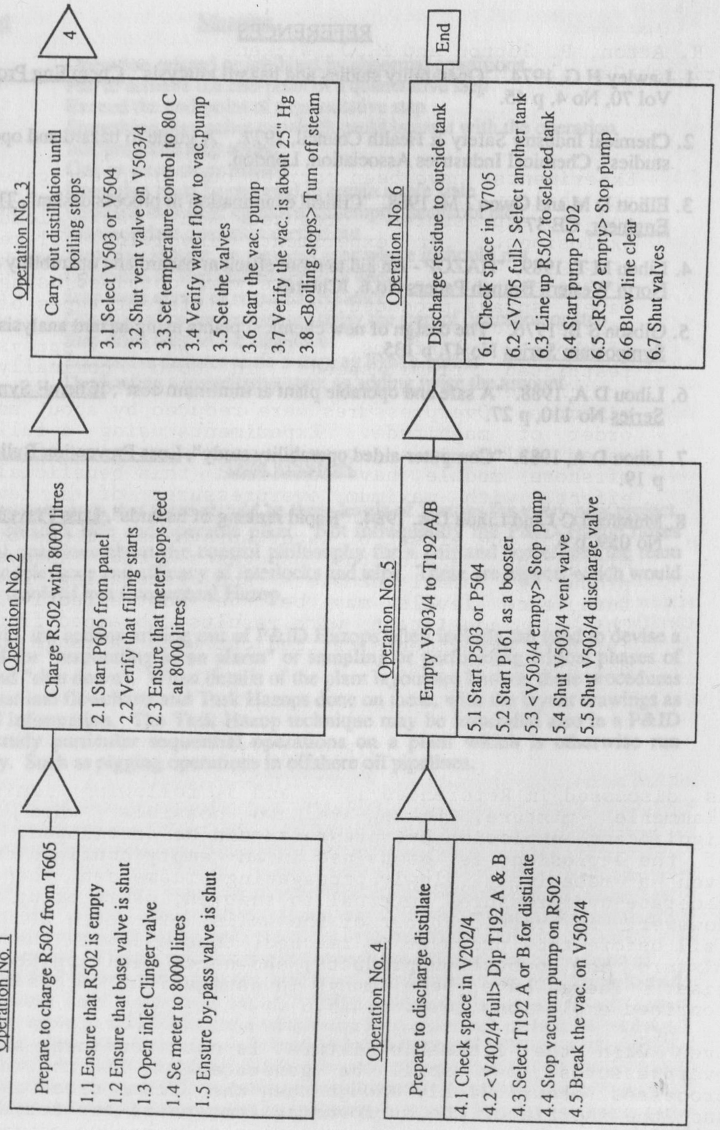

Fig.1 Flowchart of Distilling Crude Volatiles

Page 1 of 1

AN INVESTIGATION OF THE MITIGATION OF GAS CLOUD EXPLOSIONS BY WATER SPRAYS

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Experiments have been carried out to investigate the ability of water sprays to limit flame speeds and overpressures produced in gas cloud explosions. In experiments involving flame propagation through repeated arrays of pipework obstacles, successful results were obtained using water sprays produced by two different types of nozzle currently used in deluge systems on offshore platforms. These water sprays restricted flame speeds in both nominally stoichiometric natural gas-air and propane-air mixtures. Overpressures were reduced by about an order of magnitude. Experiments using a full water deluge in a geometry representative of an offshore module, have confirmed this beneficial effect, with maximum overpressures of a few hundred millibar being generated. A theoretical study of the effect of water sprays as a means of mitigating explosions suggests that sprays producing small droplets and generating low turbulence levels may be the most effective. This is consistent with results obtained from further experiments carried out with a range of different nozzles.

INTRODUCTION

As discussed in References 1, 2 and 3, following ignition of a flammable mixture, there are two possible ways in which significant explosion overpressures can be developed. Firstly, if the explosion is contained in an empty confined enclosure, even a relatively slowly propagating flame can theoretically generate overpressures internal to that enclosure of up to 8 bar. However, in practice, part of the walls of such a structure may fail before this pressure is reached, thus allowing the escape of mixture and combustion products, and hence limiting the pressure rise. There have been many investigations of such vented, confined explosions (e.g. 1,4,5,6).

Even when the flammable mixture is not confined, significant overpressures may still be generated. If the combustion processes occur quickly enough then the flame speed is enhanced and the inertia of the surrounding atmosphere creates sufficient restriction to the expansion processes to generate overpressures. The faster the flame travels, the higher the overpressure that is generated. Explosions of such a type have been known to occur when a large flammable cloud engulfs an area such as a chemical plant, and are known as gas or vapour cloud explosions. The explosion which occurred at Flixborough, in 1974, is a well known example of such an event.

Studies by British Gas (2) and others (7,8) have demonstrated that, during vapour cloud explosions, high flame speeds and overpressures are only generated by highly congested regions of plant which contain a large number of obstacles, such as areas of closely packed pipework etc. Such areas are, however, inevitably present on offshore platforms where space is at a premium. It is important, therefore, to investigate ways in which explosion overpressures might be reduced.

THE POSSIBLE MITIGATION OF EXPLOSIONS

A common approach to mitigating confined explosions is to vent the explosion using explosion relief panels. However, current confined explosion venting guidelines can only be applied with confidence to empty volumes which are no larger than 200-300 cubic metres, which have smooth walls, and in which the flammable atmosphere can be assumed quiescent at the time of ignition. Offshore modules will generally have greater volumes than those used to validate current venting guidelines. In addition, offshore modules may contain many items of equipment and pipework, which in the event of an explosion will cause turbulence, resulting in an increase in explosion flame speeds and overpressures, to levels higher than those implicit within current venting guidelines. In particular, available information suggests that in offshore modules containing extensive amounts of equipment and pipework, the flame speeds could reach such high values that the vent area at the perimeter of the module may cease to have much influence on the explosion overpressures developed.

In situations involving high speed flame propagation, studies carried out by British Gas have shown that the flame can be deflected by a solid barrier. This suggests that the use of techniques whereby flame propagation is directed out of a highly congested area into an area of low congestion, may be possible in some circumstances. However, the most inherently safe approach to mitigating explosions is to ensure that high flame speeds and overpressures are not generated at all.

Such approaches fall into two categories. Firstly, there are non-triggered (or "passive") mitigation techniques, which generally utilise the kinetic energy of an explosion to disperse an extinguishing agent or suppressant. Secondly, there are "active" mitigation techniques in which the release of suppressant is triggered as a result of gas or flame detection.

Substances used as suppressants may achieve a reduction in gas explosion overpressures by reducing the reaction rate via one or more of the following mechanisms:

(i) Removal of heat from the flame (e.g. water, flame arresters).

(ii) Chemical interference with the combustion process (e.g. halons, inhibitor dusts).

(iii) Dilution of the gas-air mixture (e.g. nitrogen, carbon dioxide).

Passive explosion barriers are an attractive alternative to triggered suppression systems because they require less maintenance and are unlikely to operate accidentally. They are an established method of explosion protection in coal mines, where they are used against coal dust-air explosions and usually take the form of tubs or troughs filled with water, arranged such that the blast wave preceding the flame in an explosion tips (9, 10) or shatters (11, 12) the container. An alternative type of passive explosion barrier is the flame arrester, widely used to protect pipes carrying flammable gases. Flame arresters generally consist of a metallic assembly containing narrow passages or apertures through which gases can flow, but which prevent the passage of a flame (13). However, in preliminary experiments carried out by British Gas, neither flame arresters, nor a static distributed inhibitor dust (ammonium phosphate) barrier nor a static distributed water barrier were effective at reducing significantly the flame speeds and overpressures associated with flames propagating at high speed through regions of congested pipework.

Active mitigation systems (14, 15), triggered during the early stages of an explosion, can reduce its consequences provided that the explosion is detected early enough, and action taken sufficiently quickly. Commonly used systems involve the release of halons, inhibiting dusts or diluents. However, such suppressants may present a hazard to personnel, and other practical considerations may also preclude the use of such systems on offshore platforms. For example, an optical system could require many detectors in order to prevent the initial flame development being obscured in a highly congested region. Also, flame speeds could be so high that the response of any system would need to be measured in fractions of a second. In addition, once triggered, any system would need to continue operation for the full duration of any gas release. These requirements may not be achievable in practice and so consideration must be given to the mitigation of the explosion before ignition has occurred.

Earlier research carried out by British Gas (2) identified the activation of water sprays before ignition as a potential way of mitigating the effects of explosions. In this work a natural gas flame, travelling at over 500m/s through repeated obstacles, was decelerated by a water spray curtain to a low speed at which only low overpressures were generated. As part of existing safety systems, offshore platforms are fitted with water deluge sprays to drench gas processing and production areas in the event of fire. Therefore, these experiments suggested that the deluge systems might provide a potential mitigation measure, if initiated on detection of a gas release.

A short experimental programme was, therefore, carried out at the British Gas Spadeadam test site to assess the ability of water deluge systems, such as those already present on British Gas platforms, to mitigate gas cloud explosions.

THE EFFECT OF WATER SPRAYS ON GAS CLOUD EXPLOSIONS

The initial experiments described below were conducted to investigate the effect on a gas cloud explosion of water sprays produced using nozzles of types used as part of the deluge systems on British Gas offshore platforms. The results of these tests, together with a theoretical analysis of the ways in which water sprays may affect flame propagation, suggest that it may be possible to design nozzles to produce sprays which have a greater potential for mitigating gas cloud explosions. Therefore, further experiments were conducted in a piperack to investigate the mitigating effect of a number of different nozzle designs. Finally, experiments were conducted to investigate the effect of a full water deluge on a gas cloud explosion, under conditions more characteristic of those present in an offshore module. In all the experiments, the water sprays were activated approximately one minute prior to ignition of the mixture.

Experiments with Nozzles used in Offshore Water Deluge Systems

These experiments were performed to study the potential of water sprays produced by two nozzle types used in water deluge systems on British Gas platforms, to mitigate explosion overpressures. The tests were designed to assess the potential of these sprays either to restrict the acceleration of a flame, or to promote the deceleration of a flame already propagating at high speed in a natural gas-air mixture. In addition, experiments were conducted to investigate the effect of water sprays on the acceleration of a flame propagating in a propane-air mixture.

The experiments were performed in the enclosure shown in Figure 1. The initial confined region was up to 15m in length, and promoted rapid flame acceleration so that a high speed flame was produced. The remainder of the enclosure consisted of a long open region formed by a steel framework covered with transparent polythene sheet to contain the flammable mixture, prior to ignition by a spark.

Obstacle arrays formed from 3m lengths of either 0.18m diameter pipes or 0.18m wide planks, arranged to give an area blockage ratio (the blocked area divided by the full cross-sectional area of the obstructed region) of 42%, were located in the initial confined region and along the length of the enclosure at spacings of 0.5 or 1.5m.

The tests were conducted using natural gas or propane (see Table 1) at nominally stoichiometric concentrations, and were

filmed by high speed cine cameras. Overpressure/time profiles were measured by piezo-electric transducers located inside the test enclosure.

Four tests were carried out in which the number, type and location of water deluge sprays were varied as detailed in Table 1. Two different types of water spray nozzles were used; a 10mm Open Pendant sprinkler with a K factor of 56, (the K factor is defined as $Q/\sqrt{P}$ where Q is the flowrate in litres/minute through the nozzle at a gauge pressure P measured in bar) and a Type 126 high velocity water spray nozzle with a K factor of 43.8. These nozzles are part of water deluge systems which have typical water supply pressures of between 2 and 4 bar and so, to ensure that the conditions in the tests were similar to those in practice, water was supplied to the nozzles at a pressure of approximately 3 bar (measured under flow conditions). For the Open Pendant nozzle, mounted 3m off the ground, and for a water pressure of 3 bar, the spray cone angle (at the nozzle) was about 160° and the spray covered an area of radius approximately 4m at ground level. The Type 126 nozzle produced a narrower spray, with a cone angle of about 90°. From a height of 3m the spray covered an area of radius 3m at ground level. In the experiments, the nozzles were spaced at either 2.5 or 3m (similar to typical nozzle spacings which are used in British Gas offshore platform deluge systems).

A summary of the experimental conditions for the four tests carried out with water sprays is given in Table 1. Details of a natural gas test and a propane test which were conducted without any method of mitigation are also included. Overpressure data is given in Table 2. The main results obtained from these experiments are summarised below.

1. A natural gas test (Test 1), performed without water deluge sprays, showed that in the absence of any method of mitigation, a sustained high speed flame, travelling at an average speed of about 500m/s, was generated, which produced overpressure peaks of greater than 10 bar. In a propane test (Test 2), also conducted without water sprays, a transition to detonation occurred approximately 15m from the spark, resulting in flame speeds of about 1800m/s and peak overpressures of over 30 bar.

2. Water sprays produced by Open Pendant type nozzles, located only in the initial confined region, reduced flame acceleration in a natural gas-air mixture (Test 3) and prevented detonation of a propane-air mixture (Test 4), thereby restricting the overpressures produced to 0.35 and 1.7 bar respectively. These overpressures were more than an order of magnitude lower than were measured in the absence of water sprays.

3. Water sprays produced by Type 126 nozzles, located only in the initial confined region, also reduced the acceleration of a flame in a natural gas-air mixture (Test 5), but were not as effective as the sprays produced by the Open Pendant type nozzles. The maximum overpressures generated in the

test using Type 126 nozzles were only reduced to approximately 1 bar, compared to 0.35 bar using the Open Pendant nozzles.

4. Water sprays produced by Open Pendant type nozzles located over the full width of part of the congested region, successfully decelerated a flame propagating in a natural gas-air cloud, from an average speed of about 500m/s to an average speed of less than 100m/s (Test 6). The flame speed/distance profile obtained from cine film analysis of this test is given in Figure 2. Flame speeds remained low within the region of water sprays, but the flame reaccelerated to high speeds once it emerged from this region. (N.B. The reacceleration of the flame in this particular test was due to the obstacles being more closely packed than in the other five tests.)

Theoretical Considerations

The results of the above experiments show that water sprays can reduce the flame speeds and overpressures generated in gas cloud explosions. However, in order to optimise the design, location and operation of water spray systems for explosion mitigation, it will be necessary to understand the mechanisms responsible for such effects.

The overpressure generated in an explosion is influenced by both the expansion ratio of the combustion process (i.e. the density ratio of burnt to unburnt gas) and also by the rate of production of burnt gas (i.e. the reaction rate at the flame front). Any reduction in explosion overpressures resulting from the use of water sprays must be through their effect on one or both of these factors.

The maximum reductions in the expansion ratio which could be produced by the water sprays used in the tests above have been estimated, based on a maximum value of 2×10^{-4} for the water volume fractions of the sprays (i.e. the ratio of the volume of water within the spray envelope to the total volume of the spray envelope), obtained from simple jet spray modelling. (N.B. Detailed measurements of the characteristics of these sprays have yet to be made, but this calculated maximum value is consistent with the results of preliminary measurements.) Even assuming that all of the energy required to evaporate the water within the spray envelopes was removed from the combustion products, the reduction in the expansion ratio was calculated to be approximately 18%. Assuming that the overpressure generated is simply proportional to the square of the flame speed (and therefore to the square of the expansion ratio), this would reduce overpressures by approximately 30%, a much smaller effect than that observed in the experiments described above. Thus, the reduction of the expansion ratio as a result of cooling of the combustion products does not appear to be the only mechanism by which water sprays lessen the violence of such an explosion.

The other mechanism by which water droplets might reduce flame speeds and overpressures is by "quenching" the combustion process. If a sufficiently large number of droplets can evaporate rapidly enough on passing through the reaction zone then they could potentially reduce reaction rates. Using available droplet evaporation models and accepted temperature profiles across a laminar flame, the calculated maximum diameter of water droplet that could be completely evaporated on passage through the reaction zone of a laminar natural gas-air flame is approximately 30μm. Current models treat a turbulent flame as a collection of laminar flamelets, which suggests that the above value of 30μm would also be appropriate for the turbulent flames in the experiments described above.

Preliminary measurements suggest that the droplet sizes produced by the Type 126 nozzle and the Open Pendant nozzle are similar; Sauter mean diameter (D_{32}) approximately 900μm. (The Sauter mean diameter is the diameter of a droplet having the same volume to surface area ratio as the total volume of all of the droplets to the total surface area of all of the droplets.) Thus, if the above analysis is valid, it might appear that the water droplets produced by these nozzles should have been too large to be effective in mitigating explosions. The reason for their apparent effectiveness can, perhaps, be explained by the fact that large droplets tend to break up into smaller ones if they are accelerated. Thus, in the flow-field ahead of the flame, it is possible that the large droplets produced by the nozzles were broken up into much smaller droplets, which then interacted with the combustion process and reduced the reaction rate.

It is important to note that in explosions involving either no or few obstacles, the turbulence field of the water sprays themselves could increase the severity of an explosion by enhancing the combustion rate. This effect was evident in the experiments described above. Comparison of the times after ignition at which the flame emerged from the initial confined region in tests with and without the water deluge operating (taken as the time of peak overpressure generation at the first transducer), show that the flame emerged from the initial confined region earlier in the tests with the active deluge, even though the peak flame speeds and overpressures were significantly lower. Simple calculations suggest that r.m.s. turbulence velocities of approximately 0.8m/s would be generated by the deluge systems tested and the work of Bradley (16) would imply a doubling of the burning velocity in this situation over that under non-turbulent conditions. This would be consistent with the halving of the time after ignition for the flame to emerge from the initial confined region in the tests with the active deluge, since the time taken for the flame to reach the first array of obstacles within the confined region accounts for most of the time between ignition and the emergence of the flame.

Overall, although the turbulence generated by the large water droplets in the sprays tested actually increased the flame speeds in the early stages of the explosions, it may be possible to design a nozzle with the same water volume fraction but which will generate lower turbulence levels and smaller droplets, and thus be more effective at flame quenching. However, the relationship between droplet size, distribution and the flow and combustion processes is a complex problem requiring further investigation before the ways in which water sprays affect the explosion process can be fully explained. However, experiments have been conducted to investigate the ability of water sprays produced by a range of different nozzle designs to mitigate gas explosions. These are described in the following Section.

Experiments using Different Types of Water Sprays in a Piperack

The aim of these experiments was to compare the ability of curtains of water sprays produced by three contrasting types of nozzle to decelerate a high speed propagating flame. They were conducted in an obstructed region approximately 25m long x 4.7m wide x 2.5m high (Figure 3), which consisted of a piperack typical of that on onshore chemical process or storage sites, but linearly reduced in scale.

Polythene sheet, supported away from the congested region by steel arches was used to contain the flammable mixture prior to ignition at one end of the piperack. Ignition was by either a high speed flame jetting into the piperack or a single low energy spark.

The high speed mode of flame propagation is characterised by the flame front travelling at the same speed and together with a leading shock wave. Previous work by British Gas (2) has shown that in order to significantly reduce overpressures, the flame needs to be decoupled from the leading shock wave. In order to compare the performance of different sprays, the minimum numbers of rows of sprays (positioned across the piperack, 0.5m apart, with each row containing nozzles at 0.5m spacings) required to decouple the flame front from the leading shock wave was determined. Because these experiments were conducted at a reduced scale, smaller nozzles and a smaller nozzle separation were used than in the previous tests.

The three nozzles chosen for these tests were:

(i) A 120° "full cone" type, which produces a uniform distribution with a Sauter mean diameter, D_{32}, of approximately 480μm at the 3 bar operating pressure used in these tests. The water flowrate for this nozzle type is approximately 12 litres/minute at 3 bar.

(ii) A 120° "flat jet" type, which produces a sheet-like distribution of water, with a similar droplet size distribution and water flowrate to the full cone nozzles.

(iii) An atomising type twin fluid nozzle, which mixes pressurised gas with the water inside the nozzle to produce a fine mist. Preliminary measurements suggest that this nozzle type produces a water distribution with a Sauter mean diameter, D_{32}, of approximately 100μm at the supply pressures used (2.5 bar for both water and air). Under

these conditions the water and air flowrates are approximately 5 litres/minute and 20 m^3/hour respectively.

The experimental arrangements for the tests carried out are indicated in Table 3, and the main results are summarised below.

1. The abilities of the sprays produced by the full cone and flat jet nozzles to decelerate a high speed flame were very similar. For both types, two rows of nozzles, 0.5m apart, were able to decelerate a flame, propagating at an average speed of over 400m/s, sufficiently to separate it from the leading shock wave. However, for both types of nozzle, a single row of sprays failed to decelerate the flame significantly.

2. The atomising nozzles were more effective than the full cone and flat jet nozzles, with a single row of sprays being sufficient to decouple the flame from the leading shock wave and decelerate the flame.

3. In tests ignited by a single spark, full cone type sprays, positioned 1m from the spark, did not significantly increase flame acceleration above that observed in equivalent tests conducted without water sprays.

These results demonstrate the ability of a curtain of water sprays to decelerate a high speed flame propagating in a gas cloud which engulfs a piperack structure. The limited data available suggests that the atomising nozzle (which produced the smallest droplets of the nozzles tested) was the most effective. This result is consistent with the conclusions of the theoretical study.

Because of the lack of confinement and the relatively low level of obstacle congestion in these tests, it is difficult for a flame, once decelerated, to return to a high speed. However, for an explosion in a structure containing a greater density of obstacles such as pipework or greater confinement, a discrete curtain of sprays might be insufficient to prevent high overpressures, as flame reacceleration might occur. Therefore, in such cases, a series of water spray curtains or a complete water deluge would probably be needed to limit the overpressures produced. The following Section describes tests using a complete water deluge.

Experiments using a Full Water Deluge in a Representation of an Offshore Module

Four experiments were performed in a partially confined structure containing pipework congestion, designed to simulate, at a reduced scale, the geometry typical of an offshore module. The experimental enclosure, as shown in Figure 4, was 4m by 10m by 2.1m high, with two adjacent solid walls and a solid roof. During tests, the other two walls were covered with polythene sheet. The obstacles consisted of steel girders and pipework. The mean volume blockage was approximately 10%, which is representative of the degree of blockage typically found in offshore modules.

The experiments were performed using nominally stoichiometric natural gas-air mixtures, ignited by a low energy spark, positioned at half height either at the centre of the 10m wall or in the corner between the two solid walls. Two tests were unmitigated but in the other two tests a water deluge, covering the whole of the inside of the rig was used. For these tests, 36 nozzles were mounted in a 4 x 9 matrix at 1m x 1m spacings, approximately 0.25m below the roof. The nozzles used were of a 90° full cone type, operating at approximately 3 bar water pressure. The water flowrate through each nozzle was approximately 12 litres/minute. These nozzles produce a uniform spray distribution, with Sauter mean diameter, D_{32}, approximately 430μm. As in the tests described in the previous Section, smaller nozzles at a reduced spacing compared to those in actual deluge systems were used because of the reduced scale of the experiments.

Figure 5 shows a comparison between the overpressure/time profiles measured by a pressure transducer inside the test enclosure in mitigated and unmitigated tests ignited by a spark in the centre of the 10m wall. The plot clearly shows the reduction in overpressure generated when the water sprays were used; from 780mbar to 280mbar. However, the maximum overpressures occurred at between 200 and 240ms after ignition in the mitigated test, compared with approximately 300ms after ignition in the unmitigated test. This difference, as in the previous tests, was probably caused by the turbulence generated by the sprays enhancing the burning rate in the early phase of the experiment, as discussed earlier.

In the test conducted without water sprays and with ignition in the corner between the two solid walls, peak overpressures of several bar were recorded within the rig. In contrast, no overpressures greater than 250mbar were recorded when the equivalent test was conducted with the water deluge operating.

SUMMARY

Experiments have shown that a water deluge system which is active at the time of ignition could significantly reduce the flame speeds and overpressures generated in a gas explosion. Explosion tests were conducted with a stoichiometric natural gas-air mixture in an idealised rig configuration, using water sprays produced by two different types of nozzle, typical of those used for deluge systems on offshore platforms. These tests demonstrated that the water sprays were able to restrict the acceleration of a flame and to decelerate a flame already propagating at a high speed, thereby reducing the overpressures generated by about an order of magnitude. These water sprays were also shown to be able to reduce the overpressures generated by a propane-air explosion.

The theoretical study suggests that water sprays reduce the everity of gas explosions by a combination of cooling the combustion products and by lessening the reaction rate. The study also indicates that a water spray which consists of very small droplets and a high water volume fraction, but which generates only low turbulence, could be even more effective than the nozzles tested.

Experiments have also demonstrated that water sprays are an effective technique for mitigating the overpressures generated by explosions in a piperack geometry and in a representation of an offshore module. Tests in the piperack geometry, using spray curtains, showed that atomising nozzles, which produce much smaller water droplets than other nozzles tested, were the most effective in decelerating a flame which was already propagating at a high speed. This result is consistent with the conclusions of the theoretical study.

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TABLE 1: SUMMARY OF CONDITIONS IN TESTS WITH OFFSHORE NOZZLES

Test	Fuel	Conc. (%)	Length of Initiation Section (m)	Obstacle Spacing (m)	Water Sprays Type	Water Sprays Number	Water Sprays Distance from Spark (m)
1	NG	10.0	12.0	1.5	-	0	-
2	Prop	4.4	9.0	1.5a	-	0	-
3	NG	9.8	15.0	1.5	OP	5	1.5;4.5;7.5; 10.5;13.5
4	Prop	4.1	12.0	1.5b	OP	5	1.5;4.5;7.5; 10.5;13.5
5	NG	10.1	12.0	1.5	126	5	1.5;4.5;7.5; 10.5;13.5
6	NG	10.0	12.0	0.5 and 1.5	OP	3 pairs	26.5;29.7;32.9

a - obstacles between 6 and 28.5m from the point of ignition only
b - obstacles between 6 and 16.5m from the point of ignition only
NG - Natural Gas (92.5% methane, 6.5% ethane, others 1%)
Prop - Propane (over 98% pure)
OP - Open Pendant nozzle, 126 - Type 126 nozzle

TABLE 2: MAXIMUM OVERPRESSURES AND ARRIVAL TIMES IN TESTS WITH OFFSHORE NOZZLES

Dist from Spark (m)	Test 1 P	Test 1 t	Test 2 P	Test 2 t	Test 3 P	Test 3 t	Test 4 P	Test 4 t	Test 5 P	Test 5 t
16.2	13.0	551	-		0.35	266	1.7	296	0.95	281
23.0	2.8	569	-		0.19	293	0.47	312	0.48	301
26.6	-		47.4	539	-		-		-	
34.2	3.5	593	-		0.08	323	-		-	
40.0	-		35.4	546	-		-		-	
41.2	22	609	-		0.08	338	-		-	

P = Maximum Pressure in bar
t = Time of Arrival of Maximum Pressure in milliseconds
No pressure data was recorded in Test 6

TABLE 3: SUMMARY OF CONDITIONS FOR TESTS IN PIPERACK

Test	Ignition	Water Sprays Type	Water Sprays Number of Rows (3 nozzles per row)
7	Jetted Flame	Flat Jet	2
8	Jetted Flame	Flat Jet	1
9	Jetted Flame	Full Cone	2
10	Jetted Flame	Full Cone	1
11	Jetted Flame	Atomising	1
12	Spark	Full Cone	2

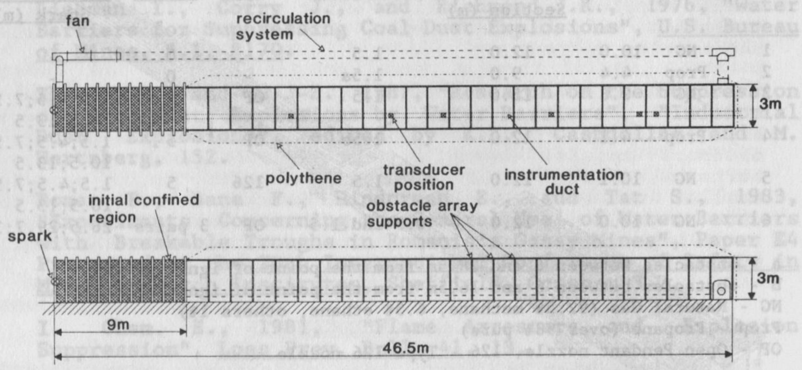

Figure 1: Diagram of test rig used for experiments using actual water deluge nozzles.

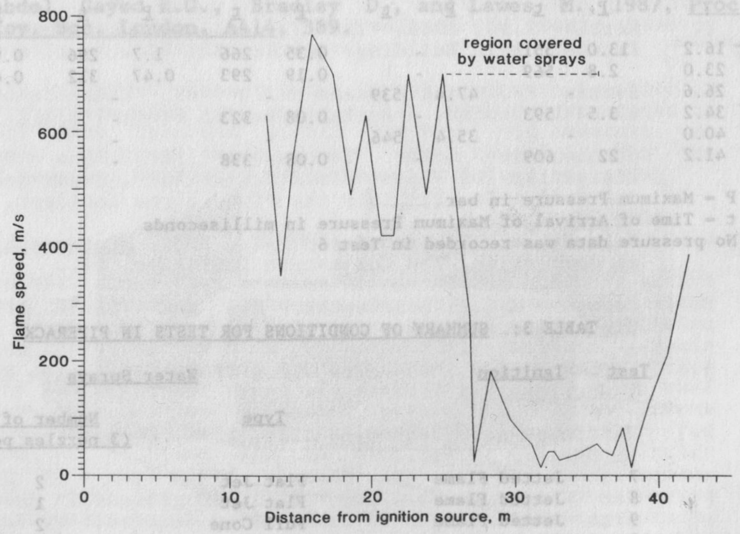

Figure 2: Flame speed/distance profile demonstrating the deceleration of a high speed flame by water sprays.

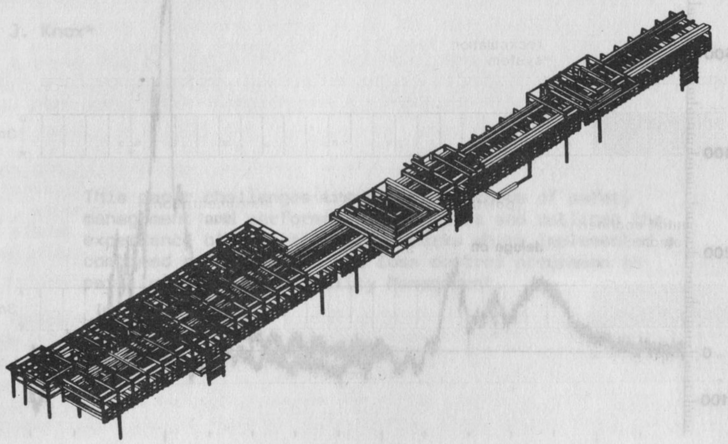

Figure 3: Schematic Diagram of Replica Piperack (length 25m).

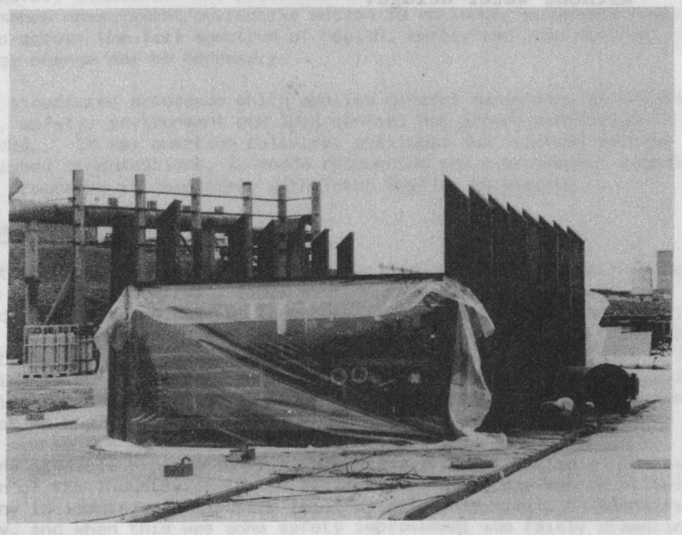

Figure 4: Photograph of rig used to represent an offshore module.

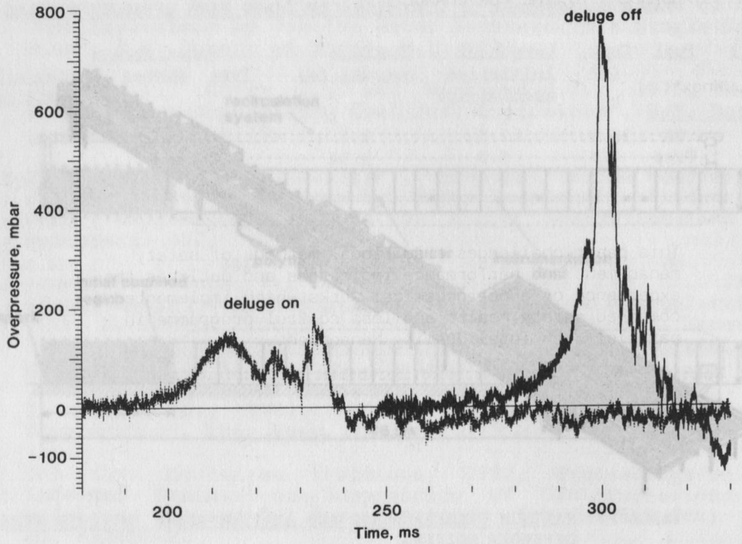

Figure 5: **Comparison of overpressure/time profiles recorded at the same transducer for equivalent tests with and without water deluge.**

SAFETY STANDARDS - A TIME FOR CHANGE

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This paper challenges traditional methods of safety management and performance indicators and outlines the experience of a petrochemical works which implemented a combined safety,health and loss control programme in parallel with Total Quality Management.

INTRODUCTION

Where safety standards have plateaued or the traditional approach of performance measurement/corrective action is no longer achieving sustained results across the full spectrum of health, safety and loss control, a strategy change may be necessary.

A structured programme which applies general management principles to health, safety, environment and loss control has proved beneficial in many instances. It may question cultures, attitudes and existing systems in established organisations, it needs resourcing and a management commitment. Such a programme is compatible with Total Quality Management.

Performance Measurement

It may be said that in many large companies handling chemicals today safety is 'out of control', since statistics show that although over the last 2 decades or so the number or frequency rate of incidents, has steadily reduced, it has perhaps now reached a 'plateau'. Safety Advisers are thus unable to predict whether next years performance standard will rise or fall. The situation is therefore not 'under control'. Also if we are preoccupied with Lost Time Accident Frequency Rate as the basis for safety performance we may well not be applying our remedial actions in the right areas.

One possible explanation for this state of affairs lies in the evolution pattern of the industry. In the early days, technology was relatively simple and many incidents were hardware related, generally simple to identify and to rectify, and when this was done safety improvement was fairly dramatic. (See Fig 1)

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