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The Development of the Two-Dimensional Steam Explosion Code LeFIX

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1. Introduction

We first developed the numerical models called LeSiM(Lagrangian estensible Simulation Modules) [1,2] simulating the movement of the Lagragian particles and their interactions with the surrounding fluid. By directly implementing these modules into the code, any fluid dynamic code should then be capable of simulating the interaction between the Eulerian fluid and the Lagrangian particles with only minimal change to the code. LeSiM was first directly tried with the two-phase fluid dynamic code K-FIX[3].

The modified code was called LeFIX(Lagrangian extended K-FIX) and was given the version number of 0.1. Basically, this version of LeFIX[4] was essentially K-FIX with LeSiM built in. The modification was done so that the information regarding the initial properties of the Lagrangian particles could be read from the input file for K-FIX and that the information regarding the interactions between the Lagrangian particles and the Eulerian fluid may be passed between LeSiM and K-FIX. The results of this first try showed that it was possible to directly put LeSiM into K-FIX for the calculation[5]. In this paper, the developments and the verifications for several new versions of LeFIX are introduced.

2. Governing Equation & Constitutive Relation

Based on the equations employed in K-FIX[3], two sets of conservation equations for mass, momentum, energy for two phase flow are solved in LeFIX.

Two correlations for drag coefficients are implemented in LeFIX, one for the bubbly flow and one for the droplet flow[6,7].

For the droplet flow, the drag coefficient is written as

$$D = \alpha_f^{-2.7} \frac{3}{4} C_D \frac{\rho'_g \left| \vec{v}_l - \vec{v}_g \right|}{R_d} \qquad (1)$$

For the bubbly flow, the drag coefficient is written as

$$D = \alpha_g^{-2.7} \frac{3}{4} C_D \frac{\rho'_l \left| \vec{v}_l - \vec{v}_g \right|}{R_b} \qquad (2)$$

The calculation of the phase change rate and the heat transfer rate are interwound. In general, it is postulated that the heat would be transferred between the liquid phase fluid and the liquid-vapor interface and between the liquid-vapor interface and between the liquid-vapor interface and the vapor phase fluid. Any imbalance between these two amounts of heat is then considered used for phase change. The heat transfer rates from the vapor to the interface, the heat transfer rate from interface to the liquid, an the phase transition rate is written as

$$q_{gs} = H_{gs}(T_g - T_l) \qquad (3)$$

$$q_{sl} = H_{sl}(T_s - T_l) \qquad (4)$$

$$M = (q_{gs} - q_{sl})/(h_g - h_l) \qquad (5)$$

The coefficients for the convection heat transfer used for the heat exchange between the interface and each bulk are extracted from TEXAS-V[6], which is originally based upon the correlation given by Ranz and Marshall[8].

3. Simulation and Results

The rising bubbles under the superheat condition were used to test LeFIX. The system of interest was a closed cylindrical tank filled uniformly mixed water-steam. As the Figure 1, the height of the tank was 1.0 m and the radius was 0.5m. For the simulations, the system was nodalized on the rz plane into 12x12 mesh with dz of 0.1m and dr of 0.05m. It must be emphasized that the first column at the vertical axis, the last column at the wall, the first row at the bottom and the last row at the top of the system acted as the boundary. No calculation was done for the cells at the boundary.

In the simulation, the mixed water-steam had the steam volume fraction of 0.5 and was at the temperature of 395 K, with the initial pressure of 0.1 MPa. The time step of 0.00002 second was also used for the simulation. From the simulations, the steam volume fraction obtained along the vertical cells at the radial positions of 0.025m at 5 seconds is a major comparison parameter.

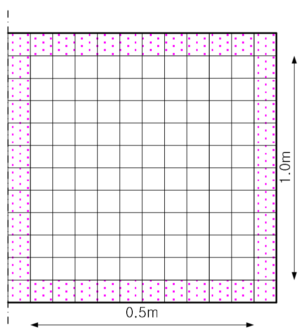

Figure 1. Nodalization of the system to be simulated

4. Verification

The developments and verifications for several new versions of LeFIX were done step by step. LeFIXv0.1 was developed by incorporating LeSiM into K-FIX2d. LeFIXv0.1 gave the same solution with K-FIX2d in the bubble growth problem. LeFIXv0.2 is the same code with LeFIXv0.1, but the bubble rising problem is set up for the verification of new versions of LeFIX.

LeFIXv0.3 was developed by adding flexible nordalization ability to LeFIXv0.2. By this, we can lessen the burden of the compiling work. LeFIXv0.4 was developed by changing the unit from cgs to MKS. We must note that original K-FIX2d is written under the cgs unit. In the Figure 2, LeFIXv0.3 and LeFIXv0.4 gave the same solution as LeFIXv0.2. This means that LeFIXv0.3 and LeFIXv0.4 is well defined code.

LeFIXv0.5 is first version of LeFIX to simulate FCI, in which include the correlation for FCI phenomena such as new equation of states, the heat transfer between liquid and vapor, phase change, and the drag. The new equation of states has little effect on the solution as shown in Figure 3. However, the heat transfer including phase change and the drag must affect on the solution and we couldn't obtain the solution. We need to make an effort on fitting these correlations into LeFIX or to advance the iteration scheme.

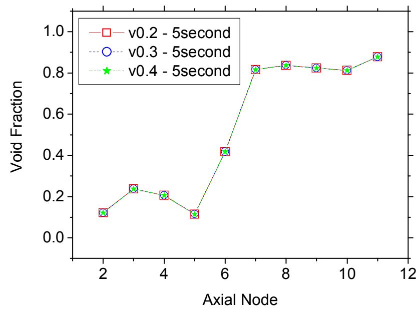

Figure 2. Effects of Flexible nordalization, MKS unit

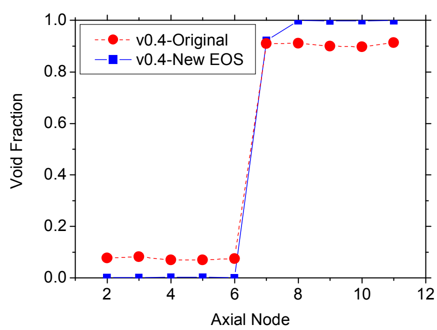

Figure 3. New EOS effect on the LeFIX calculation

5. Conclusion

It is obvious that the heat transfer including phase change and the drag is a major problem for the current version of LeFIX. In addition, the calculation stability of LeFIX and the period in which it can simulate must be improved and extended.

There is also a concern regarding the applicability and the correctness of various correlations and criteria employed in LeFIX. The parametric tests on these correlations and criteria will also be necessary and must be conducted.

Apart from the above immediate objectives, LeFIX will be also modified in order to fully incorporated LeSiM so that the interaction between the two-phase fluid and the particles can be utilized. Due to the possible large quantity of energy exchange, the better scheme for treating and solving the energy equations will be necessary. The interaction between the liquid water and the single heated particle and between the liquid water and the injected column of molten fuel are two possible scenarios for testing the applicability of LeSiM included LeFIX

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