Application of Water Packing Mitigation Scheme to the SPACE Code

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1. Introduction

SPACE is designed for the analysis of two-phase thermal hydraulic phenomena during transients or accidents occurred in nuclear power plants. It uses two-phase three-field governing equations. Several mesh systems and numerical schemes have been tried so far[1-4]. In these days, a lot of effort is being made to enhance robustness of the SPACE code. In this paper, water packing mitigation scheme is designed and incorporated to the SPACE code, for the purpose of relieving numerical instability taking place when a computational cell is about to be filled with water. Also some of the application results will be presented.

2. Water Packing Mitigation Scheme

Water packing mitigation scheme is incorporated to the SPACE code to mitigate pressure spikes that may distort transient solution. This section will explain the water packing mitigation method, detection logic and momentum equation modification. It involves a detection scheme to determine when a pressure change occurs in a cell containing mostly liquid, and then imposes changes to the momentum equations, followed by a recalculation of pressure gradient coefficient vector.

2.1 Water packing detection logic

The detection logic used in the water packing scheme evolved from experience gained in running a vertical fill problem. The detection logic requires the following formula for the pressure:

$$P^{n+1}_{owner} \geq P^{n}_{owner} + 0.0023\, P^{n}_{owner}$$

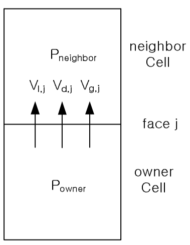


Fig. 1. Vertical arrangement of adjacent cells

Where "owner" cell is the cell that water packs and "neighbor" cell is the next cell. In the "owner" cell, the detection scheme also requires the following conditions.

- void fraction $\alpha_g \leq 0.12$ in the "owner" cell
- liquid temperature $T_l < T^s$ in the "owner" cell
- the "owner" cell to be flagged as vertically stratified
- the next cell above to be highly voided

If a cell satisfies all conditions above, the cell is flagged to be "true". And then momentum equation is treated as below.

2.2 Momentum equation modification

The next part of the scheme involves altering the liquid and droplet momentum equation so that only small pressure changes will occur when the cell fills with water. The new time step face velocities can be written as follows.

$$U^{E(n)}_{g(id)} = {}^{expt}U^{E}_{g\,(id)} - \xi^{E}_{g(neighbor)}\delta P^{(n)}_{(neighbor)} + \xi^{E}_{g(owner)}\delta P^{(n)}_{(owner)}$$
$$U^{E(n)}_{l(id)} = {}^{expt}U^{E}_{l\,(id)} - \xi^{E}_{l(neighbor)}\delta P^{(n)}_{(neighbor)} + \xi^{E}_{l(owner)}\delta P^{(n)}_{(owner)}$$
$$U^{E(n)}_{d(id)} = {}^{expt}U^{E}_{d\,(id)} - \xi^{E}_{d(neighbor)}\delta P^{(n)}_{(neighbor)} + \xi^{E}_{d(owner)}\delta P^{(n)}_{(owner)}$$

In the above equations, ${}^{expt}U^{E}_{k\,(id)}$ contains all the old time terms and $\xi^{E}_{k(neighbor)}$ or $\xi^{E}_{k(owner)}$ contains all the terms that multiply the pressure change. The first change to the liquid and droplet momentum equation is to set ${}^{expt}U^{E}_{l\,(id)}$ and ${}^{expt}U^{E}_{d\,(id)}$, except ${}^{expt}U^{E}_{g\,(id)}$, to 0.1 m/s to insure the explicit liquid and droplet velocities are going to from the "owner" cell to the "neighbor" cell (Fig. 1). The second change to the liquid and droplet momentum equations is to multiply the $\delta P^{(n+1)}_{(owner)}$ or $\delta P^{(n+1)}_{(neighbor)}$ terms by a large number FACTOR. For example, in case owner cell of face is the cell having water packing, $\xi^{E}_{k(neighbor)}$, $\xi^{E}_{k(owner)}$ and explicit velocities are redefined as the following formula.

$$\xi^{E}_{g(owner)} = \xi^{E}_{g(neighbor)} = \xi^{E}_{g(id)}$$
$$\xi^{E}_{l(d)(owner)} = \left(FACTOR\right)\xi^{E}_{l(d)(owner)}$$
$$\xi^{E}_{l(d)(neighbor)} = \xi^{E}_{l(d)(neighbor)}$$
$${}^{expt}U^{E}_{l\,(id)} = {}^{expt}U^{E}_{d\,(id)} = 0.01 m/s$$

3. Application Results

3.1 Test Problem

For the assessment of water packing mitigation scheme, the SPACE code is applied to a one-dimensional vertical fill problem. The test domain, as shown in Fig. 2, consists of 10 vertical cells. The inlet boundary condition is given at the lowest face, and the outlet boundary condition is given at the uppermost face: the inlet liquid velocities are 0.005~0.05m/s, and the outlet pressure is 10 bar.

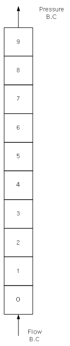
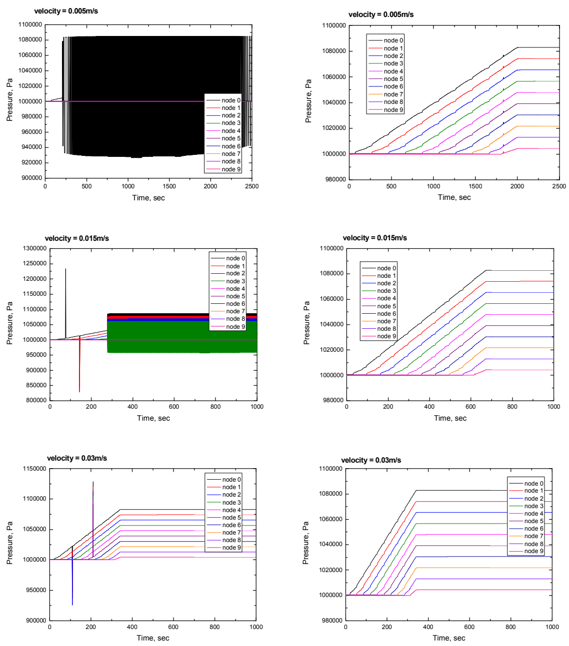
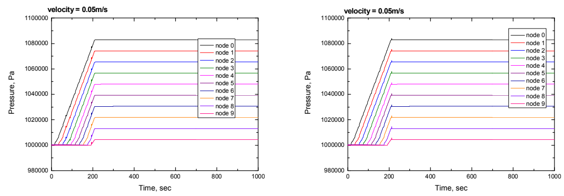


Fig. 2. One-dimensional vertical fill problem

3.2. Result

In Fig. 3, the left column of figures shows the variation of pressure when water packing scheme is OFF, and the right column of figures is for the case the water packing scheme is ON. In case it is not activated, the unphysical pressure spike is found and it is impossible to advance time step, or calculate reasonable solution. Severe distortion of the transient solution like this is usually found when vapor is disappearing from, and water is about to fill during computational time. A large increase in pressure during filling disappeared when water packing scheme is ON.





Water packing logic OFF   Water packing logic ON

Fig. 3. Pressure variation during the vertical fill test

4. Conclusions

In this paper, a water packing scheme is designed and incorporated to the SPACE code and an assessment is performed for a one-dimensional two-phase fill problem. The test results show that the pressure spikes are suppressed, when activating water packing scheme. In conclusion, the water packing mitigation scheme is expected to be helpful to enhance the numerical stability of the SPACE code.

Acknowledgment

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REFERENCES

[1] S. Y Lee, Development of a Hydraulic Solver for the Safety Analysis Codes for Nuclear Power Plants(I). Korean Nuclear Society Spring Meeting, 2007.
[2] M. T. Oh, “Development of an Implicit Scheme to Solve Three Dimensional Three Field Equations,” Korean Nuclear Society Spring Meeting, 2008.
[3] J. C. Park, “Application of an Unstructured Mesh Semi-implicit Scheme to Multi-D Two-phase Flow,” Korean Nuclear Society Spring Meeting, 2008.
[4] C. E. Park, “Developmental status of the staggered mesh hydraulic solver in SPACE,” Korean Nuclear Society Spring Meeting, 2009.