Assessment of Feeder Wall Thinning of Wolsong Nuclear Power Plants

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1. Introduction

The reactor of CANDUs of Wolsong Nuclear Power generating station is composed of 380 pressure tubes. The primary heat transport circuit of CANDU connects each pressure tube to headers on the way to and from the steam generators. The feeder is A-106 carbon steel, and suffers from wall thinning by Flow Accelerated Corrosion. Excessive thinning deteriorates the pressure retaining capability of piping so that the minimum allowable thickness of feeder should be maintained throughout the life of feeder. The feeder wall thinning should be monitored by in-service inspection. Knowledge-based inspection strategy needs to be developed since combination of high radiation field and geometric restriction near the tight bend location makes extensive inspection very difficult.

A thermo hydraulic assessment using computational fluid dynamics software and feeder wall thinning simulation experiments using plaster of Paris may provide valuable information to understand characteristic features of the feeder wall thinning. Plant in-service inspection database may be another source of valuable information.

This paper summarizes a review of feeder wall thinning in Wolsong CANDU station. W-1 feeder suffered significant thinning so that it is being replaced along with the plant refurbishment campaign. The other units, W-2~4, are still in the early portion of their operation life. A result of feeder wall thinning simulation test using plaster of Paris is presented. The knowledge presented in this paper is important information to design a knowledge-based in-service inspection program of feeder wall thinning.

2. Flow Accelerated Corrosion

FAC is a type of corrosion of carbon steel, accelerated by fast flowing coolant at high temperature and under reducing atmosphere. The accelerating role of the fast flow is to enhance the mass transfer of ferrous ions at the iron oxide/water interface into the bulk of flowing water. FAC is widespread among carbon steel piping in the power plants [1]. FAC has been an extensively active degradation mechanism of the carbon steel secondary side piping of pressurized water reactors. The piping failure incidences caused by excessive thinning have been reported. The thinning rate of feeder, less than 0.13mm/year at fastest, is not as fast as the secondary piping of PWR, as high as a few mm/year. However, the feeder is small bore piping so that the lifetime accumulated thinning can lead to deteriorated structural integrity.

The major factors affecting FAC may be divided into the chemistry factors and the hydraulics factors. The chemistry factors are Cr content of steel, pH, dissolved oxygen, and temperature. The hydraulic factors include flow velocity, geometry of piping, steam quality (or void fraction), and surface roughness. The hydraulic factors are important because they govern the local mass transfer coefficient. It is understood generally that the FAC rate is proportional to the mass transfer coefficient, as equation (1).

$$\text{FAC rate} = k \times (C_S - C_\infty) \qquad (2)$$

k: mass transfer coefficient (m/sec)

Cs: concentration of ferrous ions at the oxide/water interface

C∞: concentration of ferrous ions in the flowing bulk

3. A FWT Simulation Test

A FWT simulation test was performed using plaster of Paris specimen and a loop. The specimen simulates identical flow geometry to feeder. The loop controls circulation and chemistry of water. The wall thinning of the plasters of Paris specimen is measured after the end of each test.

Table 1 and Fig. 1 summarize the result of the simulation test. Fig.1 indicates that the mass transfer coefficients calculated from the simulation test and plant measurement data coincides pretty well. The mass transfer coefficients were calculated using the equation (2) using the analogies shown in Table 1. It is noted that the figure wall thinning is the typical FAC as controlled by the mass transfer reaction of ferrous ions.

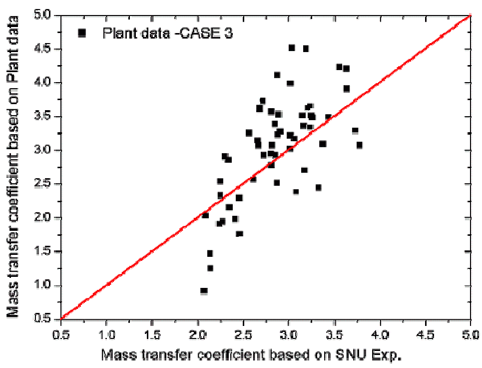

Figure 1 Mass Transfer Coefficients calculated from plant data and plaster of Paris

Table 1 Comparison of plaster of Paris and feeder

	plaster of paris	Ferrous ion
ρ_s (kg/m^3)	1550 g/l	7900
C_w	30 g/l	12.2 ppb
C_{∞}	28.79	5.6 ppb
Δr (mm)	measured	UT-detection
Δt	hour	EFPY
Diffusion coefficient(m^2/sec)	0.728×10^{-9}	0.5×10^{-9}

4. Wall Thinning of Wolsong feeder

It is empirically understood that the thinning rate of each feeder is proportional to QV. Q is the mass flow rate (kg/sec) and V is the linear flow rate (m/sec) of each channel. The operation condition of each channel is assessed from the cumulated operation data. W-1 operation data were averaged between 6034~8028 full power days, and W-2 between 1512~4089 full power days. It is noted that the temperature of W-2 feeder is slightly higher than W-1 feeders, so that the flow velocity is faster for W-2 than W-1. The higher temperature means higher void fraction, and thus faster flow under the same mass flow rate.

The minimum wall thickness as measured each in-service inspection of W-1 feeder is regressed with the EFPY as scaled by multiplying QV factor, as shown in Fig. 2. QV factor is defined as 1 for the feeder with the highest QV value, and proportionately defined for other feeders. QV factors of 2inch and 2.5inch feeders are calculated separately. There are 320 2.5inch channels, and 60 2inch channels. The minimum thickness is the thinnest value taken among the seven measurement points covering extrados of each bend for each inspection. The slope in Fig. 2 may be considered as the average thinning rate calibrated by QV factor. The statistical parameters from the regression are listed in the accompanying table. It is noted that the y-axis intercept coincides with the estimated initial thickness for 2.5 and 2inch feeders. It is understood that the QV model gives reasonable regression.

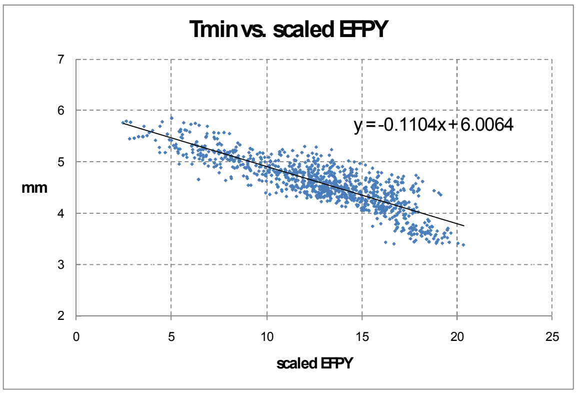

Figure 2 Minimum wall thickness vs. scaled EFPY

It is noted that the slope is considerably lower for 2inch feeder than for 2.5inch feeder. The ratio of the slopes is 1.38. It is understood that 2.5inch feeders are higher power channels, and thus faster flow. The ratio of average QV value of 2.5inch feeder to 2inch feeder is calculated as 1.46, as Q is corrected by dividing with the cross section area each. The ratio of the average QV value, 1.46, coincides well with the ratio of slopes, 1.38, indicating again that the QV model provides reasonable correlation.

W-2 feeder wall thinning databases were regressed. The slope is far less than W-1, only 41% for 2.5inch feeder, indicating that the average feeder wall thinning rate is far slower for W-2 than W1.

It is believed that the slow thinning of W-2 is due to the higher chromium content in W-2 feeders. It should be noted that the still small Cr content in W-2 feeder, 0.051% average, drastically reduced the wall thinning.

5. Conclusions

1) FWT is a typical FAC reaction which is proportionate linearly to the mass transfer coefficient governed by local hydraulics.
2) FWT is proportionate linearly to QV of each channel.
3) W-2 feeder is significantly less susceptible to wall thinning than W-1 feeder. It is believed that the small content of chromium in the steel is the cause of the difference in susceptibility

REFERENCES

[1] Bindi Chexal et al., Flow-Accelerated Corrosion in Power Plants, TR-106611-R1, Electric Power Research Institute, 1998