Study of liquid-vapour phase change with a two-fluid compressible model

In industrial process, heat transfer can play a great role and often limit the global efficiency of the production (as for the vapour production in power plants; for the chemical substances production in chemical engineering; etc.). Most efficient exchangers relies on the enthalpy formation occurring during phase change. That's precisely the case for several energy conversion processes involving the vaporisation of a liquid (as in vapour generators).

Inside this liquid phase, the vapour phase is created as bubbles. By increasing this phase change phenomenon in order to intensify heat transfer, these bubbles may collapse into clusters, forming vapour film on large surfaces, between the heated wall and the liquid. Due to the more insulating properties of the vapour with respect to the liquid, this film can dramatically drop the heat transfer to the liquid, resulting in an overheating of the solid wall and possibly leading to its damaging. This phenomenon, nowadays well identified, remains very hardly reachable by numerical prediction.

In order to better explore the conditions of this change in vapour nucleation, some tools are needed to describe and simulate accurately these physics. Numerical modelling is one of them and we propose to develop and validate one of this kind during this thesis.

In addition to two phases (liquid and gas), these flows involves heat and mass transfer through the interface, as well as viscous and surface tension phenomena which are very difficult to model. Common approaches used to numerically describe interfaces (such as Level-Set method, Volume-Of-Fluid, …) are sometimes limited to represent these heat and mass transfer phenomena between two distinct phases with their real thermodynamic properties.

Among the alternative approaches to represent two phases, the two-fluid interface capturing model allows to guarantee good properties for mass and energy balances thanks to the conservative equations for each fluid. Moreover this model avoids to have a geometric reconstruction of the interface between the two media which can lead to some algorithmic complexity on unstructured meshes.

Flows of interest are generally treated as being incompressible in first approximation, especially the liquid. But due to the natural compressibility of the gas phase, a compressible approach is used in the chosen model [1] for both fluids, including liquid. This weakly-compressible approach, combined with a single velocity for both fluids, eases the inclusion of a phase change model compatible with thermodynamic properties of fluids.

However in the targeted range of flows, the Mach number in the liquid is extremely low: it causes difficulties for the correct numerical resolution of the hyperbolic system, where classical numerical schemes exhibit too strong numerical diffusion. A suited numerical scheme [2] is then used to bypass this problem and to have accurate low-Mach results, by reducing numerical diffusion and computational effort.

The first objective of this thesis is to consolidate the aforementioned models, in order to make them more efficient for targeted phase change applications where numerical constraints deteriorate computations (restrictions due to temporal stability for e.g., etc). During the implementation, the candidate will possibly enhance the two-fluid low-Mach scheme on numerical basis (energy equation discretization, diffusive terms implicitation, …) and also regarding the algorithm (study of efficient libraries to solve linear system in the context of high performance computing,…).

Automatic mesh refinement feature will be possibly implemented to reach sufficient spatial resolutions.
These developments will be conducted in view of the second objective of this thesis: elaborate and validate a numerical scheme to study liquid-vapour phase change.

Requirements
- Training with solid background in numerical methods for fluid mechanics.
- Skills in scientific languages (Fortran, C) required.
- Skills in parallel programming (MPI) are valued.

Host laboratory
LIMSI, Computer Science Laboratory for Mechanics and Engineering Sciences
Orsay (20km south from Paris), France
www.limsi.fr

Supervisory staff
- Supervisor : Marie-Christine Duluc (Associate Professor CNAM, LIMSI),
- Co-supervisor : Nicolas Grenier (Associate Professor Université Paris-Sud, LIMSI)

Contact for applications
N. Grenier, grenier@limsi.fr, +33 1 69 15 81 95

References
[1] G. Chanteperdrix, P. Villedieu, J.-P. Vila, A compressible model for separated two-phase flows computations, in: ASME 2002 Joint US-European Fluids Engineering Division Conference, American Society of Mechanical Engineers, 2002: pp. 809–816.
[2] N. Grenier, J.-P. Vila, P. Villedieu, An accurate low-Mach scheme for a compressible two-fluid model applied to free-surface flows, Journal of Computational Physics. 252 (2013) 1–19.