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Analysis of Fouling Resistance in Safety-Related Heat Exchangers

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1. Introduction

As a part of nuclear safety activities, developed countries have performed Periodic Safety Review (PSR) to verify and improve the safety of operating Nuclear Power Plants (NPPs). In 1999, it was decided by the Korean Atomic Energy Safety Committee to adopt the PSR program. PSR is officially legislated in 2001 as a 10-year-basis safety evaluation process. Since the first tentative application of PSR for Gori Unit 1 in 2000, it is now progressing well [1, 2]. Generally PSR assesses the cumulative effects of plant ageing and plant modifications, operating experience, technical developments and site aspects. The reviews include an assessment of plant design and operation against current safety standards and practices [3]. After reviewing activities, safety is enhanced by implementing the corrective actions and/or safety improvements.

When a PSR was performed in Gori Units 3-4, several safety-related heat exchangers in the Reactor Coolant System (RCS) such as a letdown heat exchanger were pointed out as the components necessitating a corrective action which is the analysis of fouling resistance. The fouling resistance is used as an important parameter to evaluate the safety as well as the economics of heat exchangers. However it is difficult to develop a credible analysis procedure due to considerable discrepancy between normal operating conditions and design conditions. This issue was identified while we were conducting a study in KNICS (Korea Nuclear I&C System) R&D program. We might be able to guess other NPPs in Korea are likely to have the same issue.

This paper involves the characteristics of the safety-related heat exchangers and the methodology to develop the analysis procedure.

2. Methods and Results

In this section, the fundamental characteristics of the safety-related heat exchangers, particularly a letdown heat exchanger are described. The methodologies for determining fouling resistance and monitoring its change are explained.

2.1 Characteristics of Safety-related Heat Exchangers

The letdown heat exchanger is a normal shell-tube type model, which is located in the CVCS (Chemical and Volume Control System). The reactor coolant is going through the tube side, and the CCW (Component Cooling Water) is flowing up and down through the baffles in the shell side. In order to maintain the functional requirements of the CVCS during normal conditions as well as transient conditions, the size of the letdown heat exchanger is determined as largely as the one that can support a maximum anticipated heat load. Table 1 summarizes some design parameters of the letdown heat exchanger in Gori Unit 3-4, and Table 2 shows the status of its sensor installation.

Table 1. Design parameters of the letdown heat exchanger

	Shell Side	Tube Side
Flowrate (kg/sec)	62.75	7.51
Inlet Temperature (°C)	40.56	193.33
Outlet Temperature (°C)	58.33	46.11
Pressure (kPa)	690	2,517
Pressure Drop (kPa)	95	35
Passes	2	8
Outer Diameter (m)	0.559	0.019
Length (m)	-	4.166
Number	-	284
BWG (Birmingham Wire Gauge)	-	18

Table 2. Status of sensor installation (O: installed, X: none)

	Flowrate	Temperature		Pressure	
		Inlet	Outlet	Inlet	Outlet
Shell	X	O	O	X	X
Tube	O	O	O	X	O

During a normal operation, the flowrate of both sides keeps up the range of 1/2~1/5 design flowrate. Therefore the fouling resistance determined in a test condition, which is termed a 'test fouling resistance (r^T),' cannot be reasonably compared with that of a design condition, which is called a 'design fouling resistance (r^D).' It necessitates a correction factor which projects the design fouling resistance into a new one which is decided assuming a clean heat exchanger is operating in the test condition, which is termed a 'projected fouling resistance (r^P).' Figure 1 depicts how fouling resistance are compared in this study.

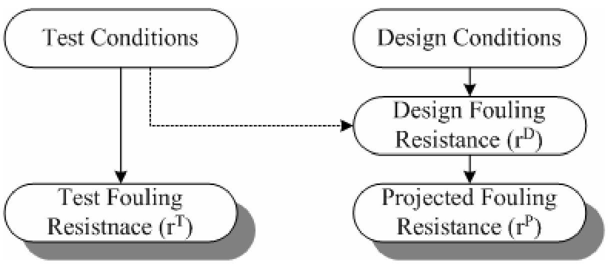

Figure 1. Determination of fouling resistance

2.2 Analysis of Fouling Resistance

The purpose of this study is to monitor the test fouling resistance and to compare it with the projected fouling resistance. This kind of condition monitoring well corresponds with the signal validation framework proposed by a NUREG [4]. Figure 2 illustrates the entire fouling coefficient monitoring process based on the framework in the NUREG report.

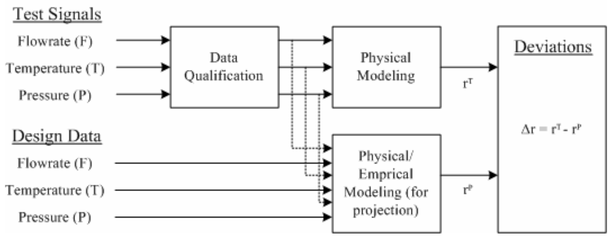

Figure 2. Concept of fouling resistance monitoring process

The kernel of this framework is to determine the test and to estimate the projected fouling resistance. An overall heat transfer coefficient, U of a heat exchanger is defined as Eqn. (1).

$$U = \frac{1}{1/h_o + r_o + r_w + r_i(A_o/A_i) + (1/h_i)(A_o/A_i)} \qquad (1)$$

where h is film coefficient,
r is fouling resistance,
A is heat transfer area,
subscript o stands for tube outside,
subscript i stands for tube inside,
subscript w stands for wall,

Since both of the tube inside and outside fouling resistances are not achievable at the same time, we assume they have the same value as Eqn. (2) and define it an average fouling resistance.

$$r_i = r_o = r_a \qquad (2)$$

Finally we will get the average fouling resistance derived from Eqn (1) and (2) as follows:

$$r_a = \frac{1}{1 + A_o/A_i}\left[\frac{1}{U} - \frac{1}{h_i}\frac{A_o}{A_i} - \frac{1}{h_o} + r_w\right] \qquad (3)$$

Using a few heat transfer correlations and either test signals or design data, we are able to determine U, h, r_w, and A. If we use test signals, we will take r^T. If we apply design data to Eqn. (3), then we will get r^D. In a test condition which is different from the design condition, both of the inside and the outside h are changed due principally to two effects: 1) changes from design fluid temperature, and 2) changes from design flowrate [5]. In order to correct these effects, the EPRI report provides temperature and flowrate correction curves. The corrected h is derived to Eqn. (4), and Eqn. (4) is applied to the determination of the inside as well as the outside projected film coefficients.

$$h^P = h^D \times (K_t \times K_f)^T / (K_t)^D \qquad (4)$$

where K_t is temperature correction factor,
K_f is flowrate correction factor,
superscript P stands for projected value,
superscript D stands for design value,
superscript T stands for test value.

Replacing the results of Eqn. (4) to Eqn. (3), we will get r^P which is comparable with r^T. An early warning module could be developed because we have two comparable parameters as a way of evaluating the thermal performance of the safety-related heat exchanger. The early warning module consists of statistical process charts monitoring the deviations between r^T and r^P (See Figure 2). The statistical process charts monitor the trend of the deviation and generate an alarm when the deviation exceeds the specified set-point which is decided by ASME standards [6]. Generally the early warning capability of the statistical process charts is strongly dependent on a signal condition, so X-R chart, CUSUM (CUmulative SUM) chart, and SPRT (Statistical Probability Ratio Test) were implemented in a single user interface for conservative warning [7, 8]. The fouling resistance analysis procedure developed by the proposed methodology was applied to five safety-related heat exchangers in Gori Unit 3-4 and a computer program was also delivered in order to make it easy to apply the developed procedure.

3. Conclusion

This paper dealt with how we manage thermal performance of the safety-related heat exchangers in NPPs, which might be useful as the groundwork of PSR post-review activities. It could be a part of ageing management program for a successful PSR program.

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