MESH TOPOLOGY MODIFICATION METHOD FOR SOLVING MULTI-REGION COUPLING PROBLEMS WITH PHASE CHANGE

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Introduction

The aim of the present work is to develop a mesh topology modification method for solving the multi-region coupling problems with phase change. A lot of phenomenons involving coupled multi-region problems with phase change, such as liquid frozen/melting, machining, nozzle erosion and solid fuel combusiton etc. The ultimate goal of the work is to investigate variety of effects on the dynamic evolving process of this type problems, such as the effects on the combustion rate of solid propellant combustion. The method was developed using the foam-extend 3.2 version.

The main techniques under developing this method involve: multi-region conjugate heat/mass transfer[1], interface tracking[2] and mesh topology changes[3, 4, 5]. For multi-region coupling problems, the fully-coupled model using a Dirichlet-Neumann partitioned method is adopted. The region's interface is tracked using the method of clsvof with phase change. A new RegionMeshTopoFvMesh class and a new mesh modifier cellAdditionRemoval for handling the dynamic change of the mesh topology have been implemented. The cells can add or remove from one region to another region by the rules of interface tracking or the variables assigned, for example, when the cells temperature of solid region larger than some value , those cells will be removed from solid region and add into fluid region, shown as in figure 1.
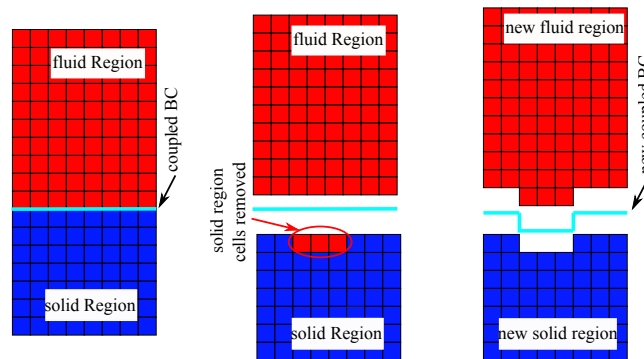

Figure 1: mesh topology modification

Overview of Implemented Technology

The entire computational domain is discretized into Cartesian mesh. Each region has its own mesh and governing equations. The matrix equation systems of each region solved individaully and coupled at the multi-region interface boundaries. The coupled boundaries are imposed by the Dirichlet-Neumann conditions. The governing equations describing fluid systems comprise equations for mass continuity, species continuity, momentum and energy. The governing equations for the solid regions comprise the energy equation and interface tracking equations. When phase change of regions happened, the mesh topology will update. The solution algorithm implemented for mesh topology modification method of solving the multi-region coupling problems with phase change is as follow:

1. Define multiple meshes, one for each region.

2. Create field variables on each mesh.

3. Judge if the mesh topology needed to change by tracking the interface of the regions or comparing with the assigned some field value. If mesh topology needed to change, then update the mesh topology and mapped the fileds of regions.

4. Set up separate governing equations for each region considered.

5. Solve the separate matrix equation systems.

6. Couple the solution obtained in Step 5 at the boundary interface among the regions.

7. Sub-iterate on the coupled solution until convergence is obtained.

8. Go to next time step.

Applications

Two cases finished by this work shown in this part. The geometry configuration of the first case comes from paper[1]. There are two regions, the one above is fluid region and the one below is solid region, as shown in figure 2.


Figure 2: Geometry configuration in case one

Compare with the case in paper [1], the mesh topology change method developed by this work is added in this case. The rule of removing cells in this case is by assigning a temperature value, when the temperature of solid region cells is larger than the value assigned, the cell will removed from solid region and added into the fluid region. Figures 3-5 show the topology change, velocity and temperature filed separately in local part. From the results, it can be seen that the solid region becomes smaller with the temperature that comes from fluid region increment. The whole dynamic process simulated by this case can be used to study the phenomenon with simple phase change, such as the melting of ice.

Figure 3: The topology structure change
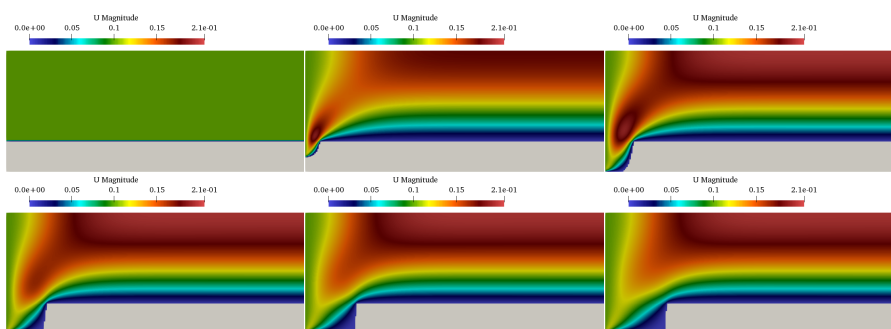
Figure 4: The velocity field

Figure 6 shows another case computed by the present work, it demonstrates the dynamic combustion process of some kind of solid propellant in the temperature filed. Compared with case above, the fluid region contains chemical reactions and the solid region contains the clsvof with phase change mehods in this case. With the help of the method developed in this work, some effects on the combustion of solid fuel can be investgated, such as ambient pressure, the initial temperature of solid region and even the formula of the propellant.
Development of the adaptive mesh refinement technique nearby the coupled interface and a parallel implementation model is still in progress.
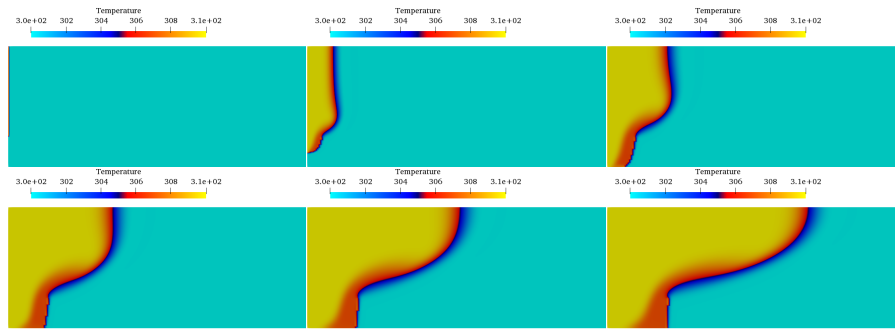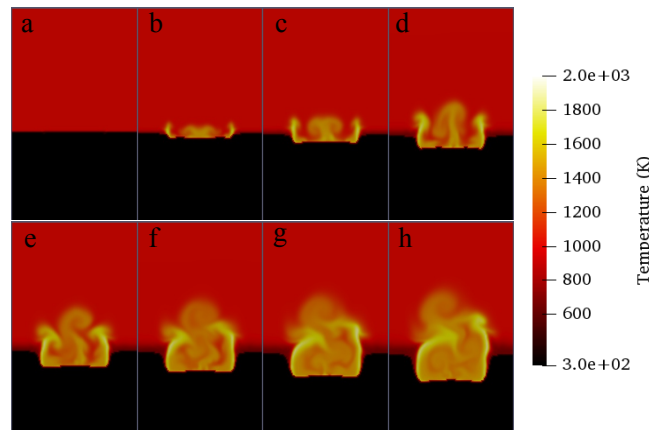
Figure 5: The temperature field

Figure 6: The temperature field of dynamic combustion processing of solid propellant

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