

Numerical simulation of boiling during the quenching process

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Abstract

The modelling of the quenching process is presented. Since cooling is primarily ensured by the boiling process, our first concern is the phase change. During the quenching process, the solid is initially at a temperature higher than the Leidenfrost point. Therefore, the film boiling mode is dominant when compared to the boiling phenomena. In order to simulate this mode, different stages need to be treated, from the generation to the growth of a film of vapour followed by its detachment.

In this work, a single mesh for the solid and fluid domains is considered on which a set of global equations needs to be solved, this approach being known as a monolithic approach. The advantages of this method are: avoid the knowledge of an empirical parameter, such as the heat transfer coefficient between water/vapour and solid, simplify the method since phases are geometrically represented by LevelSet function. Usually, dealing with film boiling mode is complicated because of the lack in the film size. Therefore, we consider first the simple problem of a single vapour bubble growth and motion. In fact, nucleate boiling is considered as one of the most difficult challenges for direct simulation. The complexity remains in determining numerically with enough precision the position of the liquid-vapour interface. In our case, a LevelSet method is used to locate the interface between each phase and to mix their physical properties, such as density and viscosity. The level set function ϕ is computed using a convected LevelSet method, introduced and detailed in [1].

Fundamental understanding of bubble growth is essential to predict boiling heat transfer phenomena. In the present study, we report a detailed study of single bubble behaviour. The first step is to compute the bubble growth rate. Robinson [2] remarked that the growth controlled by conduction is the largest part of the growth period. To compute the interface growth velocity, the Gibbs Thomson relation is used. We note that this velocity is function of the temperature which is computed by solving a convection diffusion equation and an empirical growth constant specified by comparing numerical and experimental results. The application of this approach in a 3-D test shows that the evolution of the growing radius is proportional to the square root of time. In the current study of the bubble behaviour, the next step is to simulate the bubble rising and to predict the final shape. The surface tension plays a dominant role in defining the bubble's shape and has been included as a source term in Navier Stokes equations [3]. It requires the computation of the local curvature which is obtained from the second derivative of the LevelSet function. However using a linear finite element method such issue represents another difficulty. A stabilized finite element method is used to discretize Navier Stokes equations [4]. Numerical results concerning the rising bubble problem are in good agreement with these found in the literature [5].

To simulate the generation of a vapour film during the quenching process, a heat source is used to warm up the surrounding liquid. As the growth velocity is proportional to the temperature difference, the vapour will appear when the liquid temperature is higher than the boiling temperature. The transport velocity, used in this three dimensional example, results of the sum of the fluid velocity solution of Navier-Stokes equation and the given growth

velocity. As shown in **Figure 1**, a continuous vapour layer is formed between the heated solid and the surrounding liquid. The vapour is removed on the upper portion of the solid, which is analogically to Taylor instability. From this test, we can deduce that, in the quenching process, the dipped metal provides a natural generator of vapour.

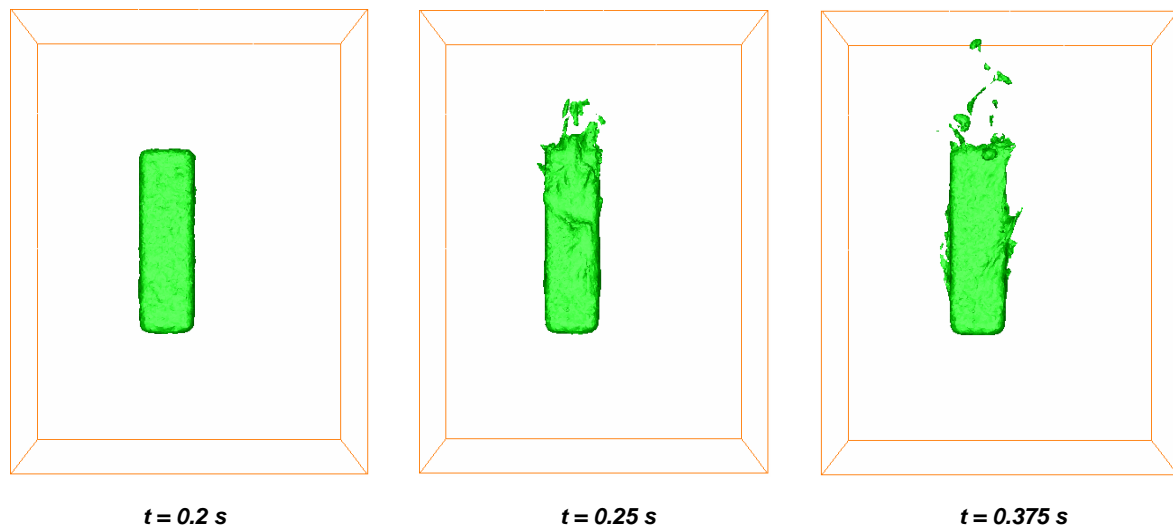


Figure 1: Interface plot for a three-dimensional vapour film generation test.

The application of this approach in a 3-D test shows the evolution of the bubble shape. This method is also applied to simulate the generation of a film of vapour followed by its detachment. Further experimental work is in progress to compute the growth constant, by comparing numerical and experimental results.

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