I- COUPLING LEVEL SET / VOF / GHOST FLUID METHODS: DESCRIPTION AND APPLICATION ON JET ATOMIZATION

II- LEVEL SET / GHOST FLUID METHOD FOR VAPORIZING TWO-PHASE FLOWS

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1 Introduction

Multiphase flows with interactions between phases are involved in many industrial processes. Among them, sprays are a wide field of research both for experimental studies and for modeling and numerical simulations. It appears more and more difficult to separate modeling and measurement problems; but we are here only concerned with numerical simulations in order to help in the understanding of physical mechanism and specific behaviors in jet atomization where nearly no experimental data are available. In recent years numerous studies have been devoted to two phase flow modeling and, in particular, the transport processes of droplets in turbulent flows have been more and more precisely described by numerical simulations. However, it clearly appears that one step beyond is to develop specific approaches to describe interface behaviors.

Such numerical studies have been carried out using either "front tracking" methods or "front capturing" methods. Front tracking methods [Nobari et al 1996, Unverdi and Tryggvason 1992] are based on the Lagrangian tracking of marker particles that are attached to the interface motion. They appear suitable when irregularities on the interface curvature are not too large, but they are not well adapted to describing topological changes of the interface. In particular, merging of two interfaces depends on an interaction time parameter which can be of great influence phenomenon. In order to be more efficient, the method should be coupled with subgrid modeling which can predict the interaction time parameter accurately. Note, moreover, that large computer resources are required for 3D studies.

Two main approaches are involved in the "front capturing" method, namely the Volume of Fluid method (VOF) and the Level Set method. The VOF method describes the volumetric fraction of each phase in grid cells. They were developed in the 80's and have been commonly used for some years. The main difficulty of the method is that 2D interface reconstruction appears quite difficult, and 3D reconstruction is numerically prohibitive on 3D domain. A consequence can be some uncertainties on the interface curvature and thus on the surface tension forces. Nevertheless, let us mention that realistic and predictive simulations can be carried out [Rieber and Frohn 1995, Gueyffier et al 1999, Gueyffier 2000, Scardovelli and Zaleski 2003]. Interface reconstruction can be avoided by assuming a continuous volumetric fraction throughout the whole computational domain, which means that an interface thickness is introduced [Benkenida and Magnaudet 2000]. The method is then quite similar to the Level Set method in its continuous force formulation.

The basis of the Level Set methods has been proposed by Osher and Sethian [1988]. The interface is described with the zero level curve of a continuous function defined by the signed distance to the interface. To ensure that the function remains the signed distance to the interface, a redistancing algorithm is applied, but it is well known that its numerical computation can generate mass loss in under-resolved regions. This is the main drawback of level set methods. To describe the interface discontinuities, two approaches can be used, namely the continuous force formulation ("delta" formulation), which assumes that the interface thickness is 2 or 3 grid meshes wide, and the Ghost Fluid Method (GFM), which has been derived by Fedkiw et al [1999] to capture jump conditions on the interface. The GFM approach not only avoids the introduction of a fictitious interface thickness, but it is also suitable to provide a more accurate discretization of discontinuous terms, reducing parasitic currents and improving the resolution on the pressure jump condition[Kang et al 2000, Tanguy and Berlemont 2005].

In the primary break-up of a jet, a lot of topological changes occur (interface pinching or merging, droplet coalescence or secondary break-up). The numerical method should describe the interface motion precisely, handle jump conditions at the interface without artificial smoothing, and respect mass conservation. A method is presented here, where interface tracking is performed by a Level Set method, the Ghost Fluid Method is used to capture accurately sharp discontinuities, and a coupling between the Level Set and VOF methods is made to ensure mass conservation [Sussman and Puckett 2000, van der Pijl 2005, Menard et al 2007]. A projection method is used to solve incompressible Navier-Stokes equations. Development of the methods to reactive flows, namely droplet vaporization, is then described with particular attention on the extension of the velocity field in the liquid phase, by setting a divergence-free velocity extension.

2 Numerical methods

2.1 Interface tracking

Level Set methods are based on the transport of a continuous function ϕ which describes the interface between two mediums [Sussman et al 1997, Sethian 1999]. That function is defined by the algebraic distance between any point of the domain and the interface. The interface is thus described by the 0 level of the level set function. Solving a convection equation determines the evolution of the interface in a given velocity field $\vec{\mathbf{V}}$ [Sethian 1999]:

$$\frac{\partial \phi}{\partial t} + \vec{\mathbf{V}}.\nabla \phi = 0 \qquad (1)$$