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Thermal Stratification Experiments for Inlet Nozzle of Steam Generator

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1. Introduction

Nuclear power plant components suffer pipe shedding, cracking, thermal fatigue, bending and supporting bracket breakage during their life span. Notably, the horizontal inlet nozzle of steam generator is prone to thermal stratification frequently due to its operational characteristics. As a result, PWR power plants in many countries including the U.S.A. suffered a lot of pipe cracks and leakages around the late 1970s, as the thermal stress inflicted by thermal stratification formed in the horizontal inlet nozzle of steam generator during transition (auxiliary feedwater injection) was not reflected on power plant design.

Therefore, we classified the nuclear power plants in Korea into KSNP and W.H. plants (Kori # 1,2,3,4, Yeonggwang # 1,2 and Uljin # 1,2) and conducted an experiment on thermal stratification and thermal cycling in relation to the volume of auxiliary feedwater injected into the horizontal inlet nozzle of steam generator and hot water flowing back from steam generator. As a result, it was found out that KSNP was hardly prone to thermal stratification while thermal stratification occurred in the horizontal inlet nozzle of steam generator in W.H. power plants, necessitating a solution to address such a phenomenon.

2. Methods and Results

This experiment was intended to test thermal stratification behavior in the horizontal inlet nozzle of steam generator in W.H. power plant and the test was designed and fabricated on the basis of dynamic similarity, assuming determined by the temperature difference between hot and cold water and its volume, etc. as a major dimensionless parameter. The test rig arrangement is as outlined in Figure 1.

Notably, the steam generator O-ring was fabricated as a straight line and the J-nozzle with 6 simple 5cm-wide holes at every 25cm. The horizontal inlet nozzle was made out of 0.15m-wide and 0.3m-long transparent acrylic tube. Stainless steel plates were used to build the cuboid-looking hot and cold water baths 0.5m^3 and 1.0m^3-big respectively and each line was fitted with pump, flowmeter and valve. In addition, the hot water bath was circulated and heated by a boiler adequately. And the temperature distribution around spots of interest was measured by DAS (Data Acquisition System) through 0.127mm-wide K-type thermocouples positioned.

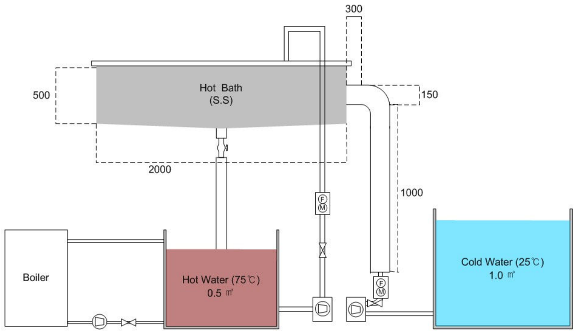

Figure 1. Test Rig Diagram

Assuming that auxiliary feedwater was injected, temperature distribution in the horizontal inlet nozzle steam generator with cold water and hot water flow through J-nozzle and O-ring inside steam generator. In addition, since the flow of hot water influx would not be constant in real power plants, hot water flow was made to vary infinitely within a prescribed flow range. In addition, thermal cycling and stripping experiments were also performed as a part of each experiment and the curvature radius of the curved spot joining the horizontal section with the vertical section was modified to see its impact on thermal stratification.

Table 1. Test Matrix

Test Type \ Plant Type	W.H. Plant	KSNP	Curvature radius
Aux. Feedwater & Hot Water Flows	Exp. A	Exp. B	C.R. 0D
Thermal Cycling Thermal Striping	Exp. AC Exp. AS	Exp. BC Exp. BS	C.R. 0D
Modification of Curvature Radius	Exp. AD	Exp. BD	C.R. 1.5D

2.1 Experiment A

Thermal stratification started to develop 60 seconds after the hot water flow began to vary, as cold water flowed in from the bottom of the curved spot of the horizontal section. And 120 seconds after the experiment commenced, hot water began to stand at the top of the curved spot and the horizontal section with cold water flowing underneath. Then, 180 seconds later, the hot water standing in the curved spot began to disappear while the hot water in the top of the horizontal section continued to stand (forming thermal island). The thermal island was reduced significantly in size and existent locally. Then, over time, the hot water layer (thermal island) at the top of the horizontal section disappeared. On the other hand, hot water hardly made its way into the horizontal section, as the hot water inlet was located right over the feed ring.

2.2 Experiment AC & AS

Had there been thermal cycling mechanisms, specific temperature distribution fluctuation would have appeared. However, it was confirmed that the temperature distribution of each thermocouple group converged toward the auxiliary feedwater temperature in time without any thermal cycle, which is deemed to be ascribable to the fact that the flow of auxiliary feedwater and hot water was small and the pressure variation inside the steam generator was not considered in this experiment.

2.3 Experiment AD

When compared with the results of the experiments where curvature radius was not considered, auxiliary feedwater flowed upward a bit more slowly from the bottom of the curved section of the horizontal line. However, it was found out that the curvature radius of the curved section adjoining the horizontal inlet nozzle in W.H. power plant did not have any significant impact on thermal stratification in reference to the given flow of auxiliary feedwater. However, it was observed that the thermal island was a bit more elongated (lengthwise).

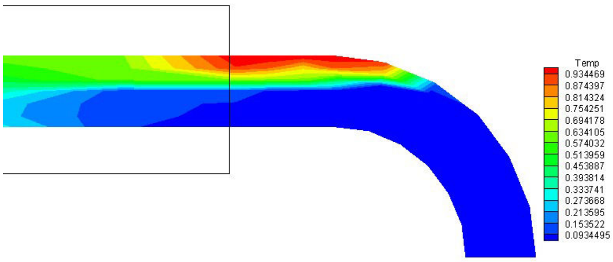

Figure 2. Temperature Distribution When R_i is 72.4 (t=120sec)

2.4 Experiment B & BD

Cold water was pushed like piston through the curved section and the horizontal line of the inlet nozzle deep into the steam generator feed ring. In addition, variation of hot water flow had little bearing on thermal stratification. Therefore, thermal cycling experiment (Experiment BC & BS) was not necessary.

3. Conclusion

We performed assessment of thermal stratification in the horizontal inlet nozzle of the steam generator in W.H. power plants and KSNP in reference to auxiliary feedwater and hot water flows and curvature radius and conducted thermal cycling and stripping experiments as well to arrive at the following conclusions:

(1) Thermal stratification is highly likely to occur in the horizontal inlet nozzle of the steam generator in W.H. power plants when auxiliary feedwater is injected;
(2) Thermal stratification is more at the mercy of the auxiliary feedwater flow than the (hot water) flow conditions within steam generator;
(3) Thermal cycling was hardly observed in the thermal cycling and stripping experiments targeting the horizontal inlet nozzles of the steam generator in W.H. power plants;
(4) The curvature radius of the horizontal inlet nozzle of the steam generator in W.H. power plants did not have significant impact on the thermal stratification in the piping system but had some impact on the size and the duration of thermal island;
(5) Thermal stratification development criteria for the horizontal inlet nozzle of steam generator was found to be R_i>10 in conservative terms;
(6) In the thermal stratification experiment targeting the horizontal inlet nozzle of the steam generator in KSNP, thermal stratification was hardly observed.

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