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ON THE NUMERICAL SIMULATION OF TWO PHASE LIQUID-VAPOR PHENOMENA

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Summary The computation of boiling phenomena raises several difficult issues, one of them being the necessity of accounting for both incompressible and compressible phases in the same computational domain. We have developed two different numerical approaches for dealing with such a situation. One of them makes use of a single pressure which has the status of a thermodynamic pressure and obeys a Helmholtz type equation. The other method is of the Low Mach number type where the pressure is split into a mean thermodynamic pressure defined in the gas phase, and an additional field which ensures mass conservation and which obeys a Poisson equation with an inhomogeneous source term in the gas. These two methods are compared in two simplified configurations consisting of an enclosure subjected to sudden heating at its walls and initially containing either solely a perfect gas or a combination of both an incompressible liquid and a perfect gas.

INTRODUCTION

The numerical simulation of boiling flows and phenomena raises many different and difficult issues, from both modelling and computational standpoints. Several of these difficulties, such as implementing surface tension, dealing with the interface between two phases, tracking of the interface, coalescence, etc. are common to the simulation of flows of isothermal and incompressible multiphase fluids. They have received much attention in the recent past and are still the subject of intensive ongoing research [1]. One specific issue in the simulation of boiling phenomena is the coexistence of a liquid and a gas phase in a non-isothermal environment, the gas being made up totally or partially of the liquid vapor. This necessitates the development of algorithms capable of handling both an incompressible and a compressible fluid in the same computational domain. Indeed although the liquid phase may be considered as incompressible, the vapor phase should be necessarily modelled as compressible. This is particularly true if one considers boiling in a closed vessel such as a steam engine or a pressure cooker. In such devices it is the fact that the mean pressure in the gas can rise above the atmospheric pressure that allows the liquid-vapor phase change to take place at temperatures well above $100C$, improving the Carnot efficiency or reducing the cooking time.

Handling the coexistence of both incompressible and compressible phases in the same domain raises specific difficulties. This is due to the fact that computational techniques for dealing with either phase are very different in nature and while efficient for dealing with the phase they were developed for become very inefficient if applicable at all in the other limit. Indeed, numerical methods for compressible flows become very inefficient when dealing with very low speed flows. Explicit methods are faced with stability criteria that prevent simulations over the time scales of interest while implicit methods suffer from convergence difficulties due to the poor conditioning of the Jacobian matrices. On the other hand standard incompressible methods cannot handle compressibility effects at all.

The central question for dealing with such configurations is the status of the variable called pressure. In classical compressible flows the pressure is the thermodynamic pressure satisfying the equation of state while the pressure that appears in the incompressible equations is defined up to an arbitrary constant and is just a Lagrange multiplier of the divergence free condition. Furthermore it is known that the variations of the pressure corresponding to flow speeds of velocity V are of order ρV^2 which can be very small for flows of light low speed fluids and this raises the issue of finite precision arithmetic used in digital computers. For instance air flow velocities of $10^{-2}ms^{-1}$ correspond to differences in pressure of $10^{-4}Pa$, which cannot be represented in single precision arithmetic within a pressure field whose mean value is equal to the atmospheric pressure $\simeq 10^5 Pa$, independently of the poor conditioning of the Jacobian matrix.

The inefficiency of compressible algorithms in the low speed limit and the unavailability of well suited equations of state for the liquid phase have promoted the development of specific methods of the low Mach number type. Such methods were initially designed to handle low speed gas flows which can experience large variations of the mean pressure such as discharging flows from pressurized vessels [2] or natural convection flows due to very large temperature differences for which the Boussinesq approximation is no longer valid [3, 4]. In these methods the pressure is split into a mean pressure that can evolve in time and an additional component which is responsible for satisfying the continuity equation. This pressure splitting inhibits the local coupling between pressure and density, thus avoiding the simulation of acoustic waves and alleviating the corresponding stability criteria.

To shed some light on these issues, we have developed two different numerical algorithms aimed at the numerical simulation of these phase change liquid-vapor phenomena. One of them makes use of a single pressure variable, which has the status of a thermodynamic pressure. Defining a generalized equation of state by means of the characteristic function of the gaseous phase, it can be shown that this thermodynamic pressure obeys a Helmholtz type equation [5]. The other one follows the low Mach number approach and the pressure is split into a mean value which needs to be defined in the compressible phase and a small correction responsible for satisfying the continuity equation defined in the whole computational domain. This results in a Poisson equation for this correction, whose source term is inhomogeneous in the gaseous phase.

RESULTS

In the paper we will describe the two methods and compare them in two test cases thereby allowing us to check the effectiveness and efficiency of these methods for addressing such configurations. Both test cases consist of a closed vessel subjected to heating at the walls. In the first case we consider a medium consisting of a single homogeneous fluid which is a perfect gas. In the second case we consider a two-phase medium: a circular bubble of air (considered to be a perfect gas) trapped in the middle of a hundred micron square container of water (treated as an incompressible liquid). To isolate the phenomena of interest buoyancy effects are neglected in both cases. Some results for the second test case are presented in figures (1) and (2). The time variation of the mean pressure in Figure (1) clearly shows the mean pressure rise in the container as a result of the corresponding increase in the temperature of the air bubble. Interesting to note is the initially constant mean pressure during the phase of heat diffusion in the liquid. Figure (2) shows the velocity field at a time of 2.7 ms. The water is completely immobile while the flow in the interior of the air bubble, although quite small, is a result of the compression of the gas.

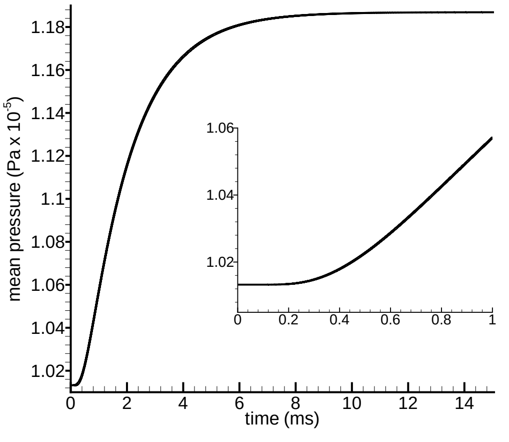

Figure 1. Case 2 : mean pressure vs. time

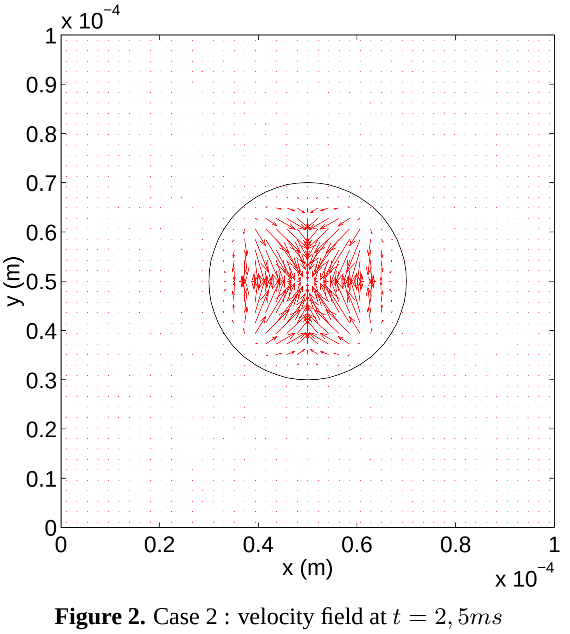

Figure 2. Case 2 : velocity field at $t = 2,5ms$

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