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Application of an Unstructured Mesh Semi-implicit Scheme to Multi-D Two-phase Flow

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1. Introduction

KOPEC has been developing a system thermal hydraulics solver for safety analysis of nuclear power plants, using two-fluid, three-field governing equations for two phase flow [1]. Several numerical schemes, such as collocated, staggered, semi-implicit, and implicit schemes, have been tried so far.

In this paper, the collocated semi-implicit scheme is applied to multi-dimensional, multi-phase flow. The test problems are designed to cover the two-phase settle down phenomena, liquid-vapor interaction at the free surface in a simple rectangular cavity. The regular hexahedral, and the unstructured prism meshes, generated by the mesh generation tool, GAMBIT [4], are used for these tests

2. Analysis Methodology

In the collocated semi-implicit scheme, discretization is performed by integrating the governing equation over a general polyhedral shape of control volume. The collocated mesh system, where all dependent variables share the same control volume, is also used instead of the staggered one. It uses Rhie and Chow interpolation scheme[2] imitating the staggered grid solution to avoid the checkerboard effect. The phasic velocities at the face are substituted into continuity and energy equation. As a consequence, the cell matrix inversion leads to a single equation involving only pressures. This is done for each cell, giving rise to the system pressure matrix. After the system pressure matrix is solved, the solutions for independent variables are obtained by the back substitution. The detailed descriptions for the discretization and the semi-implicit methodology are given in Reference[1,3].

3. Test Result

3.1 Test problem

The test geometry, as shown in Fig. 1, is a 10 m x 10 m rectangular cavity, and the whole domain consists of 100 uniform regular hexahedrons or 200 uniform unstructured prisms.

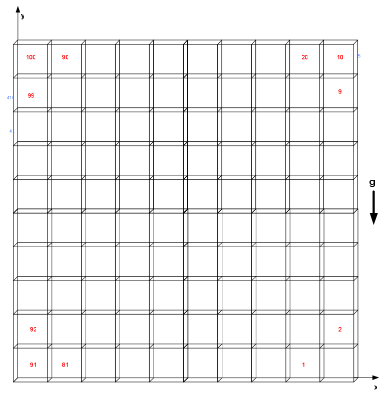

Figure 1 Geometry of the test problem

3.2 Test results

3.2.1 Settle down test.

Settle down test was set up to demonstrate the phase separation. The initial void fraction is 0.5 in the whole test domain. When the test starts, as shown in Figure 2, liquid fraction is slowly increased from the initial value, 0.5, at the lower part of cavity, since liquid field settles down by gravity. Finally, the lower half part is filled with liquid and the other part of cavity is filled with vapor phase. This test results show that the collocated semi-implicit scheme simulates the settle down phenomenon. It is also found that the same results can be obtained by using the unstructured prism mesh.

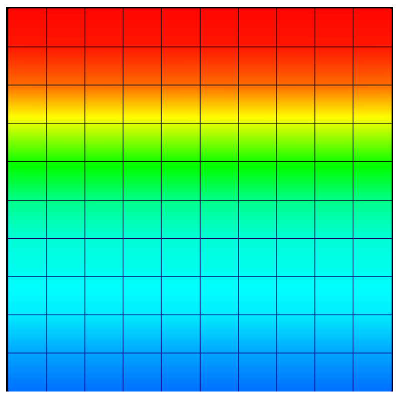

Figure 2 Result of settle down test

3.2.2 Dam break test.

In this test, 50 volumes of the left hand side are initially filled with liquid and the rest volumes are filled with vapor. When the test starts, as shown in Figure 3, the liquid head difference between the left and right side drives the liquid level to oscillate up and down. The oscillation amplitude gradually decreases due to wall friction, and leads to the stable state in 25 seconds. The same results are also shown in case of using the unstructured prism meshes.

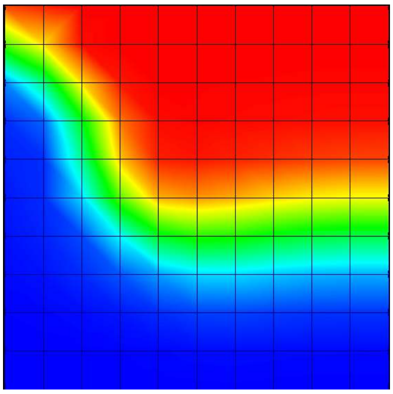

Figure 3. Result of dam break test

3.2.3 Air injection test

In this test, the bottom 80 volumes were initially filled with subcooled liquid. The superheated vapor was injected through top two faces of the left hand side wall, and the outlet boundary condition is given at top face of the right hand side: the inlet flow velocities are 10 m/s, and the outlet pressure is 10bar. Fig 4 shows the liquid level oscillates periodically due to the blow-out effect of the injected vapor and interfacial drag between vapor and liquid. The test results show that wave pattern is reasonable in the qualitative aspect.

4. Conclusion

The application scope of the collocated semi-implicit scheme, which is under development as a hydraulic solver of SPACE code, is extended to the complicated multi-dimensional, two-phase flow. The unstructured meshes including regular hexahedron and prism are also tested. The test results show that the collocated semi-implicit scheme works properly for various two-phase flow phenomena including the phase separation, liquid-vapor interaction at the free surface, regardless of the mesh type chosen.

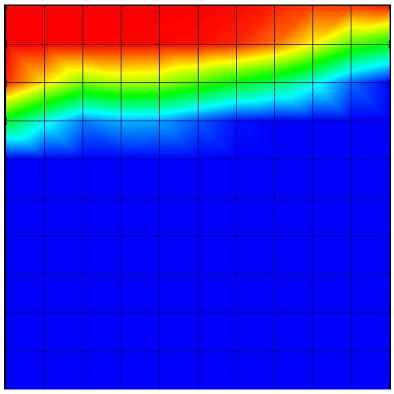

Figure 4 Result of air injection test

Acknowledgment

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[4] Gambit User Guide