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APPLICATION OF RELAP5/MOD3.2 TO THE PREDICTION OF TWO-PHASE MIXTURE LEVEL SWELL AND LIQUID ENTRAINMENT FROM THE TWO-PHASE MIXTURE SURFACE DURING DEPRESSURIZATION IN A VESSEL

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ABSTRACT

The comparison of the RELAP5 results with the present experimental data has been performed to investigate the applicability of RELAP5/MOD3.2 code in the analysis of the two-phase mixture level swell and the liquid entrainment/off-take phenomena from the two-phase mixture surface in a vessel during a rapid depressurization. A series of experiments have been performed with a scaled high-pressure test vessel with 2.4m height and 0.3m ID. With the appropriate nodalization and time step, RELAP5 results showed reasonable agreement with the present experimental data in the relatively gradual depressurization. In the relatively rapid depressurization, however, the axial void fraction profile and discharged mass flowrate predicted by RELAP5 did not agree well with those of the present experiment. RELAP5/MOD3.2 under-predicted the axial void fraction distribution and the discharged mass flow rate of two-phase mixture due to the under-prediction of the amount of liquid entrainment/off-take during depressurization.

1. INTRODUCTION

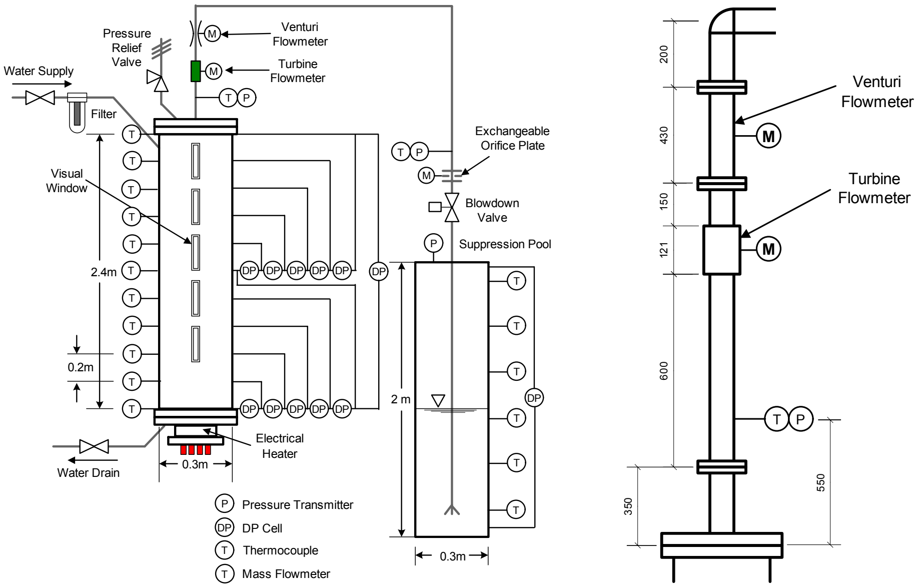
The Advanced Power Reactor 1400 (APR1400) has adopted an advanced design feature of a safety depressurization system (SDS) to depressurize rapidly the primary system and to initiate High Pressure Safety Injection System (HPSI) in case of events beyond the design basis accident such as Total Loss of Feed Water (TLOFW). An important aspect of the SDS design is the determination of the bleed capacity of the SDS connected to the pressurizer of a nuclear reactor and the level swelling of the reactor core. While the pressure of the primary system is rapidly decreased, two-phase level swelling occurs due to the flashing of the super-heated water in the pressurizer. As a result of the formation of voids due to the flashing and the level swelling of two-phase mixture, the vertical distance between the break and two-phase mixture surface becomes shorter and the combining force between water and steam is reduced at the surface of the two-phase mixture. Consequently the water entrainment by the discharged steam is accelerated and the larger amount of liquid is discharged through the break than that of the case in which the only pure steam is discharged with no liquid entrainment. It is, therefore, a considerable interest to investigate the applicability of the existing thermal hydraulic code to such situation. In this study, RELAP5/MOD3.2 has been adopted as the analysis code and its results have been compared with those of the present experiments.

2. EXPERIMENTS

A series of experiments has been performed to analyze the two-phase mixture level swell and the liquid entrainment phenomena from the two-phase mixture surface in a vessel during a depressurization. A schematic diagram of the experimental apparatus is shown in fig.1. In the present study, the test vessel has been scaled so that the time constant of depressurization of the test vessel has the same value with that of the pressurizer of APR1400. The two-phase mixture level swell and the axial void fraction distributions have been measured using ten DP-cells installed with 0.2m intervals along the test vessel. The mass flowrate of the two-phase mixture discharged from the top of the vessel has been measured using turbine and venturi flowmeters installed in the blowdown line. The detailed information about the experiments has been described in Ref.1. The controllable test parameters in the present experiments were the initial pressure (10 – 28.74bars), the initial water level (435% - 81.0% of full height), and the orifice inner diameter (10mm, 17.5mm, and 20mm). A series of the experiments have been carried out for the various combination of test parameters as summarized in table 1.

3. RESULTS AND DISCUSSION

The comparison of the RELAP5 results with the present experimental data has been performed to investigate the applicability of RELAP5/MOD3.2 in the analysis of the two-phase mixture level swell and the liquid entrainment/off-take phenomena from the two-phase



(a) Schematic diagram of the experimental apparatus

(b) Blowdown line with two flow measurements

Figure 1. Depressurization and level-swell experimental apparatus.

Table 1. Important Parameters of the present experiments

Parameters	values
Height of the test vessel	2.4m
Inside diameter of the test vessel	0.3m
Inside diameter of the blowdown line	0.05m (2 inch)
Inside diameter of the exchangeable orifice plate	10mm, 17.5mm, 20mm
Initial pressure in the test vessel	10 – 38.75 bar
Initial water level in the test vessel	43.5 – 80.8%

mixture surface in a vessel during a rapid depressurization. The two cases were considered in the comparison. The first case represents the situation in which the depressurization takes places relatively slowly with the orifice inner diameter of 10mm. The second case represents the situation in which the transient takes place relatively rapidly with the orifice inner diameter of 17.5mm so that the off-take takes place at the early stage of the depressurization. The comparison has been performed with the pressure transient, the discharged mass flowrate, and axial void fraction distributions during the depressurization. The test parameters for each case are shown in Table 2. The RELAP5 model of the present experimental apparatus is shown in Fig.2. The test vessel was modeled by a pipe component which consists of 12 sub-volumes. The number of sub-volumes of the test vessel has been adopted by the sensitivity analysis with the various nodalization and time steps[1]. At its upper end, the test vessel was connected to a blowdown pipe which is modeled by 7 sub-volumes. The end of downstream of the blowdown pipe was connected to the time-dependent volume to simulate the external condensing pool under atmospheric pressure condition. At this junction, the size and form loss factor of the break was controlled. For the level swell simulations during a rapid depressurization in a vessel with RELAP5, the pressure transient in a vessel was imposed as a boundary condition. The boundary condition was obtained by tuning the form loss factor at the break with experimental data in a given break size, the initial pressure, and the initial water level.

Table 2. Test parameters for RELAP5/MOD3.2 simulation

Parameters	Case I	Case II
Inner Diameter Exchangeable Orifice Plate	10 mm	17.5 mm
Initial pressure in the test vessel	29.5 bar	30.01 bar
Initial water level in the test vessel	1.5 m (62.5%)	1.7 m (70.8%)

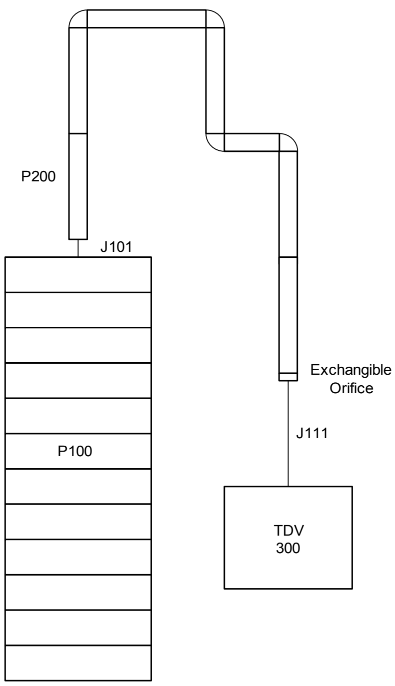
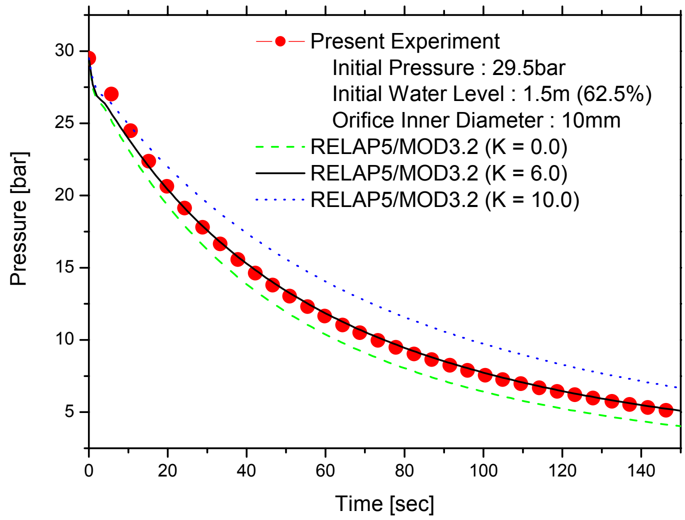


Figure 2. Nodalization of the present experimental apparatus.

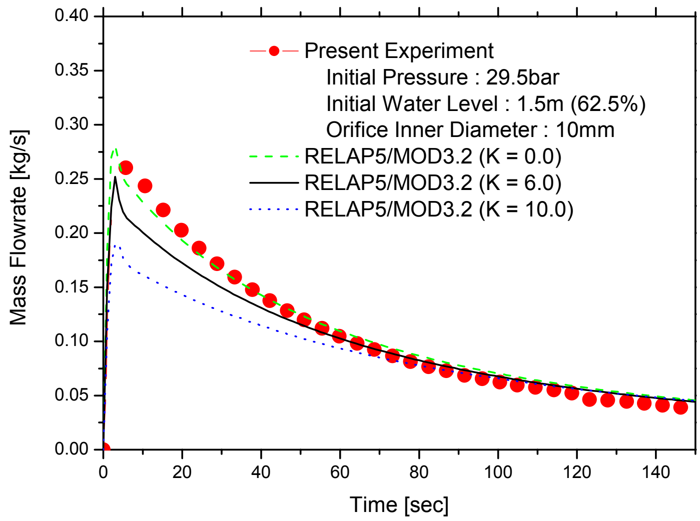
When the orifice plate inner diameter is 10mm with the initial pressure of 29.5 bar and the initial water level of 1.5m (62.5% of full height), the pressure transient in the test vessel was tuned best with the form loss factor of K = 6.0 with that of the experimental data as shown in Fig.3. The pressure transient in the test vessel undergoes a slightly sudden decrease in the RELAP5 simulation at the initial stage of the depressurization. However, the results of the present experiment do not show such a trend because the pressure in the vessel has responded with some time delay after the sudden openning of the blowdown valve. Therefore the discharged mass flowrate through the break decreased smoothly after its maximum value had been reached. The discharged mass flowrate in RELAP5 simulation under-predicted slightly the results of the experiments at the early stage of depressurization. It was considered that this discrepancy in the discharged mass flowrate arose from the under-prediction of the liquid entrainment from the swelled surface in REAP5 simulation. As the depressurization proceeded, however, the difference between the RELAP5 results and experimental data became smaller than those of early stage of the depressurization because the pressure transient results of RELAP5 became similar to those of the present experiment.

The axial void fraction distributions at 5 sec and 50 sec after the initiation of the depressurization are shown in Fig.4. At the early stage of the depressurization, the axial void fractions were lower than the results of the RELAP5 because the void generation by flashing was delayed in the experiments. At the time of 50 sec after the initiation of the depressurization, the level swelled and the axial void fractions showed good agreement between the results of the present experiment and RELAP5 simulation except in the lower part of the two-phase mixture. In the present experiment, the void generation in the lower part of the two-phase mixture was lower than that in the upper parts of the two-phase mixture. This fact showed that there existed some non-equilibrium state between the upper part and the lower part of the two-phase mixture. The void generation by flashing in the super-heated water, therefore, has taken place mainly in the upper part of the two-phase mixture.

The comparison of RELAP5/MOD3.2 results with those of the present experiment is done for the case of initial pressure of 30.01bar, the initial water level of 1.7m (70.8% of full height), and the exchangeable orifice diameter of 17.5mm (Case II). Figure.5 shows the pressure transient results in the test vessel with RELAP5 for various form loss factors at the break. After the initiation of depressurization, RELAP5 results have undergone a sudden decrease of the pressure about 7.7 bar within 5sec, and then the pressure has decreased gradually. However the pressure transient results of the present experiment have not shown any sudden decrease of the pressure. Therefore, the pressure transient results of RELAP5 have not been tuned well with those of the present experiment.

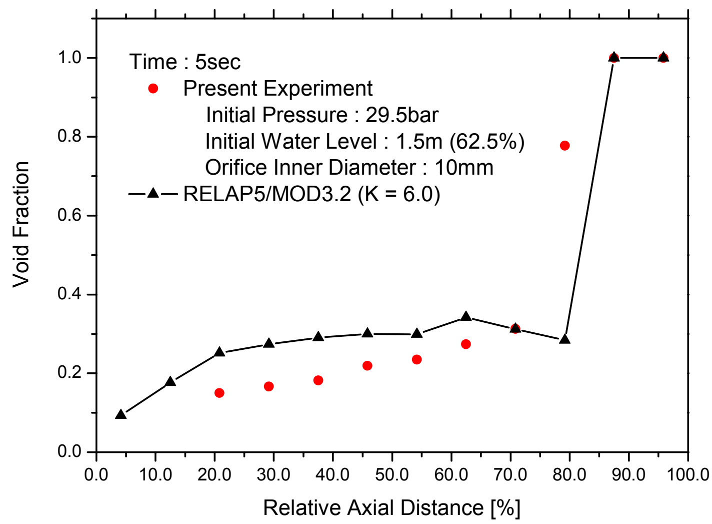


(a) Pressure transient in the test vessel

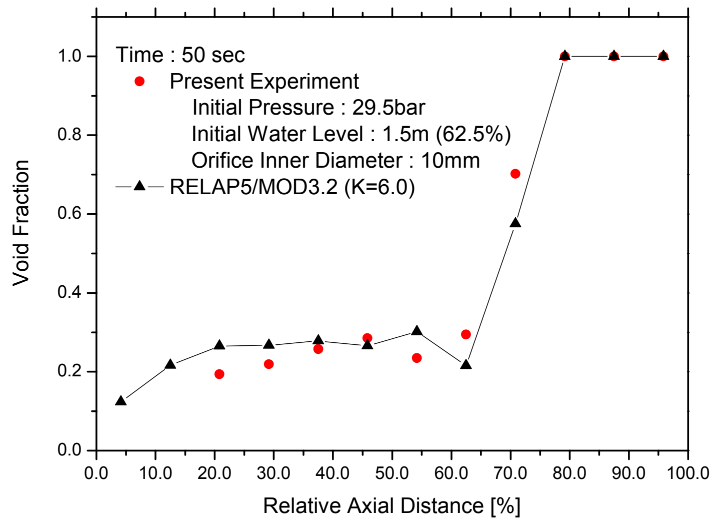


(b) Discharged mass flowrate

Figure 3. Pressure transient and discharged mass flowrate for the case I.



(a) Time = 5 sec



(b) Time = 50 sec

Figure 4. Axial void fraction distribution with time after the initiation of the depressurization.

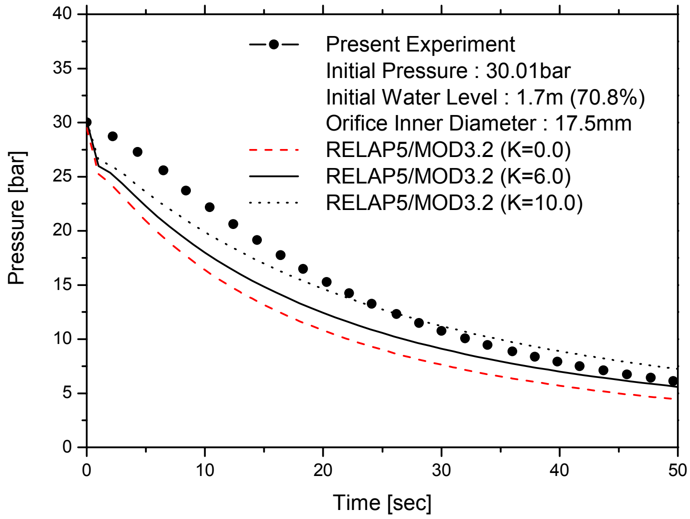
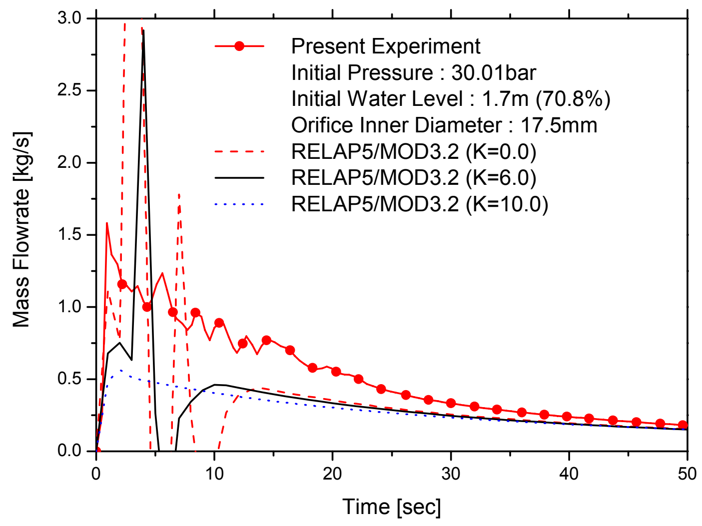
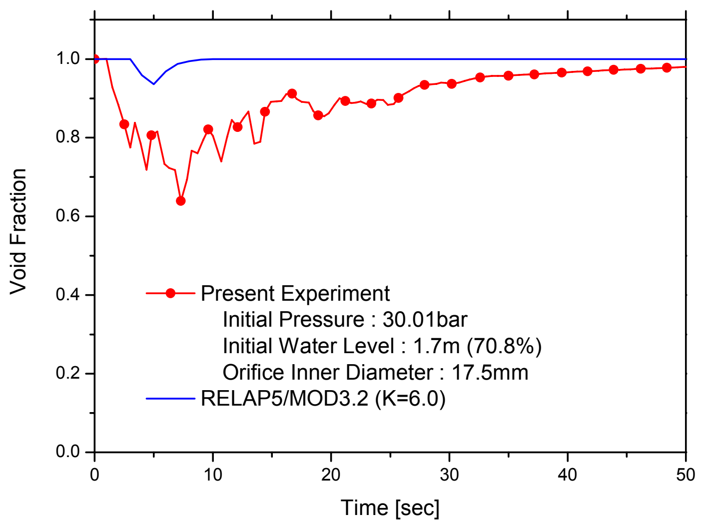


Figure 5. Pressure transient in the test vessel for case II.

The discharge mass flowrate in RELAP5 simulation has increased sharply and oscillated at the early stage of depressurization because the two-phase mixture level has raised to the vicinity of the top of the vessel and the discharged fluid through the blowdown line has been in two-phase state. It was assured by DP-cells installed at the top region of the vessel and two flowmeters installed at the blowdown pipe in the present experiment, however, the results of RELAP5 under-predicted about two times as low as those of the present experiment. Figure 6(b) shows the comparison results of the void fraction in the blowdown line at the location in which the two flowmeters were installed. The void fraction calculated by RELAP5 at that location has under-predicted that of the present experiment. According to the RELAP5 prediction, the liquid off-take took place slightly at the time of about 5 sec after the initiation of the depressurization and then the only pure steam was discharged through the blowdwon line. However, the off-take took place in very long time period in the present experiment. This fact is one of the reasons for the difference of the discharged mass flowrate between the predictions of REALP5 and the present experiment results. As the depressurization proceeded, the difference between both results became smaller and RELAP5 results showed good agreement with those of the present experiment at the last stage of the depressurization.



(a) Discharged mass flowrate



(b) Void fraction at the location of flowmeter

Figure 6. Discharged mass flowrate and void fraction in the blowdown line for the case II.

At the time of 20 sec after depressurization, the axial void fraction results of RELAP5 have been compared with those of the present experiment as shown in Fig.7. RELAP5 predicted well the void fraction in the lower part of the two-phase mixture, but under-predicted largely the void fraction in the upper part of the two-phase mixture compared to those of the present experiment. In the present experiment, the difference between void fractions in lower and upper parts of the two-phase mixture is very large because of the non-equilibrium state. In the RELAP5 simulation results, however, the axial void fraction increased gradually as the axial distance increased.

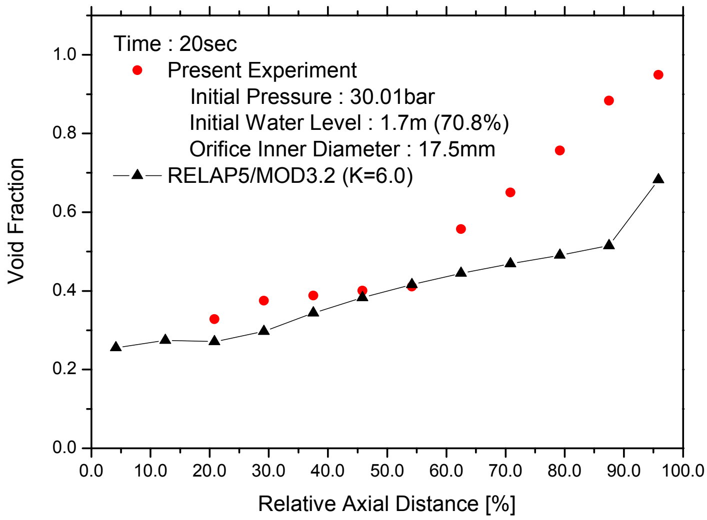


Figure 7. Axial void fraction distribution at the time of 20sec after the initiation of depressurization.

3. CONCLUTIONS and RECOMMENDATION

The comparison of the RELAP5 results with the present experimental data has been performed to investigate the applicability of RELAP5/MOD3.2 in the analysis of the two-phase mixture level swell and the liquid entrainment/off-take phenomena from the two-phase mixture surface in a vessel during a rapid depressurization. The two cases were considered in the comparison. The first case represents the situation in which the depressurization takes places relatively slowly with the orifice inner diameter of 10mm. The second case represents the situation in which the transient takes place relatively rapidly with the orifice inner diameter of 17.5mm so that the off-take takes place at the early stage of the depressurization.

The comparison has been performed with the pressure transient for the discharged mass flowrate, and axial void fraction distributions during the depressurization.

With the appropriate nodalization and time step, RELAP5 results showed reasonable agreement with the present experimental data for the first case. In the second case, however, the axial void fraction profile and discharged mass flowrate predicted by RELAP5 did not agree well with those of the present experiment. In the experiment, the two-phase mixture surface swelled rapidly up to the entrance of the break and the large amount of water entrained by the discharged steam. RELAP5/MOD3.2 under-predicted the axial void fraction distribution and the discharged mass flow rate of two-phase mixture due to the under-prediction of the amount of liquid entrainment/off-take during depressurization.

The water entrainment/off-take is one of the most important phenomena in the determination of the discharged mass flowrate in the rapid depressurization. It is unable to analyze this phenomenon qualitatively in the present experiments because the relationships of its key parameters can not be identified in the rapid transient experiment. More analytical and experimental works for the water entrainment/off-take in a vessel are recommended.

ACKNOWLEDGEMENTS

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REFERENCES

1. M. H. Chun, et al., "Two-Phase Mixture Level Swell and Water Entrainment from the Mixture Surface during Depressurization," KEPRI Technical Report, TR99NJ13.J2001.614, (2001).