Verification of the SPACE Code Using Conceptual Test Problems

Myung Taek Oh*, Chan Eok Park, and Gyu Cheon Lee
Korea Power Engineering Co., 150 Deokjin-dong, Yuseong-gu, Daejeon, 305-353
**Corresponding author:mtoh@kopec.co.kr*

1. Introduction

A general purpose multi-dimensional two phase thermal hydraulic analysis code, SPACE (Safety and Performance Analysis CodE for nuclear power plants) has been developed utilizing two-fluid three-field governing equations [1-2]. In order to assess applicability of SPACE as a system analysis code, various developmental assessment calculations have been performed so far. In this paper, some of its application results, such as manometer, cross tank problem and two phase flow in an annulus, will be presented.

2. Test Plan

2.1 General description

The SPACE is designed to predict the thermal-hydraulic response of nuclear reactor vessel and coolant systems to the anticipated transients and the postulated accidents, dealing with the following fluid flow features.

- Steam/water/droplet mixture flow
- Transient flow as well as steady state flow
- Non-condensable gas transport in the steam-gas mixture
- Multi-dimensional flow as well as one-dimensional pipe-flow
- Flow through porous body

In order to cope with the above requirements, two-fluid, three-field governing equations are adopted in the SPACE. The three fields are comprised of gas, continuous liquid and droplet fields. The gas field is assumed to be a mixture of vapor and non-condensable gas. The governing equations also involve porosity to take into account the structural material impact on the fluid flow.

2.2 Assessment problems

A total 12 developmental assessment calculations have been performed to assess whether the SPACE code meets properly the code requirements. Table 1 lists 12 problems, which includes a brief description of the objective of each problem.

Table I: Problems for the SPACE validation

Problem Type	Test Objectives
1-D Single Phase and Two Phase Flow Problems	
● Nine-Volume Water Over Steam	Gravitation head effect, Two fluid kinematics
● Manometer Problem	Non-condensable state, Oscillatory flow
● Branch Reentrant Tee Problem	Tee model using branch component
● Cross-Flow Tee Problem	Tee model using cross flow feature
● Cross Tank Problem	Cross feature, Recirculation
● Boron Transport Test	Boron transport
● Boil-off Problem	Phase transition, Interphase drag
Multi-D Single Phase Flow Problems	
● Single Phase Cavity Flow Problem	Multi-dimensional single phase flow
● Single Phase Annulus Flow Problem	Single phase flow in an annulus
Multi-D Two Phase Flow Problems	
● Two Phase Cavity flow Problem	Multi-dimensional two phase flow
● Two Phase Annulus Flow Problem	Two phase flow in an annulus
Integral Effects Problem	
● Typical PWR Problem	Typical PWR, System modeling, Control System

These are a collection of problems that have been performed by KOPEC. In addition to these problems, various problems which contain the phenomenological problems, the separate effects test and the integral problems, have been performed by other institutes, as a series of code validation effort.

3. Test Results

3.1 Manometer problem

Nitrogen-water manometer is set up to check the validity of the non-condensable gas model and the momentum formulation. The first 50 volumes are oriented vertically downward and the last 50 volumes are oriented vertically upward. To initiate the oscillation by head difference, the bottom 15 volumes on the left hand side and the bottom 35 volumes on the right hand side are filled with water at 20bar and 350K.The remaining volumes are initialized with dry nitrogen at the same pressure and temperature. The liquid oscillates back and forth between the two vertical columns with non-decreasing amplitude because wall friction option is turned off. Analytically, the amplitude of the liquid velocity should be remained at the +/-2.75m/s. As shown in figure 1, calculated amplitude remains at +/-2.81m/s. The calculated period of oscillation by the code is shown to be about 4.68 seconds, which agrees well with the theoretical value, 4.58 seconds.

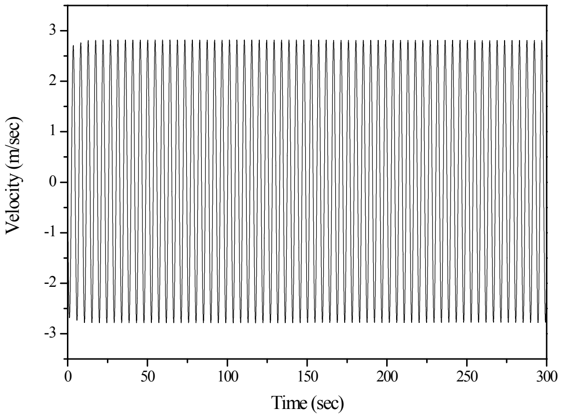

Figure 1 Liquid velocity at the bottom of the manometer

3.2 Cross tank problem

The cross tank problem is set up to test whether the code could properly model the response for symmetric behavior without abnormal flow, which may appear as recirculation of two phase or single phase flows. The cross tank is modeled using two pipe components that consist of 19 volumes, respectively. The pipe components are connected using cross junctions. The bottom 15 volumes in each pipe component are filled with water at 0.1014MPa and 305K. Volume 16 in each pipe component contains a mixture of air and water with void fraction of 0.5. The remaining volumes are initialized with dry air at the same pressure and temperature.

As shown in figure 2, all of the cross-flow junction mass flow rates remain near zero without non-physical flow anomalies. The result demonstrates that the code models properly the multi-dimensional effects using cross junction feature.

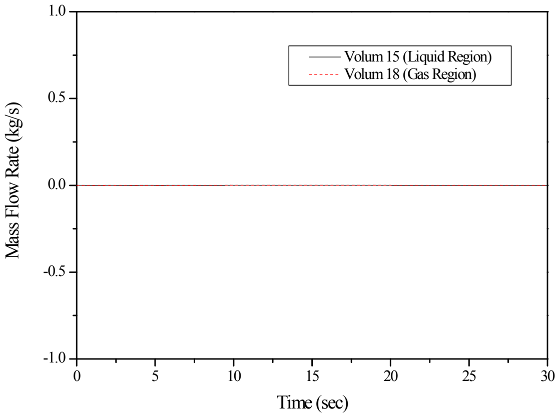

Figure 2 Mass flow rate

3.3 Two phase flow in an annulus

In order to verify the ability of multi-dimensional analysis, the code is applied to annulus two phase flow problem at cylindrical coordinate system. The test domain consists of 360 volumes that are initially filled with vapor. The water is injected at the velocity, 0.2m/sec, through the right bottom of the annulus geometry. The pressure outlet boundary condition is given at the left bottom.

Figure 3 shows the velocity vectors and the void fraction distribution after 60 seconds. The flow is appeared to be dominant toward the outer wall due to centrifugal force. The test result shows that the flow pattern is reasonable in the qualitative aspect.

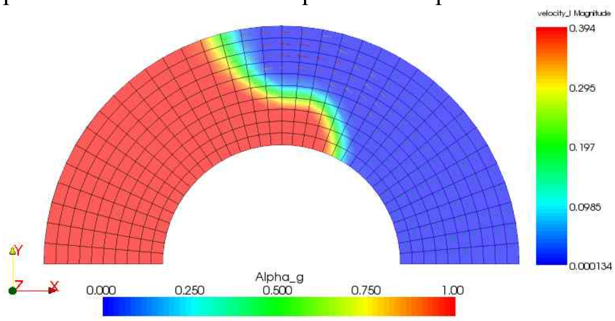

Figure 3 Velocity and void fraction distribution at 60s

4. Conclusions

As an effort for verification, 12 developmental assessment calculations have been performed. Though only some results are shown here, most of 12 test results are quantitatively and qualitatively in good agreement with the physics of each problem. In order that the SPACE is fully verified as a system analysis code, more intensive study including comparison of its predictions on wide variety of events with the results from experiments will be performed for the next step.

Acknowledgment

This study was performed under the project, "Development of safety analysis codes for nuclear power plants" sponsored by the Ministry of Knowledge Economy.

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] C. E. Park, "Developmental status of the staggered mesh hydraulic solver in SPACE," Korean Nuclear Society Spring Meeting, 2009.