DISPERSION EXPERIMENTS IN A 1:5 SCALE OFFSHORE MODULE

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The devastating effects resulting from explosion model predictions and full-scale explosion experiments carried out for realistic offshore facilities have increased the interest in predictions of ventilation and dispersion processes for such facilities. There is, however, a significant gap in current knowledge in this field to be able to do such predictions. One way to increase the level of knowledge is the performance of experiments in relevant geometries. Such experiments are in fact non-existing. In this light Christian Michelsen Research decided a few years ago to perform an experimental study of gas cloud build-up in a scaled version of an offshore module. The present paper reports on the results of these experiments.

Key words: offshore installations, dispersion, gas safety

INTRODUCTION

Recent full-scale explosion experiments carried out in a rig of 25.6 m x 8 m x 8 m show that there is a potential of generating very high and therefore damaging pressures by gas explosions in homogeneous, stoichiometric gas clouds filling the entire module [1]. Predictions made by sophisticated explosion models such as FLACS [2] confirm the findings of the full scale explosion experiments and show that this potential also exists for other modules with different dimensions and/or layout. The potential pressures are such that it appears impossible from both a practical and economical point of view to build modules to withstand such pressures.

The starting point of the experiments and worst case studies performed with explosion models: a stochiometric homogeneously mixed gas cloud filling the entire module, is unlikely to occur under realistic circumstances. In reality the flammable part of a gas cloud is more likely to be non-uniform in concentration, filling only a part of the module. The most common cause for a gas cloud build-up in an offshore module is a jet release. Due to the mixing in the jet itself the released gas is mixed with air. Further transport into the module occurs either due to a recirculation in the module resulting from the jet or by the ventilation.

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Explosions due to non-homogeneous gas clouds filling only a part of a module are expected to give rise to lower explosion overpressures than those expected from homogeneous, stoichiometric clouds in the same module as described above. It should be remarked, however, that turbulence generated by especially the jet release may enhance the explosion.
In the light of the findings of the full scale explosion experiments, predictions made by sophisticated models and the expectations regarding non-homogeneous clouds there exists a need to be able to predict the consequences of gas explosions for realistic conditions.

The first step in such an approach is to understand the processes involved in the build-up of gas clouds in offshore modules. As already indicated in [3] the processes involved in dispersion in congested semi-confined volumes such as offshore modules are not fully understood. In addition to that there is a lack of experimental work performed to study dispersion processes in congested rooms representative for offshore geometries. Some years ago Christian Michelsen Research performed an experimental study of gas cloud build-up in a scaled version of an offshore module.

This paper presents some of the main results these experiments revealed and the main conclusions resulting from this work.

EXPERIMENTAL SET-UP

The experiments were performed in a 1:5 scale representation of a compressor module The module is 8.0 m long, and has both a height and width of 2.5 m. The module contains a deck plate positioned 1.25 m above the floor. This deck plate is solid with some grated areas. In the rig there are several obstacles representing the main equipment in the compressor module such as the compressors themselves and two control rooms at the deck plate (See Figure 1). The internal volume is 50 m^3.

In the present experiments the roof, floor and the two long sides of the module were solid. The remaining two walls of the module, the south and north end, were covered by standard weather louvre walls. One of the two long side walls was made of with a transparent plexiglass wall to allow for filming of the dispersion process.

To be able to simulate natural ventilation in the module a fan was attached to the north end of the module. The fan was connected to the module by a flow diverter made out of plastic sheeting held by a steel framework. The fan speed was variable. The experiments were performed for bulk wind speeds of 0 m/s, 0.3 m/s, 0.6 m/s and 1 m/s.

The fuel, gaseous methane or propane, was released into the module from a 3 m^3 tank. For methane initial pressures in the tank of mainly 10 and 20 bar were used. In tests using propane initial pressures of 5 and 7 bar were used. The pressure in the tank was not maintained and hence the pressure in the tank gradually decreased simulating a blowdown situation. The release point was primarily in the centre of the module at the upper deck. The orifice diameter was either 4 mm, 10 mm or 20 mm. Three main jet directions were used: up, upwind and downwind.

The fuel concentration was monitored continuously using 10 aspirating hot wire probes (type 55P99S with a 5 µm Pt-plated Tungsten wire (Dantec)). Six probes were located on the upper deck while four probes were located at the bottom deck. The locations are indicated in Figure 1. The probes were located at either 0.2 m, 0.7 m and 1.0 m above the lower and upper deck, respectively. In each experiment the height of all probes was similar. The height was varied in between the experiments. The signals from the probes were amplified, conditioned and recorded on a digital acquisition system.

RESULTS

The results of the tests are presented for each of the varied parameters.

Effect of release direction

The accumulation of gas inside the module is strongly dependent on the relative direction of the jet release to the ventilation flow in the module and the possible interaction of the jet with equipment or walls.

If the jet release is parallel and in the same direction as the ventilation flow and the jet does not impact on any equipment the flammable part of the cloud will have a cigar shape with large concentration variations [4]. However, when the jet interacts with obstacles, pipes or vessels a different flow pattern is formed completely changing the concentration pattern of the gas inside the module. A typical example of this is a test where a jet release occurred from the centre of the module at the upper deck. The release occurred from a 20 mm orifice connected to the tank at a 10 bar overpressure (methane). The jet was pointing downwind (0.6 m/s wind speed). All probes were located at 0.7 m above the lower or upper deck. In the experiments the upwind located probes C1, C2 and C7 and also C8 (see Figure 1) at the lower deck did not indicate any gas. The highest concentration was measured at C6 (12.3 % v/v) which is located exactly in the downstream direction of the point of release. A high concentration was also measured at C5 (10.7 % v/v) indicating a recirculation flow probably caused by the large obstacle located at the south-west corner of the upper deck (Figure 1). For comparison the probe located at more or less the same location on the other side of the centreline of the jet measures a maximum concentration of 4.1 % v/v. The recirculation flow causes a concentration at the location of probe C3 of 2.7 % v/v. This probe is located upwind from the point of release.

Pointing the jet perpendicular to the wind direction results in a more uniform gas distribution across the entire module. The main reason for this is the fact that the jet impacts on the roof of the module, causing large vortices with dimensions in the order of several meters. An example is a test using methane where a 20 bar tank pressure was released through a 20 mm nozzle pointing upwards. All probes were located at height of 0.7 m from the respective decks. At the upper deck, where the release occurred, maximum concentrations of 49.5 % v/v, 41.4 % v/v, 45.8 % v/v 48.7 % v/v and 38.5 % v/v were measured at C2, C3, C4, C5 and C6 respectively (See Figure 1). At the lower deck, however, lower maximum concentrations were measured (8.9 % v/v, 20.6 % v/v and 15.7 % v/v at C7, C9 and C10). The wind speed in the test was 0.6 m/s.

Figure 2 shows examples of concentration profiles measured in another test where the methane jet was pointing upwards (10 bar tank pressure, 10 mm orifice, 1 m/s wind speed). The Figure shows the concentration profile at two points located at the upper deck: C3 (located upwind of the release) and C6 (located downwind). The concentration profiles are fairly similar showing almost identical increases and decays indicating that jet releases can result in at least locally almost uniform gas distributions in an offshore module.

Pointing the jet release opposite to the wind direction resulted in an even gas distribution in the module as well. An example is a test where methane was released from a 20 mm orifice pointed against a 0.6 m/s wind. This test resulted in maximum concentrations at the top deck of 22 % v/v, 14 % v/v, 14 % v/v, 11.7 % v/v, 15 % v/v and 10 % v/v at probes nos. C1 to C6 respectively. In the lower deck area gas was only monitored in the south part of the module (9 % v/v at C9 and 11 % v/v at C10). The main reason for this pattern (no gas in the lower deck area on the upwind side) must be fresh air being sucked in from the lower deck through the grating into the jet at the upper deck at this end of the module. On the downwind side of the module gas can ingress into the lower deck area. The probes were also in this test at 0.7 m from the respective decks.
Similar tests were carried out where the height of the probes was varied. A result is shown in Figure 3 where the concentration profile is measured at the same location (C4) but at two different heights, 0.2 m and 0.7 m from the upper deck. Also this result shows the uniformity of the mixture in the rig due the mixing process when the jet is pointed against the wind.

Effect of wind speed

The accumulation of gas inside a module in case of an accidental gas release will to some extent also be dependent on the ventilation of the module. Performing tests with similar leak conditions but varying ventilation demonstrates this. Choosing leak conditions where a methane jet is pointing upwards leaking from a 20 mm nozzle connected to a 10 bar reservoir and average bulk flow velocities through the module of 1 m/s, 0.6 m/s and 0 m/s we see that for the highly ventilated module the sensors at C1 and C2 (upper deck, upwind side) do not notice any gas. The other sensors on the upper deck measure concentrations in the range of 17-23 % v/v. A wind speed of 0.6 m/s results in the cloud engulfing the entire upper deck. The gas concentrations were relatively uniform as well reaching values of 20-30 % v/v on the upper deck. In the non-ventilated case the gas concentrations are very uniform as well but much higher than for the 0.6 m/s wind speed case, viz. 40-50 % v/v.

Figure 4 presents gas concentrations for these three tests measured at probe C5. The Figure shows that the initial phase of gas build-up at this location is very similar demonstrating the dispersion process at this location is entirely dominated by the jet itself. The rate of concentration increase for the unventilated case decreases due to lower flow rates from the nozzle as the driving pressure in the tank decreases but since gas is not carried away by ventilation the concentration will keep on increasing as long as gas is released into the module. For the ventilated cases the gas concentration will increase only as long as the leak rate is larger than the amount of gas which is carried away by the ventilation. When these two are equal the maximum concentration is reached followed by a continuous decrease.

The effect of ventilation is also shown in Figure 5. The Figure shows a concentration profile measured at C1 during a methane release from a 10 bar reservoir through a 20 mm nozzle. A wind speed of 0.6 m/s is applied. After the concentration has reached an equilibrium state, i.e. when the gas supply equals the outflow of gas due to ventilation the gas leak is suddenly closed off. After shut off the gas concentration drops quite rapidly, showing the effectiveness of the ventilation. Then after 25 s this event is repeated, but now the peak concentration is somewhat lower due to reduced pressure in the methane reservoir and thereby reduced mass flow through the nozzle.

Effect of gas density

The majority of the experiments performed in the present investigation were performed using methane as a flammable gas. Some experiments were performed with propane. A direct comparison between methane and propane is not possible since different release rates were applied.

All of the tests performed with propane gave a relatively even distribution of the fuel in the upper deck area of the module. The concentration levels varied accordingly the ventilation rates in a similar manner as the methane tests Also for a no wind condition peak concentrations at the upper deck varied from 8-20 % v/v (lower release rate than used for methane). These findings indicate that the buoyancy forces are too small to drastically change the gas distribution as long as the jet is present, i.e. the jet jet will dominate the mixing and dispersion process of the gas irrespective of the density of the gas.

Effect of release rate

Some tests were performed varying the leak rate. It appeared that the size of the cloud varied accordingly the leak rate. Tests performed for a wind speed of 0.6 m/s with leaks pointing upwards from 10 mm and 20 mm nozzles (methane, reservoir pressure 10 bar) show the following. For the test using a 20 mm nozzle a relatively uniform concentration is found in the upper part of the module with concentrations varying from 21-26 % v/v. With smaller leak (10 mm nozzle) the gas concentration is lower, approximately 10 % v/v, and the cloud does not reach the upwind end of the module. This indicates that the overall gas concentration in the flammable part of the cloud is dictated by the release rate as well as the size of the cloud. The homogeneity of the cloud, however, appears independent from the release rate.

CONCLUSIONS

From the work presented above the following conclusions can be drawn:

- For a medium and large jet release the dispersion in the module is dominated by the jet, while the actual gas concentration level is depending on natural ventilation
- For a small jet both the dispersion and gas concentration are dominated by natural ventilation
- The general trend of the experiments was that the gas concentration was very homogeneous and showed less spatial variation than previously anticipated
- In the presence of a moderate natural ventilation both propane and methane disperse in a similar manner.

These conclusions imply that with regard to the use of more realistic scenarios one should reckon with more homogeneous and larger clouds than previously anticipated. Even relatively small releases can give rise to relatively large combustible clouds in congested, ventilated enclosures.

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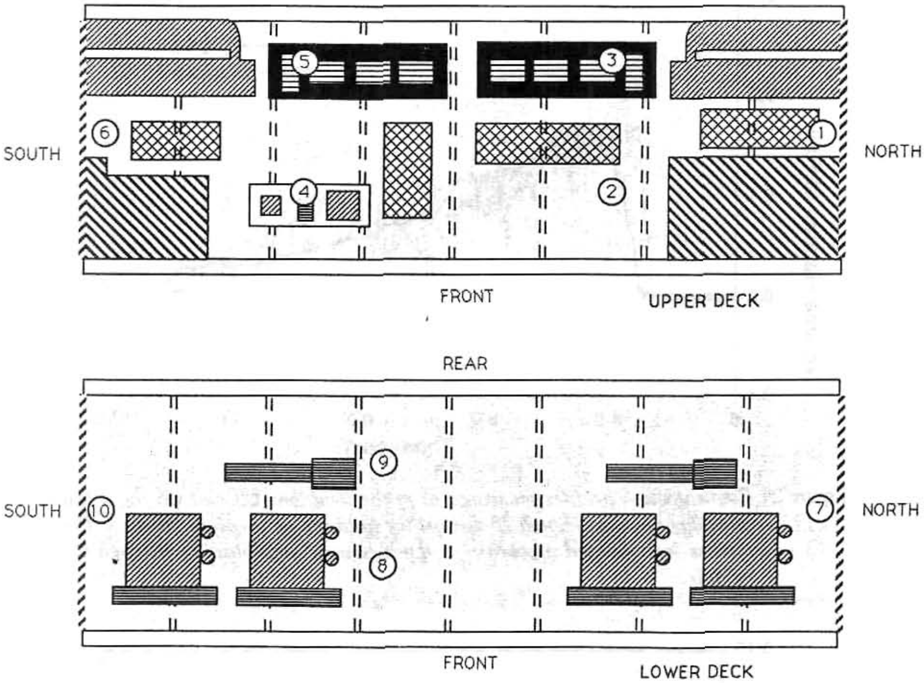

Figure 1 *Footprint of equipment located on the two decks of the compressor module used for dispersion experiments.*

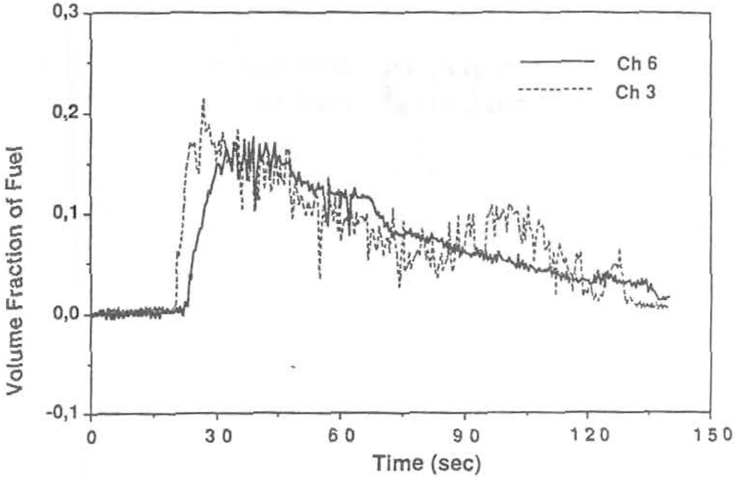

Figure 2 *Concentration profiles measured at probe locations C3 and C6 for a test releasing methane from a 20 mm orifice (initial tank pressure 10 bar). The release was pointed upwards. A 0.6 m/s wind was blowing through the module.*

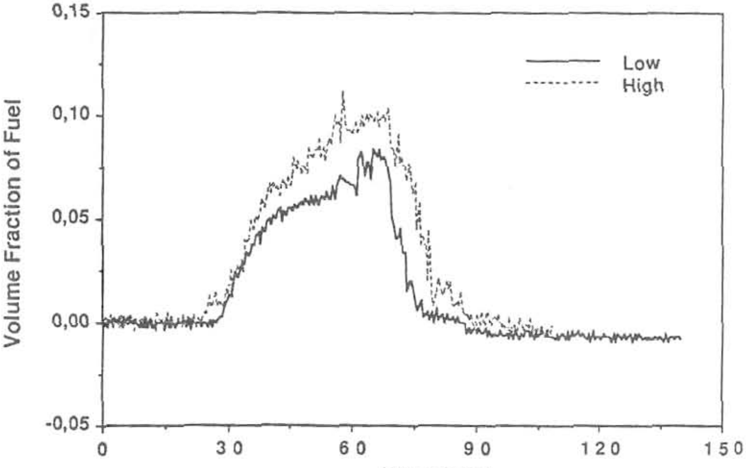

Figure 3 *Concentration profiles measured at probe location C4 in two different tests with similar test conditions (methane, tank pressure 10 bar, orifice size 20 mm pointing against the wind, wind speed 0.6 m/s). The probes in these tests were mounted at 0.2 m ("Low") and 0.7 m ("High") from the upper deck.*

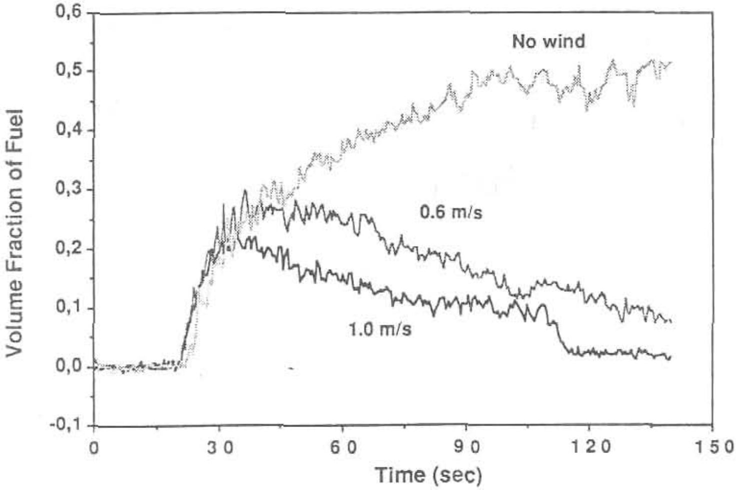

Figure 4 *Concentration profiles measured for three different wind speeds through the module (no wind, 0.6 m/s and 1 m/s). Leak conditions: methane, leak direction up, nozzle 20 mm, tank pressure 10 bar.*

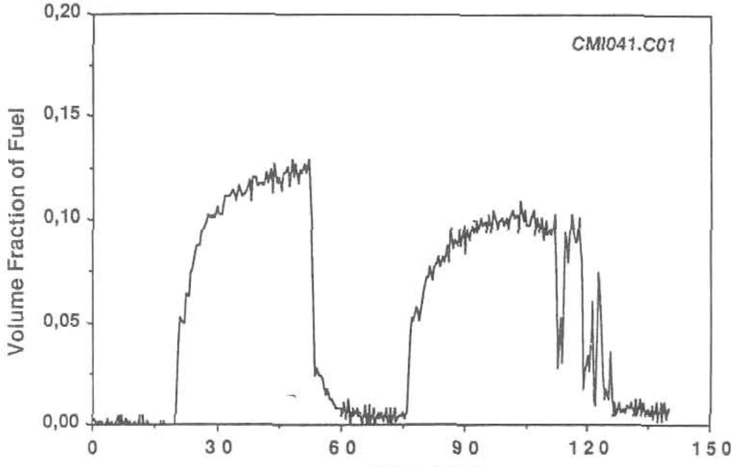

Figure 5 *Concentration profile measured at probe no. C1 during a test where a 0.6 m/s wind was blowing through the module affecting the cloud build-up resulting from a jet release pointed upwind from a 20 mm nozzle (methane, tank pressure 10 bar). The leak was stopped after 30 s, effected again after another 25 s and stopped again after another 40 s.*

Paper 9

Gaussian distribution matches experimental results for plume velocity & concentration profiles for very buoyant plumes.