Modification of TASS/SMR code for thermal-hydraulic behavior under moving conditions

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1. Introduction

It becomes more important for thermal hydraulic analysis codes to account for motion effect to analyze reactors under various conditions, such as earthquakes and floating offshore. The modified RETRAN and RELAP5 codes were developed to analyze the motion effect for reactors in a non-inertial frame [1, 2, and 3]and Kim and Lee developed a modified SPACE code, which was able to predict a three dimensional dynamic motion in the floating nuclear power plant [4]. TASS/SMR code is a one-dimensional system analysis code that can analyze the primary and secondary system. The TASS/SMR code has been developed to simulate thermal–hydraulic behavior for integrated type of reactors, such as SMART (System-Integrated Modular Advanced Reactor) during transient and accident [5].

In the present study, the governing equation of TASS/SMR code is adjusted by adding a module calculating the motion and gravitational effects on the motion and height change. The modified TASS/SMR code incorporates a gravity force as the acceleration term in the momentum equation. Thus, the momentum equation and coordinate system is modified to calculate the additional acceleration terms under the motion conditions and the change of pressure head term under the inclination condition. The modified TASS/SMR code is verified using the conceptual problems and validated using the experimental data.

2. Modification and Results

2.1 Modifications of TASS/SMR code

The TASS/SMR is a one-dimensional system analysis code for a small modular reactor of an integral type, which is able to simulate thermal hydraulic behaviors using the conservation equations, which consist of liquid, mixture, and non-condensable gas mass, mixture momentum, gas and mixture energy equation. The mixture momentum equation is as follows.

$$\frac{\partial}{\partial t}(\rho_m u_m) + \frac{\partial}{\partial x}\left[(1-\alpha)\rho_l u_l u_l + \alpha \rho_g u_g u_g\right] = -\frac{\partial P}{\partial x} - K_f \Phi^2 \frac{\rho_m u_m |\rho_m u_m|}{2\rho_m} + \rho_m g \tag{1}$$

To predict additional factors that affect the hydraulic behavior under the motion and inclination conditions, the body force term in the momentum equation is added as f_{add}. Coriolis effect, $2\Omega \times \upsilon$ is neglected in f_{add} term because it is perpendicular to flow direction.

$$f_{add} = \rho\left(\frac{d^2R}{dt^2} + \frac{D\Omega}{Dt} \times r + \Omega \times (\Omega \times r)\right) \tag{2}$$

where,

$$\frac{d^2R}{dt^2}\text{ : linear acceleration} \tag{3}$$

$$\frac{D\Omega}{Dt} \times r\text{: tangential acceleration} \tag{4}$$

$$\Omega \times (\Omega \times r)\text{ : centrifugal acceleration} \tag{5}$$

2.2 Results of modified TASS/SMR for conceptual problem

The modified TASS/SMR code is verified using the conceptual problem that has a manometer geometry [6]. The selected problems are swaying and rolling motion as shown in Table I.

Table I. Summary of conceptual problem

Parameter	Problem-1	Problem-2
Water level	0.5m	0.5m
Motion type	Swaying	Rolling
Motion condition	Direction: y Acc.: 5m/s^2	Amplitude: 30° Period: 600 s

Fig. 1 shows a nodalization and conceptual problem. A water level in each vertical pipe in Fig. 1 is maintained a constant level when the constant acceleration is applied in the y-direction. The assumed acceleration of y direction is 5 m/s^2.

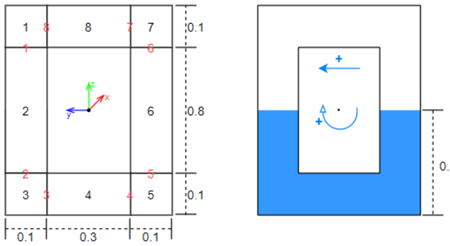

Fig. 1. Schematic diagram of conceptual problem

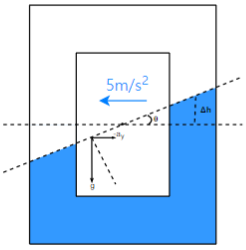

Fig. 2. Schematic of swaying condition

The comparison between the analytical solution and results of the modified TASS/SMR is shown in Fig. 3. The modified TASS/SMR code predicts the water levels of the left and right pipe to 0.397, 0.601 m, and the analytical solutions are 0.398, 0.603 m. It shows a good agreement within 0.4% error.

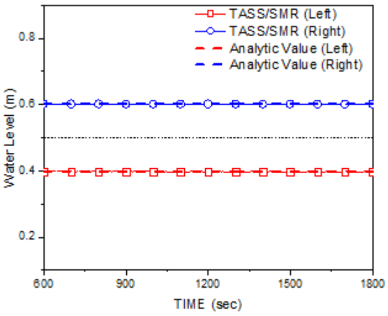

Fig. 3. Water level under sway motion

Next, the assumed rolling condition is an amplitude of 30°, and period of 600 seconds. The rolling angle is expressed the sinusoidal wave function is as follows.

$$\theta = A\sin\left(\frac{2\pi}{T}\right) \quad (6)$$

where,
A: rolling amplitude,
T: rolling period

The analytical solution and calculation result are shown in Fig. 4. The prediction of the TASS/SMR code shows good agreement with the analytical value within 0.1% error.

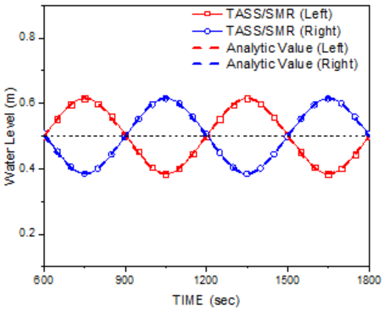

Fig. 4. Water level under rolling motion

2.3 Results of modified TASS/SMR for experimental results

The modified TASS/SMR code is validated using the experimental results, which were conducted under the natural circulation condition with different inclinations [7]. Fig. 5 shows the schematic diagram of the SEA (SMART Experimental Apparatus), which installed a leaning supporter for inclination at the bottom of the apparatus. Fig. 6 represents a cross-sectional view of the SEA. The SEA was designed to measure an asymmetric flow distribution owing to various inclinations of the integral type reactor under natural circulation condition.

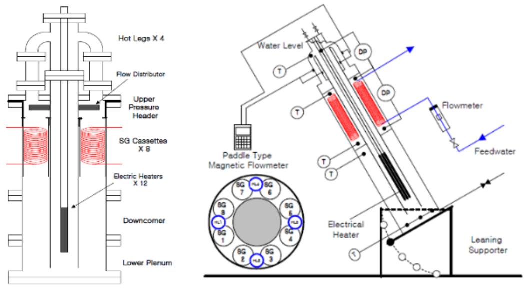

Fig. 5. Schematic diagram of SEA

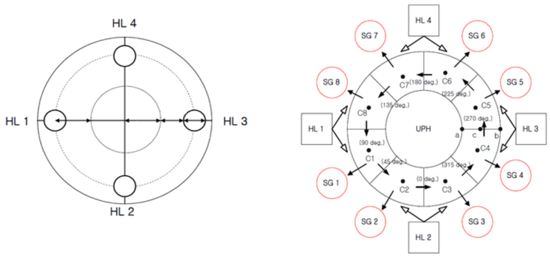

Fig. 6. Cross-sectional view of SEA

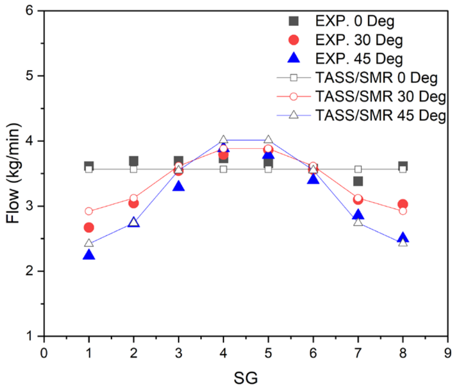

Fig. 7 mass flow at SG

Fig. 7 shows the mass flow at the steam generator (SG) under the inclined condition. The SG1 and SG8 are located at the low position under the inclined condition, and the SG4 and SG5 are located at the high position. The measured average flow with the inclination angle of 30°, and 45° is reduced by 92% and 85% of the average flow with the vertical condition, respectively. The mass flow at the high position is larger than that at the low position since the driving force at the high position is higher. The maximum difference of the mass flow among the SGs is 33%, and 47% for inclination angle of 30°, and 45°, respectively. The modified TASS/SMR code properly predicts a trend of the flow distribution in the SGs for each inclination angle, and the average mass flow with the inclined angle of 30°, and 45° predicts to be reduced by 93% and 88%, respectively. The maximum difference of the mass flow among the SGs is predicted by 26% and 44% for inclined angle of 30° and 45°, respectively, because the code slightly under-predicts the crossflow rate at the upper pressure header.

3. Conclusions

The TASS/SMR-S code is modified to calculate thermal hydraulic behavior under three-dimensional fluid motion and it shows a good prediction performance in conceptual problems and a validation case. For the two-dimensional manometer problem, the calculation results of the code show a good agreement with the analytical solutions. The modified TASS/SMR code is validated using the SEA results. The asymmetric flow distribution among the SGs is predicted well under the inclination condition, and amplitude and period of the flow oscillation are also predicted properly under the rolling condition. Additional systematic validation should be conducted to verify the effect of tangential and centrifugal acceleration.

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