Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Modular Feedwater and Steam Lines Heat Transfer Effect on the Thermal Performance of a Once Through Steam Generator

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1. Introduction

Steam generator cassette (SGC) of an integral type reactor is a once-through modular type and installed inside the reactor vessel. Modular feedwater line (MFL) penetrates the upper part of the reactor vessel side wall and is connected to the bottom head of the SGC. Modular steam line (MSL) also penetrates the upper part of the reactor vessel side wall and is connected to the top head of the SGC. Due to the design characteristics of the MFL and MSL layout, the MFLs are enclosed by the MSLs (Figure 1). One SGC has six MFLs and six MSLs. The six MFLs are enclosed by one thick metal cylinder with six cylindrical holes for steam flow. The water stagnant inside the enclosure of the MFL functions as a first thermal barrier against the heat transfer from the hot side of the enclosure metal to the cold side of the feedwater. With this layout the concern of well-known thermal shock problem of the feedwater nozzle can be substantially reduced. However there is an adverse heat transfer between the feedwater in the MFLs and the steam in the MSLs, which results in the degradation of steam quality (or superheat) from the SGC tube exit.

In this paper, a heat transfer between the MFLs and the MSLs and its effect on the steam superheated quality are discussed. A mathematical model for the heat transfer between the MFLs and the MSLs has been developed. The calculated results reveal that the degradation of superheated steam quality from the experimental SGC tube exit at low flow conditions is due to the heat loss from the MSLs to the MFLs through the heat resistance between those. From the calculation results, to minimize the heat loss from the MSLs, it is concluded that design modifications for the MFLs and the MSL layout or alternatively the increase of the feedwater temperature are necessary.

2. Mathematical Models

As shown in Figure 1, the sectional view of cassette nozzle and horizontal enclosure assembly of the MFLs shows that there are at least two different heat transfer structures, which are encircled in that Figure and should be modeled differently. Horizontal enclosure assembly of the MFLs shown in Figure 2 is symmetrical cylinder structure and therefore can be modeled with heat balance equation. Feedwater nozzle shape, where a steam directly contacts the cold wall of the MFL, is not so simple and may be modeled mathematically with proper geometrical simplification. Pressure drop in tubes is not large and therefore it is not considered in this heat transfer analysis.

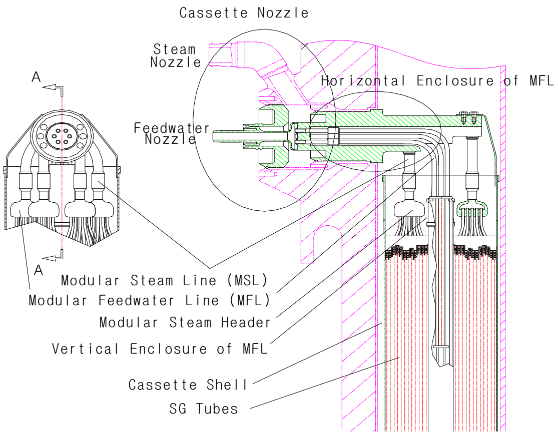

Figure 1 The SGC with sectional view

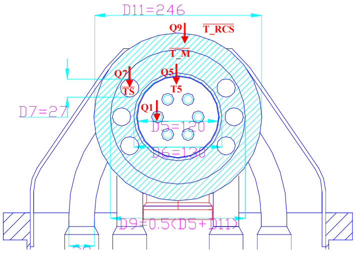

Figure 2 Horizontal enclosure of the MFL

2.1 Heat Balance Equations for Enclosure of the MFLs

In general, a heat balance equation for N tubes in the enclosure can be written as:

$$\dot{Q}_1 = \dot{m}_1 dH_1$$

$$d\dot{Q} = \dot{Q}_5 - N\dot{Q}_1 = \dot{m}_5 dH_5$$

$$\dot{Q}_M - \dot{Q}_5 = N\dot{m}_7 dH_7$$

$$\dot{Q}_1 = U_{15} A_1 \Delta T_{15}$$

$$\dot{Q}_5 = U_{5M} A_5 \Delta T_{5M}$$

$$\dot{Q}_7 = U_{7M} A_7 \Delta T_{7M}$$

$$\dot{Q}_M = U_{M11} A_M \Delta T_{M11}$$

where H is the enthalpy and $\dot{m}$ is the mass flowrate. The meaning of the number in the subscript is shown in Fig. 2. Overall heat transfer coefficients are as follows:

$$U_{14} = \frac{1}{\frac{1}{h_1} + \frac{0.5D_1}{k}\ln\frac{D_4}{D_1} + \frac{D_1}{D_4 h_4}}$$

$$U_{78} = \frac{1}{\frac{1}{h_7} + \frac{0.5D_7}{k}\ln\frac{D_8}{D_7} + \frac{D_7}{D_8 h_8}}$$

$$D_8 = F \cdot \sqrt{\frac{4}{N\pi} A_{hatched} + D_7^2}$$

$$A_{hatched} = \frac{\pi}{4}(D_{11}^2 - D_5^2)$$

where F is geometrical shape and subscript 4 means the outer pipe of the MFL.

$$U_{59} = \frac{1}{\frac{1}{h_5} + \frac{0.5D_5}{k}\ln\frac{D_9}{D_5} + \frac{D_5}{D_9 h_9}}$$

$$U_{911} = \frac{1}{\frac{1}{h_9} + \frac{0.5D_9}{k}\ln\frac{D_{11}}{D_9} + \frac{D_9}{D_{11} h_{11}}}$$

2.2 Heat Balance Equations for Cassette Nozzle

At the region of the cassette nozzle, steam from the MSLs directly contacts the wall of the MFLs. Heat transfer region of the nozzle may be divided into three sub-regions, as shown in Figure 3, depending on their structure. However in this paper, region B is assumed to be the representative characteristic structure of the nozzle for calculation simplicity. Then, heat balance equation can be setup using the concept of total resistance between steam and feedwater:

$$R_{total} = \frac{1}{h_1 A_1} + \frac{1}{kS} + \frac{1}{h_s A_s}$$

$$\dot{Q}_1 = \dot{m}_1 dH_1$$

$$\dot{Q}_s = \dot{m}_1 dH_s$$

$$S = \frac{N 2\pi L}{\ln(\frac{R}{r}) - \frac{1}{N}\ln(\frac{Nr_1}{r})}$$

Shape factor S is based on reference 1. L is a length of heat transfer region of interest, r_1 is inner diameter of one MFL, r and R are respectively centric and outer diameter of enclosure of the MFLs.

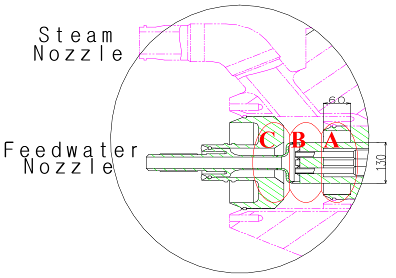

Figure 3 Detail of cassette nozzle

2.2 Heat Transfer Coefficients

Heat transfer coefficients used in this study is summarized in Table 1. The outside of horizontal enclosure is treated as wall boundary temperature.

Table 1 Empirical correlations for heat transfer coefficients

Correlations	**SG tube/MFL**	**Enclosure of MFLs**
Forced convection	**SKBK[2]**	**Kutateladze[3]**
Mixed & natural convection	**Kutateladze[3]**	**Kutateladze[3]**
Partial SNB	**Rohsenow[4]**	
Fully developed SNB	**Bergles & Rohsenow[5]**	
Onset of nucleate boiling	**Bergles & Rohsenow[5]**	
Condensation at SGC nozzle		**Shah [6]**

3. Results

Though region B is external condensation shape, Shah's condensation heat transfer coefficient is adopted with proper adjustment of flow quality with respect to flow rate. As shown in Fig. 4, the comparison of calculation results with experimental data clearly reveals that steam quality degradation is due to the heat loss of steam flow in the MSLs to feedwater flow in neighbor MFLs. Fig. 5 helps to understand what happens through the heat structure of the SGC.

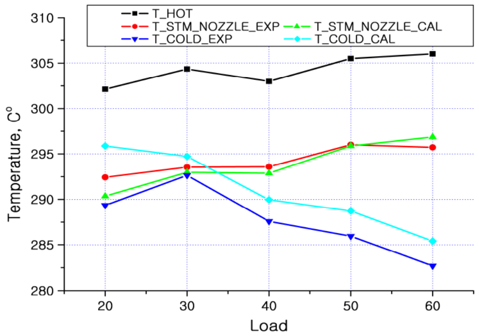

Figure 4 Fluid temperature profiles with load changes

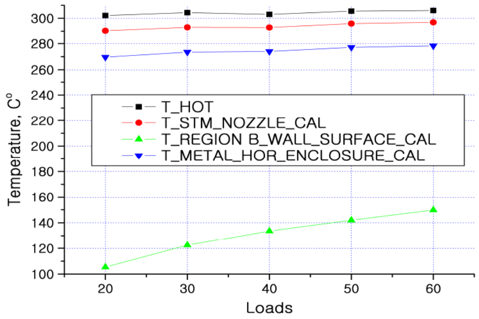

Figure 5 Metal temperature profiles with load changes

4. Conclusion

From the analytical explanation for the main cause of degradation of the steam quality at the SGC nozzle, design improvement of internal flow structure of the SGC nozzle is recommended.

REFERENCES

[1] F. M. White, Heat and mass transfer, Addison Wesley Publishing Company, 1988.

[2] Steam Generator with helically coiled heat transfer area, analytical method (IZH ER.500609.001), SKBK.

[3] S. S. Kutateladze, V. M. Borishansky, Handbook on heat transfer, Gosenergoizdat, Moscow, 1959.

[4] Rohsenow, W. M., A method of correlating heat transfer data for surface boiling of liquids, Trans. ASME, Vol. 84, pp. 969, 1962.

[5] Bergles, A. E., and Rohsenow, W. M. The determination of forced-convection surface boiling heat transfer, J. Heat Transfer, Vol. 86, pp. 365-372, 1964.

[6] Shah. M., A general correlation for heat transfer during film condensation inside pipes, Int. J. Heat Mass Transfer, Vol. 22, pp. 547-556, 1979.