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Design modification of a feedwater heater impingement baffle to mitigate shell wall thinning by flow acceleration corrosion

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HIGHLIGHTS

- Sometimes, wall-thinning of pipelines occurs fatal accidents in power plants.
- Wall-thinning of feedwater heater is caused by mainly flow acceleration corrosion.
- FAC is caused by the flow from reattachment of jet-streams in heater.
- We verified this phenomenon by analyzing data from experiment and numerical analysis.
- Also, the optimized impingement plate type is suggested to minimize the damages.

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ABSTRACT

The feedwater heaters of many power plants can experience severe wall thinning damage, which accelerates as the plant ages. Several nuclear power plants in Korea have undergone this wall thinning damage around the impingement baffle inside feedwater heaters installed downstream of the turbine extraction stream line. At the baffle point, the extracted steam from the turbine exists as a two-phase fluid at high temperature, high pressure, and high velocity. Since it flows in the reverse direction after impinging the impingement baffle, the shell walls of feedwater heaters may be affected by flow acceleration corrosion. This paper describes a comparison of a numerical analysis using the FLUENT code and downscaled experimental data in an effort to determine the root causes of shell wall thinning of feedwater heaters. The numerical analysis and experimental data were also confirmed by actual wall thicknesses as measured by flow visualization. To compare the degree of shell wall thinning, a test of the mitigation rate on squared-type impingement baffle plates compared with the mitigation rate of other types of impingement baffle plates (squared, curved, mitigating, and multi-hole type) was done inside the shell of a feedwater heater. This paper describes the experimental procedures and the numerical analysis of these comparison data. These experiments were done using conditions similar to those found in a real feedwater heater. Flow visualization was done in order to verify the experimental results and the numerical analysis. From the comparison of the results of the local velocity profiles and the wall-thinning measurements, this study shows that mitigating type and multi-hole type impingement baffle plates are more effective than other baffle plates in preventing decreases in pressure concentration and pressure value.

1. Introduction

Local wall thinning in the shell of a secondary feedwater heater of a nuclear power plant is a phenomenon caused by extended operation of the feedwater heater. Previously examples of such wall thinning mainly occurred in pipes through which fluids flow at high velocities. As a result, studies regarding wall thinning have focused only on pipe flow. Accidents caused by local wall thinning in the shells of feedwater heaters have frequently occurred in South Korea and in many other countries. The incidence of similar accidents is expected to rise as plants continue to age. Compared to pipe flows, the inside of a feedwater heater experiences complex flow patterns due to the heat exchange pipes and baffles, and thus wall thinning occurs locally. Therefore, an accurate determination of the cause of thinning in feedwater heaters is essential (Kastner and Riedle, 1986). In power plants, feedwater is heated by a steam generator using a two-phase jet steam from a high and low pressure turbine. Therefore, impingement baffles are installed inside high and low pressure feedwater heaters in order to protect the heat exchange pipes. Purge stream hits the impingement baffle and returns to

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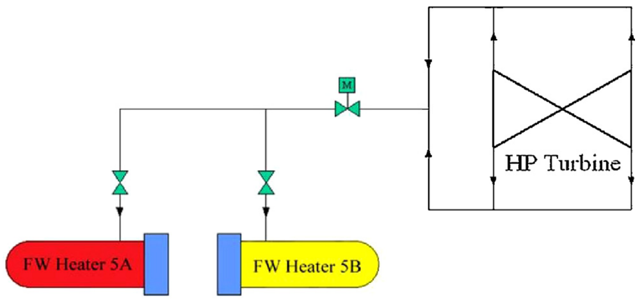

Fig. 1. Schematic diagram of extraction steam system.

the walls. This flow pattern causes local wall thinning on the shell walls of the feedwater heater (Point Beach 1, 1999). Many domestic and foreign power plants, including plants in the United States, have been studying techniques for local wall thinning prevention, but currently the only measure of local wall thinning is post-accident measurement using the UT (ultrasonic test) (Fort Calhoun, 1999).

Since the late 1980s, many cases of local wall thinning inside feedwater heaters caused by reattachment of jet-streams have been reported in United States, Canada, and France. The amount of this type of damage is increasing as the number of years of plant operation increases. A case of wall thinning has occurred in Korea as well, but only a temporary flush patch weld solution has been applied (KNHP, 2000). Therefore, the correlation between the reattachment of the dispersal jet-stream and local wall thinning should be examined, and a fundamental mitigation study is necessary for design improvement. In addition, a commercial numerical analysis program, *FLUENT*, was used to analyze fluid flows in the feedwater heater, and the result was compared with local flow velocities based on the shell thickness measurement data around the extracting nozzles. Furthermore, an experimental device was developed to understand the actual fluid phenomena around the inner impingement baffle plate of the feedwater heater and experiments for fluid visualization and local flow velocity measurement were conducted. This research demonstrated that local shell wall thinning of feedwater heaters is caused by the streams passing the extracting nozzles being reflected by the impingement baffle plate rather than flowing along it. After the investigation of the cause of local shell wall thinning, a follow-up study was conducted to determine if local shell wall thinning could be mitigated by using a method that alters the direction of the fluid flow, which previously faced the thinned wall (Kim et al., 2008a,b).

In addition, this study tested a two-phase condition by using a humidity controller to establish conditions similar to those in the field. A numerical analysis and related experiments were conducted in order to compare and verify mitigation of local shell wall thinning by inner mitigating and multi-hole impingement baffle plates. In short, we conducted a fluid analysis of the impingement baffle plate of the feedwater heater and compared the numerical analysis with the experimental results to verify the validity of the shell wall thinning mitigation measures.

2. Experiment and numerical analysis

To understand the reflected fluid flow and wall thinning characteristics, the commercial data-processing numerical analysis program *FLUENT* was used (Choudhury, 1993). A 5A feedwater heater for a domestic pressurized-water reactor-type two-phase nuclear power plant was used in the model. Steam and water from a high-pressure turbine and a 6A feedwater heater flow into the 5A feedwater heater shell. Therefore, this study objected the extracting

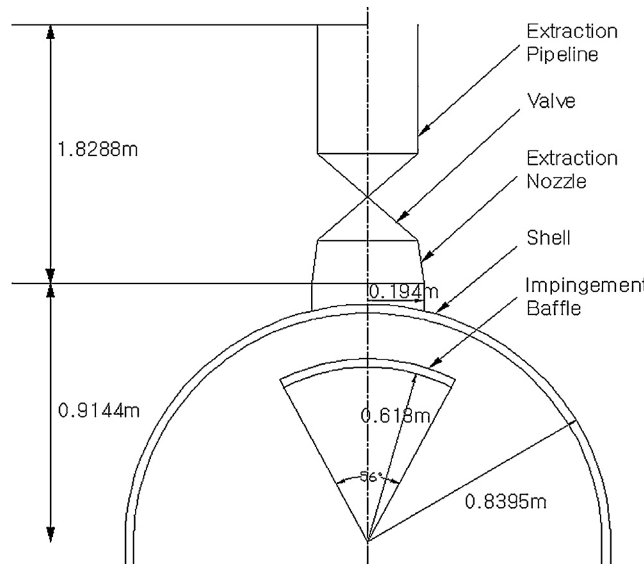

Fig. 2. A half cross-sectional view.

line that severely affects the shell and the impingement baffle plate, which is installed to protect the heat exchange pipes from damage caused by high temperature, high pressure, and high speed steam inflow into the 5A. Fig. 1 shows steam extraction schematics of the 5A and 5B feedwater heaters in the high pressure turbine. The law of similarity is applied to the experimental model as the feedwater heater experimental model was not able to reproduce the actual interior conditions. In short, if geometric similitude and kinematic similitude are satisfied when the dimensionless independent variables are equal, then the dimensionless dependent variables are equal as well. The experimental model was downscaled by 1/2 to ensure that the geometric similitude and the kinematic similitude were equal since the fluid direction was equal to the original form. The model scale was applied in all dimensions. The principle of approximate similitude was employed for the Re number of the dynamic similitude since the original form was too large. In the experiment that satisfied the Reynolds similitude, the model test speed becomes larger than the actual value and results in unrealistic physical phenomenon. In fact, Cengel and Cimbala (2006) suggest that a fluid is insensitive to the Re number when it is between 10^3 and 10^5. In other words, it is valid to examine the fluid effect in the actual form by using extrapolation or analytical methods if the Re number is proven to be large enough. Thus, in

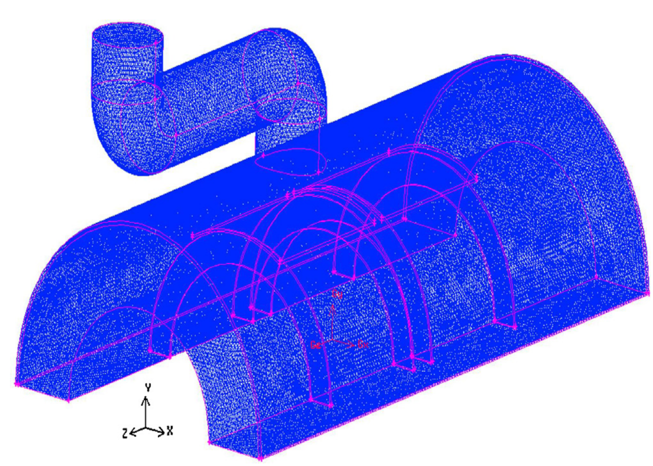

Fig. 3. Modeled geometry and cell divisions.