An experimental set-up study accidental industrial LPG releases

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AN EXPERIMENTAL SET-UP TO STUDY ACCIDENTAL INDUSTRIAL LPG RELEASES

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Abstract

The objective of the atmospheric dispersion research project of the INERIS is to develop models of flashing releases as encountered in realistic industrial environments. Equivalent source models exist for flashing release in current long rang dispersio n models. Several factors can, however, invalidate simplified equivalent source models, especially in the very near field where obstacles can be found.

To perform his project objective, the INERIS takes part in a European project called FLIE (Flashing Liquids in Industrial Environment) and also works on a project supported by the French ministry of the environment. In FLIE project, INERIS carries out large-scale trials of propane and butane releases. The French part of the project is to develop a tool able to evaluate the gas and the liquid fraction (aerosol part and liquid pool) in the near field of the flashing release.

This INERIS paper aims to present the large scale experimental set-up and the main current results. The experimental set-up is located in the INERIS site. It allows to perform propane and butane liquid releases at ambient temperature with a regulated pressure from the saturation pressure to 15 bar with an orifice (circular or rectangular shape) of an equivalent diameter from 10 mm to 25 mm. It is possible to realise free jets but also impinging jet by introducing obstacle at a maximum distance of 2 meters from the release point.

During releases, several parameters are recorded :

- Ambiant conditions : direction and speed of the wind, temperature, humidity and atmospheric pressure.
- Release tank : pressure (the regulation of the pressure is possible), temperature at several heights in the tank and at the liquid /gas interface, weight of the tank.
- Release point : pressure and temperature.
- In the jet : a Dual Phase Doppler Anemometer allows to measure speed and size of particle aerosol at several locations in the jet.

- Rain out : Six bonds equipped with continuous weight measurements are used to study the phenomena of liquid pool formation.
- Obstacle : Six surface temperature.

To develop models requires experimental validation data. Up to now, little of experiments were carried out on a great scale with such a variety of measurements. The obtained results reveal some points which are few discussed in the literature and can be useful to develop models of flashing releases.

Introduction

Liquefied gasses are in widespread use in industry due to their chemical or physical properties. The substances involved may be flammable and explosive like LPG and also toxic and corrosive like ammonia. In parallel, numerous industrial processes use fluids that are overheated compared with ambient temperature conditions. Following a failure of the confinement around an installation, the hazards faced can be instantaneous, as with the explosion of flammable products, or differed as is the case with releases of toxic products.

As part of its activity relating to accident hazards, INERIS must especially determine safety perimeters around industrial installations. A research project was therefore set up. The objective of the atmospheric dispersion research project of the INERIS is to develop models of flashing releases as encountered in realistic industrial environments. Equivalent source models exist for flashing release in current long rang dispersion models. Several factors can, however, invalidate simplified equivalent source models, especially in the very near field where obstacles can be found.

To perform his project objective, INERIS takes part in a European project called FLIE (Flashing Liquids in Industrial Environment) and also works on a project supported by the French ministry of the environment. In FLIE project, INERIS carries out "large-scale" trials of propane and butane releases. The French part of the project is to develop a tool able to evaluate the gas and the liquid fraction (aerosol part and liquid pool) in the near field of the flashing release.

The FLIE project brings together four partners (GexCon company from Norway, University of Hertfordshire from England, Von Karman Institute for fluid Dynamics from Belgium, Institut National de 1'Environnement Industriel et des RISques from France) including INERIS for performing large scale tests. The purpose of these tests was to improve the knowledge of the dispersion of liquefied gasses in the presence of obstacles located in the immediate vicinity.

This INERIS paper aims to present the large scale experimental set-up and the main current results.

What happens in the event of an accidental release ?

The consequences of an accidental release will depend on the one hand on the initial storage conditions, and also on the environment. This is because the presence of obstacles of sufficient size may affect the jet and change the characteristics of the toxic or flammable cloud.

At the breach level, in the case of an accidental release of liquefied gas, the product released is suddenly placed in under such temperature and pressure conditions that a part of the liquid vaporizes violently. This phenomena is generally called a "thermodynamic flash" or "flash". The sudden vaporizing of part of the liquid leads to a fragmenting of the liquid jet into fine droplets whose diameter and speed will be especially dependent on the deviation between the initial product temperature and the boiling point of the product at atmospheric pressure.

This phenomena is illustrated in figure 1.

In the absence of any obstacle, after a length of a few times the diameter from the breach, a two-phase jet develops. This jet is made up of droplets in suspension in a mixture of gas and ambient air that is drawn along. The atmospheric dispersion of this two-phase jet is notably dependent on the environment. This is illustrated in the figure 2.

In cases where no obstacles are present along the path of the jet, the different contributions to the formation of a flammable or toxic cloud are as follows:

- a quantity of product is likely quasi-instantaneously vaporized due to the flash phenomena at the breach level;
- a quantity of product will likely form a pool on the ground (commonly called rain-out) that then evaporates into the atmosphere due to the various phenomena of mass and heat transfer ;
- a quantity of product is likely drawn into the air in aerosol form.

In this case, the estimation of the main amounts of vapor and liquid consists in studying the evaporation of the formed drops and the formation of a liquid pool at ground level. This estimation is an important aspect to determine a realistic source term to provide input into an atmospheric dispersion model.

In the case of a release in the presence of obstacles, the interaction between the jet and the obstacle may notably change the calculation of the source term which will be more difficult. Actually, in addition to the three contributions mentioned previously, three phenomena could occur :

- a part of the liquid will be captured by the obstacle (run-off) ;
- a part of the droplets will evaporate in contact with the obstacle (at least during the first instants, before the obstacle cools down) ;
- a part of the drops splits, leading to the creation of smaller sized drops.

In the case of an impacting release, it is important to determine what becomes of the drops after impact. To do this, it is necessary to know the characteristics of the drops prior to impact (diameter and speed) as well as those of the wall (temperature, roughness, presence or absence of any liquid film).

The experimental set-up

The experimental set-up, developed in order to understands this phenomena, is located in the INERIS site. The figure 4 shows the release field and the control room in the background. The figure 5 is a diagram of the experimental set-up.

The experimental set-up allows us to perform propane and butane liquid releases (the release point is presented in figure 5) at ambient temperature with a regulated pressure from the saturation pressure to 15 bar with an orifice (circular or rectangular shape : see figure 6) of an equivalent diameter from 10 mm to 25 mm. It is possible to carry out free jets but also impinging jet by introducing obstacle at a maximum distance of 2 meters from the release point.

During releases, several parameters are recorded :

- Ambiant conditions : direction and speed of the wind, temperature, humidity and atmospheric pressure.
- Release tank : pressure (the regulation of the pressure is possible), temperature at several heights in the tank and at the liquid /gas interface, weight of the tank.
- Release point : pressure and temperature.
- Inside the jet : a Dual Phase Doppler Anemometer allows to measure speed and size of particle aerosol at several locations in the jet.
- Rain out : Six bonds equipped with continuous weight measurements are used to study the phenomena of liquid pool formation.
- Obstacle : Six surface thermocouples.

Some Results

This section deals with results obtained with propane release experiments.

Jet structure

Some results can already be presented relating mainly to jet structure :

- right after the expansion zone, the small drops are mainly found along the center whereas the largest ones are the most numerous around the edges;
- moving away from the expansion zone, an asymmetry appears progressively between the upper and lower parts of the jet; it appears that the largest drops accumulate under the jet, this is the consequence of gravity effect. ;
- It is possible to find a similitude law to determine the longitudinal speed component within the jet. This law depends on the release configuration.

The initial results tend to show that what happens to the drops present within the jet is primarily influenced by the evaporation, by the interaction between jet turbulence and gravity. The importance of each of these influences depends apparently essentially on the size of the drops.

In other words, the measurements seem to show that there are approximately two types of behavior for drops present within the jet and which are at least partly dependent on their size :

- for the finest drops, the behavior is characterized by convection within the jet, with drops evaporating within the jet;

- for the largest drops, inertia and the gravity mean that they are less likely to follow the jet and therefore better able to exit the jet.

The calculation model developed by INERIS seems to match the results obtained in the context of this initial set of tests. The main difficulty always lies in determining the initial speed for starting the calculations. This determination will be one of the main challenges of subsequent trial runs. This is because in the next set of trials, we plan to focus the measurements (with a finer coverage) on the area closest to the leak section, in order to explore the expansion zone, as far as possible.

Mean Diameter

The figure 7 shows the number of droplets (probability function) in the observed class versus droplet diameter. The table 1 shows the effect of taking into acount or not the greatest droplets in order to calculate the mass mean diameter.

According to these results we can see :

- it is necessary to analyse the results in terms of mass. This is an uncommon way of interpreting the results. Actually this is more common to consider that the greatest diameter is 200 microns and most of the correlation are made with this consideration.
- the under-estimation of the number of large drops leads to a speed of evaporation always too high : by using the mean diameter coming from the droplet smaller than 200 microns the diameter lost is 10%, actually a lost of 1 % seems more realistic.
- the peak corresponding to the greatest droplets might be in part the consequences of PDA problems. The VKI researchers (our FL1E partners) think that the drops exist but there is an over-estimation due to PDA mask. If we assume that the number of wide measured droplets are over-estimated with a factor two, the difference between mean diameter keeps strong.

The problem of the measurement of the rain out

The figures 8, 9 and 10 show some results that come from impacting jet of propane. The trial experiments conditions are :

- storage pressure : 9.6 bars,
- orifice diameter : 10 mm,
- distance of the obstacle distance : 0.86 m,
- ambient conditions : temperature : 22.5 °C,HR : 65%, temperature humidity dew point : 16.2°C.

INCORPORER*Discussion and analysis*

Free jet

Water of the atmosphere makes part of the rainout due to a phenomena of jet-entrainment that mix the released propane with moist air. The measured mass in the bonds (

Figure 8) result from an equilibrium between rain out of this mixing and his evaporation.

When all the phenomena (release output orifice, rain out) are in a steady-state, as seen in Figure 10, in terms of temperature, a slope can be observed on the curve. The component evaporation is certainly very weak, during the jet the air could be saturated with LPG vapours. In a first approximation the measured slope could be interpreted as the sum of phenomena that concern the mixing.

Once the jet has stopped, a compressed air is drawn to accelerate evaporation. It seems difficult to know what really happens because of the solid or liquid water state. In addition it could be assumed that LPG has been captured within the ice because this one melts by forming multiple cavities.

After total evaporation of what must be mainly LPG (at least in the propane case), the quantity (mainly water ?) of remaining liquid is measured. This data should be considered more or less as the amount, in the low range, of water that has been mixed in the jet.

Impinging jet

During the impinging jet, the previous phenomena exist, but in addition the obstacle absorb some phenomena and change the kinetic.

The obstacle must be cooled before one can observe liquid fall into the bonds. It is seen that freeze is produced on the obstacle. This ice is likely produced during the jet because of the low temperature of the obstacle.

Conclusions and perspectives

To develop models requires experimental validation data. Up to now, little of experiments were carried out on a great scale with such a variety of measurements. The obtained results reveal some points which are few discussed in the literature and can be useful to develop models of flashing releases.

Measurement of the propane rainout mass is complex. Water of the atmosphere makes part of the rainout due to a phenomena of jet-entrainment, so the rainout mass measured in the bonds correspond to LPG mass plus water mass. The special kinetic of reevaporation from the freeze water makes the estimation of the LPG mass contribution more difficult.

An possible perspective to that work could be to carry out laboratory experimental trials that allow us to control temperature and humidity in the ambient or confine atmosphere.

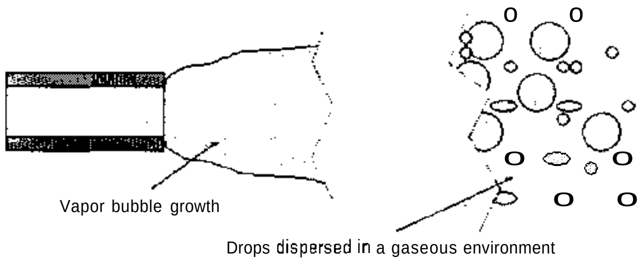

Figure 1 : Schematic diagram of a two-phase jet

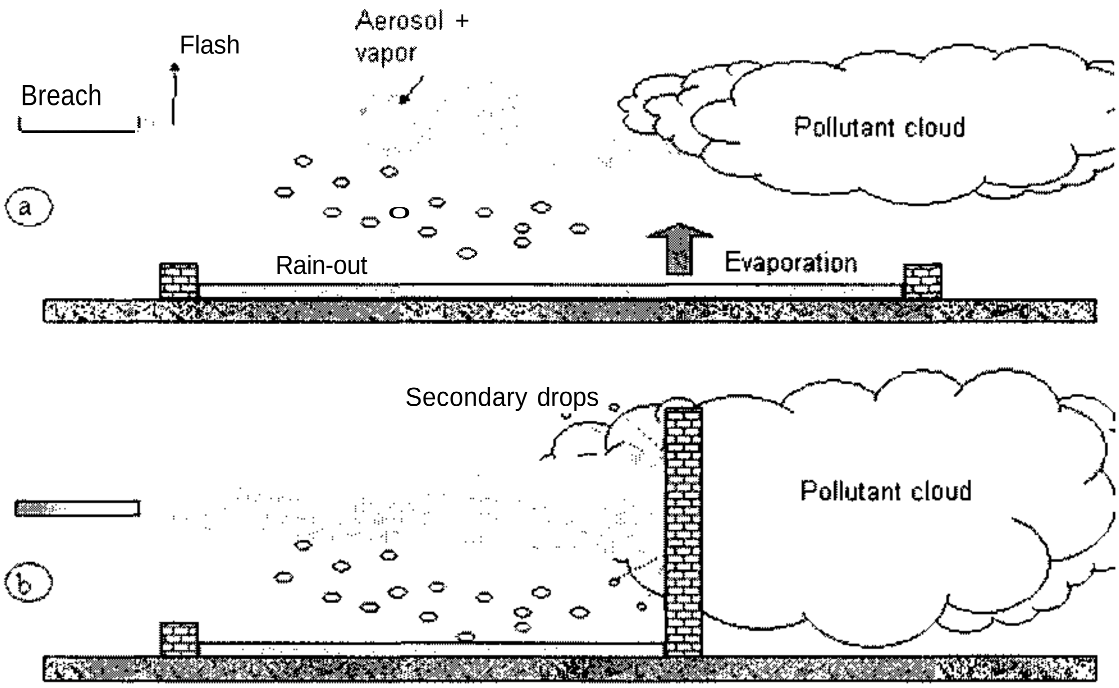

Figure 2 : Diagram showing the different contributions to the formation of a polluting cloud following the appearance of a two-phase release

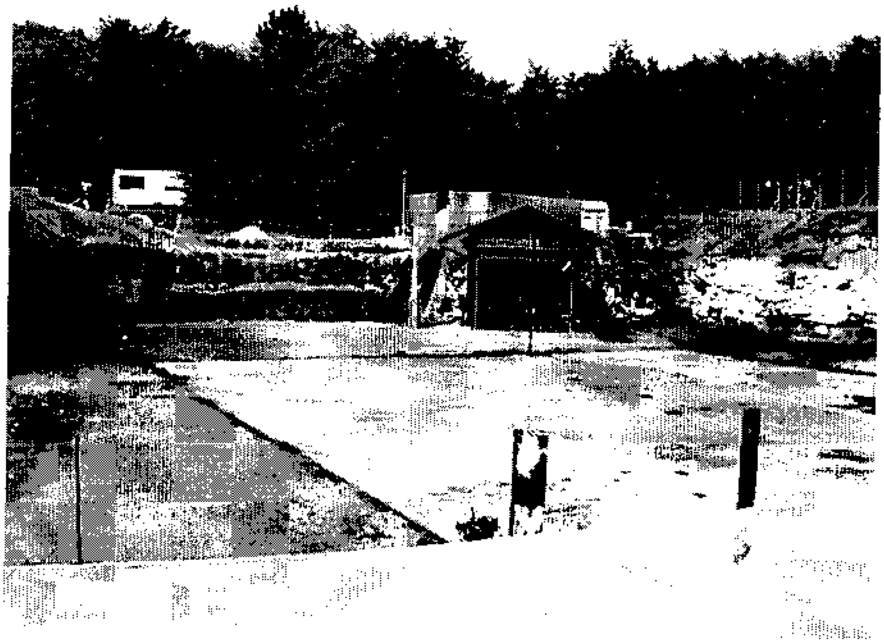

Figure 3 : The release field with the control room in the background

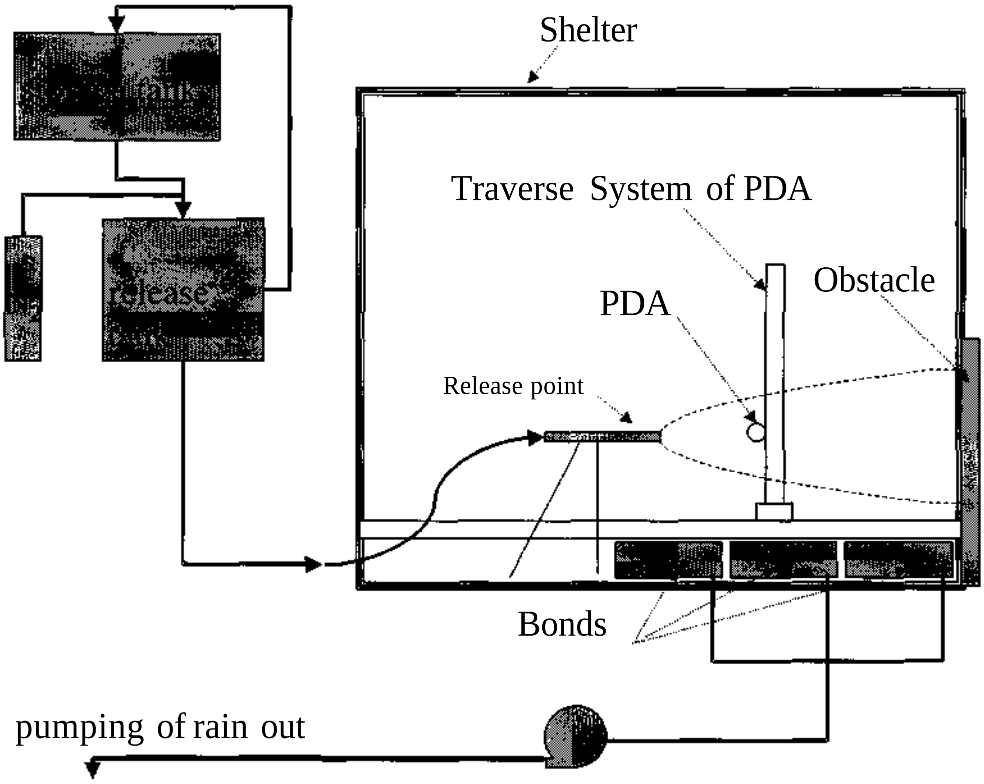

Figure 4 : Diagram of the experimental set-up

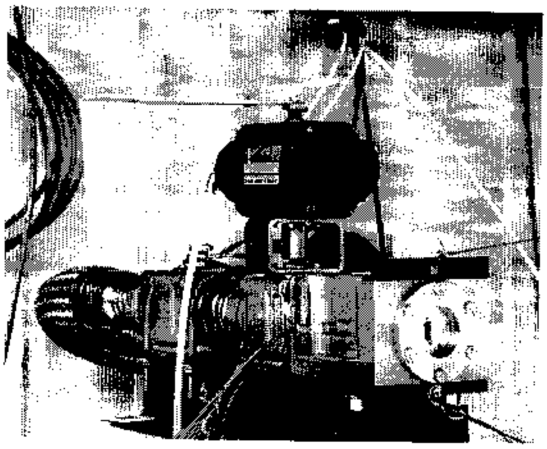

Figure 5 : The release point

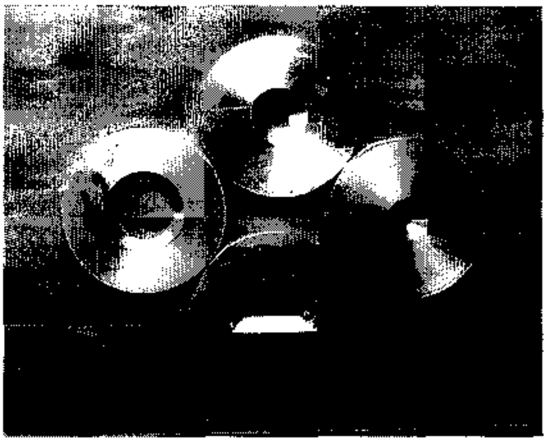

Figure 6 : Example of orifice shapes

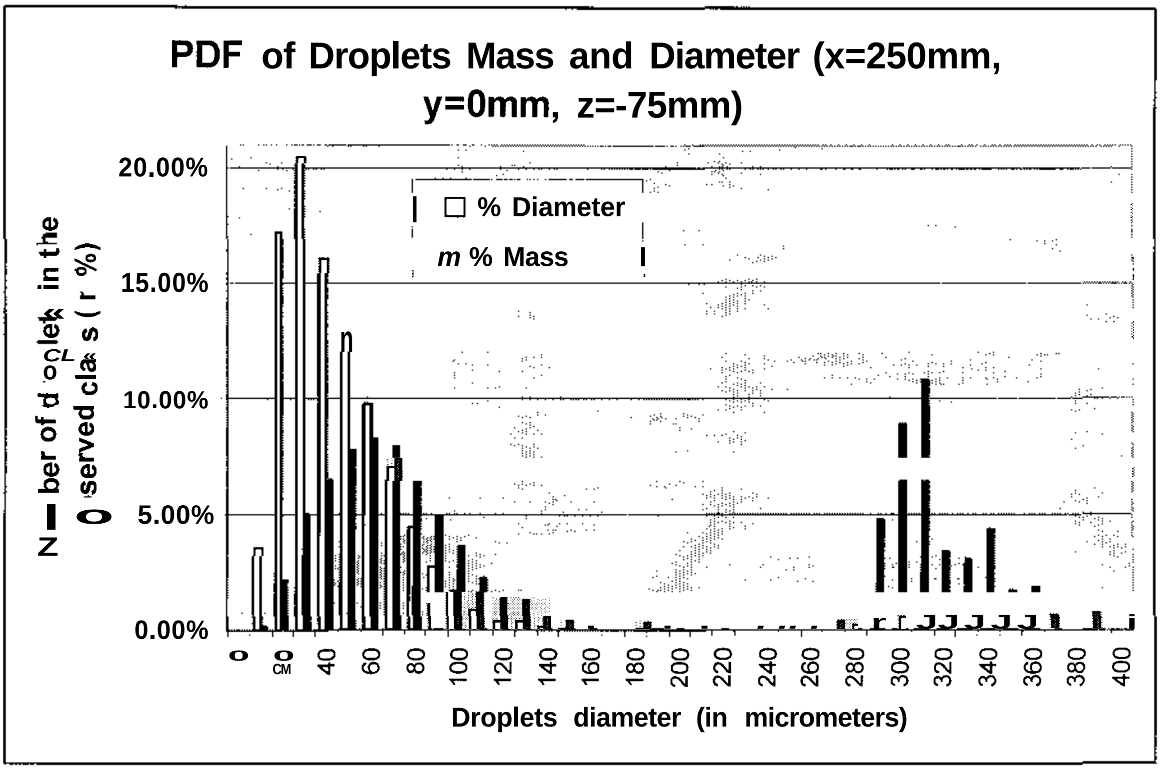

Figure 7 : Number of droplets in the observed class (in %) versus droplet diameter for a free jet of propane at 7.5 bar through an orifice diameter of 25 mm

Rain out measurement

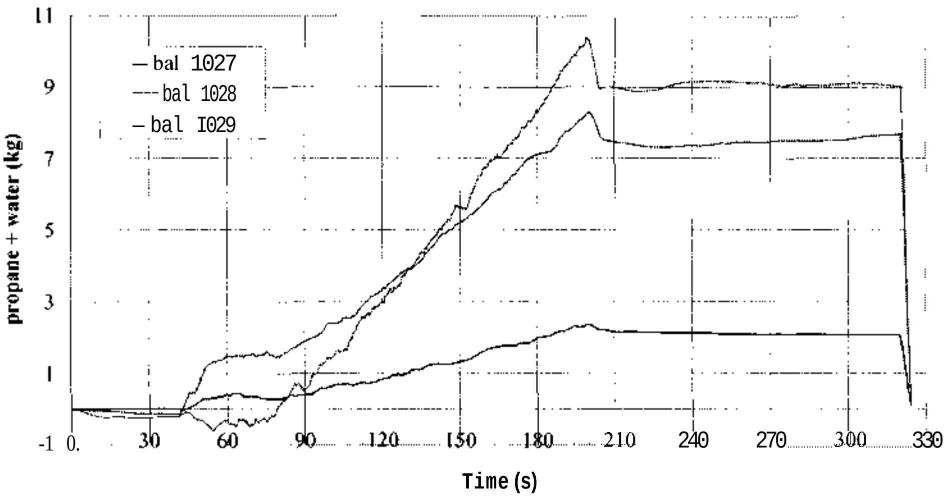

Figure 8 : Measurement of rainout mass (propane + water) in bonds

Propane Weight & MassFlow

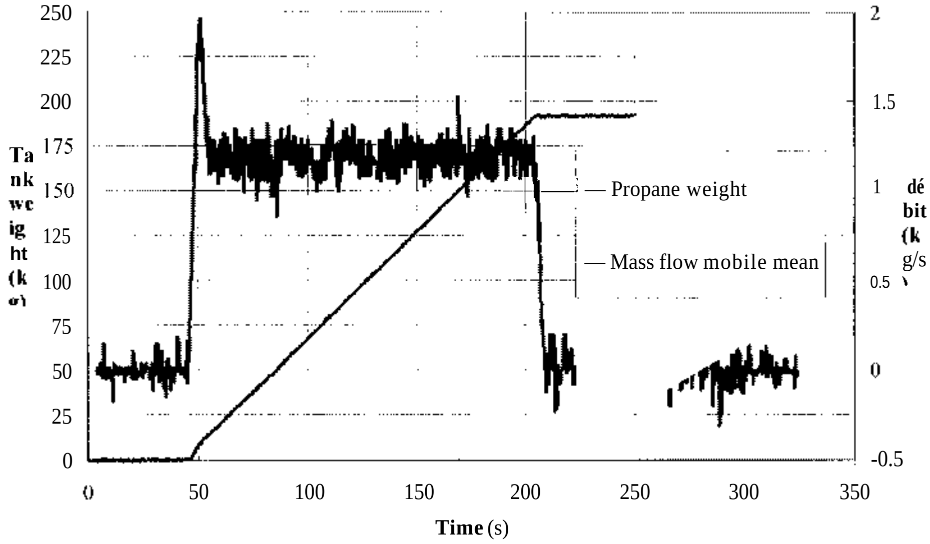

Figure 9 : released mass flow and propane weight

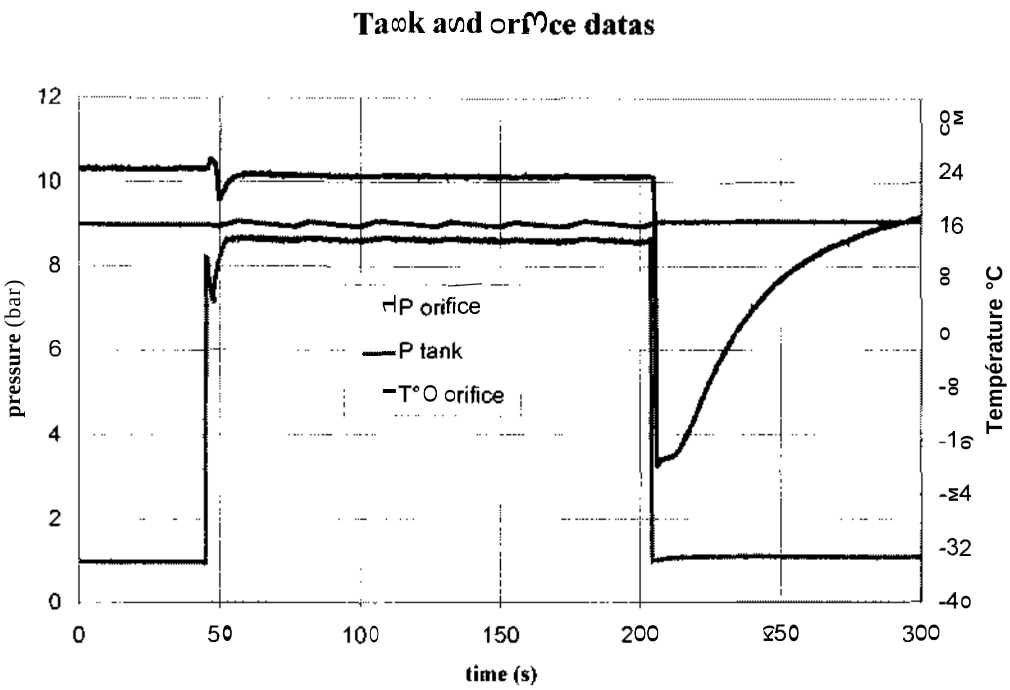

Figure 10 : tank and orifice datas : pressure and temperature

	Location : x=100, y=0, z=-50	Location : x=250, y=0, z=-75
a) droplets > 200 m : % in number of droplets	1.94 %	2.01 %
b) droplets > 200 m :% in mass of droplets	34.9 %	40.8 %
c) Mass mean diameter with droplets < 200 m	58 m	53 m
d) Mass mean diameter with droplets < 400 m	92 m	91 m

Table 1 : results for diameter droplets greater than 200 m : number of droplets (%) (a) and mass of droplets (%) (b), mass mean diameter with droplets diameter < 200 m (c) and droplets diameter < 200 m (d)