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A Method to Establishing Tube Plugging Criterion for Heat Exchangers with Straight Tubes

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1. Introduction

There are two kinds of tube shape in shell and tube type heat exchangers in nuclear power plants. One is a heat exchanger using U-shape tubes, which is used for making up for the displacement in the axial direction due to a thermal load. Because of this characteristic of U-shape tube, the U-shape tubes are used for heat exchangers operated in high temperature such as steam generators and high pressure heaters nevertheless U-shpae tubes are susceptible to crack initiation in the bend region. Another is a heat exchanger using straight tubes. The difference of thermal expansion coefficients between the shell and tube materials causes the stress in axial direction of tube. Because of the axial stress due to thermal load, the straight tubes are used for heat exchangers operated in low temperature such as CCW (Component Cooling Water) heat exchangers and condensers.

It is inevitable for the materials of the components to be degraded as the power plants become older. The degradation accompanies increasing maintenance cost as well as creating safety issues. The materials and wall thickness of heat exchanger tubes in nuclear power plants are selected to withstand system temperature, pressure, and corrosion. However, tubes have experienced leaks and failures and plugged based upon eddy current testing (ET) results. There are some problems for plugging the heat exchanger tubes since the criterion and its basis are not clearly described. For this reason, the criteria for the tube wall thickness are addressed in order to operate the heat exchangers in nuclear power plant without trouble during the cycle.

There are many codes and standards to be referred for calculating the minimum thickness of the heat exchanger tube in the designing stage. However, the codes and standards related to show the tube plugging criteria may not exist currently. In this paper, a method to establish the tube plugging criteria of BOP heat exchangers, which is based on the USNRC Regulatory Guide 1.121, is introduced and the tube plugging criteria for the TPCCW heat exchanger of Yonggwang NPP No. 1 and 2. This method relies on the similar plugging criteria used in the steam generator tubes.

2. Methods and Results

The USNRC Reg. Guide 1,121 based on the safety factors, which is the ratio of the applied stress and the strength of material, mentioned in ASME Sec. III. Using eddy current testing, it is not easy to know the shape of the cross-section of thinned tube. The thinned shape will be between the eccentric shape (Fig. 1(a)) and the uniform shape (Fig. 1(b)). Fortunately, the stresses for the thinning ratio of the eccentric shape and uniform shape are not much different as shown by Fig. 2. In this paper, it is assumed that the thinned shape is uniform.

The steam generator tube plugging criteria depends on the USNRC Regulatory Guide 1.121, Bases for Plugging Degraded PWR Steam Generator Tubes. The Guide 1.121 says the following factors should be considered: 1) the minimum tube wall thickness needed for tubes with defects to sustain the imposed loading under normal and accident conditions, 2) between the inspections, the allowance of degradation, 3) the crack size permitted to meet the leakage limit allowed per the technical specification. The last one is not clearly needed for the tubes of the BOP heat exchangers.

As shown by previous paragraph, the Guide treats two conditions, the normal operational condition and the accident condition. The basis of the judgement for the steam generator tube integrity is the safety factors mentioned in ASME Sec. III. The requirements for the tube to be satisfied for the normal operational condition are the same as the general machine design. Therefore, it is convenient to apply the Guide directly to the BOP heat exchanger. In this paper the maximum stress due to the normal operation condition and thermal gradient is calculated. Then the stress with the safety factors mentioned in ASME Sec. III is compared with the yield strength and tensile strength of tube material at the appropriate temperatures in order to establish the required tube wall thickness. The material properties are given by ASME Sec. II Part D.

The requirements of the Guide for the accident condition are connected with two postulated accidents. They are the steam line break and loss of coolant accidents (LOCA). While the first one can be applicable to establish the tube plugging criteria of the BOP heat exchangers, the second one cannot. For considering the first accident condition, the maximum stress due to the design pressure without shell-side pressure is calculated. Then the stress with the safety factors mentioned in ASME Sec. III is compared with the yield and tensile strength of tube material at the design temperatures in order to establish the required tube wall thickness. The LOCA condition cannot be considered directly to the heaters. The steam generator tubes are supposed to be pressed by outside pressure during the LOCA. Observing this fact, the similar condition is adopted for the tubes of heaters in this paper. The minimum wall thickness required for this condition is calculated adopting the well-known formula.

The stresses in the CCW and TBCCW (Turbine Building Component Cooling Water) heat exchanger tubes in nuclear power plants are compressive stresses (Figure 3) because the tube side pressure is smaller than the shell side pressure. It is very hard for materials to be failed due to the compression. Figure 4 shows the stresses including the end effects. Even though the end effects are considered, the calculated stresses in the 95% thinned tube are lower than the yield strength of the tube material. Therefore, the elastic stability should be considered for the failure mechanism of the CCW and TBCCW heat exchangers

Figure 5 shows a critical pressure for the thinning ratio for the CCW heat exchanger of a nuclear power plant as an example.

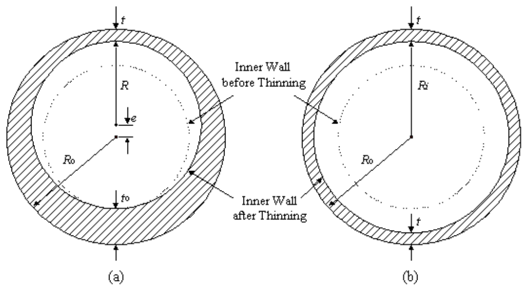

Figure 1. Thinned shapes (a) eccentric, (b) uniform

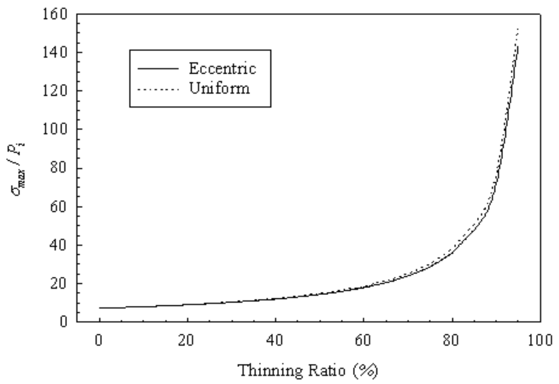

Figure 2. Stresses in the tube with the eccentric and uniform cross-section for the thinning ratio

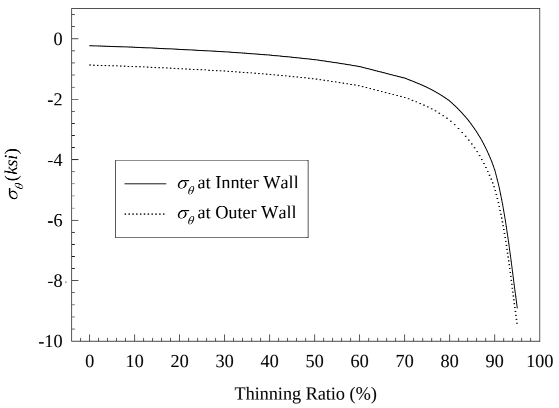

Figure 3. Max. hoop stresses at operating condition for the thinning ratio

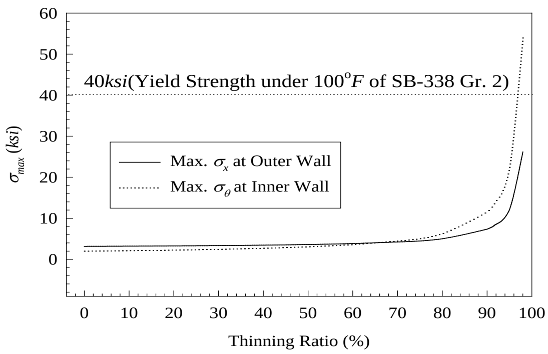

Figure 4. Max. stresses at design condition according to the thinning ratio

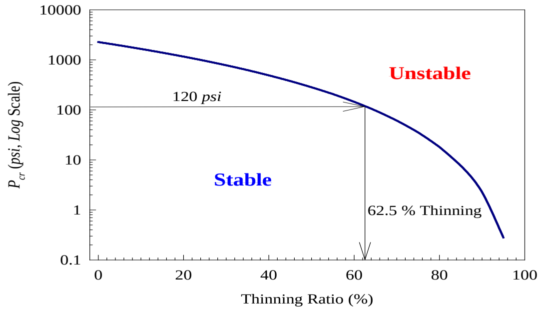

Figure 5. Critical pressure for the thinning ratio.

Table 1. Plugging criteria for a CCW heat exchanger in a nuclear power plant

Condition	Results	
	Without End-Effects	With End-Effects
Operation	Compression	Over 90%
Design	Compression	Over 90%
Stability	62.5%	
Criterion	62.5%	

3. Conclusion

A method to establish the tube plugging criteria of heat exchangers with straight tubes are introduced based on the USNRC Regulatory Guide 1.121. As an example, the tube plugging criterion for the CCW heat exchanger of a nuclear power plant is provided.

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