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GOTHIC Evaluation for the Realistic Heat Load of Containment Spray Heat Exchanger in Uljin Unit 3 and 4

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1. Introduction

The component cooing water (CCW) system in Uljin Unit 3 and 4 remove the heat load from the safety equipment during the accident such as loss of coolant accident (LOCA) and dump it into the ultimate heat sink (UHS). A specific temperature of UHS is assumed in design stage of nuclear power plant and in the accident analysis such as containment integrity evaluation. This temperature should be managed by technical specification and the plant should be shut downed if the monitored temperature exceeds this temperature limit. Because of global warming, this shutdown possibility is gradually increased and then the plant operation margin is getting worse. Therefore the temperature limit needs to make higher than a current value so as to recover the operation margin. In order to increase it without design changes of current load components, the heat loads of CCW heat exchanger, especially containment spray heat exchanger load which is the largest heat load, have to be reduced. This paper describes the evaluation method for the realistic heat load of containment spray heat exchanger using GOTHIC computer code.

2. Model

2.1 Containment Analysis Model

The size of CCW heat exchanger (CCWHX) was determined by considering of total safety heat load during post-LOCA. The containment spray heat exchanger (CSHX) heat load of these heat loads is the largest one, which it is approximately 80% of total safety heat load.

In the design stage the CSHX heat load is estimated by assuming the containment sump liquid temperature to be the saturated liquid temperature for total containment pressure and the outlet temperature of CCWHX to be fixed at 110 °F. Judging from the liquid in containment sump water to be subcooled, this bounding analysis is explicitly over-conservative. Therefore it is important to evaluate more realistic CSHX heat load with maintaining the conservatism in order to use the reduced heat load to increase the UHS temperature limit.

To assist in the evaluation of CSHX performance during post-LOCA, a containment sump temperature evaluation has to be performed to determine "worst-case" sump temperature during the CSHX to be in service.

For this evaluation, Key assumptions used to maximize sump temperature are as follows:

- Decay heat is added to the reactor vessel water instead of causing boil-off directly (Heater 1H inside control volume 2 in Fig. 1)
- Vessel thick metal energy is similarly added to the RCS water instead of causing boil-off directly(Heater 2H inside control volume 2 in Fig. 1)
- All safety injection and recirculation water available is assumed to enter the vessel with no spill (Boundary Condition 2F and 6F in Fig.1)
- All water entering the reactor vessel is available for removing heat(maximizing spillage of hot water to the sump)

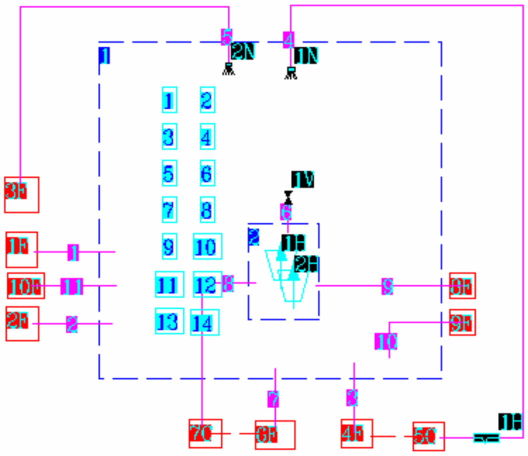

Fig. 1 GOTHIC Model for evaluating the Containment Heat Exchanger Heat Load

2.2 Heat Exchanger Performance Evaluation Model

In GOTHIC [1], the heat (Q) transferred in the CSHX from hot fluid to cold fluid is calculated by ε-NTU method as below;

$$Q = \varepsilon C_{\min}(T_{hi} - T_{ci}) \tag{1}$$

where, C_{min} is the minimum heat capacitance between the hot fluid and the cold fluid, T_{hi} and T_{ci} are the inlet temperature of the hot fluid and the cold fluid, respectively. the heat exchanger heat transfer effectiveness (ε) is given by thhe heat capacity ratio, the number of heat transfer units (NTU) and heat exchanger type. The NTU is calculated by UA/C_{min} ; U is the overall heat transfer coefficient and A is the heat transfer area. U is calculated from the shell side film coefficient(ho), the tube side film coefficient(hi), thermal resistance through tube wall(t/k_w ; t is the tube thickness) and the fouling resistance as follow;

$$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_i} + \frac{t}{k_w} + R_f \qquad (2)$$

The film coefficient for the outside of the tube has to be considered carefully because it gives the ideal heat transfer coefficient for the ideal tube bank which the total fluid flow is considered as a full cross flow. However, the shell side fluid flow in real heat exchanger is not cross flow entirely and there are some bypass flows through the leakage or bypass paths such as tube-to-baffle, baffle-to shell and tube bundle to shell.

In the design package or thermal design method of heat exchanger such as HTRI[2] and Bell & Dellaware Method[3], the heat transfer coefficient in the shell side is calculated from the heat transfer coefficient for the ideal tube bank corrected by correction factors due to the leakage flow and the non-cross flow fraction. In order to address this problem in GOTHIC, the following two actions have to be performed.

a) To set cross section area for the cross flow at the design value used in HTRI package, which is used for calculating Reynolds number
b) To adjust tube thickness (t in Eq(2)) so that the GOTHIC calculating U is set at the design overall heat transfer coefficient.

3. Evaluation

To verify the technical approach in Section 2.2, the performance of heat exchanger is evaluate by GOTHIC for the design parameters. In this model, GOTHIC calculates U-value by Eq. (2) with the adjusted tube thickness. The results show U-value predicted by GOTHIC to be nearly same as the design U-value and the deviation from design heat load is just 1.8%(193.6 MBTU/hr(design) vs. 197.1 MBTU/hr)

Fig. 2 shows the sensitivity result for the containment sump temperature. The deviation represents the difference between the vales with non-adjusted tube thickness and those with the tube thickness adjusted so that GOTHIC gives the design U-value at the design sump temperature of 270 °F. As seen in Fig. 2, the standard deviation of the deviation of U-value is less than 1%, and even the heat load deviation is not sensitive on the sump temperature. Therefore Section 2.2 approach is valid for thermal performance model of heat exchanger in GOTHIC.

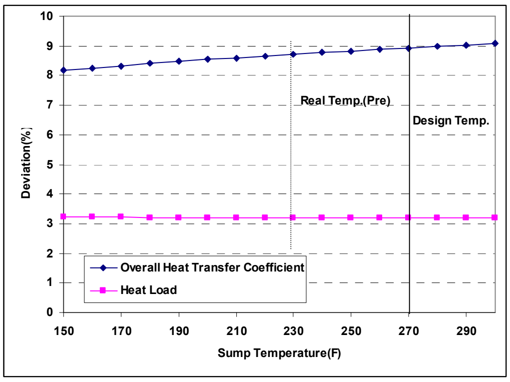

Fig. 2 Sensitivity Analysis for Sump Temperature; Deviation = (U with non-adjusted tube thickness – U with adjusted tube thickness)/ U with adjusted tube thickness)

Fig. 3 shows the final results of the heat load and the sump temperature. Curve “A” means the heat load when the design U-value to be constant for the sump temperature is used and curve “B” represents the heat load from the realistic U-value but the adjusted tube thickness to be applied. As seen in Fig. 3, the maximum heat load difference is about 2.1 MBTU/hr. This additional margin can be used in increasing the UHS temperature limit.

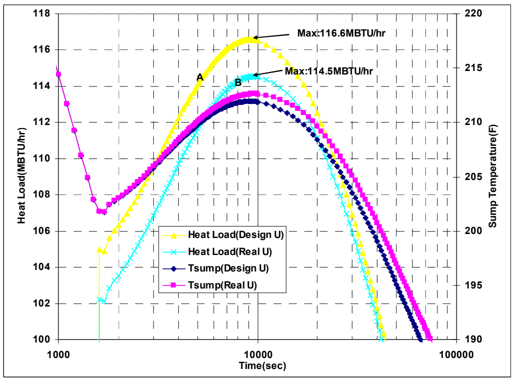

Fig. 3 Heat load predicted by GOTHIC; double ended pump suction slot break , fouled condition, spray flow of 3500 gpm.

4. Conclusion

In this paper, heat exchanger model in GOTHIC for the its realistic performance evaluation is developed and its validity are reviewed by sensitivity analysis and GOTHIC analysis for confirming the design parameter. The analysis show the approach which is proposed in this paper to be valid for thermal performance model of heat exchanger in GOTHIC.

REFERENCES

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