Tube Repair Criteria for Heat Exchangers with U-Tubes Applying USNRC Reg. Guide 1.121

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1. Introduction

As the power plants become older, it is inevitable for the materials of the components to be degraded. The degradation accompanies increasing maintenance cost as well as creating safety issues. It is urged for the nuclear power plants to reduce operating and maintaining costs to remain competitive. The thermal efficiency of the power plant affects the cost efficiency. The inspection of balance-of-plant (BOP) heat exchanger tubes becomes important to reduce the cost by preventing the lowering thermal efficiency. 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.

The feed water heater is a kind of heat exchanger which raises the temperature of water supplied from the condenser. The heat source of low-pressure heaters is the extraction steam from the low-pressure turbine. If the tube wall cannot withstand the pressure, the feed water flowing inside the tube intrudes to shell side. This forces the thermal efficiency to be low.

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, and the tube plugging criteria for some heat exchangers in a nuclear power plant are introduced. 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 applying well-known formula.

The plugging criteria should include factors for increase in the flaw size between the inspections, which is normally 10% of the installed wall thickness, and for the NDT error, which is also 10% of the installed wall thickness. Including these factors, the tube plugging criteria for some heat exchangers with U-shape tubes are established as in Table 1.

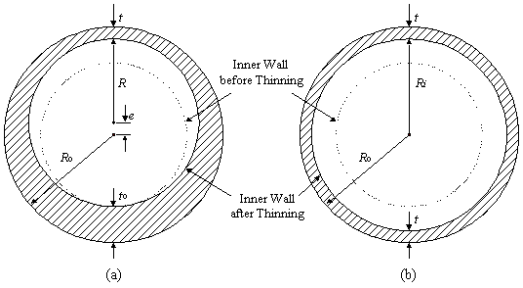

Figure 1. Thinned shapes (a) eccentric, (b) uniform

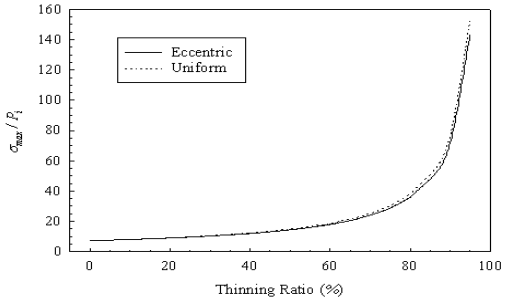

Figure 2. Stresses in the tube with the eccentric and uniform cross-section for the thinning ratio

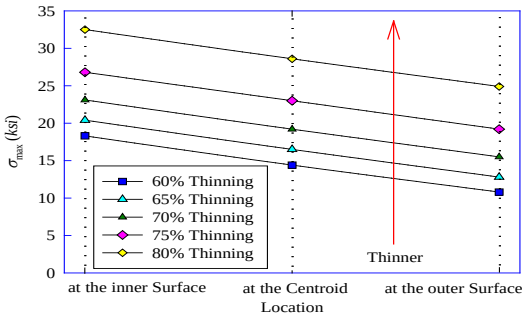

Figure 3. Max. stresses at the inner, central and outer surfaces for the various thinning ratio at design condition

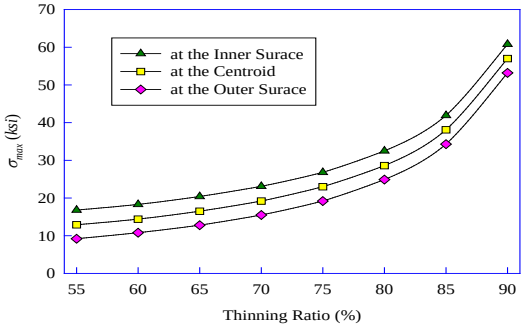

Figure 4. Max. stresses with respect to thinning ratio at design condition

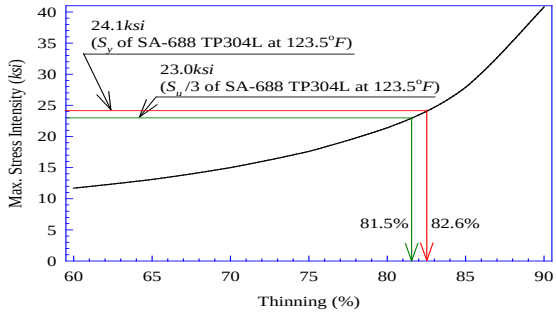

Figure 5. Minimum wall thickness required for a heat exchanger (No. 1) at normal operation.

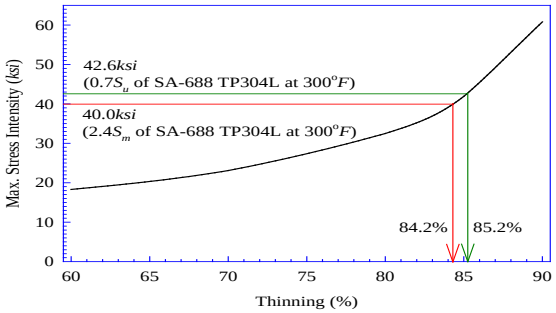

Figure 6. Minimum wall thickness required for a heat exchanger (No. 1) at design condition.

Table 1. Plugging criteria for some heat exchangers (named No. 1, 2, 3)

	Heat Exchanger		
	No. 1	No. 2	No. 3
Operation	81.5%	77.5%	78.7%
Design	84.2%	80.6%	80.6%
Calculated	81.5%	77.5%	78.7%
Criteria	61.5%	57.5%	58.7%

3. Conclusion

A method to establish the tube plugging criteria of heat exchangers is introduced based on the USNRC Regulatory Guide 1.121. As an example, the tube plugging criteria for heat exchangers with U-shape tubes are provided.

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