Thermal Flow Analysis for a Severe Cold-water Injection Transient Condition in the Purification System Line and the Heat Transport System Line

Man Heung Park,a Kwang Chu Kim,a Hag Ki Youm,a Sun Ki Lee,b Seung Ryul Hong b
a Korea Power Engineering Company, Inc., 360-9, Mabuk-Ri, Kusong-Eup Yongin-Shi, Korea, pmh@kopec.co.kr
b Korea Electric Power Research Institute, 103-16, Munji-Dong, Yusung-Ku, Taejon 305-380, Korea

1. Introduction

In the Wolsong NPP, the purification line joined with the PHTS(primary heat transport system) pump suction line shares with the D_2O feed line. Therefore, the severe cold-water injection thermal shock transient can be occurred in the purification line due to the interchange of the purification flow and the feed flow. AECL performed stress analyses on this purification line with the finite element method. The results demonstrated that the stresses of the weldolet were within the allowable limits of NB-3000 Section III for the severe cold-water injection transient.[1] But AECL performed thermal analyses not including the fluid region and heat transfer coefficients were used for inner and outer wall surfaces. In this study, thermal flow analysis using finite volume method was performed on the PHTS piping and the purification piping in condition of AECL's cold-water injection transient. The results derived from this analysis will be used as primary data of the stress and fatigue analysis.

2. Model Description

2.1 Analysis Scope

Figure 1 is the schematic of the PHTS pump suction line(20″ schedule 80) and the purification line(4″ schedule 40) used in this analysis. This purification line is connected with D_2O feed system line and shutdown cooling system line in the plant. The model range of purification piping connected to the PHTS piping is from weldolet to support passing the second elbow. Flow rate and temperature in the PHTS pump suction line are 1900 kg/s and 266°C. The cold-water injection transient conditions in the purification line are changed according to the time as shown in the figure 2(a) and (b). Initial maximum temperature and mass flux are due to inflow of purification flow and the minimum condition is due to inflow of feed flow. Valve stroke time for flow change is assumed as 9 second. Figure 3 is the grid system used in the CFD analysis. Meshes were clustered near weldolet and wall.

2.2 Numerical Schemes

The FLUENT code, which uses the finite volume method, is used for the thermal flow analysis. Mass, momentum, turbulence and energy conservation equations were used as governing equations. RNG(Re-Normalized Group) k-ε model was used as the turbulent model. The SIMPLE algorithm and the second order upwind scheme were used. The fluid and solid used in this analysis are the heavy water(D_2O) and the carbon steel(SA-106), respectively. The properties of materials are defined as the function of temperature. Unsteady computation is calculated at 0.2 second time interval.

3. Results and Discussion

Figure 4(a) and figure 4(b) are the temperature distributions in the middle sectional area and the inner wall of the PHTS piping at 10 second, respectively. Temperature gradients are shown in the wall thickness. In the inner wall of the PHTS piping, the region of low temperature expressed with an ellipse is shown in the non-symmetric shape due to inflow direction from the purification line. Figure 5 shows the temperature distribution at 30 second. The magnitude of low temperature region is smaller and temperature in the weldolet is decreased than that at the 10 second due to the decrease of flow rate and temperature of purification cold-water. The severe temperature gradient is observed in the oblique shape in the upper part of the weldolet expressed with a circle in the figure. Figure 6 shows the temperature distribution at 50 second. The shape of temperature gradient expressed with a circle is changed from perpendicular shape to oblique shape. The temperature difference in the lower of weldolet, joined with the purification piping, is shown continually.

Figure 7 shows the positions for measuring the temperature and figure 8 is the results of temperature according to the time. Temperature change in each point is shown due to the change of inflow mass flux and temperature in purification line. The shape of temperature variation curve according to the time is different between forward point and backward point. This is due to the reattachment length. That is, because the point 1 is continually included in the recirculation zone by the purification injection, the temperature variation of the point 1 is absolutely dependent on the purification cold-water. On the contrary, because the point 2 and the point 3 are included in recirculation zone by the purification injection in the maximum inflow condition but are not included in the minimum inflow condition, those are dependent on the PHTS line hot-water in the minimum inflow condition.

4. Conclusion

In this study, thermal flow analysis was performed on the PHTS piping and the purification piping in the severe injection transient. Because the hot-water in the PHTS line and cold-water in the purification line are joined in the different conditions versus the time, the severe temperature gradients are shown in the weldolet and the inner wall of the PHTS piping. The temperature variation in the inner wall of the PHTS piping is different according to the position affected by the recirculation zone. The analysis results derived will be used as primary data of the stress and fatigue analysis.

REFERENCES

[1] AECL, Stress Analysis of Purification Weldolet-Root Cause Investigation, 86-33350-220-003, 2001.

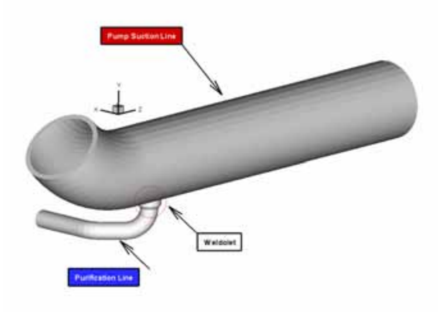
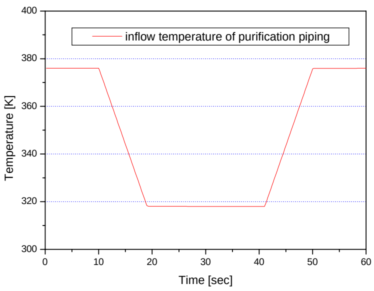
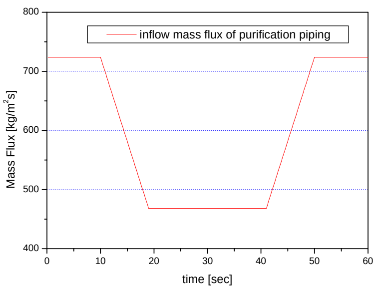


Figure 1. Schematic of piping layout.



(a) Inflow temperature transient.



(b) Inflow mass flux transient.

Figure 2. Inflow conditions from purification line.

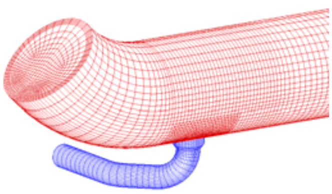
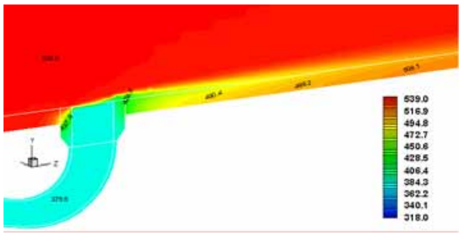
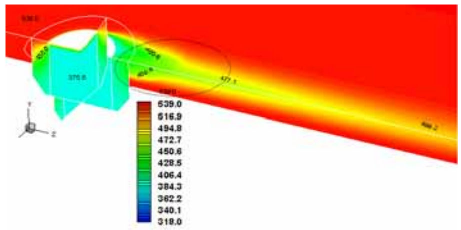


Figure 3. Grid system.



(a) Middle sectional area



(b) Inner wall surface

Figure 4. Temperature distribution at 10 second.

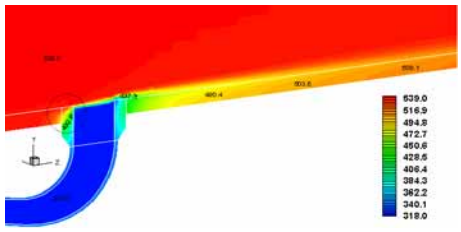


Figure 5. Temperature distribution at 30 second.

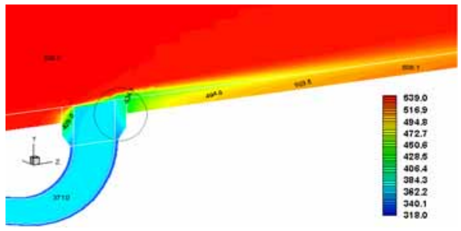


Figure 6. Temperature distribution at 50 second.

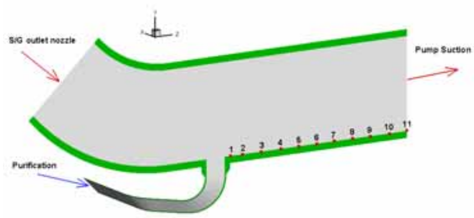


Figure 7. Schematic of temperature measurement positions.

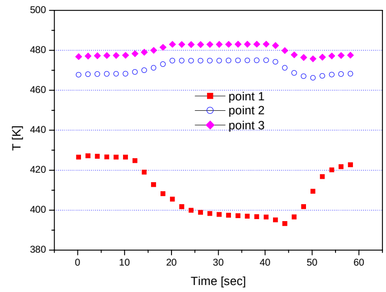


Figure 8. Temperature variation versus the time.