Tracking of Steam Generator Thermal Performance Trends

S. K. Park [a*], H. D. Kim [b], S. J. Lee [c], D. M. Shin [c], N. C. Cho [c]
[a]*Korea Atomic Energy Research Institute, Daedeokdaero 1045, Yuseong, Daejeon, 305-353*
[b]*Korea Electric Power Research Institute, 65 Munji-Ro, Yuseong, Daejeon, 305-760*
[c]*Nuclear Engineering and Technology Institute, 25-1, Jang-Dong, Yuseong, Daejeon, 305-343*
[*]*Corresponding author: skpark@kaeri.re.kr*

1. Introduction

A significant number of pressurized water reactor (PWR) plants have reported decreases in their steam generator steam pressure during the last several years [1, 2, 3]. Because a steam pressure decrease causes a reduction of the electrical power generating capacity directly, a steam generator's thermal performance is one of the important issues for steam generator maintenance. Therefore, the Korea Hydro & Nuclear Power Company has established an on-line acquisition system for plant operational parameters as a part of the Steam Generator Management Program (SGMP). Recently, plant-specific tools for calculating the overall heat transfer coefficient and the global fouling factor were also constructed and applied to some plants.

2. Methods and Results

2.1 Prediction of an Overall Heat Transfer Coefficient

Heat transfer rate (Q) for heat exchangers can be calculated by

$$Q = UA(F\Delta T_{\mathrm{m}}) = \frac{A(F\Delta T_{\mathrm{m}})}{R''} \qquad \text{eq. 1}$$

where U is the overall heat transfer coefficient, A is the active heat transfer area, R'' is the total thermal resistance, ΔT_{m} is the log mean temperature difference between the two fluids, and F is a factor less than or equal to one that accounts for the deviation from a pure counter flow heat exchanger.

If the secondary fluid temperature distribution of PWR steam generators is approximated as a constant by neglecting a subcooling of the fluid entering the bottom of the tube bundle from the downcomer, the factor F is one regardless of the steam generator geometry. Then the overall heat transfer coefficient and the total thermal resistance for PWR steam generators become

$$U = \frac{1}{R''} = Q \ln\left(\frac{T_h - T_s(P_s)}{T_c - T_s(P_s)}\right)\frac{1}{A(T_h - T_c)} \qquad \text{eq. 2}$$

where T_h and T_c are the primary coolant temperatures at the hot and cold legs respectively, and T_s is the saturation temperature corresponding to the steam generator steam pressure.

2.2 Prediction of a Global Fouling Factor

Global fouling factor accounts for the inside and outside fouling factors of all steam generator tubes. The global fouling factor (R''_f) can be tracked from the history of an overall heat transfer coefficient and calculated by

$$R''_f = R'' - R''_o = \frac{1}{U} - \frac{1}{U_o} \qquad \text{eq. 3}$$

where R''_o and U_o are the total thermal resistance and overall heat transfer coefficient respectively at the initial operation before the steam generators are fouled.

2.3 Parameters for the SG Performance Tracking

Inputs to calculate the history of global fouling factors and overall heat transfer coefficients are thermal hydraulic design data and operational data recorded over the operating life time of plants. The substantial operational parameters required are the primary coolant temperature, feed water flow rate and temperature, steam pressure, and the number of plugged tubes for each outage. Primary coolant flow rate, letdown flow rate in a steam generator, and the steam flow rate are needed to ensure the evaluation of a steam generator's thermal performance.

2.4 Trends of the Steam Pressures

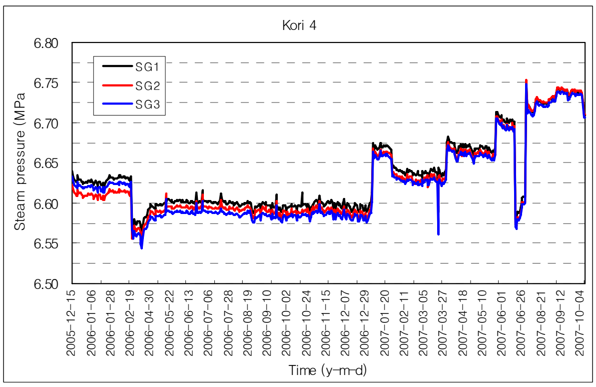

Fig. 1 Trends of the steam pressures.

Figure 1 shows the steam pressure trends of the Kori 4 nuclear power plant from December 2005 to October 2007. The steam pressures decreased slightly up to the end of 2006 and then jumped up four times after the beginning of 2007. The nuclear power plant has indicated oscillations of a steam generator water level since August 2006. It was suspected that the flow holes on the tube support plates were clogged due to a sludge deposit. Thereafter the reduced power operations of 97%, 95%, and 93% of a full power were performed on January 6, March 30, and May 24, 2007 respectively. ASCA (advanced scale conditioning agent) cleaning was also carried out from the second to fifth of July 2007 in order to remedy the oscillation of steam generator water level. Except the fourth jump of the steam pressure on August 6, 2007, the abrupt step increases of three times for the steam pressures before June 14, 2007 are coincident with the thermal power decreases of the nuclear plant.

2.5 Trends of the SG Thermal Performance

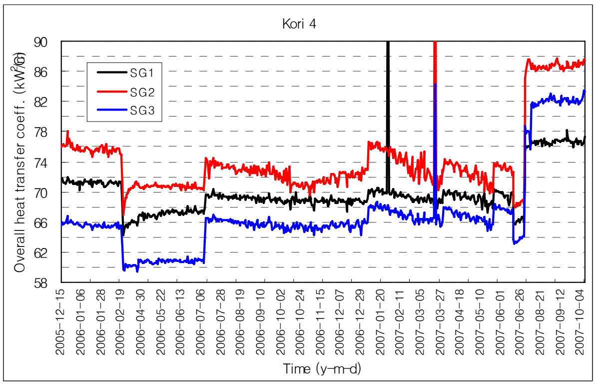

Fig. 2 Trends of the overall heat transfer coefficients.

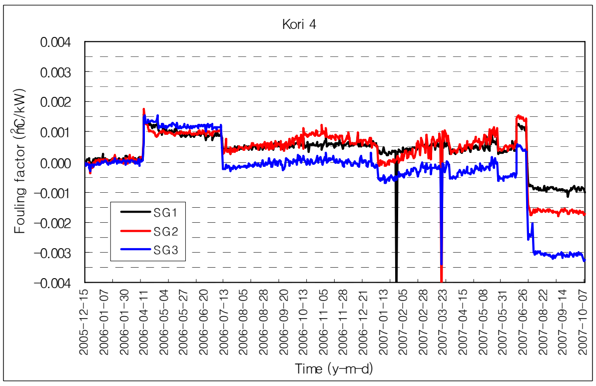

Fig. 3 Trends of the overall fouling factors.

Steam pressure decreases are caused by not only a fouling on tube surfaces but also a plant thermal power decrease or a tube plugging increase. Therefore trends of the heat transfer coefficients or fouling factors are needed to evaluate the degradation of the steam generator performance due to a sludge deposit.

Figure 2 and Figure 3 show the overall heat transfer coefficients and global fouling factors. Because the initial operational data were not obtained, the fouling factors in Figure 3 were calculated by assuming that the state of the steam generators on December 15, 2005 was a base line. Therefore only the qualitative trends of the fouling factors are useful.

The overall heat transfer coefficients and the global fouling factors were not changed abruptly during the period of the reduced power operations. However the global fouling factors and the overall heat transfer coefficients slightly increase and decrease, respectively for each reduced power operation period. On the other hand the overall heat transfer coefficients jumped up after the ASCA cleaning was performed. The global fouling factors also decreased considerably after the ASCA cleaning. These mean that the ASCA cleaning helped the recovery of the steam generator thermal performance for the Kori 4 nuclear power plant. However it was reported that a chemical cleaning did not always recover a steam generator's thermal performance. It is known that the effect of a chemical cleaning on the recovery of a steam generator's thermal performance depends on specific plants [2].

3. Conclusions and Future Work

Domestic plant specific-tools for evaluating a steam generator's thermal performance have been developed and the trends of the steam generator's thermal performance have been also evaluated for the Kori 4 nuclear power plant, especially.

The overall heat transfer coefficients and the global fouling factors indicated the degradation and recovery of the steam generator thermal performance before and after the ASCA cleaning clearly.

In order to increase the usefulness of the overall heat transfer coefficients and the global fouling factors for monitoring a steam generator's thermal performance, the accuracy of the instruments to measure the operational parameters should be enhanced and uncertainty analyses on the instruments are needed.

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