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Analysis of Leak and Plugging Condition for Feedwater Heaters

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1. Introduction

As operating years of domestic nuclear power plants are increasing, a concern for damaging of heat tube in feedwater heater and increase of tube plugging rate caused by erosion and corrosion of heat tube in feedwater heater is emerging. In fact, most of feedwater heater failures result from damaging of heater tubes. Tube damage and plugging in feedwater heater can cause reduced electric power output and heat consumption rate or degraded performance of surrounding equipment.

Tube damage in feedwater heater occurs from damaged pressure boundary, inflow of foreign substances, erosion and corrosion. Once a heat tube is damaged, the water jet from the damaged spot is spread out to surrounding tubes. Since a feedwater heater is operated under 2-phase flow condition and has physically complicated structure, it cannot be approached on shell side. Therefore, test and inspection to check tube degradation is relatively difficult. Even though tube leak does not affect surrounding tubes, it obviously affects efficiency of turbine cycle and reduces economic feasibility in the long run. For this reason, systematic management is required on thermal performance for feedwater heaters.

In this paper, PEPSE (Performance Evaluation of Power System Efficiency) [1], one of the generic-purpose power plant simulation program, was used to construct a heat balance model for turbine cycle. The model was used to analyze the effect of change in key variables related to thermal performance of feedwater heater on turbine cycle, thereby preparing a thermal performance management strategy for feedwater heaters. Study was conducted on 6 units that represent each reactor type among domestic nuclear power plants (NPPs) in operation, but this paper described the results of high pressure feedwater heaters in a Korean standard NPP, which shows high possibility of tube damage due to large shell-tube pressure difference.

2. Methods and Results

This section explains the analysis method for tube damage and tube plugging in feedwater heater and illustrates the simulation results.

2.1 Feedwater Heaters in NPPs

A feedwater heater is one of core devices in charge of regeneration cycle at power plants. A feedwater heater is the heat exchanger that extracts a portion of steam from turbine and preheats feeding coolant before supplying it to steam unit in order to increase efficiency of turbine cycle and minimize thermal stress inflicted on steam unit [2]. Zones are generally divided into Desuperheating Zone, Condensing Zone, and Drain Cooling Zone according to operating conditions. A certain zone may not exist. Fig. 1 shows a 2-zone feedwater heater mostly used in NPPs. A 2-zone feedwater heater is composed of Condensing Zone and Drain Cooling Zone. The feedwater heater used at the site is a shell-tube type where heat is exchanged through tube without mixing fluids on both sides [3].

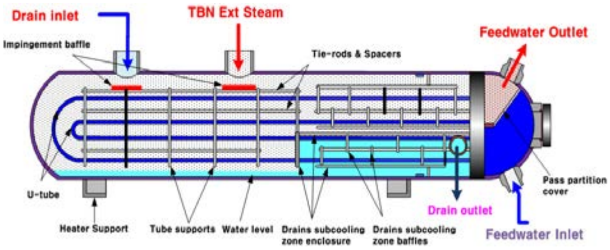

Fig. 1. Schematic diagram of Feedwater Heater (2-zone, Shell-Tube type) in NPP

Terminal Temperature Difference (TTD) and Drain Cooling Approach (DCA) are generally used as performance indicators of feedwater heaters. TTD is the difference between saturation temperature of steam pressure inside feedwater heater and feedwater temperature at the tube outlet of feedwater heater. DCA is the difference between drain temperature of steam extraction of feedwater heater and temperature at the tube inlet of feedwater heater. Equations of TTD and DCA are as follows.

$$\mathrm{TTD} = T_{SAT}(\text{Shell inlet}) - T(\text{Tube out})$$

$$\mathrm{DCA} = T(\text{Shell out}) - T(\text{Tube in})$$

2.2 Plant Modeling

Modeling was performed on the turbine cycles for 6 units at representative NPPs of Korea. They were based on the heat balance under VWO and 100% load, and all feedwater heaters were classified into multiple trains to embody performance degradation mode other than leakage and plugging. During verification of the model, thermodynamic physical properties and turbine expansion diagram in all positions presented on the heat balance diagram under each load were cross-checked to investigate whether they agree within an error range. The completed model was named as reference model, and it was used to performance sensitivity study under leakage and plugging conditions.

2.3 Tube Leak Simulation

Various simulations can be done according to position of tube damage. This study simulated a situation in which feedwater is leaked at the inlet of heating tube and drained to the shell inlet side.

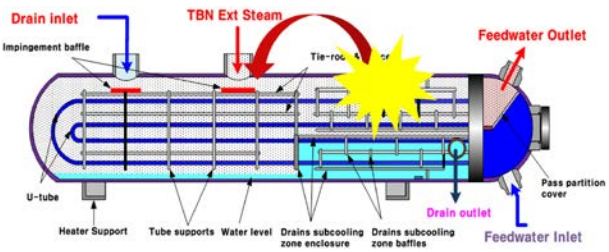

Fig. 2. Schematic diagram of tube leak model

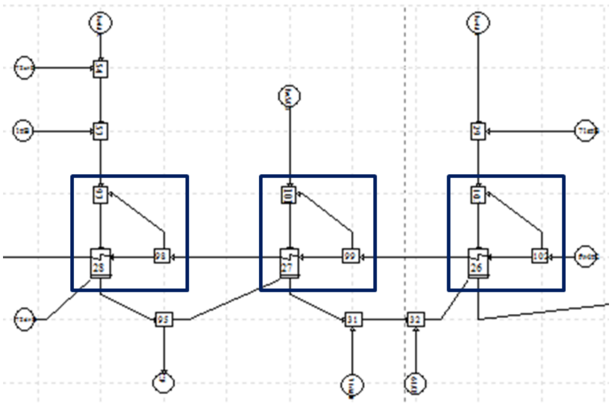
Fig. 3. Schematic diagram of PEPSE model of tube leak

Fig. 2 shows the schematic diagram of a damaged heat tube in feedwater heater. Fig. 3 shows a PEPSE model that simulates a damaged tube. Simulation was carried out on three cases of high pressure feedwater heater as shown in Fig. 3.

Presuming a virtual leak situation, the leakage rate of the damaged heat tube simulation was configured up to 5% of tube-side flow in feedwater heater. The results of simulation on three types of high pressure feedwater heaters for Korean standard NPP are as follows.

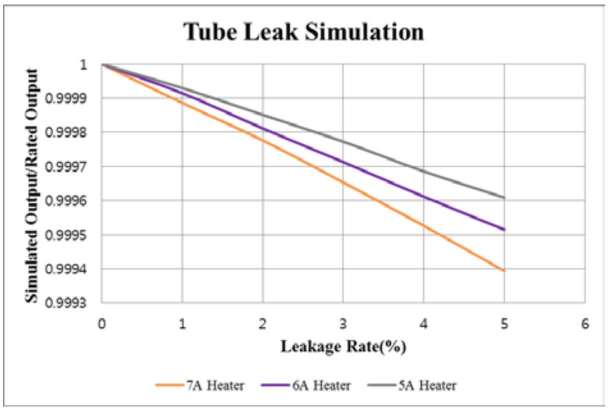

Fig. 4. Tube leak results on electric power

Fig. 4 shows the results of PEPSE simulation for tube damage. The vertical axis of the graph represents an electric power output of the corresponding unit (normalized load: simulated output / rated output), and the horizontal axis is a leakage rate compared to feedwater flow. All feedwater heaters show that electric power output linearly decreases with increase of leak. When the final stage performance of feedwater heater was degraded at the same leakage rate, the effect on overall turbine cycle was shown to be the largest. Despite the fact that leakage rate was up to 5% of feedwater flow, the effect of tube leak on cycle seems insignificant. However, this must be closely managed to maintain integrity of the surrounding tubes and equipment. As mentioned earlier, since there are many types of leak, a multilateral study will be followed in the future to review the effect on electric power output.

2.4 Plugging Simulation

Tube plugging is performed when leak is detected and its amount is not allowed. Modeling of tube plugging was done on the reference model similar to Section 2.3. Tube plugging simulation was done up to 25%. Unlike the tube leak simulation described in Section 2.3, tube plugging was assumed up to 25% considering tube plugging rate of feedwater heaters at existing NPP.

In this paper, the simulation was carried out with the reference model on three cases including high pressure 7A/6A/5A feedwater heater respectively (Individual case), high pressure A train / low pressure A train (Train case), and 7A/B, 6A/B, and 5A/B high pressure feedwater heater (Pair Case).

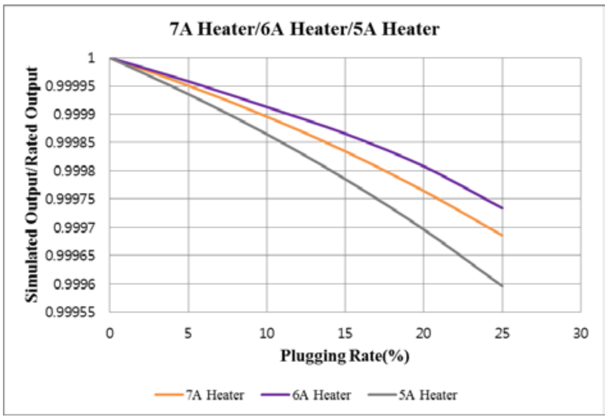

Fig. 5. Tube plugging for individual cases

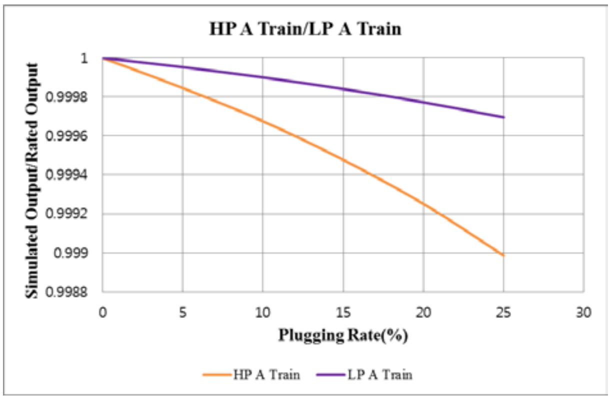

Fig. 6. Tube plugging for train cases

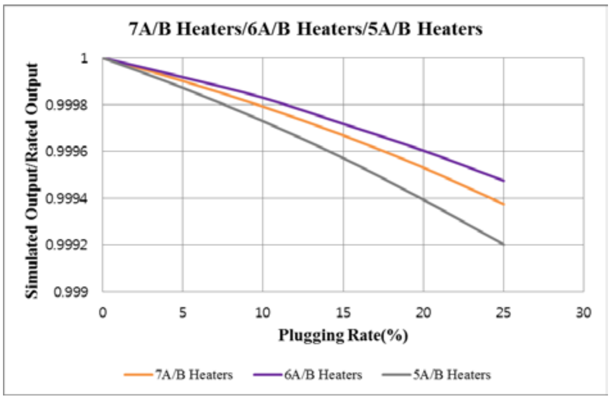

Fig. 7. Tube plugging for pair cases

Fig. 5, 6 and 7 present the results of tube plugging modeling based on the reference model. The vertical axis of the graph represents electric power output of the corresponding unit (normalized load: simulated output / rated output), and the horizontal axis represents tube plugging rate. Performance degradation of feedwater heater No. 5 was found to have greater effect on cycle compared to other heater. In case of the reference model, the heat transfer of feedwater heater No. 5 is larger than other feedwater heaters as well. The results indicate that performance degradation of feedwater heater has greater effect on electric power output of cycle depending on heat transfer of the corresponding feedwater heater. Also in the plugging simulation on each train, high pressure A train decreased electric power output of more cycles compared to low pressure A train. However, overall decrease of electric power output was not noticeable for one series of plugging because heat transfer efficiency was increased on the other normal side. Decrease of electric power output of A train simulation was identical to the sum of decrease of electric power output for high pressure feedwater heaters 7A, 6A and 5A. The results of A train simulation can be predicted using the results of simulation on feedwater heater A. Lastly, feedwater heater A/B had the same trend as the results of simulation on feedwater heater A, and electric power output reduction of the reference model was about twice as large for simulation on feedwater heater A. The simulation showed that the effect of A train tube plugging and A/B tube plugging on cycle can be predicted based on the effect of tube plugging in feedwater heater A on cycle. Performance degradation of feedwater heater has greater effect on electric power output of cycle depending on heat transfer of the corresponding feedwater heater.

3. Conclusions

In this paper, the heat balance models for turbine cycle were constructed as a part of effort to develop the thermal performance management system for feedwater heaters in NPPs. The model was used to analyze the effect of changes in key variables related to thermal performance of feedwater heaters on a turbine cycle. If the thermal performance of feedwater heater can be quantitatively calculated, it can be utilized as a management guideline to make decisions on replacement and maintenance, thereby reducing engineering cost.

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