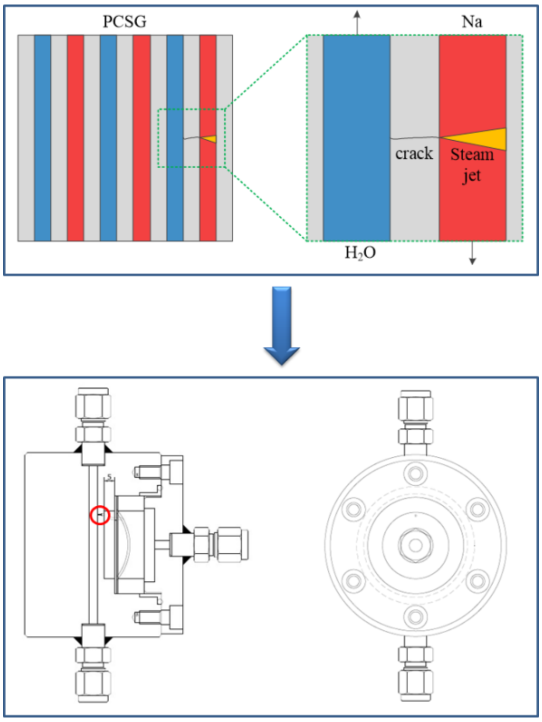

Figure 5: Test section modeling and design

Whole loop for SWR experiment inside of the PCSG is shown in Figure 6. Piping, tanks, and measuring instruments are also designed. This apparatus consists of three parts such as sodium side (red line), water side (blue line), and venting system (gray line).

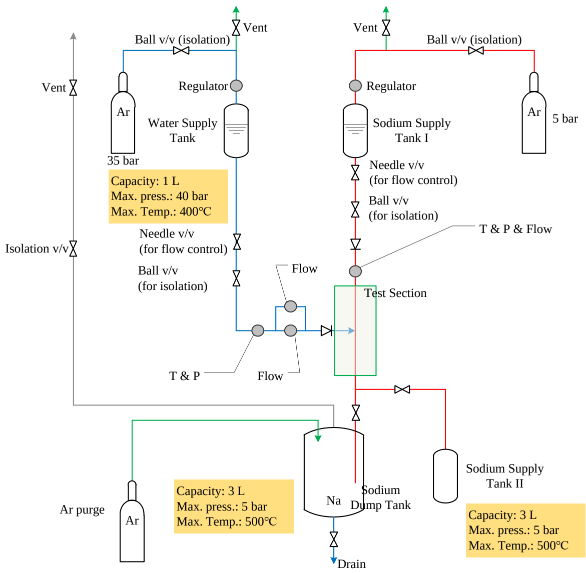

Figure 6: Schematic of the SWR experimental apparatus

3. Manufacturing the SWR Test Facility

Now, manufacturing experimental apparatus is finished. Various tests such as pressure and sealing test, temperature test and so on are performing now. The front view of finished apparatus is shown in Figure 7.

Figure 7: The front view of the experimental apparatus

Two tanks (blue box in Figure 8) located above glove box is storage tank. Left and right tank are water storage tank and sodium storage tank, respectively. These two tanks are enveloped by heater. And pneumatic isolation valves are installed at downstream of two tanks. Sodium and water pipe (orange box in Figure 8) are located in the glove box for safety. Flow meters, thermocouples, and manometers are mounted on the both side piping. Sodium dump tank and sodium storage tank II (red box in Figure8) is located beneath the glove box. These main components are assembled into a SWR test facility.

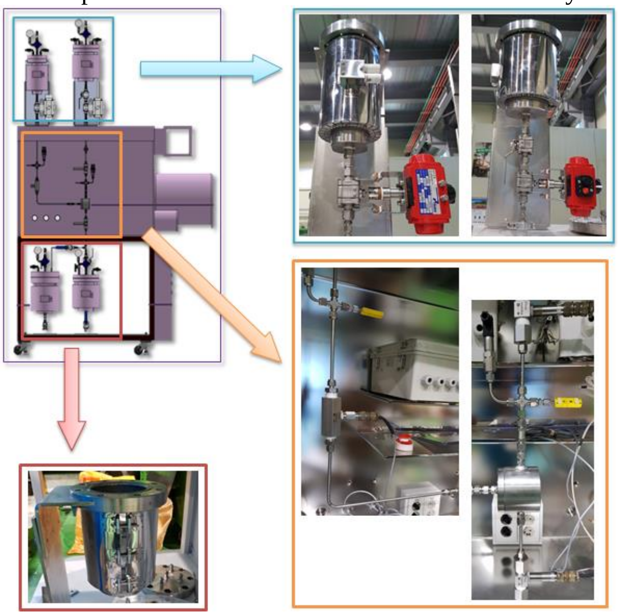

Figure 8: Main components of the SWR test facility

4. Conclusion

An experimental apparatus is designed and manufactured to verify the safety feature of the PCSG against the SWR. To show it, impingement wastage rate will be measured to confirm expected wastage resistance of the PCSG. Also acoustic signals will be measured to estimate feasibility of the acoustic detection system for the PCSG. Manufacturing experimental apparatus had been completed. Now, various tests excluding sodium are performing. Tests including sodium will be performed after all preliminary tests are completed. The SWR in the PCSG is not studied until now. Therefore, it is expected that safety feature of the PCSG is verified through this experimental study.

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