Title of the PhD Research Project: influence of turbulence on the fragmentation of a liquid jet into another liquid.

Research Unit : LEMTA Applied and Theoretical Mechanics and Energy Laboratory UMR 7563 CNRS-Lorraine University

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Short Description:

To improve the understanding of the premixing stage during nuclear vapor explosion, the PhD candidate will develop new measurements (using four-frame particle image velocimetry) and modelling (using Lévy stable laws) of turbulence fluctuation during the fragmentation of one liquid into another. Three different liquids (water, a transparent substitute of density two and liquid Wood's metal) with three different densities (1,2, 10) will be injected at high velocity into a large stagnant water pool (to minimize small size effects). Using complementary experimental and theoretical tools, the fragment size PDF, the fragmentation rate and a mass-energy-momentum budget are expected to be obtained as conclusions to this work.

Doctoral School: SIMPPE

Keywords: Nuclear Safety, Liquid fragmentation, Turbulence, Particle Image Velocimetry

Vapor explosion is one of most dramatic aftermath of a nuclear core meltdown. This explosive phenomenon is akin to a detonation. This supersonic event is related to the cascading fragmentation of the nuclear fuel into the coolant leading to its rapid evaporation, the superheat being released almost instantaneously.

MC3D software is one of the rare software able to model severe nuclear accidents. Two separate applications PREMIX and EXPLO are dedicated to the modelling of Fuel-Coolant Interaction as the explosive phase is following a first premixing stage. MC3D is internationally acknowledged as a reference software to ascertain this phenomenon. However, some physical mechanisms are still locking the clear understanding of the problem and this limits the confidence that authorities can have in the forecasting of severe accidents. Among these unsolved problems is the correct modelling of fragmentation during the premixing stage. The size and dispersion of the fragments is one of the main parameters governing the triggering of the explosion. LEMTA and Lorraine University have begun to work together with IRSN and its partners (EDF and AREVA now FRAMATOME) on this topics in ANR Project RSNR ICE (2014-2018).

This led to the development of the JeDi (Jet Diphasique) experimental platform in LEMTA (M. Hadj Achour, 2017). This apparatus allows for the injection of 250kg of low meting point liquid metallic alloy (Woods'metal) in two cubic meter of water, released up to 10 m/s through a 2cm hole. The Reynolds and Weber number obtained in this facility, respectively close to several hundred thousand and several thousand, as well as the amount of metal released, make this installation unique worldwide.

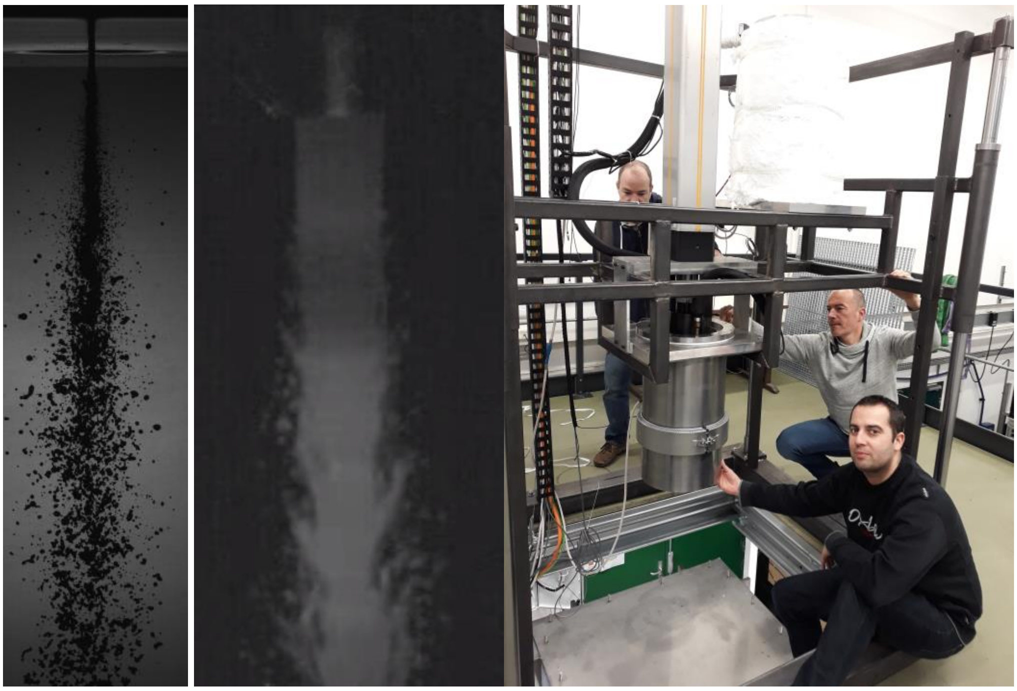

Figure 1: from left to right, small scale test (1mm nozzle) of injection of liquid metal, of surrogate density 2 fluid (with fluorescent dye) and building the JeDi experiment.

The main scientific problem is that it is, still nowadays, very difficult to ascertain the influence of turbulence level on the fragmentation mechanism of liquids. This is a fundamental problem, which can be found in many industrial areas (car engine, aeronautics, process industry, agriculture…etc.) and which become critical here as the injection speed (either due to pressurization or gravity) and the expected size of the hole in the container lead to very high Reynolds number, Weber number and a strong influence of turbulence levels.

The JeDi experiment will allow for the precise measurement of several interacting data, which are almost never measured together:

- A precise control of the injection velocity through a 5 tons linear electric actuator
- The size (and size-velocity) distribution of the fragments (either post mortem or in-line with a phase Doppler anemometer); First results (M. Hadj Achour, 2017) show that log-Lévy stable laws are adequate candidates to describe the size distribution. They are common in turbulence.
- A measurement of turbulence scales, levels, velocities and acceleration through a Dual Particle Image Velocimetry (PIV) system. This measuring systems, which exists in three copies worldwide (two of which are dedicated to supersonic gas flows, the present one being the only one dedicated to liquid-liquid systems), allows for the high speed (200Hz) acquisition of a quadruplet of images (separated each by 2 microseconds). This will allows the measurement of turbulence scales, levels, velocities and acceleration.
- This will also allow precise measurement of the entrainment rate of the surrounding fluid into the fragmenting jet. The fragmentation rate and the entrainment rate are closely related and understanding this mechanism is the key that may allow present results, obtained in the liquid-liquid case, to be extended to the liquid-vapor-liquid case (where optical measurements are almost impossible due to the presence of many interfaces).

- As PIV measurement will be only made in the surrounding water due to the opacity of the liquid metal, a density 2 transparent liquid substitute (with the same optical index as water) will be used allowing for the measurement of turbulence levels both inside and outside the fragmenting fluid. This is also a unique feature of this experiment.

The expected development of the thesis is in three separate and new experimental tasks and three related theoretical tasks begun in (M. Hadj Achour, 2017):

- Test of the installation with injection of water into water. This will allow for the development of the Dual PIV algorithms. Note that there has been recently important improvement in the understanding in turbulent/non-turbulent interface in high-speed single-phase jets. Our new measurement tool will be tested in this reference case.
- Injection of density two transparent liquid into water.
- Injection of liquid metal into water.
- Modelling of the fragmentation size PDF (using Lévy laws)
- Modelling of the entrainment of a fragmenting liquid jet into another
- Building a mass-energy-momentum budget in a fragmenting liquid jet

This thesis is complementary to the other joint thesis that will be undertaken at IRSN on the explosion phase. Strong interaction between the two theses are expected as the high-speed turbulent mixing between two phases is at the core of both studies. However the work developed at IRSN will be more focused on real applications on vapor explosions through the use of MC3D software (and some DNS using Basilisk) whereas present thesis is focused on the premixing stage and will be undertaken at Lorraine University LEMTA where it will use its unique experimental facility and expertise in turbulence modelling.

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