On the free surface problem of multi-dimensional/channel calculations of RELAP5

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1. Introduction

Free surface boundary problems have been well known in the computational fluid dynamics [1,2]. Recent trial extension of RELAP5 [3,4] to multi-dimensional calculation brings us to meet this problem. Traditionally, the sharp horizontal boundary between the liquid and vapor in the pipe has been taken care of by using the vertical stratification model. However, if the code is applied to multi-dimensional calculation, the model may not be adequate.

This paper will show the main cause of the problems and will discuss one of the possible solutions.

2. Identified Problems

During the developmental activities of multi-dimensional RELAP5 the test case as shown in the figure 1 is calculated. The test case consists of 12 axial,

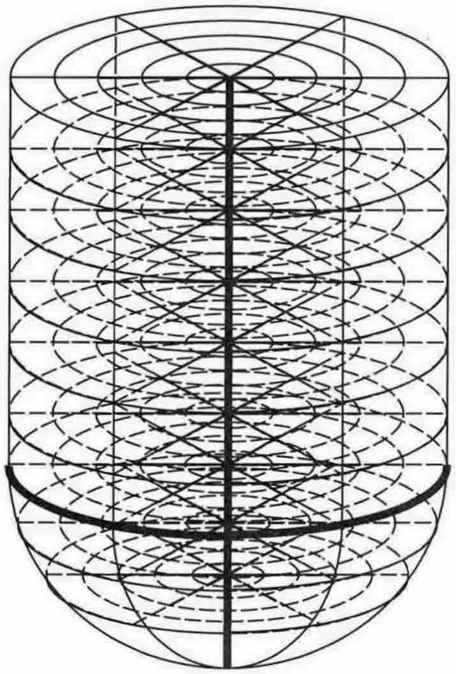

Figure 1. Cylindrical and hemi-spherical combined sections for test case.

5 radial and 6 circumferential sections. Cylindrical height and radius are 6m and 2.5m respectively.

Initial conditions for all nodes are the same; 155bar, half-filled with saturated water. Original expectation of the calculation is that the settlement of the liquid to the bottom part may develop a sharp and stable interface in the middle of the cylinder. But, the interface is not stable. Instead, the interface becomes oscillatory. The fluctuation amplitude is not negligible (~300kg/sec in figure 4).

3. Cause of the Problem

The stability of mano-metric oscillation of RELAP5 calculation has long been investigated and documented. However, if multiple channels are inter-connected by cross-flow junctions, a false momentum calculation happens.

3.1 False Momentum Calculation Mechanism

In figure 2, if the steam filled node is on top of the mixture filled node, and gravity effectively separates two nodes. However, liquid velocity of the junction does not become zero as shown in figure 3.

The main reason for this is that the junction properties (such as void fraction) are estimated by averaging the two adjacent nodes. Therefore the junction liquid fraction for the figure 2 is non-zero and the explicit liquid velocity as well as the velocity derivative for this junction will get finite values. Most of the time, the gravity force makes the liquid velocity direct downward and acts like a pump.

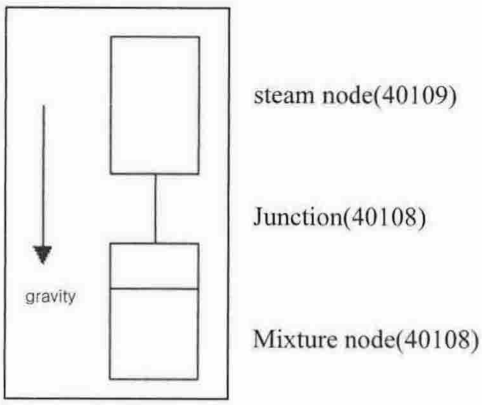

Figure 2. False momentum calculating configuration

The falsely calculated momentum flux drives the channel to flow downward until the diversion flow to the adjacent channel negates the drive. In return, adjacent channel may push downward back by its false momentum flux again. This cyclic process will continue to result in the observed fluctuation.

3.2 The consequence of false momentum calculation

The falsely calculated liquid velocity may not cause any problem for mass/energy conservation because they are calculated based on the donner cell properties.

However, momentum flux calculations are affected regardless of whether the upwind derivative scheme or the derivative central scheme is used.

4. Interim Solutions

Even though the vertical stratification model is selected at all junctions, fluctuations can not die out. Therefore, more direct correction scheme is tried. The method is to check whether the liquid fraction of the upstream node is nearly zero (<1.0d-10). If it is, then set the velocity and velocity derivative to nearly zero (multiply 1.0d-30 to calculated values). The modified part of code looks like as follows;

```
if(velfj(i) >= 0.0d0) then
      if(voidf(k) < 1.0d-10) then
            velfj(i) = 1.0d-30 * velfj(i)
            vfdpk(ix) = 1.0d-30 * vfdpk(ix)
      endif
else
      if(voidf(l) < 1.0d-10) then
            velfj(i) = 1.0d-30 * velfj(i)
            vfdpk(ix) = 1.0d-30 * vfdpk(ix)
      endif
endif
```

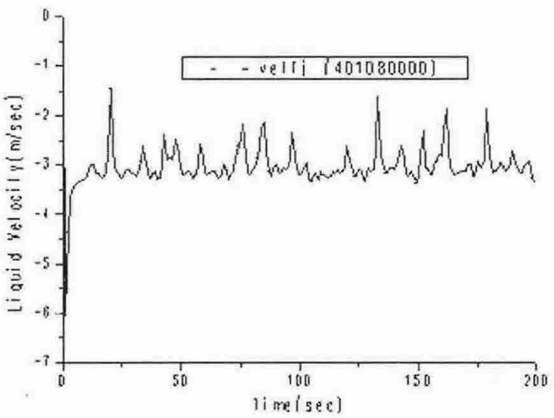

Figure 3. False Velocity in original version

Where the variables velfj, voidf, and vfdpk, are liquid explicit velocity, liquid fraction, and liquid velocity derivative respectively. The indices i, k, and ix represent junction index, volume index and junction scratch space index in REALP5 respectively. These modifications are implemented in the subroutine vexplt of RELAP5. After these modifications, the flow fluctuations occurred during the simulation disappear as shown in figure 4.

5. Discussions and Conclusion

Free boundary conditions occurred in the multi-dimensional RELAP5 is different from those in CFD. In RELAP5 calculation, the surface tension may be ineffective to stabilize the interface because the size of the node is too big to have appreciable tensional force. The vertical stratification model may be good for manometric oscillation but may not be good for multi-dimensional case. The modifications made in this study are very effective to mitigate fluctuations. But further detailed investigations on the theoretical aspects should be made.

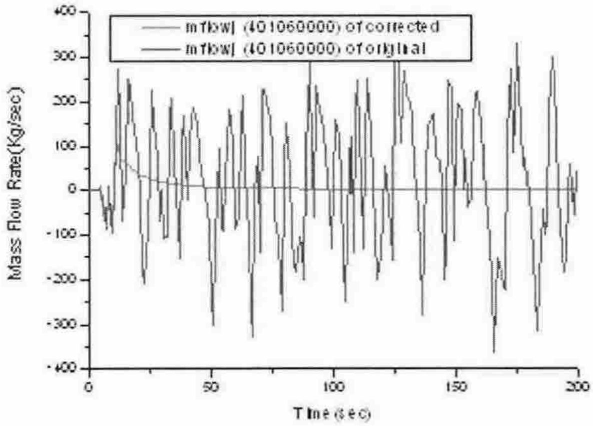

Figure 4. Mass flow fluctuation in original version and mass flow convergence in corrected version

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