

Numerical simulation of boiling on 3D unstructured grids

Guillaume Sahut, Giovanni Ghigliotti, Patrick Bégou, Philippe Marty, Guillaume Balarac

Univ. Grenoble Alpes, CNRS, Grenoble INP, LEGI

Laboratoire LEGI, 1209-1211 rue de la piscine, Domaine Universitaire, 38 400 Saint-Martin-d'Hères, France

guillaume.sahut@univ-grenoble-alpes.fr

Extended Abstract

Two-phase flows are characterized by the existence of an interface between the two phases. Therefore, numerical simulations of two-phase flows require high accuracy on the methods used to model the interface motion. Different families of methods exist to keep track of the interface, among them are Front Tracking [1], Volume Of Fluid [2] and Level Set methods [3]. We have developed a solver in the finite volume-based YALES2 framework [4] for numerical simulations of boiling. We use a Level Set method where the liquid-vapor interface is defined as the 0-level of the Signed Distance Function to the interface. The advantages of using the Level Set method compared to the Front Tracking and Volume of Fluid methods are the easier computation of the interface geometrical properties such as normal vector and curvature, and the ability to inherently handle interface topological changes such as coalescence and atomization. The Level Set field is continuous at the interface, thus no interface reconstruction procedure is needed after advection. The interface motion is then represented by the advection of the Level Set function by the fluid velocity. One notorious problem is that the advected Level Set function is no longer the signed distance function to the advected interface, and so a reinitialization step is needed. On structured cartesian grids, two well-known methods exist to reinitialize the signed distance function: the Fast Marching Method (FMM) [5] and Hamilton-Jacobi's method (HJ) [6]. The FMM updates node lists to solve the Eikonal equation $\|\vec{\nabla} \phi\| = 1$ in both phases, ϕ being the signed distance function, from the closest nodes to the interface to the farthest nodes to the interface. HJ's method solves an unsteady version of the Eikonal equation and does not require node list updates but requires a high-order scheme to compute $\vec{\nabla} \phi$. The classical versions of these methods require cartesian grids. On unstructured grids, one has to deal with the geometrical properties of the simplices to extend the FMM or HJ's method. We base our work on the paper of Tanguy et al. [7] and aim at extending the method to unstructured grids. To this purpose, we use an extension of the FMM on triangles and tetrahedra by means of the MshDist library [8]. Once the signed distance function is reinitialized, the interface normal vector \vec{n} and curvature κ are respectively given by $\vec{n} = \vec{\nabla} \phi / \|\vec{\nabla} \phi\|$ and $\kappa = -\vec{\nabla} \cdot \vec{n}$. HJ's method has also been extended to unstructured grids. The normal vector and curvature are computed with the same equations. HJ's parallel algorithm is quite complex and will be addressed in an upcoming publication. We then use these geometrical properties of the interface to solve the incompressible Navier-Stokes equations fully coupled with the temperature advection-diffusion equation. The physical phenomenon of boiling induces discontinuities of different fields at the interface. We use the Ghost Fluid Method [9] to handle these discontinuities. The boiling phenomenon is taken into account at the interface by the mass transfer rate computed from the temperature fields on both sides of the interface. The mass transfer rate \dot{m} is given by $\dot{m} := (-\lambda_{liq} \vec{\nabla} T_{liq} \cdot \vec{n} + \lambda_{vap} \vec{\nabla} T_{vap} \cdot \vec{n}) / L_v$, where λ_X and T_X are respectively the thermal conductivity and the temperature of phase X , \vec{n} the interface normal vector, and L_v the fluid latent heat. Because the knowledge of both the liquid and vapor thermal gradients is needed at the same location (the interface), we use Aslam's extrapolation method to extend the temperature from one phase to the other in a narrow band approach [10]. The mass transfer rate, coupled with a density difference between the two phases, induces a discontinuity in the velocity field at the interface. In addition, the mass transfer rate also contributes to the pressure discontinuity at the interface (that depends also on the surface tension). Through these discontinuities, the Navier-Stokes equations are coupled with the mass transfer rate, leading to a two-way coupling of the momentum and thermal equations. We validate our method on unstructured grids against the analytical test case of a growing 3D bubble in a quiescent superheated liquid where the mass transfer rate is computed at the interface from the temperature

fields [11]. Our numerical tests show the consistency of the methods. A better evaluation of the convergence order of the methodology is in progress.

References

- [1] G. Tryggvason, B. Bunner, A. Esmaeeli, D. Juric, N. Al-Rawahi, W. Tauber, J. Han, S. Nas and Y.-J. Jan, "A Front-Tracking Method for the Computations of Multiphase Flow," *J. Comp. Phys.*, vol. 169, no. 2, pp. 708-759, 2001.
- [2] W. F. Noh and P. Woodward, "SLIC (simple line interface calculation). [Usable in 1, 2 or 3 space dimensions]," *Fifth International Conference on Numerical Methods in Fluid Dynamics*, 1976.
- [3] S. Osher and J. A. Sethian, "Fronts propagating with curvature-dependent speed: Algorithms based on Hamilton-Jacobi formulations," *J. Comp. Phys.*, vol. 79, no. 1, pp. 12-49, 1988.
- [4] V. Moureau, P. Domingo and L. Vervisch, "Design of a massively parallel CFD code for complex geometries," *CR Mec.*, vol. 339, no. 2-3, pp. 141-148, 2011.
- [5] J. A. Sethian, "A Fast Marching Level Set Method for Monotonically Advancing Fronts," *Proc. Natl. Acad. Sci.*, vol. 93, no. 4, pp. 1591-1595, 1996.
- [6] M. Sussmann, P. Smereka and S. Osher, "A Level Set Approach for Computing Solutions to Incompressible Two-Phase Flow," *J. Comput. Phys.*, vol. 114, no. 1, pp. 146-159, 1994.
- [7] S. Tanguy, M. Sagan, B. Lalanne, F. Couderc and C. Colin, "Benchmarks and numerical methods for the simulation of boiling flows," *J. Comput. Phys.*, vol. 264, pp. 1-22, 2014.
- [8] C. Dapogny and P. Frey, "Computation of the signed distance function to a discrete contour on adapted triangulation," *Calcolo*, vol. 49, no. 3, pp. 193-219, 2012.
- [9] R. P. Fedkiw, T. Aslam, B. Merriman and S. Osher, "A Non-oscillatory Eulerian Approach to Interfaces in Multimaterial Flows (the Ghost Fluid Method)," *J. Comput. Phys.*, vol. 152, no. 2, pp. 457-492, 1999.
- [10] T. Aslam, "A partial differential equation approach to multidimensional extrapolation," *J. Comput. Phys.*, vol. 193, no. 1, pp. 349-355, 2003.
- [11] L. E. Scriven, "On the dynamics of phase growth," *Chem. Eng. Sci.*, vol. 10, no. 1-2, pp. 1-13, 1959.