Multiphase flow in *Code_Saturne* using Level-Set method

**ABSTRACT**

In the present work, a two-phase flow algorithm is proposed for the *Code_Saturne* software. Multiphase simulation is more and more required for various applications in the field of fluid mechanics, such as micro-fluidics or liquid jets, among others. There are several methods currently used in CFD softwares, among which Volume Of Fluid (VOF) and Level-Set (LS) methods are the most common. The first presents the benefit of being mass-conservative but is not well suited for interface capturing. The latter method however introduces a signed distance function, from which a more precise interface between the two fluids can be computed.

A first approach consists in introducing a Level-Set method in *Code_Saturne* source code. Due to the moving interface, a re-initialization algorithm for the signed function had to be introduced. In order to reduce mass loss during the calculation process, a high order scheme (WENO5) has been implemented in a square lattice mesh. However, a orthogonal mesh does not match general purpose models requiring, depending on the geometry, different mesh types.

To overcome this problem, a second approach consists in implementing new algorithms so as to prevent mass loss by using the same scheme order used in *Code_Saturne* for any mesh type. Recent work has improved the accuracy of the distance function: for example, a Conservative Level-Set (CLS) is introduced to minimize the re-initialization effort and compared with previous methods regarding its mass conservation. We finally end-up with perspectives of improvements to have a fully functional algorithm in the coming future for *Code_Saturne*.

**LEVEL-SET METHOD**

- **Precise position of the interface**
  - Physical properties interface jump
  - Surface tension: Continuum Surface Force (CSF)
  \[ F_a = \int_\Omega \sigma_k(\phi) \nabla \phi \cdot \nabla \phi \, d\Omega \]
  - Interface capturing method
    - Scalar function level-set: \( \phi \)
    - Signed distance function
  \[ \varphi(x, t) = 0, x \in \Gamma \]
  \[ \varphi(x, t) < 0, x \in \Omega_1 \]
  \[ \varphi(x, t) > 0, x \in \Omega_2 \]
- **Re-initialization of the level-set method**:
  - The signed distance has the following property: \( |\varphi| = 1 \)
  - Re-initialization function of method function:
  \[ \frac{1}{\varphi} \]

**RESULTS**

Results with high order discretization scheme (WENO5)

- **Grid meshes**
  - Results computed in *Code_Saturne*.
- **Numerical results and validation from the literature**:
  - Poiseuille two phase flow test
    - Analytical results compared with numerical results
    - Validation of physical property changes
    \[ \rho(\phi) = \rho_1 + (\rho_2 - \rho_1) H(\phi) \]
    \[ \mu(\phi) = \mu_1 + (\mu_2 - \mu_1) H(\phi) \]
  - Vortex test
    - Validation of Level-Set scalar transport
- **Rising bubble test**
  - Validation of the re-initialization function

Results with Centered scheme (*Code_Saturne*)

- **Any mesh type**
  - **Level-set method**
    - Re-initialization function with small time steps
    - Modification of the re-initialization function during the iteration loop
    \[ \frac{\partial \varphi}{\partial t} = \pm \operatorname{sgn}(\varphi_0)(1 - |\varphi|) \]
  - 5% of mass loss
  - 600-700 iterations every 10 time steps
  - Bubble shape changed
- **Level-Set method with diffusion**
  - Implementation of a standard level set method for incompressible two-phase flow simulations, N. Johansson
    - Adding a diffusion term
    \[ \frac{\partial \varphi}{\partial t} = \operatorname{sgn}(\varphi_0)(1 - |\varphi|) + \alpha \nabla^2 \varphi \]
    \[ \alpha = \max(\frac{\lambda_x}{\Delta x}, \frac{\lambda_y}{\Delta y}) \]
  - 5% of mass loss
  - 4-10 iterations every 10 time steps
  - No precise interface
- **Conservative Level-Set method (CLS)**
    - Adding a compression term to balance the diffusion term
    - Initialization for \( \varphi(0) = 0.5 \)
    \[ \psi = \frac{1}{2} \left( 1 + \tanh \left( \frac{3}{2} \right) \right) \]
  - 10% of mass loss, artificial oscillations

**CONCLUSIONS AND PERSPECTIVES**

- **Algorithms with low order discretization scheme show convincing results but are still work in progress**
  - Improvement of the CLS method algorithm (with helps of CS internal functions)
  - Development of the VOSET method (coupled Volume-Of-Fluid and Level-Set methods) to prevent mass loss