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Analysis of the pressure wave propagation on water hammer problem with voiding

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Introduction

The safety relief valves (SRVs), which are one of the major components of the safety depressurization system (SDS), are used to mitigate the system pressure following an overpressure transient in the nuclear power plants (NPP). The high temperature steam, which is discharged from the SRV, is condensed in the In-containment Refueling Water Storage Tank (IRWST) after being discharged through the sparger. In a transient condition, since the unstable condensation may threaten the structural integrity, the thermal hydraulic response and the hydrodynamic load in the piping system should be evaluated to design the IRWST and sparger. The hydrodynamic load is related to the pressure wave propagation in the pipe. When the high temperature steam is discharged into the pipe through the SRV, the large pressure difference caused a normal shock in a certain position of the pipe. After the pressure wave reaches the water surface in the submerged sparger, the reflection wave may be generated into the upstream and a new pressure wave may be produced into the water. Therefore, the information for the pressure wave propagation is important for discussing the possibility of normal shock and obtaining the pressure peak in the piping system. In the previous study, the applicability of RELAP5/MOD3.3 was confirmed for the pressure wave propagation in the discharge piping system [1,2]. Now, NRC has developed the TRACE code as the unified code for the reactor thermal hydraulic analyses. Because the TRACE code has not been fully discussed for predicting the pressure wave propagation, it is interested in evaluating its capability for this phenomenon.

The purpose of the present study is to understand the basic thermal hydraulic behavior for the pressure wave propagation and evaluate the applicability of TRACE v. 4.160 to predict the wave propagation. In this study, the transient analysis was performed for the experiment which treated the pressure propagation due to the water hammer. The calculation results were compared to the experimental ones and the predictive ones of RELAP5.

Experiment and TRACE modeling

The experiment for the water hammer problem was performed at the Jozef Stefan Institute in Slovenia [3]. The experimental facility was consisted of a large water tank, horizontal pipe with 36 m and the valve at the end of the pipe as shown in Figure 1. In an initial state, the water was flowing with 0.4 m/s and the system pressure was 10 bar through the long pipe. At t=0 sec, the valve at the end of the pipe was quickly closed and the pressure pulse appeared. At t=0.06 sec, the two-phase flow due to vaporization appeared. The pressures at the valve were recorded according to the time.

For the calculation of the pressure wave propagation, the TRACE v. 4.160 was used, which has been improved from the previous TRAC code [4]. The horizontal pipe was divided to 72 volumes of 0.5 m length. The water temperature was assumed as 433 K over the system. The components 'Fill' and 'break' were used to model the quick-closing of the valve and the water tank respectively. The valve was quickly closed after 100 seconds steady calculations and the transient calculation was performed for 0.25 seconds. The maximum time step size for steady and transient calculations was 0.01 seconds and 0.0001 seconds respectively.

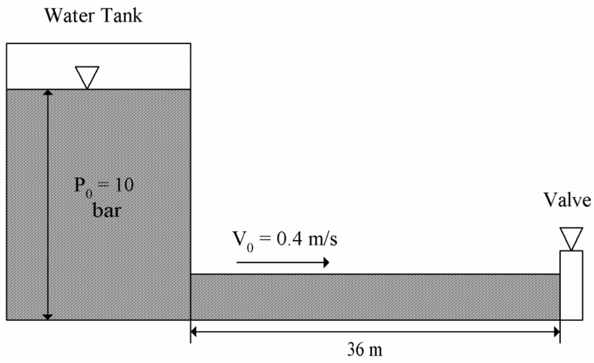

Figure 1. The water hammer experiment

Results and discussion

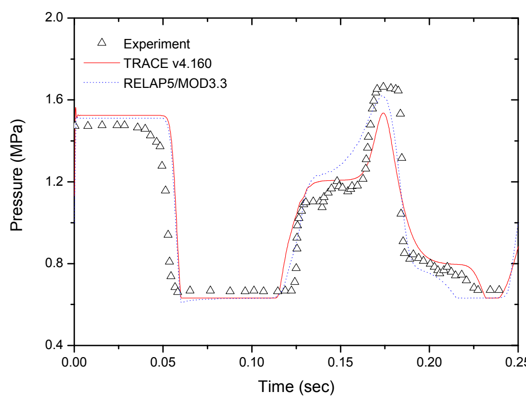

Figure 2. Comparison of pressures at the valve of the water hammer experiment

The calculation results for the water hammer problem were given in Figure 2 through Figure 4. The calculation results which obtained by RELAP5 and TRACE were compared with the experimental data as shown in Figure 2. Both codes predicted well the trends of the pressure wave response for the experiment. At near t=0.175, the pressure peak of RELAP5 calculation was a little larger than that of TRACE calculation. Generally, the pressure wave was reduced due to the interaction with vapor bubbles. In this study, the void fractions for TRACE calculation were larger than those for RELAP5 calculation as shown in Figure 4 [2]. This caused the reduction of the pressure peak for TREAC calculation although a difference of values for two calculations was very small.

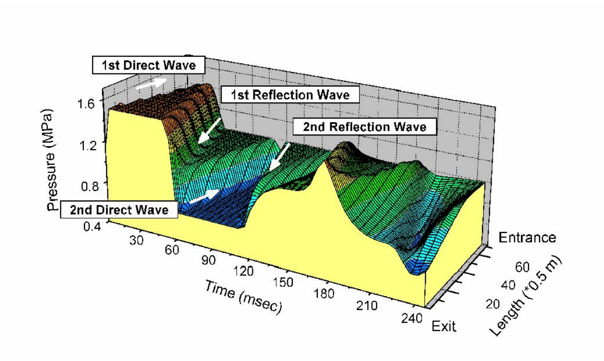

Figure 3. Pressure wave propagation along the pipe with time

Figure 3 shows the characteristics of pressure wave propagation along the pipe with time, which can be explained as follow phases;

1) The pressure at the end of the pipe quickly increased to about 1.56 MPa as soon as the valve was closed. The 1st direct wave was propagated into the upstream with about 1.56 MPa.

2) The 1st reflection wave was generated toward the exit at about 30 msec. The reflection wave was propagated into the downstream recovering the rear pressure back to 1 MPa.

3) After the reflection wave arrived at the end of pipe, the 2nd direct wave was propagated into the upstream with 0.63 MPa at about 60 msec. The pressure wave had a negative magnitude to keep the zero velocity at the end of pipe. Here, since the local pressure dropped to 0.63 MPa and reached the saturation pressure corresponding to the local temperature, the vaporization occurred at the end of pipe as shown in Figure 4.

4) At about 90 msec, the 2nd reflection wave was produced by reflection of the 2nd direct wave and was propagated into the end of the pipe. The 2nd reflection wave was reduced and was not recovered to 1 MPa due to the interaction with the vapor.

5) At about 120 msec, the 3rd direct wave was propagated into the entrance and the rear pressure was recovered to 1.53 MPa with a delay because of the vapor collapses. After about 150 msec, the pressure was propagated with a similar behavior to previous one.

Figure 4 shows the void fraction distribution along the pipe with time. At about 0.06 sec, the calculation results predicted well the experimental results which vaporization and two-phase flow appeared. According to the pressure variations, the void fraction was varied due to the vaporization and collapse of bubbles.

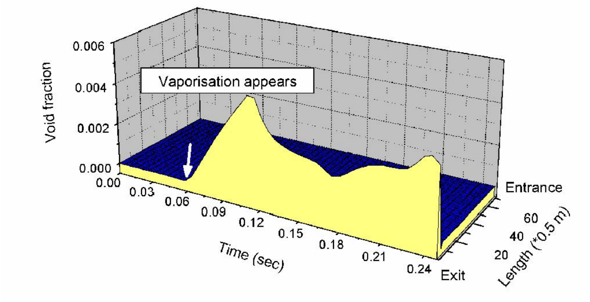

Figure 4. Void fraction distribution along the pipe with time

Conclusion

To evaluate the applicability of TRACE v. 4.160 for the pressure wave propagation in the piping system, the calculation results were compared to the experimental data and the calculation ones of RELAP5. As a result, the predicted pressure wave was well agreed with the measured data and its propagation showed well the general theory although the code had uncertainties especially in predicting the sound speed and fluid conditions which were important in the wave propagation. Therefore, for predicting the pressure wave propagation in the actual SDS piping, the TRACE v. 4.160 can be used with the same degree of accuracy of this study. Also, in this study, since the experimental and computational conditions is limited to the specific ones, the TRACE v. 4.160 should be validated for a wide range of condition of steam-air/steam-water mixture to show more advanced capabilities of the code.

Acknowledgement

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Reference

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