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Presentation of the experimental JIP SPARCLING: Inside and beyond a pressurised LNG release

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Abstract

The SPARCLING JIP was launched by TOTAL, AIR LIQUIDE, SHELL, GRTgaz & INERIS. The goal of the project was to produce high-quality experimental data on the size distribution and velocities of the LNG droplets using a dual PDA (Phase Doppler Anemometer), following the pressurized release of LNG. One area of particular concern is the potential for rainout and subsequent pool dispersion. The test programme was managed and run by INERIS at their test site at Verneuil-en-Halatte on behalf of the members of the JIP. The paper describes in detail the testing bench and test protocol, as well as the lessons learned from the use of the bench. The occurrence of rainout is then discussed.

Keywords: *pressurised LNG, two-phase release, rainout, dispersion, experimental set-up*

1. Introduction

The small-scale Liquefied Natural Gas (LNG) economy is expected to continue growing over the foreseeable future and so there is a requirement for further deployment of more delivery points in fluvial and maritime ports, not only along the main road axes, but also in city centres. Therefore, the need for more accurate risk assessment models is becoming essential for the safe deployment of this technology.

Current models used to assess the consequences of hazardous phenomena involving pressurised LNG are quite empirical and mostly based on other fluids, such as Liquefied Petroleum Gas (LPG). In addition, when available, experimental data for LNG are not necessarily fully instrumented. Yet high-quality experimental data are required to check the accuracy of the models, especially for small-scale LNG where the site footprint and distance to public is smaller than traditional major hazard sites.

As recalled by (Webber et al., 2009), "*The dispersion of releases of hazardous fluids through from loss of containment to dilution below hazardous levels can be simply considered as comprising two stages: source term formation and atmospheric dispersion…The earlier source-dominated behaviour has received comparatively less attention both theoretically and experimentally, though its importance in the overall release process is widely recognised. This is probably due to the very complex and variable behaviour during this stage and the difficulty of obtaining definitive experimental data close to the source*".

(Prince, 1983), (Thyer, 2003), (Luketa-Hanlin, 2006) and (Cleaver et al., 2007) identified that most of the experiments previously carried out involved spills of LNG and other cryogens onto water and the data for land spills was very sparse. More recent experiments on pressurized LNG releases from 2 and 3" flexible hoses have been done by Shell to quantify dispersion distances (Betteridge, 2015) ,

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but no measurement of droplet size were made on LNG releases. Most models currently used to predict this parameter are based on correlations deduced from experiments usually involving LPG (Witlox et al., 2013) or non-cryogenic fluids, such as cyclohexane or water (Johnson et al., 1999). As underlined by (Webber et al., 2009), "*with no information about droplet sizes it is not possible to predict any fall-out of liquid from the jet*".

To fill these gaps, the SPARCLING JIP was launched by TOTAL, AIR LIQUIDE, SHELL, GRTgaz & INERIS. The goal of the project was to produce high-quality experimental data on the size distribution and velocities of the LNG droplets using a dual PDA (Phase Doppler Anemometer), following the pressurised release of LNG. The test programme was managed and run by INERIS at their test site at Verneuil-en-Halatte on behalf of the members of the JIP.

The paper describes in detail the testing bench and test protocol, as well as the lessons learned from the use of the bench. The occurrence of rain-out is then discussed.

2. Description of the experimental setup

2.1 Testing site

All releases were performed on the INERIS Fire Platform. Fig. 1 shows an aerial view of this Fire Platform with the testing zone encircled in red. This zone is about 30 m long, is free of obstacles. A fence is positioned on each side of this testing zone to channel the cloud out of the Fire Platform in the last stage of its dispersion. To perform measurements in the close field of the release even when the weather is bad (rain, snow), a tent is positioned above the first meters of the release. The position of the tent (supports, lateral walls) were checked before each test to make sure they did not affect the release.

Fig. 1. *Aerial view of the testing site*

2.2 Bench description

Fig. 2 shows a schematic view of the experimental bench.

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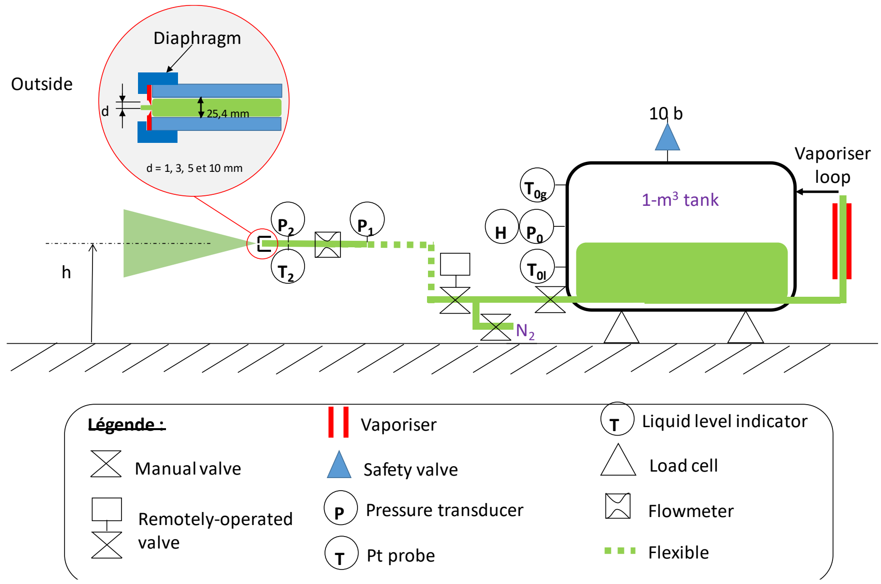

***Fig. 2.** Schematic view of the experimental bench*

2.2.1 Storage tank

The tank used to store the cryogenic fluid is cylindrical with its axis of revolution positioned vertically (see Fig. 3). It has a double-wall structure with the inner and outer envelopes respectively made in SA-240 3014 and SA-516 Gr.70 materials. Thermal insulation between these two envelopes was ensured by a vacuum-packed Perlite layer. The volume of the internal envelope is 995 L and its diameter 1150 mm. This storage can operate at temperatures varying between – 190°C and + 50°C. It was equipped with a safety valve set to open when the internal pressure exceeds 10 bar. In addition, to control the internal pressure during the release, the tank was fitted with a vaporiser. The system works (1) by bleeding part of the liquid phase from the tank, (2) by circulating this liquid within the vaporiser and (3) by injecting the vapour hence produced into the top part of the tank.

(Focus on the vaporiser)

***Fig. 3.** Storage tank for the cryogenic fluid*

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2.2.2 *Release line*

The release line has a nominal diameter of 1'' and an approximate length of 9 m. By following the flow direction from the storage tank, this line was made up of three main elements:

- a remotely-operated valve;
- a flexible hose;
- a release assembly.

Every effort was made to reduce the friction pressure drop within the flow and the heat losses with the environment. This was achieved:

- by keeping the cross-sectional area of the line as constant as possible. There is hardly no singularity in the line;
- by installing already-insulated components and, if not possible, by coating these components with a 13-mm thick layer of Insulfrax S.

The flexible hose was 7.7 m long. It was composed of two tubes made in Inox 304 L. Thermal insulation between these two tubes was provided by vacuum. Fig. 4 shows a picture of the release assembly. This assembly was built using a flowmeter, a 1'' pipe and a diaphragm that could be screwed at the end of the pipe. Different diaphragms, each of them featuring a given opening (2, 3, 5, 7 or 9 mm), were used.

Fig. 4. *Release assembly*

2.3 *Instrumentation*

2.3.1 *Tank*

When delivered, the tank was already instrumented with:

- a pressure transducer (P0 on Fig. 2);
- two Pt100 probes, one located on top of the tank to assess the gaseous phase temperature and the other in the bottom of the tank for the liquid phase (respectively T0g and T0l);
- a level indicator (H). This parameter is determined by measuring the hydrostatic pressure of the cryogenic fluid column. This provided the first method for assessing the released mass flow rate.

In addition, the tank is placed on 4 load cells with a maximal load capacity of 3000 kg. This weight measurement was the second method for assessing the released mass flow rate.

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2.3.2 Release line

A Coriolis flowmeter was used, OPTIMASS 6400 C and it was capable of operating at a maximal pressure of 40 bar with a temperature in the range – 200°C / + 40°C (see Fig. 5). Therefore, this apparatus was used as a third method to measure the released mass flow rate. The flowmeter also gave a measure of the volumetric mass and of the fluid temperature since it was equipped with a Pt500 probe. It is worth precising that this possibility of measuring the volumetric mass drove INERIS to install the flowmeter as far as possible from the tank. This was intended to control the flow phase as close as possible to the nozzle orifice.

Fig. 5. *Flowmeter Optimass 6400 C*

Pressure was also measured upstream of the flowmeter and nozzle orifice (respectively P1 and P2 on Fig. 2). Piezoresistive pressure sensors were used (range: 0 – 14 barg). It must be pointed out that these sensors were not particularly suitable for cryogenic applications. To prevent their sensitive membrane from being damaged due to direct coldness exposure, the measurement was not made in situ (i.e. directly in the cryogenic flow) but remotely. This was done by positioning the sensor at the end of a small tube tapped into the pipe of the release assembly. This tube was about 100 cm long (see Fig. 6).

Fig. 6. *Picture of the pressure transducer upstream of the flowmeter*

The temperature was also measured upstream of the nozzle orifice (see T2 on Fig. 2) by means of a Pt100 probe. This probe was flush mounted with the flow to avoid any unduly friction pressure loss. Knowing the pressure and temperature just upstream of the nozzle orifice, it was possible to apply

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the Bernoulli equation to estimate the mass flow rate, assuming that the outflow was all liquid. This was the fourth method for assessing the released mass flow rate.

2.3.2 PDA system

PDA (Phase Doppler Anemometry) is an optical technique that allows measuring the size and velocity of a moving spherical particle. The PDA technique is based upon on Doppler shift of the light reflected (and/or refracted) from a moving seeding particle. When two laser beams of the same wavelength intersect, they will interfere in the volume of intersection and form fringes. When the particle will move through this volume (also called the measuring volume), the intensity of the light reflected (and/or refracted) by this particle will vary with a frequency proportional to its velocity. Only one photodetector is required to calculate the velocity. Yet the determination of the droplet size requires two photodetectors. Indeed, when the particle passes through the measuring volume, both photodetectors will receive a reflected (and/or refracted) light of the same frequency, but the phases of the two lights will vary with the angular position of the detectors. This phase difference is function of the particle diameter.

The main requirement of the SPARCLING project, a Dual-PDA was used to measure two components of velocity and the diameter of the droplets in the close field of the cryogenic release. The Dual-PDA combines two conventional PDAs. Fig. 7 shows the positioning of the two lenses of the Dual-PDA in the close field of the cryogenic release.

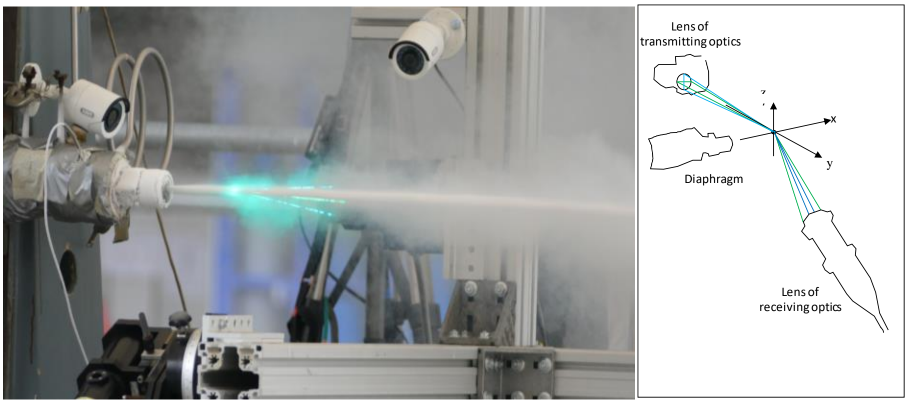

Fig. 7. *Picture of the Dual-PDA*

The two lenses were positioned on a 3-D displacement system that was remotely controlled. This system allowed the PDA measuring volume to be moved to the desired locations within the cryogenic release. The cartography performed for most of the tests is presented in Fig. 8. The x-axis represents the axis along the release direction. The z-axis is vertical.

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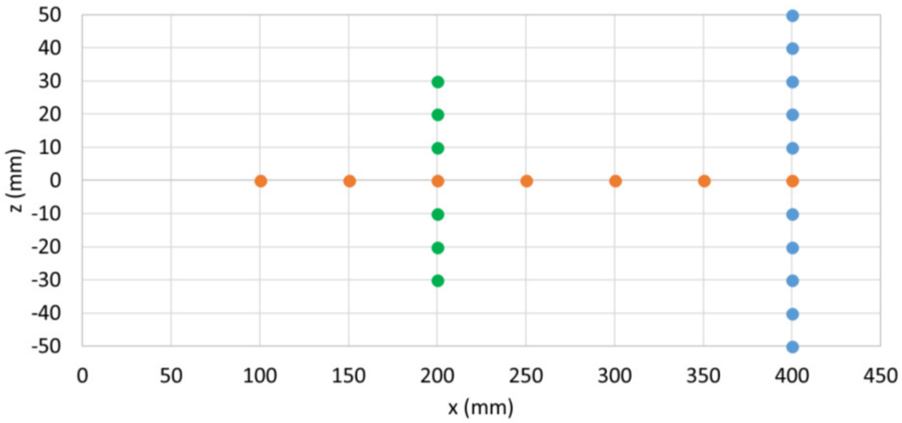

Fig. 8. *PDA cartography used*

3. Experimental campaign

3.1 Testing matrix

18 tests were performed, 16 with LNG and 2 with liquid nitrogen (LN_2). The influence of the orifice diameter and storage conditions were studied. The tests conditions are presented Table 1.

Table 1: *Tests parameters*

Parameter	**Value**
Product	LNG (16) and LN_2 (2)
Orifice diameter	2, 3, 5, 7 and 9 mm
Pressure	Atmospheric to 9 bara
Temperature	Saturated and subcooled (up to 8 bara)

The LNG composition was not available for each delivery. When it was, this composition came from the LNG terminal and was therefore representative of the composition before its transportation. To cope with this lack of information, a method was developed to measure the composition. It entailed allowing a small liquid leak from the bottom of the vessel. The released LNG was diluted with air and homogenized by the air flow. The concentration of methane, ethane and propane were then continuously measured using FTIR spectroscopy after the vaporization of the LNG. The composition was then obtained using a time integration. As expected, it was found that the proportion of methane decreased during the lifetime of a single delivery of LNG as it gradually warmed up.

3.2 Test protocol

The steps of the test protocol developed are described below.

1. Tank conditions setting

Before the test, the pressure and temperature inside the storage tank had to be set considering the test conditions. The LNG storage vessel did not have a heating element, therefore to increase the temperature of the LNG to the targeted value, it was necessary to wait for the LNG temperature to increase as a natural consequence of heat exchange with the environment. To decrease the temperature to the targeted value the pressure was decreased until it reached the corresponding saturation pressure. In the initial experiments, gas was released from the top of the tank at once, which required waiting for the conditions inside the tank to stabilize. Later, to ensure that the product is at

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equilibrium, a pressure control device was connected to the tank to maintain constantly the pressure inside the tank to the targeted value.

For subcooled releases the vaporiser was used to reach the targeted pressure just before the test.

2. Release line cooling

LN_2 was used to cool down the line before the test. This was achieved by connecting a LN_2 450 L tank to the release line as close as possible of the tank. The line was then cooled until the temperature at the orifice dropped below the liquid phase temperature in the tank.

3. LNG (or LN_2) release test

As soon as the line was cooled, the LNG (or LN_2) release was started. The vaporiser was then manually set.

- For subcooled releases it was set to maintain the pressure steady.
- For saturated releases it was set to slowly increase the pressure inside the tank until the release at the orifice became a liquid.

As soon as the release was liquid the PDA measurements were started. The criterion for the release to be liquid was that the void fraction was less than 10%. The void fraction is calculated using the density measured by the flowmeter:

$$\rho_{flowmeter} = x.\rho_{gas} + (1-x).\rho_{liquid}$$

where:

- $\rho_{flowmeter}$ is the density measured by the flowmeter,
- ρ_{gas} is the vapour density of the LNG,
- ρ_{liquid} is the liquid density of the LNG,
- x is the void fraction.

Usually the void fraction was found to be zero when the PDA measurements were triggered (especially for subcooled releases). The density measured by the flowmeter reached a plateau when it was fully liquid. It was interesting to note that the release became quiet suddenly when the release turned into liquid. It is then possible to hear the transition on the test site. As soon as the PDA measurement was over, the release was stopped and the release line was purged with LN_2.

4. Rainout

Rainout was only observed for the two tests that were performed with a pressure as close as possible to atmospheric pressure:

- Test 8b (LNG, 7 mm, 1.5 bara)
- Test 15 (LN_2, 7 mm, 1.5 bara)

The release pressures and orifice diameters are the same for the 2 tests (7 mm, 1.5 bar) but the products are different. For higher pressure, even for subcooled tests, no rainout was observed. It is worth noting that for smaller orifice diameters (≤3 mm) it was not possible to reach 100% liquid release for this pressure condition.

A screenshot of the IR camera and a picture of the jet are presented on Fig. 9 for test 8b. It gives a clear view of the jet and reveals the rain-out. The mark left by the rain-out after the release was centered about 3,5 m ahead from the release point. It was about 2 m long and 1 m wide.

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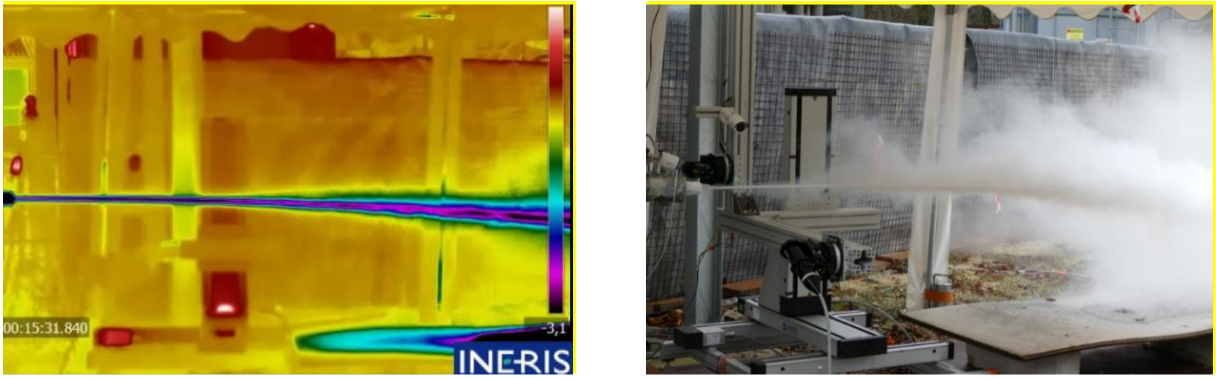

Fig. 9. *Test 8b - Rainout evidence. IR screenshot (left), visible (right).*

Fig. 10 and Fig. 11 present some pictures revealing the rain-out observed during test 15. The mark left by the rain-out after the release was centered about 3.5 m ahead from the release point. It was about 2.5 m long and 1 m wide.

Fig. 10. *Test 15 - Pictures revealing rain-out during the release*

Fig. 11. *Test 15 - Pictures showing the rain-out marks after the end of the release*

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5. Conclusions

The SPARCLING JIP was launched by TOTAL, AIR LIQUIDE, SHELL, GRTgaz & INERIS. The goal of the project was to produce high-quality experimental data on the size distribution and velocities of the LNG droplets using a dual PDA (Phase Doppler Anemometer), following the pressurised release of LNG. The test programme was managed and run by INERIS at their test site at Verneuil-en-Halatte.

The testing bench and test protocol developed is presented in detail. 16 pressurised releases of LNG and 2 of LN_2 were performed. The different release conditions parameters are presented below.

Parameter	**Value**
Orifice diameter	2, 3, 5, 7 and 9 mm
Pressure	Atmospheric to 9 bara
Temperature	Saturated and subcooled (up to 8 bara)

Rainout was observed only for the 2 tests that were performed with a pressure as close as possible of the atmospheric pressure:

- Test 8b (LNG, 7 mm, 1.5 bara)
- Test 15 (LN_2, 7 mm, 1.5 bara)

For higher pressure, even for subcooled tests, no rainout was observed.

The analysis of the experimental data produced, especially those with the PDA, is an ongoing work. The influence of the release conditions on the droplets size is being investigated.

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