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Vapour & Fire Control Testing of FOAMGLAS® PFS System (Gen 2) on LNG

Final Report

2014

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EXECUTIVE SUMMARY

Falck Emergency Services UK, also trading as Resource Protection International (RPI), an Independent Specialist Fire Consultants, was appointed by Total Oil Company to undertake a series of tests. The tests evaluated the effectiveness of passive firefighting systems, in suppressing LNG and LPG vapours and fires. Resource Protection International (RPI) was commissioned by Total to undertake this series of tests in October 2013 and the tests were undertaken at the Centro Jovellanos, Asturias, Spain, during the week commencing Monday 14 October 2013. The testing team was led by Paul Watkins of RPI.

One test was conducted and the results of the test featuring the use of the passive material (FOAMGLAS® PFS System (Gen 2)) were compared to the baseline date obtained from the reference test. FOAMGLAS® PFS System (Gen 2) is effective in concrete LNG containment pits, as demonstrated by the test results: under the ideal experimental conditions, it was apparent that there was a significant reduction in radiant heat and a relatively short fire control time.

The purpose of this report is to provide the results of the tests that were conducted by RPI, outlining all observations and subsequent conclusions. It should be noted that the conclusions may be updated and/or revised further, following a more detailed analysis of the results.

Based on what has been observed so far, with the test work having been undertaken, it is possible to make some general statements about the potential applicability of the FOAMGLAS® PFS System (Gen 2) under testing. It should be noted that any findings of the experiments were based on experimental conditions; thus, any practice should be adjusted to the varying conditions.

1. LNG reference test was performed, in order to compare the test results with regards to the FOAMGLAS® PFS System (Gen 2) with baseline results.

2. During the continuous discharge of the LNG, the vapour cloud appeared larger than when the LNG flow was stopped. This occurred when LNG was released and a fraction of the discharged LNG flashed directly, without creating the pool. Thus, the LNG vapour largely derived from the flashed LNG. This did not occur when the LNG flow was stopped and the only source of the LNG vapour was the evaporating pool. This was confirmed by observing the size of the white vapour cloud during both phases.

3. FOAMGLAS® PFS System (Gen 2) was effective in reducing radiant heat flux. The observation and experiment results demonstrate that the FOAMGLAS® PFS System (Gen 2) controls fire immediately after ignition.

4. The FOAMGLAS® PFS System (Gen 2), which consists of two layers of Foamglas, covering the total area of the test pit, provided better results (in terms of radiant heat reduction) than the FOAMGLAS® PFS System (Gen 1), in which the top layer comprised of just 10% of the pit area.

5. With regards to the FOAMGLAS® PFS System (Gen 2) only the top layer was discoloured and slightly damaged.

6. FOAMGLAS® PFS System (Gen 2) provided a consistent coverage, which helped to reduce the flame size of the LNG and ensured that

the fire was in a steady state within a short space of time. This result can be explained by the fact that the burning rate was significantly lessened by reducing the exposed area of the LNG pool.

7. FOAMGLAS® PFS System (Gen 2) does not depend on any additional procedure or supplemental application during the fire.

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1 INTRODUCTION

The release of flammable gases, such as Liquefied Natural Gas (LNG) or Liquefied Petroleum Gas (LPG), may result in the formation of a flammable vapour cloud that is often dense, depending on the ambient conditions (particularly wind speed and direction). If this cloud encounters a source of ignition within the surrounding environment, a fire may occur and this might have catastrophic consequences for nearby facilities. The characteristics of the resulting fire are dependent upon the release conditions and the environment into which the vapours are released. Various scenarios may occur, including flash fires, fireballs, pool or jet fires or even vapour cloud explosions, if the cloud is released into a congested area.

LNG and LPG pool fires emit high thermal radiation, which may prevent firefighters approaching and extinguishing the fire. Expansion foams and dry chemicals are the conventional methods used to control and suppress vapour clouds and fire resultant from LNG and LPG. Expansion foams are used to reduce radiant heat to a level where the LNG/LPG pool fires are controlled, thus allowing firefighters to approach and extinguish the fire, using dry chemicals.
Applying expansion foam to the surface of LNG can reduce radiant heat from a fire: this is because the water drained from the foam forms a frozen layer, which acts as an insulation blanket, reduces the evaporation rate and subsequently decreases radiant heat. The application of these methods depends on a number of factors, such as foam application rate, the location of the generator and the LNG/LPG containment design. Recently, there have been a number of studies conducted, as attempts to fill the gaps increased the need for LNG/LPG field experiments involving expansion foams.

Various materials, such as the FOAMGLAS® PFS System (FOAMGLAS® is a registered trademark of Pittsburgh Corning Corporation in the United States and various other countries), have been introduced in the last decade, in order to suppress fires resulting from flammable gases and reduce the effect of radiant heat on nearby objects by reducing the size of the fire. In addition, the FOAMGLAS® PFS System is free of the disadvantages associated with traditional fire-fighting foams and thus can help overcome the various difficulties that fire fighters face in using high expansion foam, such as:

1. The requirement of large quantities of water, foam and dry chemicals to ensure complete control and extinguishment of large LNG/LPG fires.
2. The necessity for the continuous application of high expansion foam, as the foam blanket can be weakened by fire and it may be necessary to replace it with a new one.

FOAMGLAS® PFS System is a non-flammable 'dry foam' material that acts as a floating barrier in insulating the surface of a burning liquid. The density of FOAMGLAS® PFS System is less than one third of the density of LNG (115 kg/m3 (+/-15%)) and it has a completely closed cell structure, in order to prevent the absorption of LNG/LPG during contact. FOAMGLAS® PFS System can be easily arranged in the shape of the containment of the spill.

The work undertaken in this report was performed by Resource Protection International (RPI). Data was recorded, with regards to investigating the performance of FOAMGLAS® PFS System (Gen 2) in suppressing and controlling the fires of LNG.

During the week commencing Monday 14 October 2013, RPI carried out a programme of tests, which were sponsored by Total Oil Company. The tests were performed at Centro Jovellanos, Asturias, Spain.

The principal objectives of the experimental programme, as outlined in this report, were to investigate the effectiveness of the FOAMGLAS® PFS System (Gen 2) on the reduction of radiant heat flux pertaining to LNG pool fires. There was also a further aim to investigate the effectiveness of the FOAMGLAS® PFS System (Gen 2) in suppressing the evolution of vapour from pools of the aforementioned hydrocarbons. Specifically, the purpose of the experiments was to obtain data on LNG fires and vapours, including vapour thermal radiative output and fire size, in terms of the use of the FOAMGLAS® PFS System (Gen 2).

In order to achieve the above objectives, two tests were conducted; in which radiant was measured using four TG-9000-9F radiometers, manufactured by Vatell. Vapour concentration was measured using Crowcon Gasman gas detectors calibrated for methane (for the LNG tests. In addition, weather conditions, including wind speed, wind direction, temperature and humidity, were continuously measured throughout the duration of the tests.

The Centro Jovellanos (CJ) industrial/marine fire training facility was used as a base for the tests. The CJ facility LNG pit (with dimensions of 2m x 2m x 1.2m depth) was used for the LNG tests.

Measurements of radiant heat without use of the FOAMGLAS® PFS System (Gen 2) were recorded for LNG, in order to compare the results with the measurements gained when the FOAMGLAS® PFS System (Gen 2) was used. General observations and the test results clearly indicated a reduction in radiant heat when the FOAMGLAS® PFS System (Gen 2) was used, which was evident by a decrease in flame size.

The purpose of this report is to deliver the results of the experiment and any observations. RPI reserve the right to modify the contents of the report, based on the on-going analysis of the test results.

2 THE TEST SITE AND INSTRUMENTATIONS

The tests were carried out at Centro Jovellanos, Asturias, Spain. The test site comprised of an LNG storage facility, an LNG release system and an LNG test pit, into which the LNG was discharged. The experiments were monitored from a control room located to the south of the LNG test pit, approximately 100m from the LNG release point. All sited instrumentation was wired back to the control room, using appropriate cables. The data generated during the tests were recorded on a computer, which was also located in the control room. During the tests, all personnel, with the exception of look-outs, were positioned near the control room.

Figure 1: The Test Site at Centro Jovellanos, Asturias, Spain

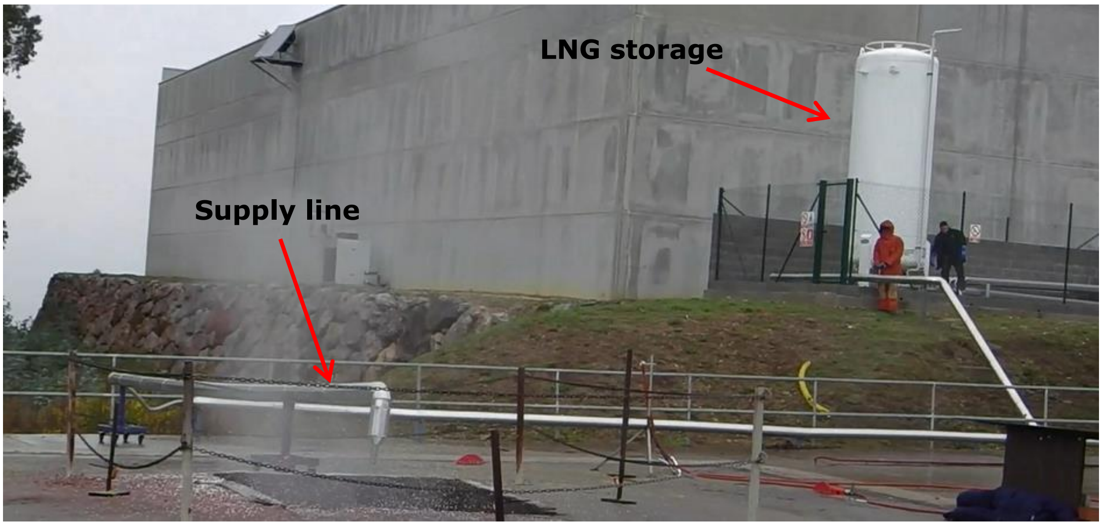

Figure 2: LNG Storage and Delivery System

2.1 LNG test pit

A diagram of the LNG pool fire test pit is shown in Figure 3: the dimensions of the pit were 2m x 2m x 1.2m depth. The pit was constructed from concrete and was reinforced with weld mesh and rebar.

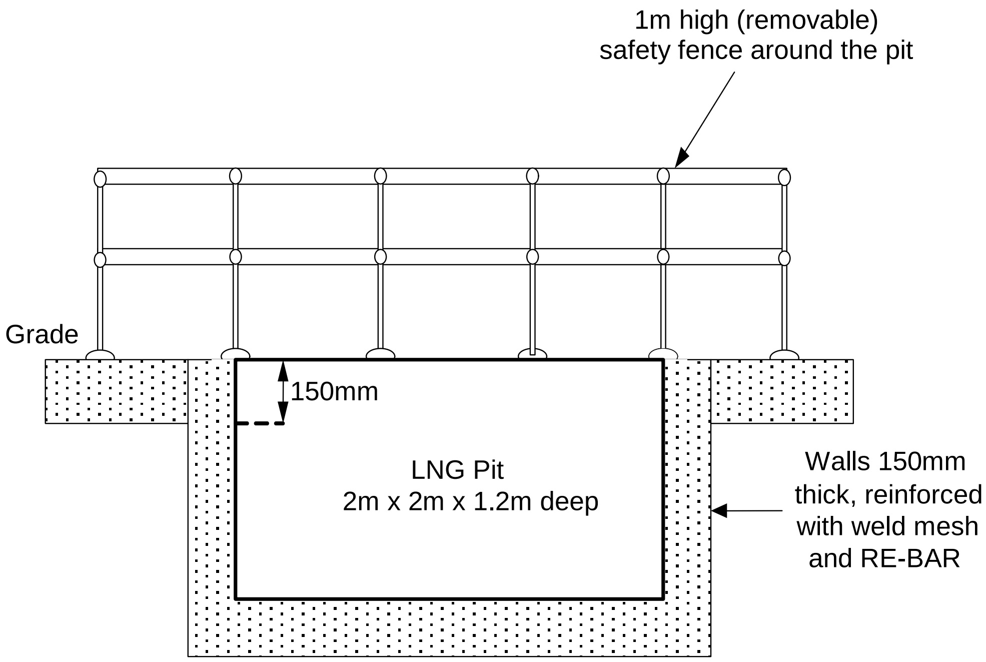

Figure 3: The LNG Test Pit

2.2 Heat Flux Gauges

During the experiments, four heat-flux gauges were used to measure the rate of heat flux from the fire. The heat flux gauge used was type TG9000-9F, manufactured by the Vatell Corporation (as seen in Figure 4). The gauges are water cooled, when constructed as a radiometer: convective heat flux is blocked from reaching the sensor by a window: this allows radiation only to be measured. This type of gauge has a maximum operating temperature of 200°C, regardless of the heat flux applied. The heat flux gauges had a 120° field of view and were tilted downwards, at an angle of 12° below the horizontal line, so that they pointed towards the base of the flame: this allowed the approximate maximum radiant heat flux at each location to be recorded.
In the experiments, the gauges were calibrated in accordance with the manufacturer's recommendations and instructions and the output of the heat-flux gauge was measured in mVs. The gauge is designed to provide an approximate output signal of 10 mV, when exposed to the specified heat flux range. A conversion factor was obtained, so that the measured voltages were converted to 'true' heat flux, in W/cm².
Each heat flux gauge was mounted on a tripod stand located at height of 1.2m above the base of the flame. The gauges were placed at the corners of the LNG pit, at a distance of 5m from the pit. The gauges were water-cooled, in order to avoid damaging them.

Before each of the tests, all cables from the heat flux gauges to the data loggers and from the data loggers to the computers were checked, as was the water cooling system. The heat flux gauges were cleaned, as they were exposed to vapour clouds, smoke and dry chemicals on a number of occasions. The results of the tests were analysed, in order to obtain measurements of radiant heat flux, using the calibration data supplied with each of the heat flux gauges. The results obtained confirmed that there was no deterioration of the heat flux gauges, in terms of them being exposed to dry chemicals or vapour clouds.

Figure 4: Heat Flux Gauge Type TG9000-9F

2.3 Cooling system

Water cooling was recommended to prevent damage to the heat-flux gauges, in the event of them being exposed to fire for long periods of time. A water cooling system was provided, consisting of two cooling water pumps, rubber tubes and two water tanks. The water tanks and pumps were located close to the control room, approximately 100m from the LNG pit, and the rubber tubes close to the pit were protected by thermal protective material.

2.4 Gas Detection

There are two types of gas detectors that may have been used to measure LNG gas concentration in the air during the experiment: point gas detectors and portable gas detectors. Point gas detectors, such as the 'Searchpoint Optima Plus' model, are designed for industrial application, in terms of the detection of any methane leaks and the concentration of the gas. The use of this type of detector involves suction of the gas by applying a vacuum into the cell of the gas detector. While it was possible to install the gas detector directly within the field for the experiment, this configuration is not flexible, due to the size and the weight of this type of gas detector. The movement of LNG vapour dispersion is very dynamic, depending on wind speed and direction; thus, it is important to set up the gas detector in order to ensure easy relocation. As a result, it is recommended that all gas detectors are placed together, with the measurement cells connected with tubes of at least 30m in length. The tubes should also be of the same type and length, in order to increase accuracy. This type of gas detector is relatively expensive and the set-up is complicated. However, an advantage is that the concentration profile can be easily obtained in the form of (time/concentration).

The second type of gas detector is the portable gas detector, and it was this type that was used in the experiments. The application of portable gas detectors includes measuring gas concentration at certain points where the point gas detectors are not available, in addition to ensuring the safety of the person conducting the experiment. Portable gas detectors have the capability to store data, using their built-in memory. The disadvantages of this type of detector are that the power is disconnected when the reading reaches over-range, in order to avoid damage to the sensor, and the reading is produced in the form of peaks.

Seven gas detectors were used to investigate the effectiveness of FOAMGLAS® PFS System (Gen 2) in suppressing the evolution of vapour from the LNG pools. The detectors used were Crowcon Gasman personal gas detectors, as shown in Figure 5, and were mounted on pole stands. They were located in the downwind direction of the LNG pit pan, at various distances. The vapours were measured with and without the use of FOAMGLAS® PFS System (Gen 2).

Figure 5: Crowcon Gasman Gas Detector

2.5 Meteorological station

Ambient conditions during the tests, particularly wind-speed, may have had an effect on the measurement of heat flux and the evaporation rate of LNG; thus, a meteorological station was used to monitor such conditions. Wind-speed and direction, humidity, barometric pressure and temperature were measured. The temperature and humidity sensors and the 3-cup anemometer, featuring a wind vane, were positioned 1.5m above ground.

Figure 6: The Meteorological Station

2.6 Data acquisition

Radiant heat flux was one of the most important measurements obtained from the pool-fire tests. For all experiments, data were recorded using the data logger MS6D, as shown in Figure 7. Two data loggers were used and each was connected to two heat-flux gauges. The voltage output from each test was measured in millivolts (mVs) and the conversion factor for the sensor was applied, in order to yield heat flux in W/cm^2. The data loggers for each of the heat flux gauges were located as close to the gauges as possible and were covered with a protective lid, in order to shield them from the flames. The signal from the data loggers was transmitted to the control room by Ethernet cables, which were protected by thermal resistant sleeves where they were likely to be exposed to fire or radiant heat.

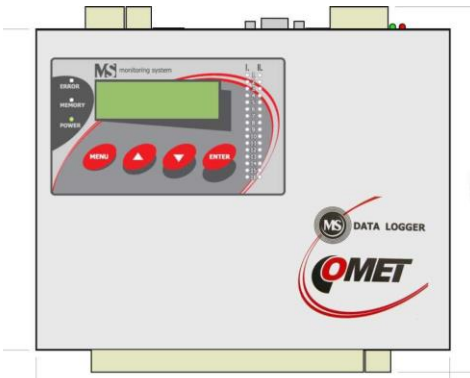

Figure 7: Data Logger MS6D

2.7 Visual Records

Two digital video cameras were used to produce visual recordings of the tests. The cameras were positioned to the side and either upwind or downwind of the test pit/pan, in order to provide different views, in accordance with the requirements of each test. These cameras can be linked to a computer, so that individual frames may be downloaded for analysis.

2.8 Other Logistics

Cables

Cables were required for the heat flux gauges and data and power supply and it is estimated that 400m of cable was used.

Tripods

Tripods were utilised to position heat flux gauges, gas detectors and the weather station and it is estimated that twelve tripods were used.

Fire Resistance Insulation

This was required to protect the cables, wires and water cooling tubes close to the LNG pit. Fire resistant insulation sleeves were used.

3 TEST PROGRAMME

3.1 Reference tests

As the main aim of the experimental programme was to evaluate the performance of the FOAMGLAS® PFS System (Gen 2) in suppressing fire pertaining to LNG, it was also necessary to conduct a test without the incorporation of this system (reference test), in order to collect baseline data that could be compared against the measurements taken when the FOAMGLAS® PFS System (Gen 2) was used. In terms of the concentration of the vapour cloud, this was measured after the discharge of the LNG liquid. The fuel was then ignited and radiant heat flux was measured.

3.2 FOAMGLAS® PFS System (Gen 2) tests

One FOAMGLAS® PFS System (Gen 2) test was performed: the LNG test was conducted in the LNG pit. In this test, the FOAMGLAS® PFS System (Gen 2) was placed into the test pit and vapour concentration was measured, upon the discharge of the LNG. The fuel was then ignited and radiant heat flux measured. The fire was extinguished using dry powder.

4 TEST PROCEDURE

Radiant heat flux from the LNG pool fire, with and without the use of the FOAMGLAS® PFS System (Gen 2), was recorded. Vapour concentration measurements for the LNG were also taken before and after application of the FOAMGLAS® PFS System (Gen 2).

With regards to the test conducted in the LNG pit, four heat flux gauges were placed at the corners of the LNG pit and seven gas detectors were placed close to the pit, in order to measure vapour concentration. The detectors were located at various distances, in a downwind direction, to cover the majority of the area where the vapour cloud was dispersed. Weather conditions were recorded for all tests. Two camcorders were used to record the events of the tests and the size of the flames from the fires.

The test procedures are set out below.

4.1 Procedure of reference test

- All equipment was checked, ensuring that the heat flux gauges were located at a distance of 5m from the edge of the LNG test pit. Atmospheric conditions were recorded, the data-loggers were checked (for recording data) and the cooling system was ready.
- The cooling pumps were activated and it was ensured that the water flowed through the heat-flux gauges at the minimum required flow rate of 60mL/minute.
- The gas detectors were switched on.
- The data loggers began to record data and baseline data.
- The LNG was released until there was a 750 kg ≈ 1.5 m^3 pool of fuel in the test pit.
- Measurements of vapour concentration (%LEL) were taken downwind for 15 to 20 minutes.
- The gas detectors were moved to a safe area.
- The LNG was ignited and the resulting fire was allowed to achieve steady burning conditions.
- Radiant heat flux data were collected for 5 to 15 minutes.
- The fire was extinguished.

- A further 3 minutes of data were collected after the final extinguishment of the fire.
- The data loggers were then switched off.

4.2 Procedure of FOAMGLAS® PFS System (Gen 2) tests

- The test began with the placement of the FOAMGLAS® PFS System (Gen 2) in the LNG test pit, when the test pit was completely empty.
- All equipment was checked, ensuring that the atmospheric conditions were being recorded and that the data loggers were ready to record the data. The heat-flux gauges were located at the designated distances from the edge of the test pit or the test pan and the gas detectors were ready.
- The gas detectors were switched on.
- Data logging began and 3 minutes of baseline data were collected.
- The LNG was released on top of the FOAMGLAS® PFS System (Gen 1) layer, until there was a 750 kg ≈ 1.5 m^3 pool of fuel in the pit.
- Measurements of vapour concentration (%LEL) were taken downwind.
- The measurement continued for a time period of at least 15 minutes.
- The gas detectors were moved to a safe area.
- The LNG was ignited and time allowed for the resulting fire to achieve steady burning conditions.
- Radiant heat flux data was recorded for at least 30 minutes.
- The final step was the extinguishing of the pool fire after being controlled (or suppressed) by the FOAMGLAS® PFS System (Gen 2). This step was completed by applying dry chemical for a few seconds, until the pool fire was completely extinguished.
- A further 3 minutes of data were collected after the final extinguishment of the fire. The data loggers were then switched off.

5 THE EXPERIMENTAL WORK AND RESULTS

A summary of each of the tests is provided below. There are notes on each individual test, along with a schematic diagram of the test set-up and details of any test in which the set-up or procedure differed. The radiant heat flux data were analysed using the calibrations supplied by the manufacturer and the measured data were converted into radiant heat flux measurements using the calibration parameters provided for each of the heat flux gauges. The concentration of the vapour taken into account was the peak point, the highest concentration measured, over measurement prior to ignition. The charts below show the heat flux measured by each of the gauges. Further data relating to flame size and behaviour were produced through an analysis of the video records.

5.1 Test 1: LNG reference test

The test began with the discharge of a certain quantity (750 kg ≈ 1.5 m^3) of LNG liquid into the pit, forming a depth of approximately 6 inches of LNG liquid (this assumption is based upon previous preparatory tests and takes into account the initial boiled-off quantity of LNG liquid). Gas detectors were place as shown in Figure 8. Gas concentration was measured for approximately 22 minutes. The gas detectors were then removed and the LNG was ignited, in order to measure radiant heat flux for a period of approximately 6 minutes. The fire was then extinguished, using dry chemical. The table below features the timeline of the test.

Tim (min)	Action
0:00	Data logging began
01:00	Cooling pumps started
03:00	Gas detectors switched on
05:00	LNG valve opened and 750kg of LNG liquid discharged into the pit
17:00	LNG valve closed
27:00	Gas detectors moved to a safe place
30:00	LNG ignited
36:00	The fire was extinguished, using a dry chemical

Weather conditions were constantly measured for the duration of the test and the average values for these are shown in the table below.

Wind Speed (m/s)	Wind Direction	Temperature (°C)	Humidity (%)
0 to 0.4	South	16.2	95

The gas detectors were placed as shown in the diagram below. As soon as the LNG liquid touched the concrete base of the pit, it vaporised. A visible white condensate cloud was then produced, as the very cold vapour condensed the water content in the air. The white vapour cloud was observed to disperse in all directions, as a result of the very low wind speed. White cloud formation is largely dependent upon the humidity of the ambient air, so it may or may not represent the actual size of an LNG cloud. After several minutes, the water spray curtains were turned on, in order to disperse the cloud, while the LNG continued to be released into the test pit. Figure 9 below features a photograph depicting the test.

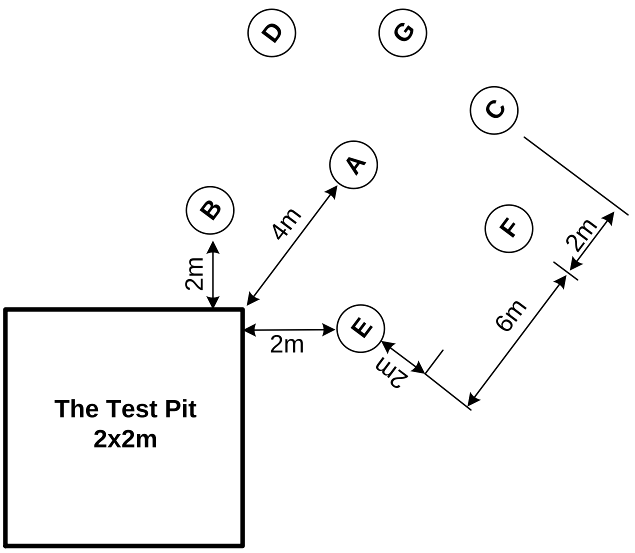

Figure 8: Diagram showing the layout of the gas detectors for test 1 (the reference test-1)

Figure 9: LNG is released into the test pit and gas concentration is measured

The figure below shows the LEL % peak points.

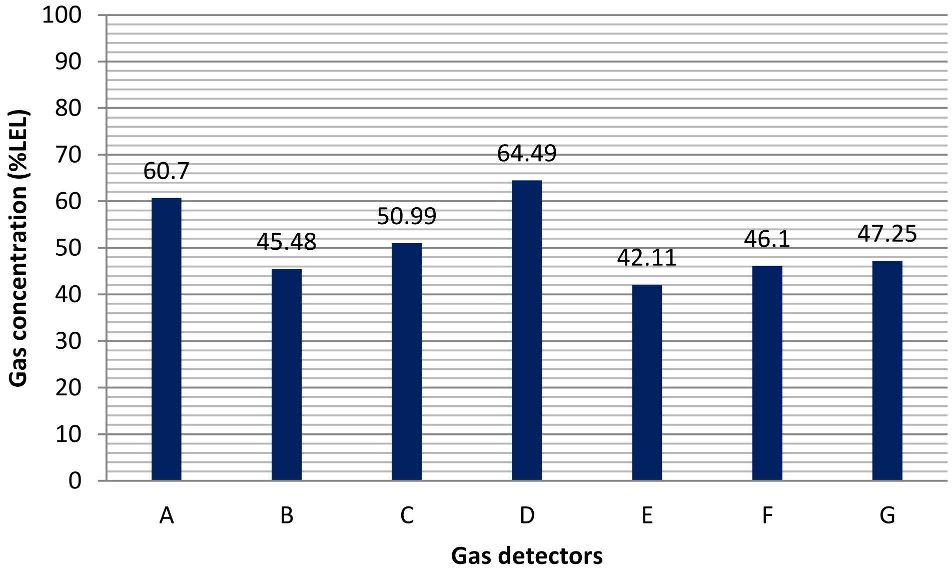

Figure 10: Gas detector measurements for the LNG reference test-1 (test 1)

The diagram below shows the layout of the radiometers.

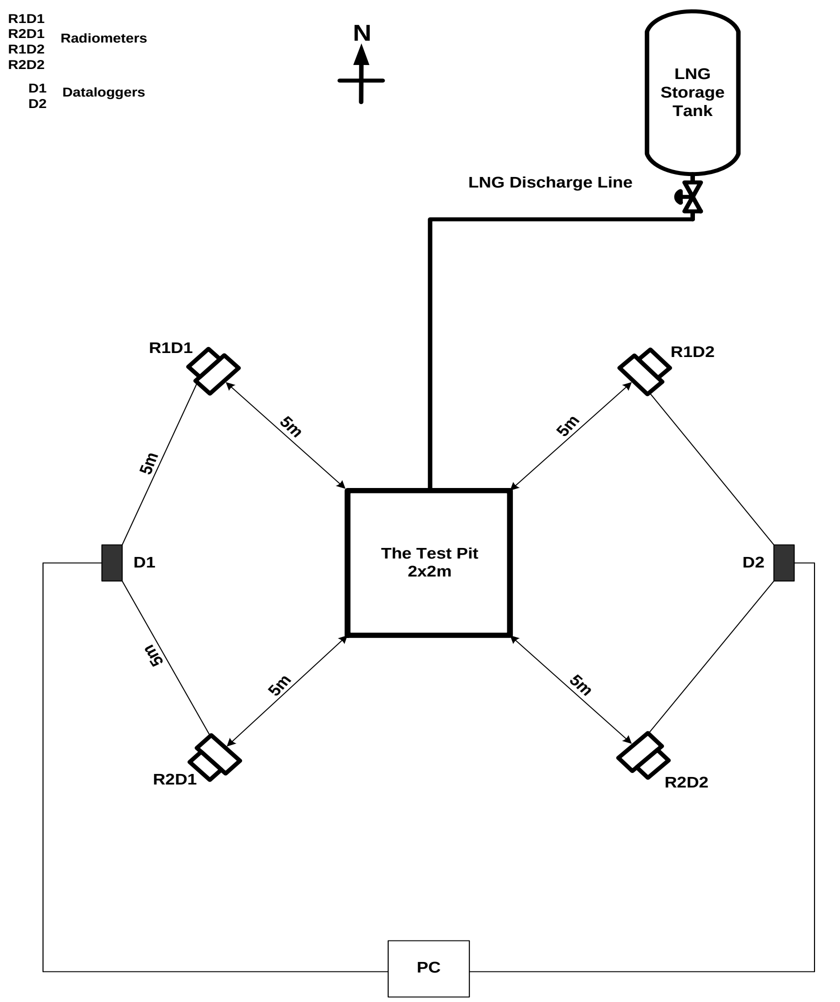

Figure 11: Layout of Equipment for the measuring of radiant heat flux

Figure 13 below shows the radiant heat flux measurements and it is apparent that the highest measurement was recorded by radiometer R2D1: this was due to changing wind conditions (speed and direction), as the wind-speed in Test 1 (the reference test) was between 0 to 0.4 m/s towards the south. Although wind speed was relatively low, it was demonstrated that the wind does have a bearing on the radiant heat flux received by the radiometers: it causes the flame to change position and thus affects the distance between the flame and the radiometer. This subsequently resulted in a lower surface emissive power and view factor, which, in turn, had an effect on the radiant heat flux received by the radiometer.

As can be seen in the photograph below, the flame was almost vertical, due to the low wind speed. The height of the flame was less than 10m.

Figure 12: Radiant heat being measured during the LNG pool fire reference test (test 1)

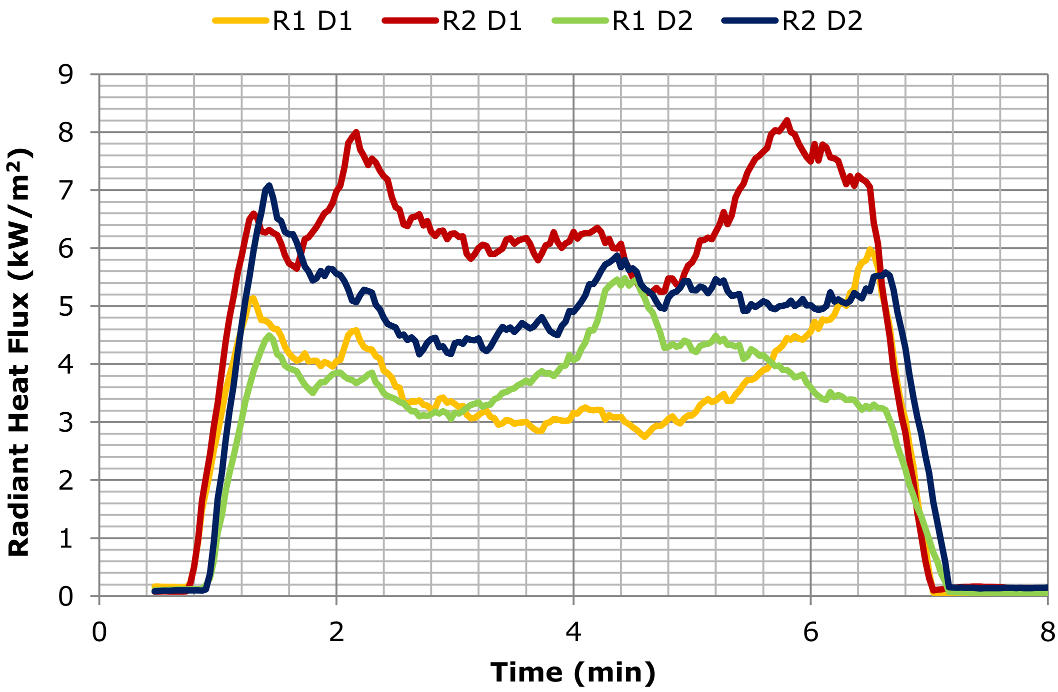

Figure 13: Radiant heat measurement for test 1

5.2 Test 2: LNG test using FOAMGLAS® PFS System (Gen 2)

The FOAMGLAS® PFS System (Gen 2) was placed in the LNG pit. A quantity (750 kg ≈ 1.5 m^3) of LNG was discharged into the pit and gas concentration was measured for 18 minutes, upon the release of the LNG. The LNG was then ignited radiant heat flux measurements were taken for 17 minutes, at a distance of 5 m from the pit. The radiometers were then moved to a distance of 2 m away from the pit and heat flux measurements recorded for a further 11 minutes.

The table below shows the timeline of the test:

Tim (min)	Action
0:00	Data logging began
02:00	Cooling pumps started
03:00	Gas detectors switched on
06:00	LNG valve opened, in order to discharge 1.5 m^3 into the pit
14:00	LNG valve closed
24:00	Gas detectors moved to a safe place
26:00	LNG ignited
43:00	Radiometers moved to 2m away from the test pit
54:00	The fire extinguished, using a dry chemical
55:00	LNG re-ignited
57:00	The fire extinguished, using a dry chemical

The photograph below shows the FOAMGLAS® PFS System (Gen 2) placed in the LNG pit. The whole surface area of the LNG pit was covered by two layers of the FOAMGLAS® PFS System (Gen 2), and steel sheets were placed on top of the FOAMGLAS® PFS System (Gen 2). The pit was completely empty when the FOAMGLAS® PFS System (Gen 2) was placed inside, and the process was completed in about one hour. Once the FOAMGLAS® PFS System (Gen 2), was inserted, the LNG liquid was discharged into the pit.

Figure 14: FOAMGLAS® PFS System (Gen 2), placement in the LNG pit

Average weather conditions during the test were as follows::

Wind Speed (m/s)	Wind Direction	Temperature (°C)	Humidity (%)
0.83	N to NW	19	80

The next step was to evaluate the effectiveness of the FOAMGLAS® PFS System (Gen 2), in terms of the mitigation of the dispersion of the LNG vapour. The location of the gas detectors were as in the previous test and, as before, gas concentration measurements varied between the detectors, in accordance with changes in wind direction. The photograph below shows the LNG vapour, when the discharge line was moved.

Figure 15: LNG vapour, after moving the discharge line

Figure 16 displays the LNG vapour concentration (% LEL) measured by the gas detectors.

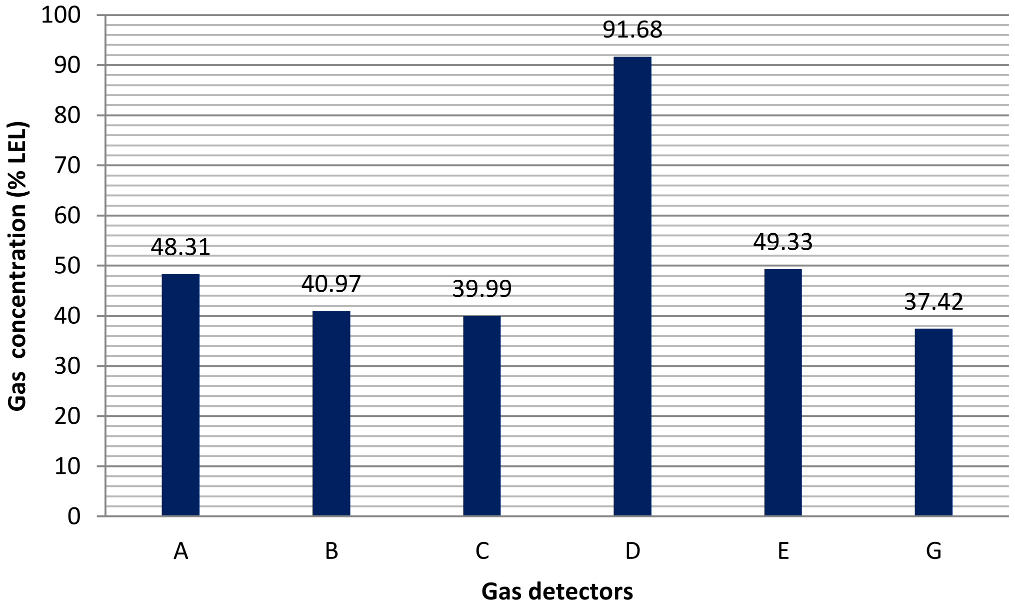

Figure 16 Gas detector measurements for the LNG test featuring FOAMGLAS® PFS System (Gen 2),

Figure 17: The LNG flame 15 minutes after ignition

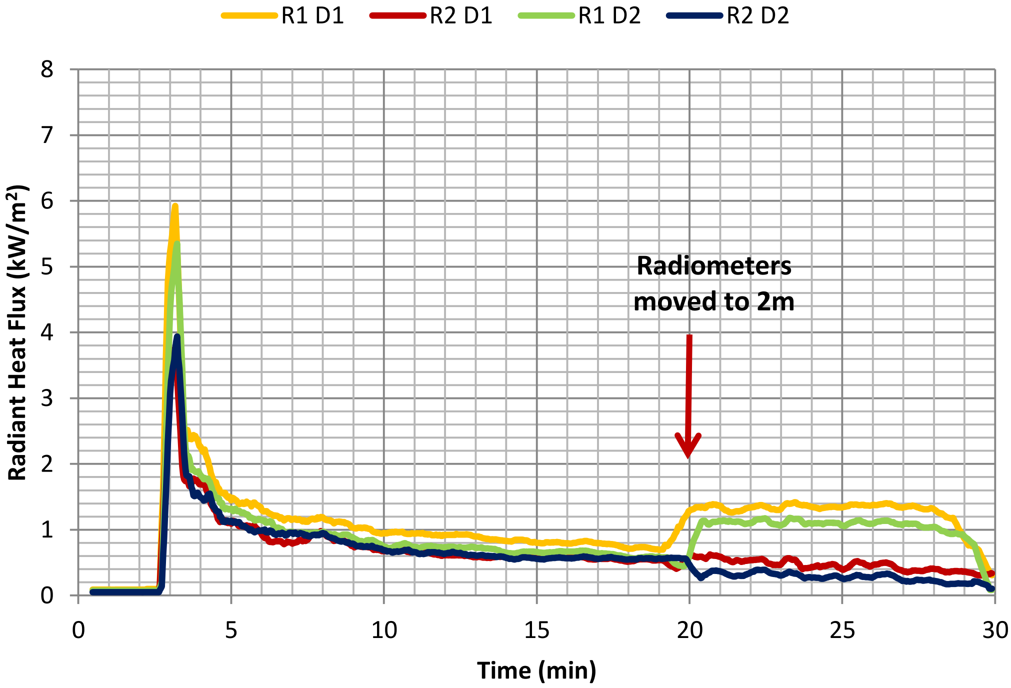

Figure 18: Heat flux measurements for the LNG test featuring FOAMGLAS® PFS System (Gen 2)

Figure 19: FOAMGLAS® PFS System (Gen 2), after the fire was extinguished using dry chemical

6 COMPARISON OF RESULTS WITH THE REFERENCE TESTS

A total of two experiments were conducted, in order to determine the effectiveness of the passive firefighting material (FOAMGLAS® PFS System (Gen 2)) in suppressing LNG fires and vapours. Both tests were conducted in the LNG firefighting training facility at Centro Jovellanos, Asturias, Spain. For each LNG test, the LNG was discharged into a concrete pit; thus, LNG vapour was produced, as a result of the phenomenon of vaporisation. The experiments also focused on the effects of the FOAMGLAS® PFS System (Gen 2) on LNG flame length; thus, all experiments were recorded, using digital cameras.

The changes in LNG radiant heat were the main focus of these experiments. Therefore, radiant heat flux was measured at various distances from the test pit. In order to demonstrate the effectiveness of the FOAMGLAS® PFS System (Gen 2), the data collected from the test were compared to the baseline data from the reference test. This section outlines the comparison of the tests conducted with and without the use of FOAMGLAS® PFS System (Gen 2).

6.1 Test 2: LNG test using FOAMGLAS® PFS System (Gen 2)

The radiant heat data from the FOAMGLAS® PFS System (Gen 2) experiment was compared with the corresponding data from the reference test and, as highlighted in Figure 20, the FOAMGLAS® PFS System (Gen 2).was clearly effective in suppressing the LNG pool fire. Radiant heat was reduced by approximately 90%, when compared to the reference test. The performance of the FOAMGLAS® PFS System (Gen 2) was comparable, if not superior, to the FOAMGLAS® PFS System (Gen 1). The use of steel sheets to cover the FOAMGLAS® PFS System (Gen 2) units helped to close the gaps between the units, thus minimising the evaporation area of the LNG pool. The LNG flame was accordingly reduced within a few seconds of ignition. Figure 21 shows a comparison of the flame height of the LNG fire, when FOAMGLAS® PFS System (Gen 2) was used, and the corresponding results of the reference test. The height of the flame was a few feet above ground, once the fire reached a steady state.

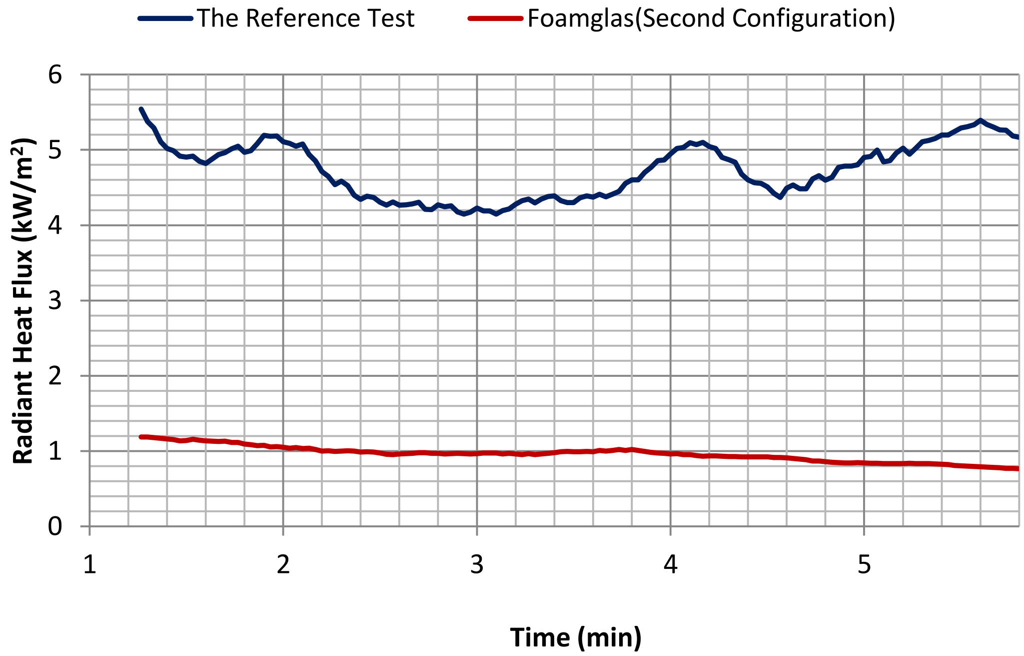

Figure 20: Comparison of radiant heat flux measurements in test 2 and test 1

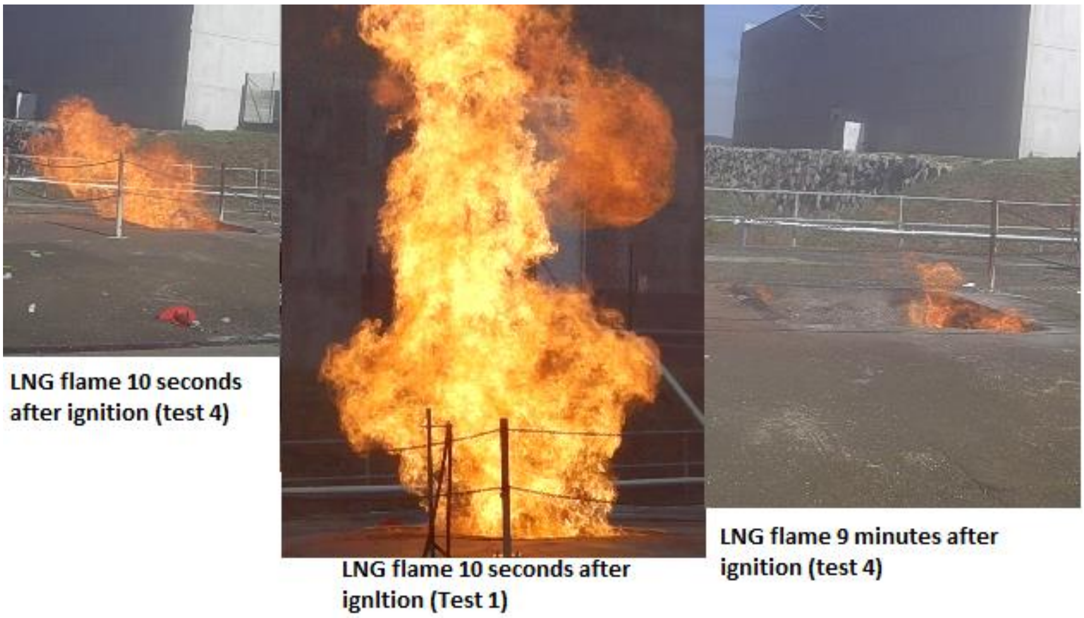

Figure 21: Comparison of LNG flame size in test 2 and test 1

The same quantity of LNG was discharged into the test pit and the locations of the gas detectors were the same as in the figure below. As soon as the LNG liquid touched the bottom of the test pit, it vaporised. A visible white condensate cloud was then produced, as the very cold vapour condensed the water content in the air. In test 2, during the initial evaporation of the LNG, the white vapour cloud spread around the test pit: the gas detectors may have recorded the highest values at this time. The vapour cloud was then observed to disperse towards the prevailing wind direction. It should be noted that, white cloud formation is largely dependent upon the humidity of the ambient air and thus may or may not represent the actual size of the LNG cloud.

In test 2, during the vapour measurement of LNG, it was observed that the size of the vapour cloud was less than that of the reference test. It can thus be concluded that the FOAMGLAS® PFS System (Gen 2) had an effect on supressing the LNG vapour. It was expected that the FOAMGLAS® PFS System (Gen 2) would perform better than the FOAMGLAS® PFS System (Gen 2)., as it is covered by steel sheets that close the gaps between the units, thus reducing evaporation area.

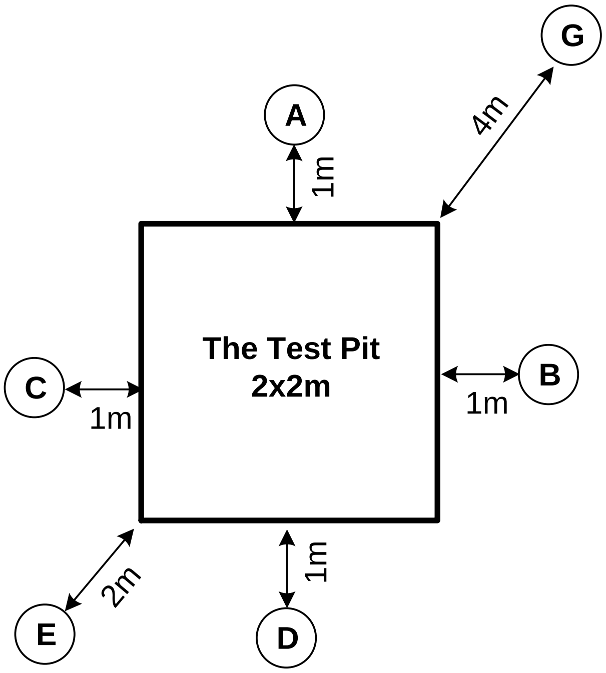

Figure 22: Diagram showing the layout of gas detectors for LNG FOAMGLAS® PFS System (Gen 2). Test.

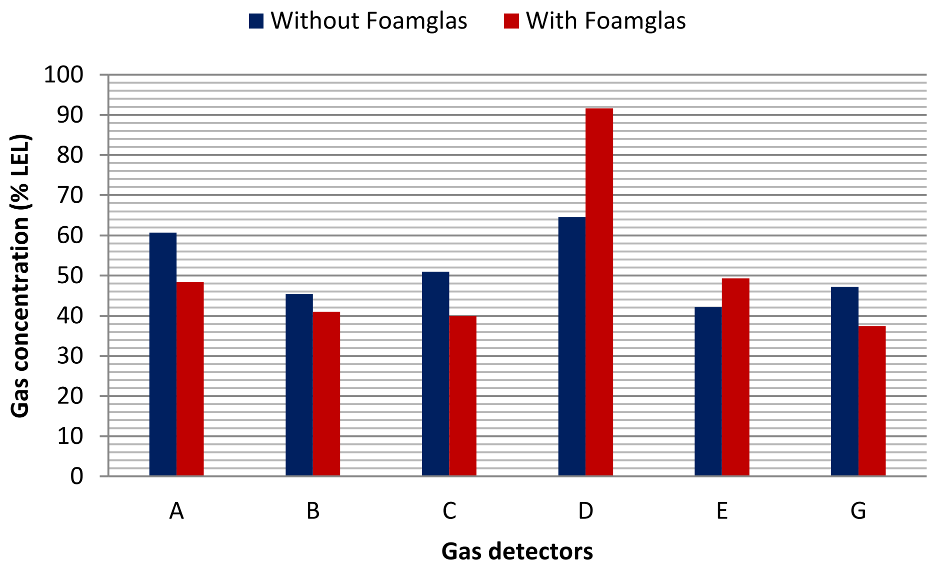

Figure 23: Comparison of gas concentration measurements in test 2 and test 1

7 SUMMARY AND RECOMMENDATIONS

Two tests were conducted, in order to investigate the effectiveness of LNG pool fire suppression methodology incorporating the use of FOAMGLAS® PFS System (Gen 2). The FOAMGLAS® PFS System (Gen 2) was placed in the LNG test pit, into which a certain quantity of LNG was discharged. The vapour concentration of LNG was measured for a period of time and then the fuel was ignited, in order to allow for the measurement of radiant heat flux. The principal instruments used in the series of tests outlined in this report were designed to measure radiant heat flux from the LNG pool fire and the gas concentration of LNG. In addition, photographic and meteorological data were obtained.

Gas concentration was recorded, in order to measure methane concentration (for the LNG test) both before and after the application of FOAMGLAS® PFS System (Gen 2). Radiant heat and vapour concentration data collected from all tests were compared to the baseline data, with the purpose of evaluating the performance of the FOAMGLAS® PFS System (Gen 2) in suppressing the pool fires and vapours (taking into account the weather conditions for each test).

The tests indicated that the size of the vapour clouds, when using the FOAMGLAS® PFS System (Gen 2) was observed to be smaller than that in the LNG reference test. The FOAMGLAS® PFS System (Gen 2) also significantly reduced radiant heat pertaining to both the LNG pool fire. This assertion is based on the experimental results, including the pool fire measurements and videos and photographs. In addition, it was observed that the FOAMGLAS® PFS System (Gen 2) provided a coverage layer that helped to stabilise the fire, with no fluctuation; it also significantly reduced flame size. Furthermore, the FOAMGLAS® PFS System (Gen 2) brought the LNG fires under control within a few seconds of ignition. The table below features a summary of the tests and the comments noted during the experiments.

With a view to providing a better understanding of future LNG vapour concentration and fire suppression research and delineating the important information to be gathered, the following recommendations are suggested:

1. Hydrocarbon (H/C) IR cameras may be used to observe the actual dispersion of invisible vapours. The hydrocarbon camera is able to capture the propane or butane cloud, enabling the observation of the movement of the cloud and the measuring of cloud size.

2. The use of point gas detectors to obtain a continuous gas concentration profile, rather than peak measurements.

3. Radiometers can be moved as close as possible to the fire while cooling is provided.

Report Ref.	Test Date	Material Used	Fuel	Vapour Measurement (min)	Radiant Heat Measurement (min)	Radiant Heat Reduction (%) Compared to Ref Test	Comments
Test 1	15.10.2013	Reference Test	LNG	22	6	-	• The average radiant heat flux recorded by all radiometers was approximately 5 kW/m^2
Test 4	17.10.2103	FOAMGLAS® PFS System (Gen 2)	LNG	18	27	90%	• After 30 seconds, the visible flame became stable and remained not much higher than 1m above the pit. Thus, radiant heat was emitted only from this part of the fire (visible fire). • The LNG flame was considerably decreased, when comparing the results to the reference test result. • A small pool of boiling LNG was observed, when the bottom layer of FOAMGLAS® PFS System (Gen 2) was removed.