Managing Explosion Risk in Arctic Areas
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Abstract
Oil and gas platform design for arctic locations is a challenge. Platform modules are traditionally built with open ends, providing natural ventilation that has a favourable effect on accumulation of a flammable gas cloud from a potential gas leakage as well as on explosion pressure reduction. However, open end design in artic locations will have a negative effect on the working environment, with a potential for high wind chill factor. This can lead to periods where workers are not able to perform maintenance on process equipment, resulting in lost production. In addition, open end design has a potential for icing of equipment.

A natural proposal could be to choose a closed end module design, where explosion panels at the module ends reduce the flow of cold air. However, studies have shown that introducing a closed module design will lead to both higher frequencies for ignition of gas leakages and higher explosion pressures, thus leading to a higher fire and explosion risk level. The increased explosion risk will lead to a higher design accidental load on structural elements, increasing construction cost.

The present paper presents an idea that may both reduce explosion risk compared to a closed module design and still maintain a satisfactory working environment in arctic areas. A concept with rotating wall elements, acting on gas detection, has the potential to reduce the strong explosion frequency by a factor of 3 compared to closed module designs.
Introduction

The present paper addresses the design of offshore topside modules for oil and gas production in the Arctic regions. However, the findings are general for explosion risk in open and closed areas, and are also applicable for exploration and land based oil and gas industry.

In the relatively near future, we expect to see oil and gas exploration in the Arctic regions. Operations in an arctic climate constitute a challenge for the working environment. Strong winds and low temperatures will lead to a strong wind chill, i.e., human experience of cold. This can lead to periods where workers are not able to perform maintenance on process equipment, resulting in lost production. In addition, open end module design has a potential for icing of equipment.

In order to keep the cold out, it is common to put up walls around the location where work is carried out. The walls may be permanent or provisional. Additional heating is not uncommon. However, the possibility for hydrocarbon leaks within the enclosed area will be a potential risk. It will be much easier to accumulate flammable gas volumes from a leakage in a closed rather than in an open area. Studies have shown that introducing a closed module design will lead to both higher frequencies for ignition of gas leakages and higher explosion pressures, thus leading to a higher fire and explosion risk level. The increased explosion risk will lead to a higher design accidental load on structural elements, increasing construction cost.

The present paper summarizes the findings regarding quantified explosion risk for traditional, North Sea platform open module design, a closed Arctic module design and a newly developed Arctic module design with active wall panels. The objective is to present the general differences in the explosion risk picture for the different designs to highlight the reducing effect of the active wall panels.

Background

The combined effect of air temperature and air movement will give increased rate of heat loss from the human skin. This is often referred to as wind chill. Low temperatures and strong wind chill may lead to medical problems for workers. Furthermore, the work capability will be reduced, and people will be more prone to take wrong actions. There exist regulations and requirements to operators’ exposure to wind chill. The most dramatic outcome will be that workers exposed to strong wind chill will not be allowed to work outside at all. This may affect production and regularity.

The easiest way to improve the working environment is to separate the process area from the cold with walls. This has been a common practice for many arctic or near-arctic land-based gas and oil production facilities. However, this solution is not so favourable for an offshore installation. Onshore, it is usually possible to separate the different processing areas or the process areas and humans by distance. This is much harder to do on an offshore installation. Furthermore, closing of the working area will increase the occurrence frequency of a large flammable cloud, and provide higher explosion pressure. The higher explosion pressure will, on land, lead to stronger demolishment, while offshore it may also be a threat to structural integrity of the whole platform.

This challenge resulted in an idea which was meant to combine the better of the two situations; a module wall that was closed during normal operation in order to establish an acceptable working environment, but open during a hazardous situation with an ongoing gas leakage.

The wall able to fulfill both these requirements consists of vertical, rotating aluminum elements as shown in Figure 1. The wall elements are coupled to the emergency shutdown system. Upon confirmed gas detection, the elements will rotate from closed to open position. In open position, they will let the wind enter the module and dilute the flammable gas cloud, and after some time reduce the volume of the flammable cloud.
The wall elements themselves are equipped with small explosion panels. Their purpose is to provide explosion pressure relief for the module if an explosion should occur before the elements have reached their open position.

**The chain of events**
The chain of events leading up to a hydrocarbon explosion or fire incident consists of several steps. The basis for explosion risk and fire risk management is to identify all explosion and/or fire hazards, and implement safety
measures in order to stop the chain of events. In general, the measures reducing the probability of occurrence of the events ought to be focused. The main elements of the chain of elements leading up to an accident are presented in Figure 2.

In order to quantify the effect of the possible risk reducing measures, the parameters affecting the probability of occurrence of explosions must be reflected in an explosion risk analysis model.

Gas leakage
The gas leakage should be discovered as early as possible. A common scenario leading up to gas leaks is erroneous position of valve during start-up from a depressurized system. Safety measurements for this event are a stepwise increase in process pressure and operators present in the process area for acoustic and visible inspection. Another common source for leakage is material fatigue after long-lasting vibration. Reduction of vibrations should be done via a vibration measurement program.

Flammable cloud build-up
The flammable cloud should be kept as small as possible. A well designed gas detector layout and segmentation/blow-down sequence should help this. Furthermore, North Sea platform module design also uses module layout for prevention of gas accumulation. Open module ends provide, in most cases, a natural ventilation rate far greater than prescribed in standards and regulations. A high ventilation rate, preventing large gas clouds, is essential for keeping the explosion risk low. Small gas clouds will both reduce the ignition probability and the generated explosion load in case of an explosion. The ignition probability is reduced due to reduced exposure probability of active ignition sources.

Ignition source control
Fast detection and reliable system for shut down of potential ignition sources are of vital importance. For equipment located in explosive atmospheres in facilities in Europe, the ATEX directive applies. According to the ATEX directive, equipment must be designed to prevent ignition from taking place. However, ignition sources within hazardous areas may still occur, for instance due to equipment fault. Thus, shut-down of potential ignition sources is a crucial measure, which is obtained by automatic initiation of shut-down of the process and electrical equipment in the module upon gas detection.

Explosion
Even if the natural ventilation reduces the gas cloud size, detection with subsequent segmentation and blow-down reduces the gas leakage rate and most ignition sources are shut down, there is still a small possibility for an explosion. Activation of the deluge system before delayed ignition of the gas cloud will for most module layouts reduce the resulting explosion pressure. Walls between modules are designed to withstand the explosion pressure.

Fire
The explosion will in most cases be followed by a jet fire. Water application will have favorable effects on the hazards from jet fires. The favourable effects include both reduction in the thermal radiation from the fire and cooling of process equipment and pipes.
In order to keep the explosion risk at an acceptable level, all of the safety measures mentioned above should be initiated. The residual risk is calculated by means of an explosion risk analysis tool.

Modelling of Explosion Risk calculations with ExploRAM

General
Scandpower's model for detailed explosion risk assessment (ExploRAM) has been applied for quantification of the mitigating effect on the explosion risk of the active panels. The ExploRAM model is in accordance with the best industry practice and NORSOK standard. The model was presented in a paper at the ERA Technology Conference "Safety on Offshore Installations" 30 November - 1 December 1999. Scandpower has carried out numerous safety studies on behalf of StatoilHydro applying ExploRAM for estimation of the explosion risk picture.

Applying ExploRAM, the explosion risk picture has been estimated in detail for 3 different modules for three different layouts:

- north sea design, i.e. with open walls and naturally ventilated
- arctic design, i.e. enclosed and mechanically ventilated with an air change rate per hour (ACH) of 12
- arctic design with active wall panels.

Three different modules were selected mainly to investigate the importance of the gross volume of the module, but also to see if the relative effect are different for local geometrical properties, e.g. length/width ratio of module, equipment density.

Detailed 3D CFD simulations were carried out for all layouts in order to assess the gas dispersion characteristics and explosion loads for a selected number of scenarios. The results from the simulations were put into ExploRAM for detailed modeling of the explosion probability distributions for the different layouts.

The simulations were based on the following properties of the intelligent weather claddings:

- the panels were 100% closed before opening
- 80% of the area of the panel opened instantaneously, i.e. the time delay between closed and open is zero, at a specified time. This means that the fluid can flow through 80% of the panel area after opening
- the weight of the panel was set to 5 kg/m² and opened at an overpressure of 50 mbarg inside the module

The main objective of the study was to investigate the relative differences between the different modules in order to highlight the risk reducing effect of the active wall panels. Consequently, most of the parameters affecting the risk picture were generalized for the three modules to rule out effects that may interfere with the relative differences.

In the present paper, only the results for the smallest of the modules studied are presented (see Figure 3). The results from the other modules were equivalent. However, it should be noted that the relative risk reducing effect increase with the size of module.

Figure 3: Module used for generic study.
The ExploRAM model
ExploRAM is a comprehensive model for explosion risk quantification. The model utilizes detailed CFD gas dispersion and explosion simulations to quantify the frequency of strong explosions. The gas cloud characteristics at the time of ignition estimated, and the result is the basis for calculation of the complete explosion load frequency distribution. The model takes into account transient dynamics of the leakage, the gas cloud, the gas detection system, shut down, blow-down and ignition source isolation.

The main challenge in explosion risk quantification is that the number of possible scenarios is infinite whereas the computing time for the simulations is long (typical computation time for gas dispersion is 5-10 per day per CPU). Thousands of scenarios must be simulated to represent the probability distribution with acceptable statistical significance, which in most projects may not to be conducted within reasonable time. Thus, the main feature of ExploRAM is to estimate the explosion risk picture based on a limited number of CFD simulations.

The CFD simulations are important to investigate the geometrical effects, i.e. the interaction between the geometrical layout and the fluid flow. Both the gas dispersion characteristics and the turbulent combustion in case of an explosion are rather sensitive to the geometrical layout.

The analysis methodology in ExploRAM is divided into the following three main steps:

1. Leak picture
2. Gas dispersion analysis
3. Transient ignition modeling
4. Explosion load assessment

The leak picture describes the probability of occurrence and the transient characteristics of leakages. The important parameters to be reflected are

A. Number of leak sources
B. Gas content in the process segments
C. Time to isolation and blow-down
D. Blow-down rate.

The generic probability of occurrence of leaks used in the study is presented in Table 1. The number of leak sources is in general estimated from historical failure data related to different process equipment and components (i.e. flanges, valves, vessels, pumps etc.). A time dependent model has been used to model the transient leaks. The gas leak rate will be reduced as a function of time because the pressure in the leaking segment is reduced. The pressure is reduced by the leak itself and the blow-down system. The model reflects both of these aspects. The blow-down system was assumed to be able to reduce the pressure to 6.9 bara within 15 minutes after initiation of depressurization. An example for an initial leak of 5 kg/s is shown in Figure 4.

<table>
<thead>
<tr>
<th>Initial Leak Rate Category</th>
<th>Probability of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (&lt; 1 kg/s)</td>
<td>57.23 %</td>
</tr>
<tr>
<td>Medium (1 - 10 kg/s)</td>
<td>29.20 %</td>
</tr>
<tr>
<td>Major (10 - 30 kg/s)</td>
<td>9.41 %</td>
</tr>
<tr>
<td>Large (&gt; 30 kg/s)</td>
<td>4.16 %</td>
</tr>
</tbody>
</table>
For **gas dispersion analysis** in a given geometry, the main parameters are:

- **E.** Location of the leak points
- **F.** Leak rate
- **G.** Jet direction
- **H.** Wind direction
- **I.** Wind speed.

These parameters sum up to an infinite number of possible release scenarios. In order to reflect the large number of leak scenarios, Scandpower has established a procedure to estimate the gas cloud characteristics for other wind speeds and leak rates than those simulated by CFD. In this way, the steady state gas cloud characteristics may be estimated for all the combinations of the parameters E to I. Typically, the gas cloud size for about 100 000 leak scenarios is estimated based on 20 - 100 detailed CFD simulations. The frequency of each of the 100 000 scenarios is quantified from the leak frequency and meteorological data, and a steady state gas cloud probability distribution is estimated. This distribution is an intermediate result displaying the distribution of expected gas cloud sizes at steady state for the different leak scenarios. The resulting distributions for the open and enclosed design are presented in Figure 5 and Figure 6, respectively. The results show that the expected gas cloud is considerable larger for the enclosed design, which is due to gas accumulation for small leaks, which is more frequent than large leaks.
Figure 5: Gas Cloud Probability Distribution, Open Design

Figure 6: Gas Cloud Probability Distribution, Enclosed Design
As the actual release scenario is time dependent, a transient gas cloud and ignition model must be established. The following parameters are reflected:

J. The number of gas detectors
K. The ignition intensity
L. The shut down philosophy with respect to ignition sources

For time dependency of the gas cloud, the effect of the leak picture has to be reflected. In the order of magnitude of 10 000 transient gas cloud scenarios are being run to represent the different possible leak scenarios in the module. These scenarios are established from the gas cloud probability distributions at steady state. Figure 7 displays an example of a transient gas cloud scenario.

![Figure 7: Example transient gas cloud model](image)

The ignition sources are modelled with intensities, and recommended generic ignition source intensities are based on analysis of reported releases and fire/explosions. In addition, there may be a dependency between the cause of the release and the presence of an ignition source. Such ignitions are modelled to take place with uniform probability within the first 5 seconds of the release.

At each time step, the probability of ignition is calculated from the exposure probability (size of the gas cloud relative to the module size) and ignition intensity related to the different ignition sources. As the size of the gas cloud at that moment is known, the frequency for the explosion scenario may be calculated. The probability for ignition source isolation is calculated at each step from the probability for exposure of gas detectors and the voting philosophy. The portion of equipment being shut down upon confirmed gas alarm is estimated from the shut down philosophy. In this particular study, it is assumed that 85% of the ignition sources are shut down.

Implementing this model for the selected representative scenarios, each with about 100 to 200 time steps, more than 100 000 explosion scenarios are identified. Sorting these scenarios with respect to the gas cloud size, the ignited cloud size frequency distribution is found. The resulting distribution for the case with open design is shown in Figure 8. The results show that the frequency for ignition of gas clouds larger than about 1 000 m³ is $1 \times 10^{-4}$ per year. $1 \times 10^{-4}$ per year is the explosion risk acceptance criterion stated by PSA (Petroleum Safety Authority Norway). Consequently, for this specific example, the module in question must be designed for the explosion loads generated from a gas cloud with a size of about 1 000 m³.
For explosion load estimation the most important factors are considered to be:

M. Concentration distribution within the gas cloud
N. Size and shape of gas cloud
O. Location of gas cloud
P. Location of ignition point

CFD explosion simulations with FLACS (FLame ACcelleration Simualtor; software by Gexcon, www.gexcon.com) are performed to estimate the explosion load. Combining the results from the explosion simulations with the probability distributions for ignited gas clouds gives the probability distribution for explosion load, which is the ultimate result from the ExploRAM model. The result for open design is shown in Figure 9. According to the PSA risk acceptance criterion, the dimensioning design pressure in this case is about 0.4 barg.
Results

In Figure 10, the accumulated probability for explosions is presented for the 3 different layouts.

The design explosion load (1·10^{-4} per year load) is a factor of 2.5 higher for the arctic design relative to the open design, and the frequency of occurrence for a given explosion load is a factor of approximately 10 lower for the open design than the enclosed design (e.g. the frequency for load above 1 barg is 1·10^{-4} per year for the enclosed design, and somewhat below 1·10^{-3} per year for the open design). The main reason for this considerable relative effect is the difference in ventilation rate. For the arctic design, the ventilation rate is set to 12 ACH (air changes per hour), whilst for the open design, the ventilation rate is more than 100 ACH for most wind conditions. Reduced ventilation rate implies that smaller gas leaks may generate hazardous gas clouds. Since the frequency of occurrence is considerable higher for small leak rates, a very prominent effect on the explosion probability distribution is observed. A secondary effect is that for open design, the impulse of the leak itself will aid the ventilation of gas out of the module. This effect is illustrated in Figure 11, where a 10 kg/s horizontal leak is direct towards the side wall of the module. For the open design, the impulse of the jet pushes the gas out of the module. For the enclosed situation, the gas is deflected by the side wall.

The explosion load probability distribution for the enclosed design with active panels is located between the distributions for the open and enclosed design. The frequency for explosions is reduced by a factor of 3 - 5 in the critical area (probability of 1·10^{-5} - 1·10^{-4} per year). The design explosion load (1·10^{-4} per year load) is a factor of 2 lower than for the arctic design. Thus, it may be stated that the risk reducing effect is considerable.

To obtain this risk reducing effect, the gas leak has to be detected fast and the response time of the panels has to be short. In this study, the response time of the panels (i.e. the time from confirmed gas to the panels are completely open) is set to 10 seconds, which is considered to be obtainable. However, reduced response time of the system will result in significant further risk reduction.

The time to detection depends on the gas detector density. If the gas detector layout is based on the requirements stated in NORSOK S-001\textsuperscript{5}, the number of detectors is considered sufficient. (The gas detector density in the model is NORSOK equivalent). Additionally, it is important that ignition sources are shut down upon gas detection.

Weak explosions are dominated by explosions taking place before the panels has opened, which is due to early ignition in scenarios were ignition sources has not been shut down, and the leak rate is sufficient to generate significant combustible volume inside the module. The explosion risk contribution due to ignitions before the panels opens decrease with the module size. This is explained by the fact that less gas is needed to result in a hazardous gas cloud for a smaller module. Thus, fast detection and opening of the active panels are more critical for small modules than for large modules.

It must be noted that the combustible gas cloud increases in size after opening of the panel for some of the leakage scenarios, which typically occurs for large leak rates or if the time to opening of the panel is long. The increase in combustible gas after opening is due to significant part of the gas cloud having concentrations above the upper flammable limit (UFL) prior to opening of the panels. Such rich gas clouds will eventually become combustible before being diluted below the lower flammability limit (LFL). At the time of opening the active panels for these scenarios, the combustible gas cloud therefore increases in size before being vented out from the module. Short detection time and fast response of the system will reduce this disadvantage. The negative effect will decrease with increasing size of the module. This is because the leak rate causing this effect increases with the module size, and the frequency of occurrence decrease with increasing leak rate.
**Conclusion**

The risk reducing effect of active panels compared with traditional weather cladding has been analyzed. The assessment has shown that the risk reducing effect is considerable. A general statement is that the frequency for strong explosion is expected to be reduced at least by a factor of 3 due to implementation of active panels instead of traditional solid weather claddings. However, the explosion risk is still considerable higher than for open designs. Other risk reducing measures should also be focused on.
References


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