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Analysis of the influence of thermodynamic speed of sound in modeling the rapid vaporization of superheated liquid (BLEVE) by employing the method of characteristics

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ABSTRACT

For a proper risk analysis of traffic accidents in road tunnels, accurate estimates of the chances and effects of these accidents is required. Our project, *Thermodynamic and Gas-dynamic Aspects of a BLEVE*, aims at contributing to a better understanding of the accident known as a BLEVE, or *Boiling-Liquid-Expanding-Vapor-Explosion*.

A BLEVE is an explosion driven by the rapid boiling of the liquid and rapid expanding of its vapor. In common boiling, the liquid is heated isobarically or depressurized at a relatively slow rate, therefore its boiling can be regarded as a process in local equilibrium whereas the BLEVE, which is of interest herein, occurs when a vessel containing PLG (Pressure-Liquefied-Gas) above its normal boiling point fails catastrophically. In a very short time frame, a great portion of liquid experiences a rapid depressurization to atmospheric pressure and starts to vaporize simultaneously. The rapid flashing and expansion of the liquid drives the air to move. In most cases, this driving force can be so strong that a shock wave is generated in the air and damage the tunnel wall.

The thermodynamic and fluid dynamic aspects, in particular of the rapid vaporization after a sudden depressurization, request a combined investigation of numerical modeling and experimental work. The insights gained will be used in predictive models for maximum overpressure in case of a BLEVE accident and will contribute to the safety evaluation of existing road tunnels and design of future ones.

A numerical model for predicting the shock wave generated in a BLEVE event was developed by G. A. Pinhasi *et. al* [1, 2]. This 1D model solved the two-phase Euler equations in EVUT (Equal Velocity and Unequal Temperature) form by the method of characteristics and was demonstrated to be able to capture and quantitatively describe the generation/propagation of a shock in the air driven by the rapid expansion of the superheated vapor-liquid mixture.

One could immediately recognize that the sonic speed is one of the key parameters for the method of characteristics since it determines how fast the characteristic wave will propagate in the media (both in air and in the two-phase mixture). As a matter of fact, the sonic speed for liquid-vapor mixture is much smaller than the sonic speed in either

phase. In [1, 2], the sonic speed for each phase was computed from its definition equation given by

$$a = \sqrt{\left(\frac{\partial P}{\partial \rho}\right)_s}$$

Then the sonic speeds for liquid and vapor respectively were averaged to obtain the sonic speed for liquid-vapor mixture in the following way,

$$\frac{1}{\rho_m a_m^2} = \frac{\alpha}{\rho_G a_G^2} + \frac{1-\alpha}{\rho_L a_L^2}$$

In above equations, a is the sonic speed, α is the void fraction, ρ is the density, P is the pressure and s is the entropy. The subscripts '*m*', '*G*', and '*L*' denote mixture, vapor and liquid respectively.

Furthermore the equation of state also plays an important role in the simulation of the rapid boiling of the superheated liquid featured by non-equilibrium processes. The equation of state used in [1, 2] is a relatively simple one, using table look up and interpolation of thermodynamic properties of specific substance [3].

Currently we are working on a new implementation of Pinhasi's 1D model as a tool for better interpretation and understanding of the physics of a BLEVE. We will improve this model by using a disequilibrium model for the mixture sonic speed [4] and, on the other hand, the equation of state for each phase in [1, 2] will be replaced by the models available in Fluidprop [5], a thermodynamic code based on homogeneous mixture of vapor and liquid, which can facilitate the numerical simulation itself and improve the accuracy of the computation at the same time.

We shall present a comparison study on the influence of sonic speed modeling on the prediction of a BLEVE by the method of characteristics. We expect that the non-equilibrium sonic speed model will predict different shock positions and finally result in different shock strengths compared with results from Refs. [1, 2]. Another relevant aspect is the model for vapor generation (bubble nucleation, bubble growth). Sensitivity of predicted shock strength on both sonic speed modeling and vapor generation modeling will be studied. The possibilities for validation using existing or new experimental data will be considered.

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