Risk Analysis of Gas Explosions on Oil Platforms

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Abstract

Risk analysis of gas explosion on oil platforms is a complicated assessment. The assessment deals with a lot of uncertain parameters and there are several different approaches to get a design pressure from an explosion. The design pressure is the pressure the structure must be able to withstand.

The purposes of this paper are to analysis and quantify gas explosions on oil platforms in a simple and direct manner. This is done by describing the physics behind a gas explosion and analysis many of the parameters that affects the explosion. The links between the parameters are analyzed by considering their correlation. The human factor courses many accidents in the oil industry as well as in other industries. Therefore, the subject is analyzed in this paper. Furthermore, an approach for getting a design pressure is described. The approach is known as a probabilistic explosion risk analysis. The analysis deals the uncertain parameters using statistics. The result is an exceedance curve where the overpressure from the explosion is given as a function of the frequency. Finally, the future of risk analysis is assessed.

Contents

1. Introduction

There will always be a probability of having an explosion when dealing with hydrocarbons (gas). That is whether it is associated with production, transport, storage or burning. The following paper only deals with gas explosions on oil platforms where the explosion and a possible following fire are considered as a major hazard.

1.1. Circumstances Which Lead to a Gas Explosion

The process of a gas cloud being ignited with the result of a rapid increase in pressure is defined as a gas explosion. Before an explosion is possible, there are several events that must occur. These events are illustrated in Figure 1-1.

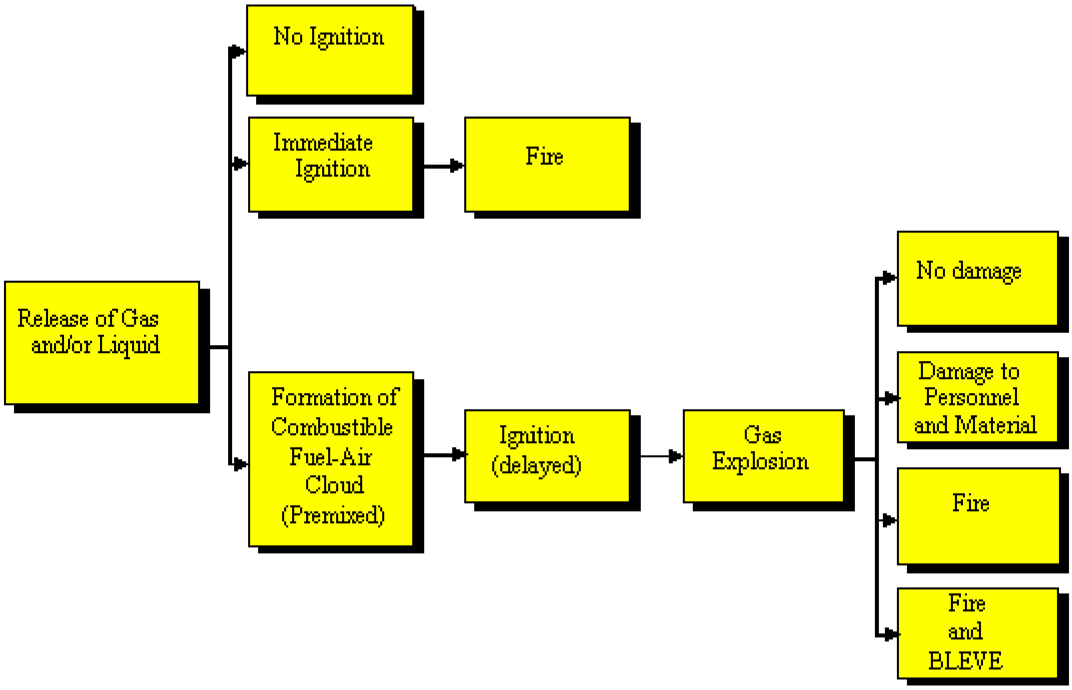

Figure 1-1: *Events leading to gas explosion. BLEVE – Boiling Liquid Expanding Vapor Explosions. (GexCon, 2006)*

As the diagram shows, it is of course not possible to have an explosion without release of gas. Secondly, the gas must be ignited and an ignition can either lead to fire or an explosion. In this paper, it is only the explosion which is treated and not fires, even though they are more common as Figure 1-1 suggest.

1.2. Severity of explosion

The most famous gas explosion on an oil platform is Alpha Piper. A gas explosion followed by a fire killed 167 men in 1988. The oil platform was delivering about 10 % of the oil and gas production in the North Sea at that point of time. This means that explosions not only can cost loss of human lifes but also have large consequences to the society due to the loss in energy production. (wikipedia, 2006)

Fires on oil platforms are more common than explosions, cf. Figure 1-1 where it is shown that fire has more branches in the event tree. On the 29th of August 2006, there was a small fire on a Norway. There was no loss of human life only a shut down of the production. (chron, 2006)

1.3. How current practice is preformed

Today, there are several ways of dealing with risk analysis of gas explosions on oil platforms. One of the most accepted methods is developed by Talberg et al. (Rambøll, 2006). The method is known as *probabilistic explosion risk assessment*. The method uses CFD[1] calculations to both simulate gas dispersion and pressure from the explosion. These simulations are treated using statistics and changes the parameters which influence the explosion. Some parameters are wind speed, wind direction, size of leakage and direction. The result is a so-called exceedance curve and an example is given in Figure 1-2.

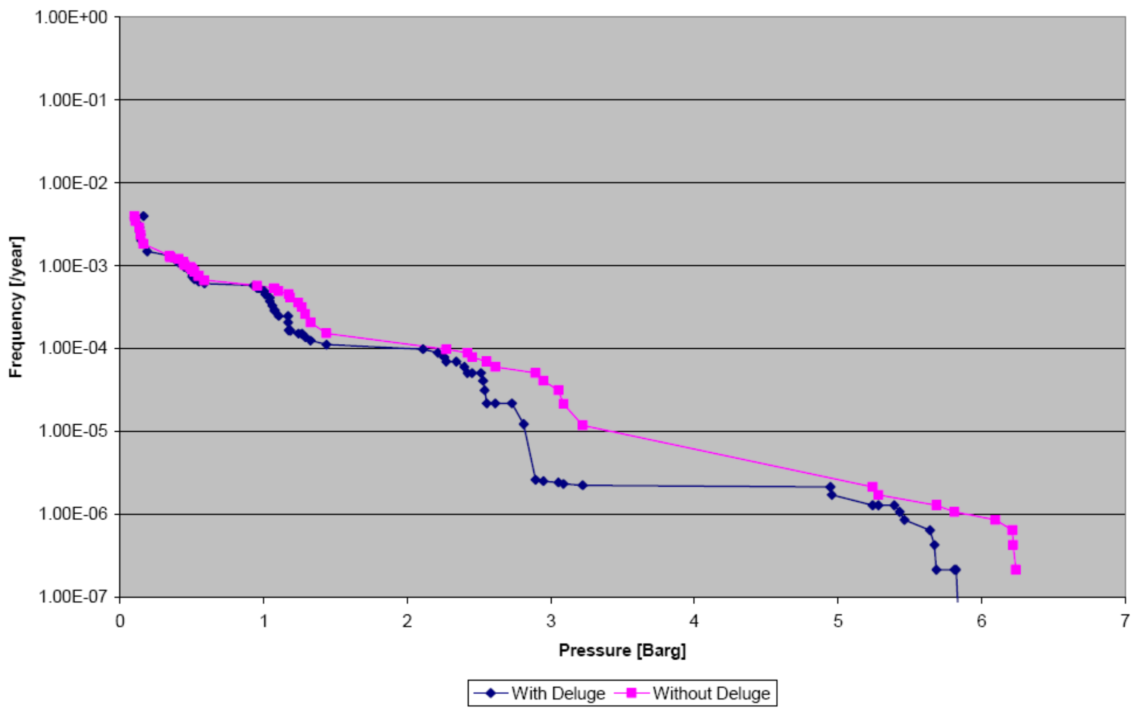

Figure 1-2: *Example of exceedance curve. (Talberg et al., ????A)*

[1] CFD – is short for Computational Fluid Dynamics and is how complicated movement of air can be solved by using computers. It is the governing equation of fluid flow (Navier Stokes equation) that is solved numerical.

Figure 1-2 indicates that the frequency, and thus the probability, of a large pressure due to an explosion decrease as the presure grows. This means that if an explosion would occur it is most likely that the pressure would be relatively small. The exceedance curve is used to estimate if the probability of a certain pressure can be accepted and if the pressure is not acceptable a redesign must be considered. For example, the structural members are designed to a pressure of 2[Barg] which means that this pressure or a higher pressure occurs once every 10,000 years because the frequency is 10^{-4}. If this frequency can be accepted, then the design pressure is correct. It is of course possible to experience a higher pressure e.g. 5[Barg] but the frequency of such a pressure is about 10^{-6}, cf. Figure 1-2.

When designing or upgrading an oil platform, these exceedance curves are an important tool to decide which frequency and pressure that are acceptable. It will never be possible to completely remove the possibility of having a gas explosion so a certain risk must be accepted. If the calculated risk can not be accepted it is possible to redesign the oil platform to a safer design, however, this is probably expensive.

2. Importance

When dealing with risk analysis and management; it is important to decide whether a risk is important or not and whether to deal with it or accept the risk. One method to filtering the important risks is illustrated in Figure 2-1.

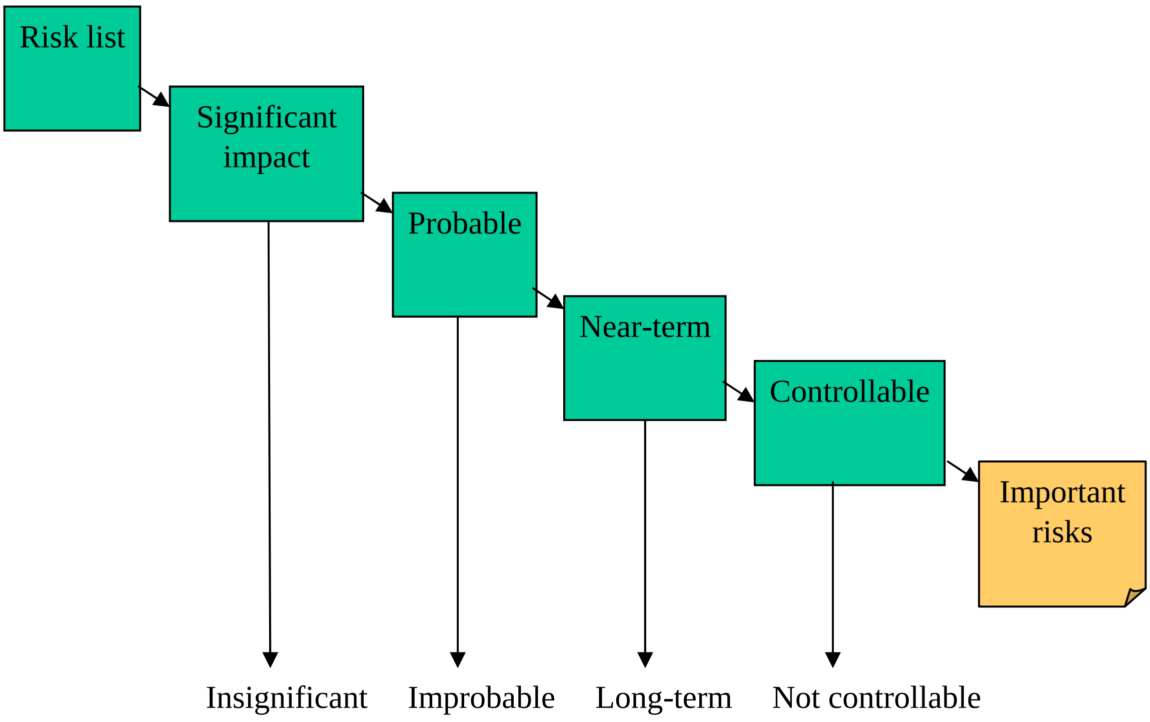

Figure 2-1: *Filtering important Risks. (Mohamed, 2006)*

The application of the method is best illustrated by an example which of cause is risk analysis of gas explosions on oil platforms. When the risk is identified the first question to ask according to the method is whether the risk has a significant impact or not. The impact of a gas explosion can be very significant like e.g. Alpha Piper. The next question to be asked is if the risk is probable or improbable. Of course, gas explosions are probable on an oil platform. However, the possibility of experience a gas explosion is very small especially for having a gas explosion with a significant impact like a total loss of the oil platform. Whether the risk is near-term or a long-term risk is the next step in the analysis of important risks. Unlike corrosion in steel, fatigue[2] in steel and carbonation of concrete[3], a gas explosion can happen in seconds and it can therefore be considered as a near-term event. Of course, by considering the probability of having an explosion which can be around one explosion in 10,000 years, a gas explosion can also be considered to be a long-term event. However, in this paper it is assumed to be a near-term event. The next step is to assess whether the risk can be controlled or not. It is not possible to remove the risk of having an explosion but the probability can be reduced e.g. by using blast walls, deluge systems and shutdown systems (Talberg et al., ????B), see section 3.2.

When the risk has been identified as an important risk, further analysis is necessary. The following section describes how risk analysis is preformed for gas explosions on oil platforms.

3. Risk Analysis

The parameters which affect a gas explosion can be divided into two; the parameters which lead to an explosion and the parameters that affect the consequences of the explosion.

In the following section, all the events that lead to a gas explosion will be analyzed. The events are described in terms of their physics and the way they are treated within terms of a risk analysis. Furthermore, the parameters that affect the consequences of a gas explosion are described.

3.1. Events that lead to a gas explosion

As shown in Figure 1-1, it is a chain of event that leads to an explosion. The first event in the chain is a gas leakage, since it is not possible to have an explosion without gas. A leak-

[2] Fatigue is a phenomenon in steel where the steel loses strength due to unloading and reloading, e.g. steel members exposed to wind or wave load.

[3] Carbonation of concrete is a chemical reaction between the concrete and the carbon dioxide in the air and the product is calcium carbonate. This reduces the concrete strength over years and is a large problem for concrete structures.

age can be caused by several different causes e.g. a hole in a pipe, overpressure in a pipe, a disconnection and so on.

Due to the dispersion of gas, the gas cloud can be divided into 3 zones with different concentrations. The first zone is closest to the leakage and the gas concentration is too high to ignite because there is not enough oxygen present. The next zone contains the critical gas concentration which can be ignited and the last zone with gas is the zone furthest away from the leakage and contains a too low concentration for ignition. An illustration of the 3 zones is given in Figure 3-1 where the leakage is from a pipe.

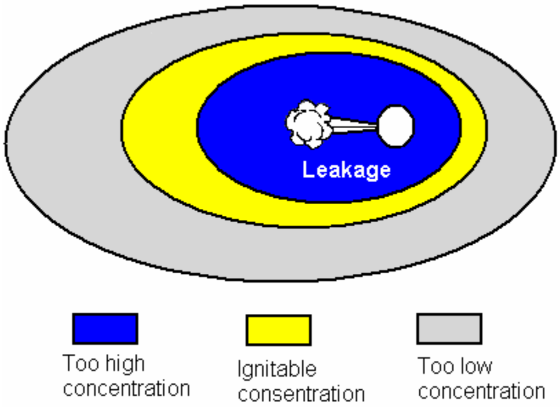

Figure 3-1: *The 3 zones.*

When designing a new oil platform, it is of course not possible to predict the size of a leakage and where it will occur. Several estimations can be made. The most educated estimations can be made be considering statistics from other similar oil platforms of their leakage sizes and sources and by using CFD simulations.

When a gas leakage occurs, there is a possibility of an ignition. The ignition can be caused by several sources and the more information there is available in the design phase, the better the prediction of the ignition source can be. It is like betting on 1 of 6 horses. If no information is available it does not matter which horse you put your money on, but if you know that one of the horses always wins, you will have a better prediction of which horse to put your money on. Examples on ignition sources are pumps, compressors, generators, all electrical equipment and personal (Berg et al., 1998). This means that the ignition like the leakage is assessed and one of the best ways of assessing ignition is looking into statistics from similar oil platforms.

If the ignition in the critical gas concentration is powerful enough, a gas explosion will occur. The consequence of the explosion depends on the size of the leakage, ignition strength and many other parameter, which are described in the next section.

From this section it is possible to make a conclusion that the assessment of the risk of gas explosions are a complicated process combined with many uncertainties. These uncertainties are not possible to quantify exactly. However, it is possible to assess the uncertainties by using statistics from similar oil platforms.

3.2. Events that Affect the Consequences of a Gas Explosion

There are several parameters which affects the overpressure from a gas explosion. In the following section, some of the most important parameters are described. These parameters are:

- Leak size
- Ignition point and strength of ignition source
- Wind
- Deluge
- Blast walls
- Ventilation
- Geometry

The leakage size is very important for the explosion. The leakage can be very powerful and create a huge cloud very fast or it can be small. Of course, the explosion will be larger if there is much gas present. However, the leakage can also be so powerful that it is not possible to ignite. Furthermore, the leakage direction is important for the gas cloud shape and size.

As mentioned earlier, the ignition sources can be several different items. The ignition sources can have different intensity and this effect the overpressure from the explosion. Furthermore, the ignition point is important e.g. the closer the ignition is to a wall the higher the overpressure will be on the wall.

Wind has a huge impact on the gas cloud. The wind gives natural ventilation and it, therefore, form the gas cloud, cf. Figure 3-2 where the effect of the wind and leakage direction is illustrated.

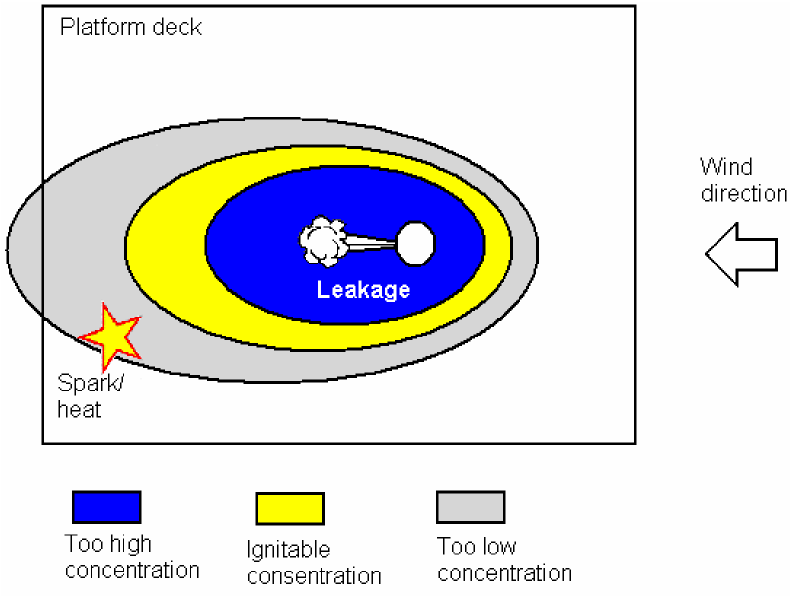

Figure 3-2: *Wind, leakage effect on the gas cloud. Note that there is a spark in the too low concentration which means that the gas does not ignite.*

Deluge is activated if gas dispersion is detected. The deluge fills the air with water and it therefore it reduces the probability of having an ignition. The overpressure is also reduced because the explosion is “wet” instead of “dry”. The effects of this are seen in Figure 1-2. (Talberg et al., ????B)

A blast wall is a wall put up to reduce the area of the gas cloud and also to reduce the area the explosion can reach. Putting up a blast wall has both advantages and disadvantages. First of all the ventilation is expected to be reduced in each sub area because of the extra walls. Since the walls reduce the area, the dispersion is also reduced to a smaller area which means that the maximal gas cloud size is reduced. The smaller area also leaves the traveling distance shorter and this will create less turbulence and therefore a smaller overpressure. A disadvantage with the dispersion is that more gas gets accumulated in the smaller areas. Furthermore, the extra walls also give a larger probability of having an ignition close to a wall which increases the overpressure. Placing of blast walls is therefore a complicated problem that must be analyzed with caution. (Talberg et al., ????B)

The ventilation is normally very dependant of the wind speed and direction. It is therefore necessary to have wind data in order to get the correct ventilation. Walls effect the ventilation and therefore it is often necessary to assess the effect of blast walls on the ventilation. In some cases the overpressure might be higher with some walls. This is seen in Figure 3-3, where the effect of removing the wall increased the ventilation rate with 80-90 %. (Talberg et al., ????A) The design without the wall is preferred because it gives lower pressures for the same frequency.

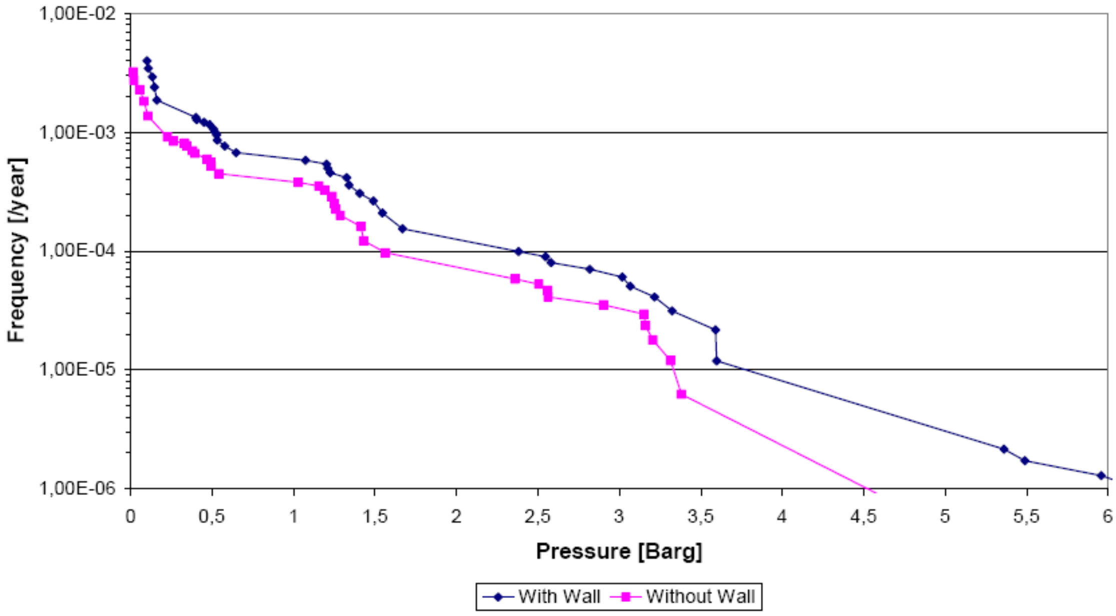

Figure 3-3: *Exceedance curves for case with and without a wall***.** *(Talberg et al., ????A)*

The geometry has a large effect on predicting the overpressure, e.g. small pipes and other items increases the overpressure. This is proven both by using full scale test and computer simulation (Talberg et al., ????A). This means that using a very coarse geometric model when simulation the overpressure gives too small overpressure. It is therefore important to have sufficient computer power to do the simulations. (Bakke et al., 2003)

3.3. Correlation

Correlation states the strength of the relationship between variables. This is best explained in a simple example. If you have a dog and it barks every time the neighbors' dog barks there is full correlation between the two dogs. The correlation coefficient is then equal to 1. However, if your dog is deaf it will just bark whenever it feels like barking and there will be no correlation between the two animals and the correlation coefficient is equal to 0. This does not mean that it is not possible for them to bark at the same time. The correlation coefficient between different variables is a number between -1 and 1 and the correlation has a huge importance for calculation of probability. Some graphic examples of the correlation coefficient are given in Figure 3-4. The figure shows the correlation coefficient in the u-space which is a space where all distributions are normal distributed, e.g. a log-normal distributions is transformed into a normal distribution in the u-space.

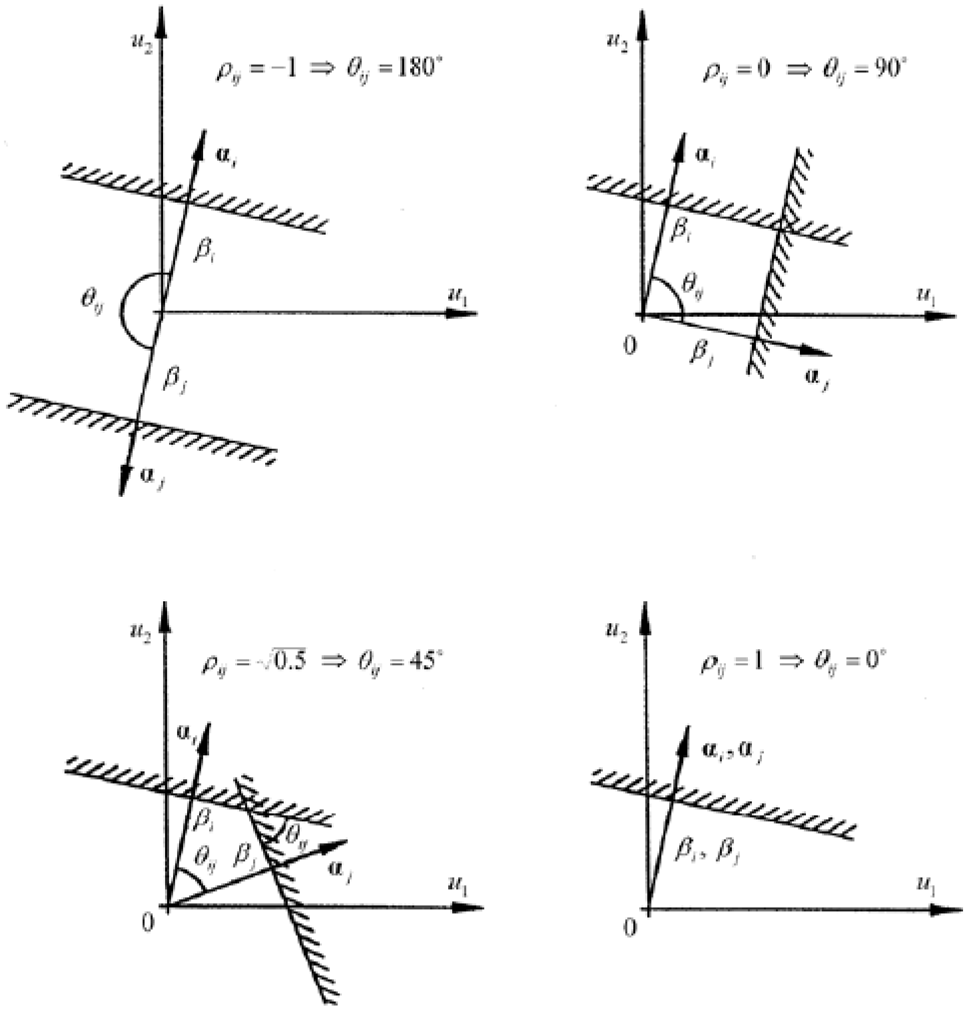

Figure 3-4: *Correlation coefficients. (Sørensen, 2004)*

It is important to know about the correlation between the variables which effects a gas explosion. For example, if the power is out it will not be possible to have a short circuit in any of the electronic devises. This means that the correlation coefficient is equal to -1.

In the following, the correlation coefficients between five variables are analyzed. The variables are gas leakage, power outage, deluge works, ignition source is electronic and ignition source is not electronic. Of course, it does not matter whether the power is out, the deluge works or which sources there will ignite the gas if there is no gas leakage. However, the gas leakage does not effect any of the other variables and the correlation coefficient is therefore 0. Depending on the wiring of the deluge system it can be correlated with the power system and they may fail together or not. It should therefore be recommended that the deluge system has a back up system to reduce the probability of failure. However, the correlation coefficient can be either 0 or 1. Assuming that there is only one ignition it will either be electronic or not which means that the correlation coefficient is -1 between the two variables. The correlation coefficients are given in Table 3.1.

	Gas leakage	Power outage	Deluge works	Ignition source is electronic	Ignition source is not electronic
Gas leakage	1	0	0	0	0
Power outage	0	1	0-1	-1	1
Deluge works	0	0-1	1	0	0
Ignition source is electronic	0	-1	0	1	-1
Ignition source is not electronic	0	1	0	-1	1

Table 3.1: *Correlation coefficients between variables.*

3.4. Human Error

In many cases, the human error accounts for a very high rate of the accidents. It is therefore important to analyze the risk of human error.

Since the human error plays a great role in many industries, there is developed a large range of programs to help determine and reduce the risk of human error. Furthermore, there are companies which do consulting in reduction of human error, e.g. Reliability Center, Inc, Relax and Talsico which are just three of the thousands of companies found on Google. The main object is always to determine the potential human errors and then assess the risk of those errors. One approach is given in the following list:

- *Break down process into discrete steps*
- *Determine potential human errors*
- *Identify positive and negative contributing factors*
- *Define barriers and controls*
- *Assess error risk*
- *Employ risk reduction strategies*

[Relax, 2006]

This approach can also be used on risk analysis of gas explosions on oil platforms. The process of the explosion is broken into discrete steps in section 3.1.

By considering each element it is possible to determine potential human errors. The first step is the leakage which can be caused by a wrong connection, too loose bolts, a disconnection and many more. Furthermore, the ignition sources could be an uncarefull welder, short circuit due to wrong wiring or perhaps just a spark from a dropped tool.

The next step is to determine positive and negative contributing factors, e.g. is it a negative factor that the people do not get enough sleep, food or perhaps pay. The error can also be caused by misunderstanding of their assignments. A positive factor is to give the people breaks so thy can keep focus on their job when they are working.

A barrier could be how long time the people should be working per day. Controls can be introduced by having a second person to go through welds, connections and so on.

The final step is to asses the errors which can be done by having people employed to survey the potential human errors and reduce them.

3.5. The Probabilistic Explosion Risk Assessment

As shown above, there are many parameters which effect the gas explosion and the consequence. It is therefore necessary to have an approach which can deal with all the parameters. This approach could be a probabilistic explosion risk assessment. The purpose of a probabilistic explosion risk assessment is to determine realistic overpressures due to the explosion. The assessment is based on probabilistic arguments e.g. different leakage sizes, ignition sources, wind direction and so on, all based on their probability of occurring. Due to all off these data simulations are preformed in CFD in order to get a gas cloud size and also to calculate the pressure. An example of the probabilistic explosion risk analysis is given in Figure 3-5.

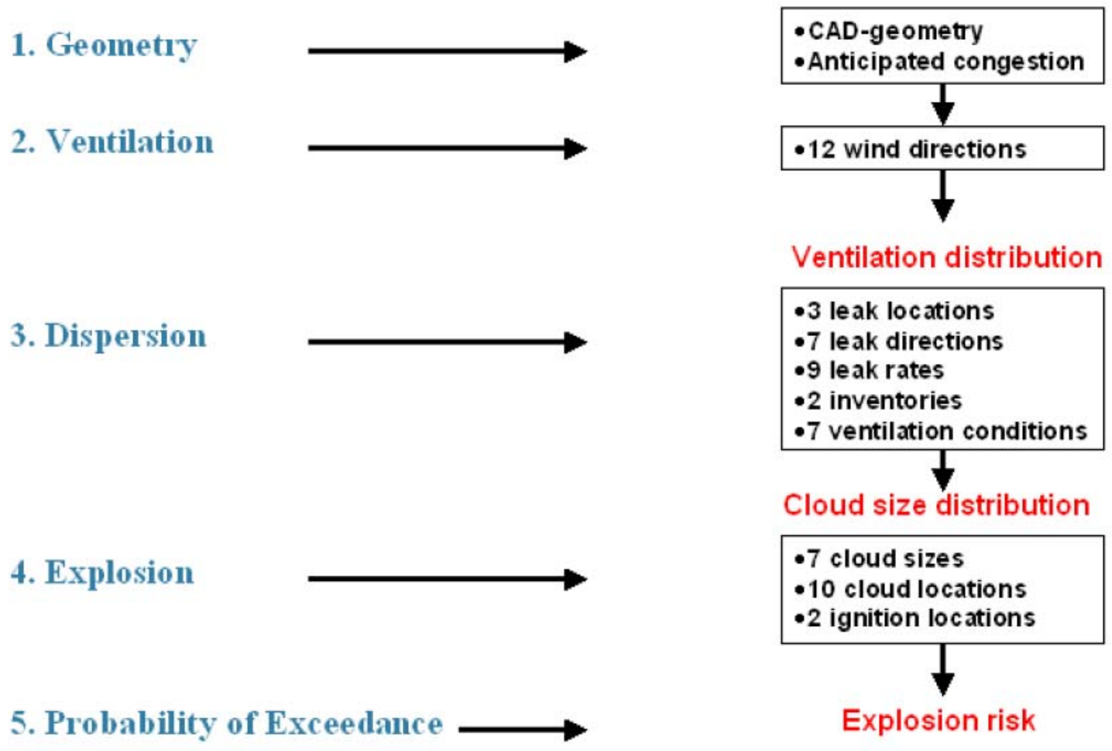

Figure 3-5: *Outline of a probabilistic explosion risk analysis. (Bakke et al., 2003)*

The amount of simulations is different from case to case and the above figure is just an example. The above example results in more than 2000 leakage scenarios which must be investigated using CFD. Since a CFD simulation takes a lot of time (normally from 1 hour to 1 day, depending on computer power) the probabilistic explosion risk analysis has a limitation in numbers of scenarios.

The results of the analysis will be an exceedance curves as the ones shown in Figure 1-2 and Figure 3-3. Different companies have different acceptance criteria e.g. one criterion could be a certain pressure with a return period of 10,000 years. This would result in the pressure with a frequency of 10^{-4}. For Figure 3-3 this would give a pressure of 1.5[Barg] in the example without walls. The designer must then design the platform for this pressure. Higher pressure is of course possible but the effect of those must just be accepted.

4. Future

When dealing with gas explosions a response surface, also known as an exceedance curve, is often required. This response surface is often modeled by using CFD to determine the volume of the gas cloud. Next, another CFD program is used to determine the explosion pressure if the gas cloud is ignited. These CFD calculations take a lot of computer power and it is therefore desirable to avoid the heavy CFD calculations. In order to do so, a generic model could be established concerning the volume of the gas cloud and another to determine the explosion pressure if the cloud is ignited. The implementation of such a model is illustrated in Figure 4-1. The illustration shows that the model builds on earlier simulation which makes the model “smart”. The concept is that it should not be necessary to make as many CFD simulations. The actual conditions such as e.g. wind data, ignition sources and geometry are typed into the generic model and the model tells which simulations it needs to predict the response surface.

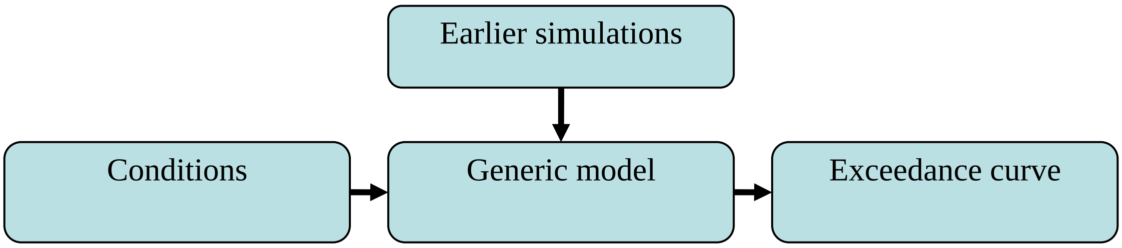

Figure 4-1: *Implementation of the generic model.*

This generic model gets “smarter” each time it is added extra data and the aim is to reduce the amount of simulations and thereby reduce the time of the risk analysis and still obtain good predictions.

A simpler method could be to use the probabilistic explosion risk analysis on existing oil platforms to identity possible high risk areas and then change those. This could be analysis of blast walls, ignition sources and so on. This would probably result in a safer design of the existing oil platforms.

5. Conclusion

The purposes of this paper are to analysis and quantify gas explosions on oil platforms in a simple and direct manner. This has been done by describing the chain of events that leads to an explosion. Each step is described and analyzed, and factors that effect the explosion are determined and analyzed. The correlations between certain chosen parameters are estimated.

The human factor is also described and one way of reducing the human error is discussed. It is believed that the human error causes more accidents than any other error source. It is therefore important to reduce the probability of human error.

A current model for analyzing the pressure from a gas explosion is described. The model is called the Probabilistic Explosion Risk Assessment and it gives the pressure as a function of frequency. The model used many CFD calculations to determine possible gas cloud sizes and the development of pressure due to an ignition. All parameters are dealt with in a probabilistic manner.

The future of risk analysis of gas explosion could be to develop a generic model that contains earlier CFD simulations in such a way that the model becomes clever and the amount of CFD simulations can be reduced.

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