Residual Life Assessment of Feedwater Heaters using Weibull Distribution Function

Se Youl Won* and Young Sheop Park
Nuclear Engineering & Technology Institute, Korea Hydro & Nuclear Power Co. Ltd.,
25-1 Jang-dong Yuseong-Gu, Daejeon, KOREA, 305-343, w1310@khnp.co.kr
**Corresponding author: w1310@khnp.co.kr*

1. Introduction

To predict the life assessment of heat exchangers, it is important to know the tube plugging rate according to the fouling rate inside the heat exchangers which causes the performance degradation. This is important because the performance degradation of heat exchangers is closely related to the system efficiency and safety operation.

In this study, feedwater heaters, being operated more than 25 years, which functions as a heat exchanger, were selected to predict the life assessment using the Weibull distribution function. We chose feedwater heaters because it is a good example of how over time, the power production and plant efficiency for damage caused by tube-and-tube collision, tube erosion etc. degrade.

2. Methods and Results

The probability method is appropriate for predicting the future damage rate because we could statistically apply the failure mechanism, operation time, and maintenance records that have occurred until now. There are three representative probability density functions that fits empirical data in life time assessment for passive type equipment: the log-normal distribution, the exponential distribution, and the Weibull distribution. Among these distribution function, the Weibull is chosen to build statistical model in this paper.

2.1 Weibull Distribution Function

The Weibull distribution is widely used to analyze the cumulative loss of performance, i.e., the breakdown, of a complex system in engineering. The Weibull distribution is also available to express variable failure phenomena by changing parameters to determine some regular relation to the operating time of the facilities. The formula for the probability density function of the Weibull distribution is presented to the following equation.

$$f(t)=\left(\frac{m}{n}\left(\frac{t-r}{n}\right)^{m-1}\right)\exp\left(-\left(\frac{t-r}{n}\right)^{m}\right) \quad (1)$$

Where, *f(t)* is the probability density function, *m* is the shape/slope parameter, *n* is the scale parameter, and *r* is the location parameter

In Eq. (1), the three parameters can be transformed into time constant, operating time, and failure number as in

$$f(t)=\left(\frac{b}{\theta-t_o}\left(\frac{t-t_o}{\theta-t_o}\right)^{b-1}\right)\exp\left(-\left(\frac{t-t_o}{\theta-t_o}\right)^{b}\right) \quad (2)$$

Where, t is time (EFPY: Efficiency Full Power Years), t_o is the failure occurrence waiting time, b is the slope of Weibull (the failure occurrence increasing rate), and θ is the time constant.

the following Eq. (2). Then, integrating Eq. (2) into time, the formula of the Weibull probability density function leads to Eq. (3), which is called the cumulative probability density function (*F(t)*). Eq. (3) is also linearly expressed in Eq. (4).

$$F(t)=\int_{t_o}^{t} f(x)dx = 1-\exp\left(-\left(\frac{t-t_o}{\theta-t_o}\right)^{b}\right) \quad (3)$$

$$Ln\left(Ln\left(\frac{1}{1-F(t)}\right)\right) = -bLn(\theta-t_o)+bLn(t-t_o) \quad (4)$$

In case of the failure prediction using the Weibull distribution function, two parameters instead of three parameters are generally used by applying zero value to the failure occurrence waiting time (t_o) as in Eq. (5).

$$Ln\left(Ln\left(\frac{1}{1-F(t)}\right)\right) = -bLn(\theta)+bLn(t) \quad (5)$$

In this paper, the Weibull distribution function using Eq. (5), which is also recommended by EPRI, is applied to predict the future tube plugging rate for feedwater heaters.

2.2 Summary of Tube plugging status

Table 1 presents the tube plugging status and the function value of tube plugging for the operation history of feedwater heaters. The cumulative tube plugging rate is calculated based on the total tube plugging numbers, The EFPY value is assumed to be 90%. Table 1 shows that the cumulative tube plugging gradually increases in proportion to the increase of operation time of the

Table 1 Tube Plugging status of feedwater heaters

t (EFPY)	Cumulative Tube plugging rate(%)		Ln(t)	1/(1-F(t))	
	Unit A	Unit B		Unit A	Unit B
9.0	4.85	0.00	2.1972	1.0509	1
9.9	5.38	0.95	2.2925	1.0568	1.0095
10.8	6.33	0.95	2.3795	1.0675	1.0095
11.7	6.43	1.48	2.4595	1.0687	1.0150
12.6	6.43	1.48	2.5336	1.0687	1.0150
13.5	6.43	8.12	2.6026	1.0687	1.0883
14.4	7.28	8.44	2.6672	1.0785	1.0921
15.3	8.12	8.76	2.7278	1.0883	1.0960
16.2	8.33	9.07	2.7850	1.0908	1.0997
17.1	8.44	9.07	2.8390	1.0921	1.0997

feedwater heaters and unit B has a high level of preventive tube plugging around 13.5 EFPY.

2.3 Prediction of Tube plugging rate

The empirical data of the feedwater heaters in unit A and B are listed in Table 1. In order to elicit the tube failure rates over the operation time using the Weibull distribution model, the regression lines and the coefficient of determination (R^2) are presented in Fig 1. The result in Fig. 1 shows that the regression line that indicates the tube failure occurrence rate is overestimated by the effect of preventive tube plugging for unit B and the low coefficient of determination shows the low reliability of the predicted failure rate.

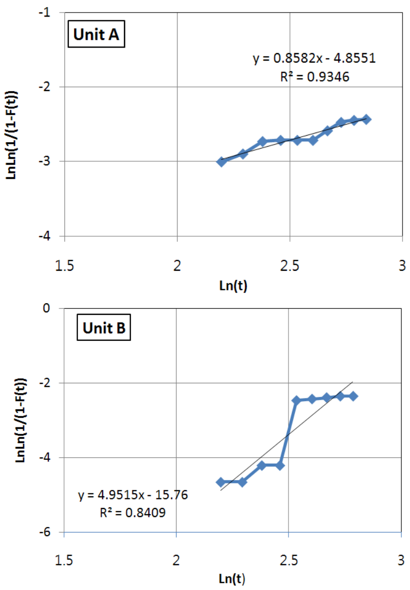

Fig. 1 Relationship between *Ln(t)* and *LnLn(1/(1-F(t))*

Fig. 2 presents the modified relation between tube failure rates and operation time by selecting a comparatively stable EFPY period, which is a later 13.5 EFPY for unit B. Thus, the result in Fig. 2 shows that the value of the low determination coefficient is replaced from 0.8409 to 0.9523 for unit B and the reliability of the failure occurrence rate is higher than in Fig. 1.

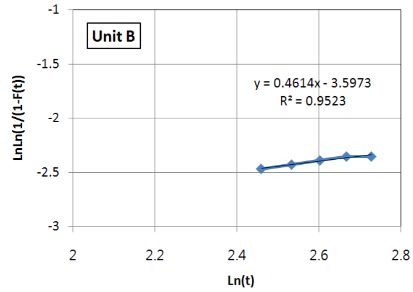

Fig. 2 Modified Relation between *Ln(t)* and *LnLn(1/(1-F(t))*

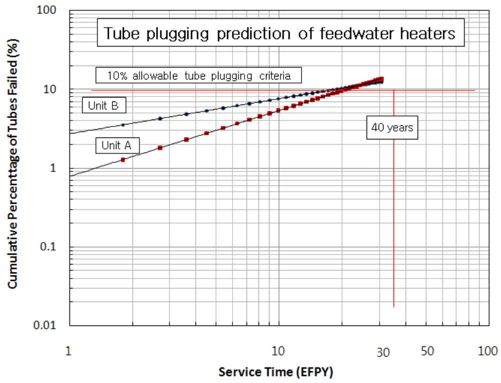

Fig. 3 Best estimated curves for life assessment for feedwater heaters

Using the result of Fig. 2, the tube plugging rate of feedwater heaters is predicted in Fig 3. The results show that the tube plugging rate of feedwater heaters exceeds the criteria of the 10% allowable tube plugging rate for both units over the period of the plant design years, 40 years (Unit A : 21.6 EFPY, Unit B: 18.9 EFPY)

3. Conclusions

As the number of commercial operating years of feedwater heaters increases, their performance gradually degrades by a continual tube plugging. In this paper, the Weibull distribution function is used to analyze the future cumulative loss of performance and to predict the remaining life of a feedwater heater, which are closely related to the system efficiency and safety operation. The results of the remaining life assessment show that the tube plugging rate could exceed the 10% allowable tube plugging criteria around 21.6 EFPY and around 18.9 EFPY for a feedwater heater referred in this paper.

REFERENCES

[1] A study on development of nuclear steam generator maintenance expert, 1996.
[2] EPRI, "Pressurized Water Reactor Generic Tube Degradation Predictions", TR-1003589, 2003.
[3] EPRI, Feedwater Heater Technology Symposium, 1004121, Proceedings August 2004.