Numerical modelling of liquid jets atomisation due to leakage of liquefied gas storage

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Abstract

The objective of this work is to develop a numerical model with the aim of simulating a two phase jet resulting from a breach or leakage in a vessel or pipe containing liquefied gas. This jet consists in three areas: the expansion zone (flash boiling, atomization), the entrainment zone (secondary break-up, droplets evaporation) and the final dispersion zone.

Among the complex phenomena involved during the injection, this work focus on the effect of the vaporization and boiling process in the jet. To represent the flash boiling phenomena that occurs at the exit of the injector up to the end of expansion zone, the Homogeneous Equilibrium Model (HEM) have been used. Consequently, gas and liquid velocities are identical at the beginning of the entrainment zone. An issue of this approach is the determination of the velocity induced by the pressure drop inside the injector and by the flash effect. The maximum kinetic energy can be estimated by the pressure drop and the variation of thermodynamic energy in the flow. Here, the velocity is considered to be driven mainly by the pressure drop, thus it is determined by the Bernoulli law. After the expansion zone, the spray is supposed to be at boiling temperature with a gas environment composed only by vapour. Thus, any increase of temperature will promotes boiling. But if some air diffuses inside the spray, a non classical vaporization process is expected. Thermodynamic conditions are at these boundaries in the beginning of a region called entrainment zone. To determine the evolution of the spray, vaporization or boiling, a special model is requested.

A thermodynamic equilibrium vaporization model were developed. During a time step, it is considered a thermodynamic system composed by a liquid droplet film and surrounding gas film. We consider that this film reaches the thermodynamic equilibrium at the end of the time step. Finally, the remaining liquid in the film at the equilibrium temperature is mixed with the droplet part not used in the film. The same is done with the gas phase. This procedure ensure a realisable thermodynamic state after the complex vaporization process.

To test the model, an atmospheric two-phase jet of butane, emanating from a circular orifice is considered. The Euler-Lagrange approach has been used for this two-phase simulation. A co-flow of air surrounds the spray injection. The mass fraction of vapour and liquid is given by the HEM model. Finally, the turbulence is modelled with the $k - \epsilon$ model.

It is complicated to have experimental results on the types of jets described above. But the INERIS were able to have more reliable measurements in temperature. The spray is surrounded by a hot gas environment. However, the temperature of the spray decreases up to a certain distance. Due to the initial droplet boiling temperature, close to the injection, the vaporization process dominates the flow. Since evaporation is an endothermic phenomenon, the spray jet cools down until there is no droplet enough. Thus the spray temperature rises only once the liquid vaporization does not have enough influence in the flow.

The modelling results show that the calculated temperature behaviour in the spray jet by comparison with the observations is generally satisfactory. This result cannot be obtained with classical vaporization model. A perspective to this work can be to add more accurate models to the internal flow of material in vessel and to the flash boiling and atomization phenomena in the expansion zone.

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