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Review of explosion mitigation measures for platform legs

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EXECUTIVE SUMMARY

Objectives

There have been a number of instances on offshore installations where an accidental release of hydrocarbons has resulted in the accumulation of a flammable atmosphere within one of the legs of the platform. Concerns have arisen that if there was an ignition and explosion within a platform leg, which is essentially a confined volume, there is the potential for an explosion that is powerful enough to cause serious structural damage to the leg and in the worst case scenario the collapse of the platform.

In response to these concerns the Offshore Safety Division of HSE have asked HSL for assistance with looking into the problem. As a first step a review has been commissioned with the following objectives:

- To review the specific explosion hazards associated with a flammable vapour or liquid release into the leg of an offshore platform

- To review existing methods of explosion prevention and protection and new methods currently under development, and assess their suitability for employment in platform legs.

- To make recommendations on suitable explosion prevention and protection measures for platform legs and for further work that may be required to validate their effectiveness.

Main Findings

A release into a platform leg is likely to produce a highly non-uniform gas cloud, with the highest gas concentrations being in the lower half of the leg, which may not completely fill the leg. Concentrations near the bottom of a leg may well be above the upper explosion limit (UEL). Ignition of such a gas cloud, depending on the extent of the gas cloud and the concentration distribution, could result in an explosion or a flash fire. Following an initial explosion the possibility of a secondary explosion or flash fire, as a result of further mixing of the gas cloud above the UEL induced by the initial explosion, needs to be considered.

Of the established mitigation measures explosion suppression or a triggered explosion barrier are considered the best suited for protecting platform legs. Before either technique can be employed with any confidence it needs to be demonstrated that they will be effective in the large elongated volumes typical of those found in platform legs and that the vertical orientation of a leg will not reduce the effectiveness of the technique. The orientation of the leg is likely to be of more significance to an explosion barrier, where the effect of gravity will be to spread the injected suppressant down the leg rather than in a concentrated “curtain” spanning the cross-section of the leg.

Of the emerging technologies explosion suppression by blast-induced atomisation from water containers has the potential for use in platform legs. To date this technique has only been tested at small and medium-scale, so considerable development work would be required to prove its feasibility, effectiveness and reliability in large vertically orientated confined volumes typical of platform legs and to establish its operating characteristics.

1 INTRODUCTION

There have been a number of instances on offshore installations where an accidental release of hydrocarbons has resulted in the accumulation of a flammable atmosphere within one of the legs of the platform. A recent example is the release that occurred in the Brent Bravo platform that led to an accumulation of vapours in the utility shaft and the death of two workers as a result of inhalation of the vapours. Fortunately in this incident and the other releases that have occurred there was no ignition. Concerns have arisen that if there was an ignition and explosion within a platform leg, which is essentially a confined volume, there is the potential for an explosion that is powerful enough to cause serious structural damage to the leg and in the worst case scenario the collapse of the platform.

In response to these concerns the Offshore Safety Division of HSE have asked HSL for assistance with looking into the problem. As a first step a review has been commissioned with the following objectives:

- To review the specific explosion hazards associated with a flammable vapour or liquid release into the leg of an offshore platform

- To review existing methods of explosion prevention and protection and new methods currently under development, and assess their suitability for employment in platform legs.

- To make recommendations on suitable explosion prevention and protection measures for platform legs and for further work that may be required to validate their effectiveness.

This report presents the findings and recommendations arising from the work undertaken to fulfil the above objectives.

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2 EXPLOSION SCENARIOS

A platform leg is essentially a strong elongated confined enclosure. Though the access points at the top of the leg will provide some explosion relief, the area of the openings compared to the internal volume are so small that any venting of the explosion will be negligible. Thus given the worst case scenario of a near uniform and stoichiometric hydrocarbon vapour/air throughout the leg an ignition could result in an explosion generating an explosion overpressure of the order of 8 bar. This is likely to be more than enough to cause failure of even a strong structure like a platform leg.

The geometry and internal structure of a leg will also tend to promote a faster explosion, ie increased rate of pressure rise, compared to an empty compact enclosure of the same volume. The large length to diameter/width ratio of legs means long flame paths and the potential for the flame to accelerate as the flame front propagates through the leg. The presence of equipment or structures within the leg will generate turbulence, as the gas pushed ahead of the flame front flows over the obstacle, which will increase the rate of combustion and thus accelerate the flame front. In general the net effect of increased flame speeds in a confined explosion is a faster rate of pressure rise, but only a small increase in the maximum pressure generated. If there were areas in the leg where the congestion level of the equipment or structures was high then there is also the possibility of greatly increased maximum explosion pressures within the highly congested region. In view of the low levels of congestion typically found in platform legs the likelihood of such local areas of high pressure occurring is considered low.

If the leg is divided into two or more compartments interconnected by small openings, ie compared to the diameter/width of the leg, then a phenomena known as pressure piling needs to be considered. This can lead to a significant increase in the maximum explosion pressure generated compared to that of a single compartment of equal volume, the pressure increasing as the explosion propagates from compartment to compartment. The mechanism for the increased pressure is as follows. The compartment in which the explosion is initiated vents into the connected compartment, raising the pressure in the compartment before the flame front propagates into it and initiates an explosion. Note in an explosion, unless it is a detonation (see below), the pressure wave travels ahead of the flame front. Increasing the initial pressure of the gas mixture will increase the maximum explosion pressure. As a rough rule of thumb the increase in maximum explosion pressure is proportional to the increase in initial pressure, eg doubling the initial pressure will double the maximum explosion pressure. The increase in pressure produced by pressure piling will depend on the relative volumes of the compartments, the dimensions of the interconnection and the number of compartments involved. Given the right conditions, especially if there are multiple compartments, it is feasible to generate maximum explosion pressures that are at least several times greater than the pressure produced in a single compartment of equal volume.

In the above discussion it has been assumed that the explosion is a deflagration, that is the flame speeds are subsonic and the pressure wave travels ahead of the flame front. If there are conditions that promote strong flame acceleration then the possibility of a transition to a detonation needs to be considered. In a detonation the pressure wave is a shock wave and it is co-incident with the flame front. For hydrocarbon/air mixtures flame speeds are typically of the order of 1.8 km/s and the peak pressure about 18 bar. Though the geometry of a platform leg will promote flame acceleration it will probably not be sufficient to generate very high flame speeds. This together with the fact that the gases that are likely to be released into a platform leg, hydrocarbon mixtures, have relatively low initial flame speeds means that the possibility of a detonation in a platform leg is considered to be unlikely. A combination of non-typical conditions, eg the release of a highly reactive gas and a high level of congestion throughout the leg, could, however, lead to a transition to a detonation within a leg.

A further assumption of the above discussion is that the leg is completely filled with a near stoichiometric homogeneous flammable gas/air mixture. In a real incident a gas release is more likely to lead to a highly non-uniform mixture that only partially fills the leg. The most common situation would be the release of a liquid and or heavier than air gas. If the release was at or near the top of the leg this would result in a liquid and gas rich layer in the bottom of the leg and a gas lean mixture in the top of the leg. For releases further down the leg the atmosphere in the top of the leg will be essentially gas free. As a consequence only part of the leg will be filled with a gas mixture within the flammable range and within that flammable volume there will not be a uniform gas concentration. Both partial fills and gas mixtures away from the stoichiometric mixture will result in reduced explosion pressures. The reduction in pressure due to a partial fill of a confined volume is roughly proportional to the fraction of the volume filled with gas mixture, ie the maximum explosion pressure in a confined volume half filled with gas mixture is about half that for the same volume completely filled with the same gas mixture. The gas mixture that produces the highest explosion pressure is generally one with a concentration just on the rich side of the stoichiometric concentration, the pressure falling as the mixture strength approaches either the lower (LEL) or upper explosion limit (UEL). In a situation where the release results in a liquid pool in the bottom of the leg and a vapour layer above the liquid which is largely above the UEL then an ignition is more likely to lead to a flash fire rather than an explosion.

Given a gas distribution as described above and an ignition, the part of the gas cloud within the explosion limits will be consumed by the explosion and maybe some of the surrounding gas as a result of the mixing induced by the explosion. The gas flow ahead of the flame front could result in some of the gas above the UEL mixing with the surrounding air or lean gas/air mixture to bring its concentration within the flammable range. After the initial explosion parts of the leg will be filled with combustion products, but there could still be regions containing gas/air mixture below the LEL and above the UEL. There thus remains the potential for a fire being initiated that consumes the gas rich region or a secondary explosion. For either to occur requires oxygen, which may have all been consumed in the initial explosion. However, as the hot combustion products cool and contract fresh air could be drawn into the leg from the top opening. Thus there is a possibility that although immediately after the initial explosion there is insufficient oxygen present for a fire or secondary explosion to occur, there could be a delayed fire or explosion once sufficient fresh air had entered the leg. The inflow of air could also cause further mixing of the gas rich cloud bringing more gas mixture into the flammable range.

Whether or not a secondary explosion or fire can occur will depend on such factors as the location of the release point, the resulting gas and/or liquid distribution within the leg, the location of the ignition source and the internal geometry of the leg. It is, therefore, not possible to come to any universal conclusions on whether an ignition will result in an explosion or fire, or whether a secondary event, fire or explosion, will occur. The likelihood of each of the events described above will need to be considered on a case by case basis for each type of leg installation.

3 MITIGATION MEASURES

In this section the various measures that could be potentially used to mitigate the effect of an explosion in a platform leg are described and an assessment made of their feasibility.

3.1 EXPLOSION RELIEF

Explosion relief is a long established mitigation technique for confined explosions. In this technique weak areas (vents) are deliberately incorporated in the walls of the confinement, which fail early on in the explosion, vent the explosion and so reduce the maximum explosion pressure generated. For example, by using correctly designed vents the pressure in a confined explosion that would normally generate an explosion overpressure of 7 to 8 bar can be reduced to a fraction of a bar. The main factors that determine the reduction in the explosion pressure achieved are the size of the vent opening and the pressure at which the vent opens. Other factors that also influence the magnitude of the reduced explosion pressure are the number of vents, one vent generally being more efficient than several of the same total open area, the location of the vent with respect to the point of ignition, the inertia of the vent cover and how the vent opens. Over the years a number of empirical equations have been developed[1] that can be used for determining the vent size and opening pressure required to keep the explosion pressure below a given level. Like all empirical equations they are only strictly valid for the range of conditions covered by the experimental data from which they have been derived and they do not account for all of the factors that can influence the magnitude of the reduced explosion pressure. One of the most comprehensive sources of guidance on the sizing of explosion vents is that given in NFPA Guide 68[2].

The construction of platform legs means that the only practicable place to locate explosion vents is at the top of the leg. Even at this location the vent area that can be provided will be limited, especially the area that can vent directly to atmosphere. The efficiency of a vent will be reduced if the discharge is restricted in any way, for example by the use of ducting to direct the discharge to open air. Thus the vent area that could be provided will be small and provide little explosion relief, especially for an elongated geometry like a platform leg. A vent is more effective if it is a close as possible to the ignition point. In a scenario with a small vent at the top of the leg and the ignition at or near the bottom the explosion relief will be minimal. The vents should be equally spaced along the length of the volume for the most effective venting of an elongated geometry, since this ensures that wherever the ignition occurs there is vent close by. For these reasons explosion relief is not considered a feasible explosion mitigation technique for platform legs.

3.2 INERTING

Inerting[3], the addition of an inert gas, is a technique that can be used to prevent an explosive atmosphere developing in the event of a leak. It is based on the fact that if the oxygen concentration is reduced below a certain level, called the limiting oxygen concentration (LOC) or minimum oxygen concentration (MOC), by the addition of the inert gas an explosion cannot occur. Typically LOC values for hydrocarbons range from about 10 to 15% v/v. The LOC does depend on the inert gas used, the higher the specific heat the more efficient the inert gas (ie a higher LOC). For example the LOC for methane with carbon dioxide as the inert is 14.5% v/v, while with nitrogen it is 12% v/v.

Inerting is not considered a feasible way of protecting platform legs, for economic and operational grounds. Legs have large internal volumes, for example the volume of the Brent Bravo leg in which the release occurred is about 16,000 m^3, and would require large volumes of inert gas to initially purge the leg and bring the oxygen concentration down to below the LOC. Thereafter, an inert gas supply would have to be available in order to replace any losses of inert gas from the leg and maintain the oxygen concentration below the LOC. Once inerted, entry into the leg, eg for maintenance or repair, would be problematic. Workers entering the leg would need to wear fully contained breathing apparatus, which is not a desirable way of working. The other option would be to purge the leg with air before entry and then re-purge with inert gas on completion of the work. The cost of such an operation would be prohibitive and it would remove the mitigation measures during a period when there is likely to be an increased risk of a release.

3.3 EXPLOSION SUPPRESSION SYSTEMS

In this technique[3] a suppression agent is injected during the early stages of the explosion, quenching the explosion and reducing the explosion overpressure. To be successful requires the explosion to be detected early enough for the suppressant to be injected in sufficient quantities to suppress the explosion before it can develop damaging overpressures. This in turn requires a reliable method of detecting the start of an explosion and an injection system capable of injecting the required amount of suppressant in a very short time period. Suppressants used have included water, various salt solutions, halons and powders. Many of the halons that proved to be the most effective suppressants have now been banned and the replacements now being used are not as effective.

Explosion suppression could be potentially an effective method of mitigating the effect of an explosion in a platform leg. To date it has not been employed for protecting confined volumes as large as found in platform legs, so before it could be used with any confidence for this application it would need to be demonstrated it would work for such large volumes. It is also usual for the suppressant to be injected throughout the entire volume, which for a typical size of platform leg would require many injection points and a very large quantity of suppressant. There is no reason why in principle for an elongated geometry such as a platform leg the injection of suppressant could not be restricted to the region around the point of ignition. This would require a more sophisticated explosion detection system and it would need to be demonstrated that such a system is reliable and that restricted suppressant injection can effectively quench the explosion. Another consideration to be taken into account when considering the suitability of an explosion suppression system is the toxicity of the suppressant. There is a risk of personnel being exposed to harmful substances if the system triggers due to a false alarm while they are working in the leg.

A variant of conventional explosion suppression system is a micromist system[4]. In this system a fine mist of water, generated by superheating water, is used as a suppressant. Tests on a relatively small-scale have shown that a fine water mist can be very effective in quenching an explosion, but it has yet to be demonstrated that such a system could quench an explosion in a very large volume such as a platform leg. An advantage of a micromist system is that the suppressant, water, is not toxic.

3.4 WATER DELUGE

It has been demonstrated that under certain conditions that the water deluge, from a platform's fire sprinkler system, can significantly reduce the explosion pressure generated by a gas explosion[5]. In order to ensure the water deluge is in operation in time to influence the explosion it has to be activated on gas detection, rather than on detection of the start of the explosion, and the gas velocities generated by the explosion have to be high enough to break up the water droplets from the sprinklers into a fine mist. The latter condition is met in open or semi-confined congested geometries which generate high flame velocities and hence high gas velocities. For a confined geometry with a low congestion level, such as typically found in a platform leg, the gas velocities will be low, there will be little break up of the water droplets and the quenching effect of the deluge will be negligible. In these circumstances the activation of a water deluge could even lead to an enhancement of the explosion pressure – the motion of the water droplets inducing turbulence in the gas mixture, increasing the burning rate and thus the explosion pressure. The use of water deluge as an explosion mitigation method for platform legs is, therefore, not recommended.

3.5 EXPLOSION BARRIERS

Explosion barriers[6] are used to reduce the consequences of an explosion in a system by confining it to just part of the system and thus preventing it propagating throughout the entire system. As such they are ideally suited to elongated confined volumes, such as pipes and ducts, or for a system comprising of two or more interconnected vessels. They can take the form of a solid barrier, like a valve or door, which physically prevents the passage of a flame front, or a barrier/curtain of a liquid or powder suppressant that quenches the explosion on entering the barrier zone. The former barriers rely on detection of an advancing flame front and a means of rapidly closing the barrier before the flame front arrives. The latter type can be either a passive system, where the air movement generated by the explosion disperses the suppressant, or an active system that requires detection of the advancing explosion and activation of a system for dispersing the suppressant.

Due to the physical size of platform legs use of a solid type explosion barrier, like a quick closing door, is not considered a feasible option. It would require a barrier of substantial construction to seal the cross-section of a platform leg and it is questionable whether such a barrier could be closed quickly enough to prevent flame passage. In principle suppression type barriers, passive or active, could be adapted for use in platform legs.

Passive stone-dust and water trough barriers have been developed[7] for the suppression of gas and dust explosions in mine galleries. In stone-dust barriers the dust is piled on loose shelves suspended from the gallery roof and in water trough barriers the troughs, made from a frangible material, are suspended from the gallery roof. Both types rely on the blast wave, travelling ahead of the flame front, dispersing the suppressant ahead of the flame, either by knocking over the shelves or rupturing the water troughs. These systems are able to quench explosions on a scale comparable to that which would occur in a platform leg, but it is questionable whether they could be adapted for use in a leg. Stone-dust barriers can be ruled out on practical grounds, but even with water troughs there could be problems in mounting the troughs in the leg. It is questionable whether the blast wave would be as effective in dispersing water from troughs suspended in a vertical running duct such as a leg compared to a horizontal duct like a mine gallery.

A recent development of a passive water trough type barrier, a blast-induced atomisation type, is probably a more promising option for use in platform legs. The water containers have an aerofoil cross-section with holes on the top surface, so that the passage of the blast wave over the container causes water to be forced out and atomised. Thus a fine droplet curtain is formed in the wake of the containers by the time the flame front arrives. In small-scale tests[8] in a horizontal duct (5.1 m by 0.3 m^2 cross-section, with one open end) this system substantially reduced the explosion overpressure generated in the duct and completely eliminated the external overpressure. Medium-scale tests[9] using a vented enclosure (3 m long by 1.5 m square cross-section) have shown that the system can also reduce the magnitude of the external explosion, ie the pressure generated by ignition of the unburnt gas vented from the enclosure. The test results also indicate that this system could be effective at much lower overpressures than a water deluge system. Water trough based systems require high gas velocities, and thus high overpressures, in order to break up the water drops into a fine mist for quenching the explosion. The blast-induced atomisation system generates a fine mist directly from the water containers and hence should be able to quench in situations where the gas velocity is low. Before this new system could be used to protect platform legs it would need to be demonstrated that it is feasible to install this type of barrier in a leg, it is effective at a scale comparable to the internal volume of a leg and to establish the range of conditions (eg gas velocities, water loadings, etc) over which it will operate. It would be important to show that the turbulence generated by the water containers and supporting structures could not under certain circumstances, for instance if the water had leaked from the containers, result in any significant increase in the explosion violence. Modification of the water containers would also be required, eg pivoting containers, to enable their use in what is essentially a very large vertically orientated duct. The question of the reliability of the system would also need to be addressed. For example how is it guaranteed the containers are always kept filled with sufficient water and if the containers are pivoted will they turn when required.

Active water barriers, called triggered barriers, have also been developed for suppressing explosions in coal mines[10]. On detection of an explosion water is discharged from containers, either from pressurised containers or by an explosive charge located in the container, into the advancing flame front to quench the explosion. These systems in theory should be easily adapted for use in platform legs. It would need to be confirmed that the vertical orientation of a leg does not reduce the effectiveness of the technique. Unlike a horizontal mine gallery the effect of gravity would tend to spread the injected water down the leg rather than keep it in a "curtain" spanning the cross-section.

3.6 GAS BARRIERS

The aim of this technique is to use barriers to restrict the spread of the gas cloud and thus reduce the severity of the explosion[11]. Barriers can range from a hard barrier, such as a blast wall, through semi-hard barriers, which are deliberately weakened walls, to a soft barrier, for example a thin membrane or a water curtain. Clearly a water curtain is not an option for a platform leg, due to its vertical orientation. Installation of hard or semi-hard barriers in a platform leg is also not considered a practical proposition. Furthermore if these types of barriers failed to prevent the spread of gas throughout the leg, eg a top release and vapour spread throughout the leg via the access doors that would have to be provided in the barriers, then there is a risk of enhancing the explosion by pressure piling. The use of a soft membrane barrier is worth further consideration, but it would only provide protection if the release is in the lower part of the leg. These types of barrier are not completely gas tight, so a release of a heavier than air gas or a liquid in the upper half of the leg would eventually spread throughout the entire volume below the point of release.

4 SUMMARY

A release into a platform leg is likely to produce a highly non-uniform gas cloud, with the highest gas concentrations being in the lower half of the leg, which may not completely fill the leg. Concentrations near the bottom of a leg may well be above the UEL. Ignition of such a gas cloud, depending on the extent of the gas cloud and the concentration distribution, could result in an explosion or a flash fire. Following an initial explosion the possibility of a secondary explosion or flash fire, as a result of further mixing of the gas cloud above the UEL, induced by the initial explosion, needs to be considered.

Of the established mitigation measures explosion suppression or a triggered explosion barrier are considered the best suited for protecting platform legs. Before either technique can be employed with any confidence it needs to be demonstrated that they will be effective in the large elongated volumes typical of those found in platform legs and that the vertical orientation of a leg will not reduce the effectiveness of the technique.

Of the emerging technologies explosion suppression by blast-induced atomisation from water containers has the potential for use in platform legs. To date this technique has only been tested at small and medium-scale, so considerable development work would be required to prove its feasibility, effectiveness and reliability in large vertically orientated confined volumes typical of platform legs and to establish its operating characteristics.

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