The benefits of using CFD for designing gas detection systems

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Many questions arise when trying to analyse or design a gas detector layout: How will the proposed layout behave for different types of leaks/gases (jet or diffusive, light or heavy)? Will the presence of congestion (pipe work, machinery or buildings) alter the effectiveness of ventilation and/or the way the gas is dispersed? What flammable cloud size is considered dangerous and how many detectors are needed to ensure it is detected?

Simplistic analytical tools can provide a global screening overview of a gas detector layout but the lack of consideration of wind speed, terrain features, geometry/obstacle details and gas leak properties make them unreliable when used outside their scope of use. Simplistic methods generally assume idealised gas clouds such as perfect spheres, but in reality gas clouds will take on very different shapes and are severely affected by the initial momentum of the leak, by obstructions, congestion and buoyancy.

The key aspect of a CFD-based evaluation of a gas detection system is the selection of several different ventilation and leak scenarios to be used for testing and challenging the detection system. Analysis of several different scenarios helps ensure the system is reliable in the most varying conditions. Furthermore, using engineering judgement, only the scenarios that would really challenge the detection system and result in dangerous cloud volumes need to be assessed. In some cases, failure to detect results from poor detector coverage in certain areas, which can be improved substantially by adding or rearranging just a few detectors.

Ventilation simulations are conducted initially in order to determine real wind flow patterns in the facility and identify areas of stagnation and areas of high wind speed. Stagnant areas can allow the smallest leaks to form significant flammable gas clouds. Conversely, high wind speeds can dilute rich gas clouds from very large leaks, resulting in large flammable clouds. Therefore, an understanding of the ventilation patterns across the facility helps in understanding the likely release scenarios that could result in dangerous clouds forming.

Dispersion simulations are then performed based on a number of wind speeds and leak rates. Leak representation is based on a range of possible combinations of leak parameters, such as leak direction, position, mass flowrate and leak direction relative to wind direction. In addition, leaks in varying types of process areas are considered, such as leaks impinging on objects, free-field jets and diffusive leaks.

This paper presents the results of a case study undertaken by Gexcon using the FLACS CFD code, showing the effects of realistic gas leaks within congested areas on an offshore oil rig. Various detector layouts are evaluated and compared to show the improvements in performance that can be achieved by testing each system against several leak scenarios. The detector layout determined by a simplistic analytical method is also tested using the FLACS code in order to compare its performance.

Risk-based detection analyses will also be discussed, whereby leak frequencies and wind statistics are combined with CFD simulation results in order to determine a more probabilistic system performance.

Keywords: Gas detection, CFD, dispersion modelling, simulation.

Introduction

Across industry, well-designed gas detection systems are important; they give an early warning of a potentially serious problem. This is crucial when the consequences of a hazard are considered, such as compensation costs, environmental impacts, loss of life, profit, assets and reputation. Therefore, the design and implementation of a gas detection system plays a major role in the industry.

Flammable gas detectors can trigger alarms if a specified concentration of the gas or vapour is exceeded, providing an early warning before a hazard is created and thereby helping to ensure the safety of people and equipment. Placing these detectors "effectively" can be difficult due to the facility geometry characteristics and its ventilation patterns, greatly affecting the dispersion of a gas release.

According to the Health and Safety Executive (HSE, 2014), the factors to consider when positioning a sensor to prevent a serious hazard are

- the process plant and equipment, to identify the most likely sources of flammable gas;
- the type of sensor;
- the properties and dispersion characteristics of the gas; and
- the ventilation patterns.

NORSOK S001 (NORSOK STANDARD, 2008) specifies that "all dangerous clouds must be detected; and the gas detection system will be optimised based on clouds resulting from small, more frequently occurring leaks".

This paper presents the results of a case study undertaken by Gexcon using the FLACS CFD (Computational Fluid Dynamics) code, showing the effects of realistic gas leaks within congested areas on an offshore oil rig. Various detector layouts are evaluated and compared to show the improvements in performance that can be achieved by testing each system against several leak scenarios. The detector layout determined by a Simplistic Analytical Method is also tested using the FLACS code in order to compare its performance.

Methodology

An Oil & Gas company contacted Gexcon in 2014 in order to evaluate the performance of their installed gas detector layouts (designed via Simplistic Analytical Methods) against accidental natural gas releases and obtain recommendations on new layout designs. FLACS simulations were carried out to give detailed data on realistic natural gas releases and form the basis for assessing the performance of the gas detection system. A key point for the study was to test the detector system with realistic gas releases that would result in natural gas clouds of significant size and yet be challenging to detect.

Software

The simulations described in this paper were performed with the CFD code FLACS (version 10.3). FLACS, developed and maintained by Gexcon AS in Norway, is an advanced tool for the modelling of ventilation, gas dispersion, fire, gas/vapour/dust cloud explosions and blasts in complex process areas.

The development of FLACS has been carried out with the full co-operation, support, direction and funding of about 10 international oil and gas companies and three legislative bodies. The code has been used in the design and explosion risk control in a large number of process areas worldwide.

Geometrical model

Experience shows that incompleteness of detail in the geometry model is one of the main sources of errors in CFD analyses. It is known that, from both simulations and experiments, explosion overpressures are very dependent upon the geometrical layout and amount of congestion of the area considered. In order to produce accurate and reliable results from a FLACS simulation it is important that the geometrical model used in the analysis is as accurate as possible.

The geometrical model (presented in Figure 1) created for use in the simulations represents two bridge-linked platforms: Drilling and Production. The Drilling Platform has a Weather deck (50 m x 20 m), where some equipment and the Helideck are present, and a Cellar deck (5 m below) with the Wellhead area (12 m x 12 m) and some redundant accommodation buildings. For additional information, the blockage ratio (representing the ratio between the occupied volume to the total available volume) of the wellhead area on the cellar deck was approximately 7% in the geometrical model. The Production Platform (49 m x 32 m) is well separated from the Drilling area by a 29 m long bridge, and comprises a Process area and Utility area, where most of the target buildings are located. More details of the level of congestion and equipment considered in the study are shown in Figure 2.

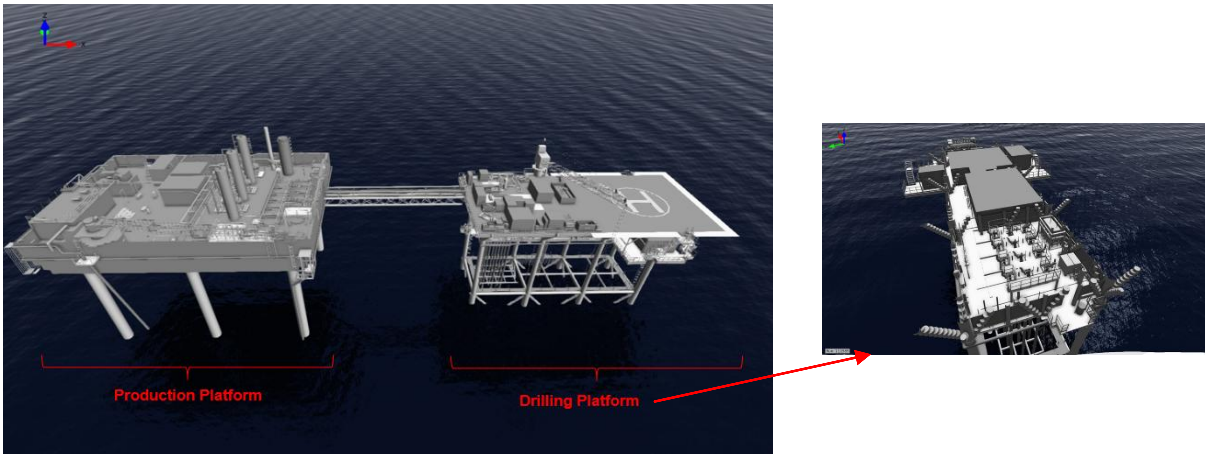


Figure 1. Two bridge-linked platform model used in the simulations.

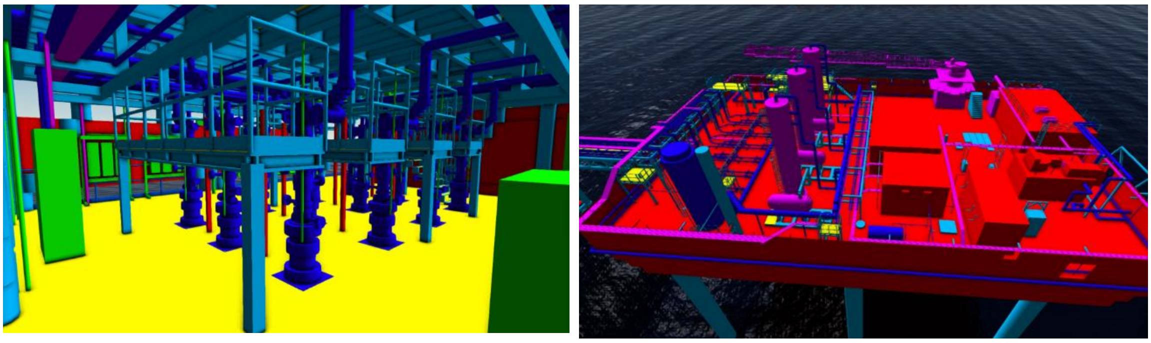


Figure 2. Geometry detail considered within the study (left: Wellhead area of the Drilling Platform, right: Production platform weather deck).

Simulation strategy

Before analysing the effectiveness of a specific gas detector layout compared to another, the assessment criteria need to be defined. The “performance” criterion defined in the current study for hydrocarbon gas detection is related to both gas concentration and explosion risk. In terms of gas concentration, a “dangerous cloud” was defined as one that could potentially be drawn into buildings on the platforms, resulting in a potential explosion within them. In terms of explosion risk, a “dangerous cloud” was defined as a volume of gas that, if ignited, could result in explosion loads that exceeded the DAL (Design Accidental Load) of target buildings and equipment.

Explosion simulations for both platforms were undertaken in the first stage, considering various gas cloud sizes, positions and ignition locations. The explosion loads were compared with the impairment criteria for target buildings and equipment to determine the size of a “dangerous cloud” to be detected.

Ventilation simulations were then conducted, considering 8 cardinal wind directions and the most frequently occurring wind speed. The air changes per hour in each area of each deck were determined from these simulations, to give an indication of how well ventilated they are. Furthermore, typical wind patterns on the decks of the Drilling and Production Platforms were also determined. These were used in the specification of potential gas detector layouts, as they allowed probable gas cloud behaviour to be established.

The last simulation stage considered a set of accidental gas releases, with various leak positions, leak rates, leak directions, wind speeds and wind directions. The results of these simulations provided detailed predictions of gas cloud sizes and dispersion patterns arising from different release scenarios, in order to determine leaks that could result in “dangerous” clouds. All scenarios were chosen to result in gas clouds of significant size, yet be challenging for the gas detection system to detect Very large clouds are often very easy to detect as they cover a larger area of the platform and so are more likely to be detected, so although they present a greater explosion risk, they are less of a concern for the gas detection system. In addition, very small clouds can be very challenging for a gas detection system to detect, however they typically pose very low explosion risk, so are still of less concern for the gas detection system. It is the “medium sized” clouds that are usually both dangerous in terms of explosion risk and difficult to detect at the same time. Therefore, the prediction of the “dangerous cloud” size from the initial explosion simulations, coupled with the results of the ventilation simulations, is crucial to defining gas leak scenarios that are truly dangerous and challenging to detect.

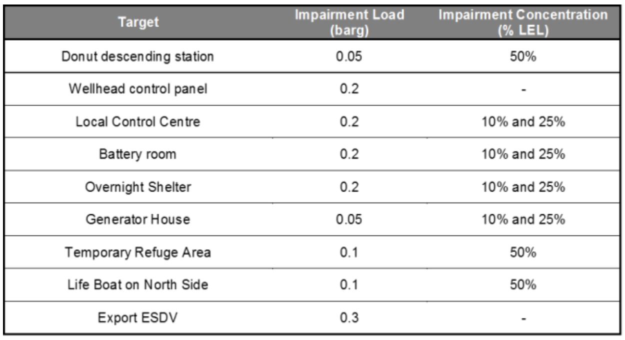
With a combination of both qualitative and quantitate assessments is possible to achieve a robust basis to design more efficient detector layouts. Various detector layouts (with different spatial configurations, number of detectors and type of detectors (i.e. point and line) were evaluated and compared to show the improvements in performance (i.e. time to detection) that can be achieved by testing each system against several leak scenarios. The detector layout determined by a Simplistic Analytical Method (or SAM) was also tested using the FLACS code in order to compare its performance.

Results and discussion

Explosion Study

As described in the previous section, the intention of the explosion simulations was to determine a "dangerous cloud” size. The impairment loads (in terms of both overpressure and gas concentration) for the facility are shown in Table 1. The impairment criteria for gas concentration relates to gas ingress into buildings that could potentially result in explosions occurring within these buildings.

Table 1. Impairment criteria for safety critical targets.



Target	Impairment Load (barg)	Impairment Concentration (% LEL)
Donut descending station	0.05	50%
Wellhead control panel	0.2	-
Local Control Centre	0.2	10% and 25%
Battery room	0.2	10% and 25%
Overnight Shelter	0.2	10% and 25%
Generator House	0.05	10% and 25%
Temporary Refuge Area	0.1	50%
Life Boat on North Side	0.1	50%
Export ESDV	0.3	-

Many different gas cloud sizes, cloud positions and ignition locations were considered. Figure 3 and Figure 4 present details of the approach for the explosion study. The red boxes represent the gas cloud locations and the green arrows show the direction towards which the clouds grow in size. The “explosion” symbol indicates the ignition location. For each gas cloud location and size, four different ignition locations were simulated (central and corner ignition at both 0.25 m above the floor and 0.25 m below the ceiling). In total, 336 explosion simulations were carried out for the Drilling and the Production Platforms.

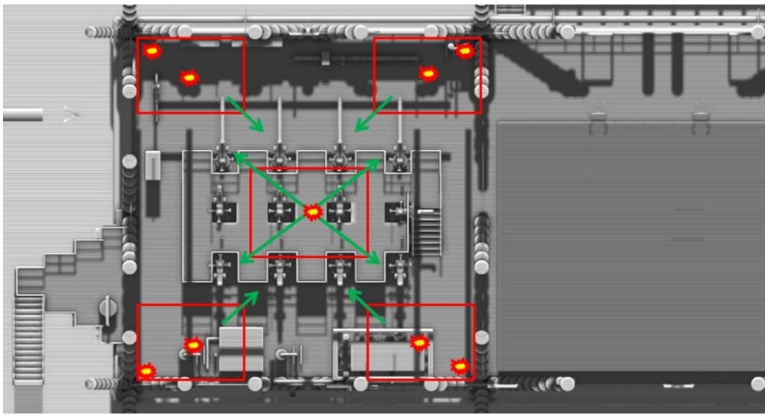


Figure 3. Gas cloud sizes and ignition locations considered for the explosion simulations on the cellar deck of the Drilling Platform.

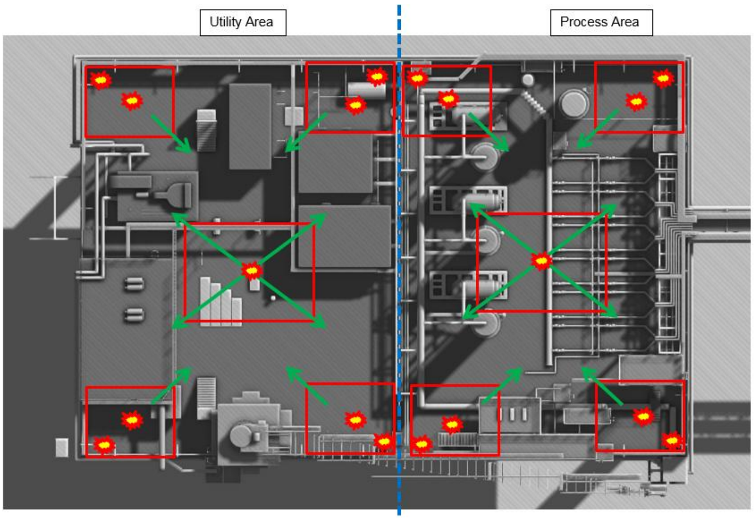


Figure 4. Gas clouds sizes and ignition locations considered for the explosion simulations on the Production Platform.

Table 2 summarises the results of the explosion simulations. The maximum overpressures on the targets are presented for the various gas cloud sizes modelled, from simulations on both the Drilling and Production platforms. The pink cells highlight where the impairment loads were exceeded. The minimum cloud size that resulted in overpressures above the impairments loads was defined as the "dangerous cloud".

It can be seen that the impairment loads were only exceeded during explosions on the cellar deck of the Drilling Platform. Furthermore, only the impairment criteria for some of the targets on the Drilling Platform were exceeded. The dangerous cloud for the Drilling Platform was therefore defined as 264 m^3.

For the Production Platform, none of the impairment loads were exceeded during the explosion simulations modelled. Therefore, it was not possible to determine a dangerous cloud size, as even clouds larger than 4,000 m^3 did not result in overpressures that were large enough to exceed the impairment criteria. As some of the targets on the Production Platform (e.g. control room, generator house, etc.) included impairment criteria in terms of gas concentration, the dangerous cloud for the Production Platform was defined based on a cloud that impaired these buildings.

Table 2. Overpressures on targets resulting from explosions on the Drilling and Production Platforms.

				Explosions on Drilling Platform								Explosions on Production Platform							
				Max. pressure (barg) for varying cloud sizes								Max. pressure (barg) for varying cloud sizes							
		Target	Impairment Load (barg)	141 m^3	198 m^3	264 m^3	337 m^3	421 m^3	466 m^3	513 m^3	613 m^3	26 m^3	209 m^3	452 m^3	872 m^3	1443 m^3	2133 m^3	2966 m^3	4151 m^3
Point pressure	Drilling P.	Donut descending station	0.05	< 0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.05	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.02
Point pressure		Wellhead control panel	0.2	0.09	0.14	0.23	0.34	0.50	0.63	0.78	1.00	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	0.01	0.02
Area average pressure	Production P.	Local Control Centre	0.2	< 0.01	< 0.01	0.01	0.01	0.02	0.02	0.02	0.02	< 0.01	0.01	0.02	0.02	0.02	0.02	0.04	0.06
Area average pressure		Generator House	0.05	< 0.01	< 0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03
Area average pressure		Overnight Shelter	0.1	< 0.01	< 0.01	0.01	0.01	0.02	0.02	0.02	0.03	< 0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04
Area average pressure		Battery room	0.2	< 0.01	< 0.01	0.01	0.01	0.02	0.02	0.02	0.02	< 0.01	0.01	0.02	0.02	0.01	0.02	0.05	0.08
Point pressure		Export ESDV	0.3	< 0.01	0.01	0.02	0.03	0.04	0.04	0.05	0.06	< 0.01	0.01	0.01	0.02	< 0.01	0.01	0.02	0.03
Point pressure		Life Boat on North Side	0.1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.01	0.01	0.03
Point pressure		Temp. Refuge Area	0.1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.01	0.01	0.03

Some details of explosion pressure contours and flame paths can be seen in Figure 5 to Figure 8. Figure 5 shows the effects of an explosion of a gas cloud that completely fills the volume of the partially confined wellhead area of the Drilling Platform, with ignition occurring in the opposite corner to the Wellhead Control Panel (WCP). The significant level of congestion in the path in between the ignition and the target location results in increased turbulence in the flame path, leading to high overpressures.

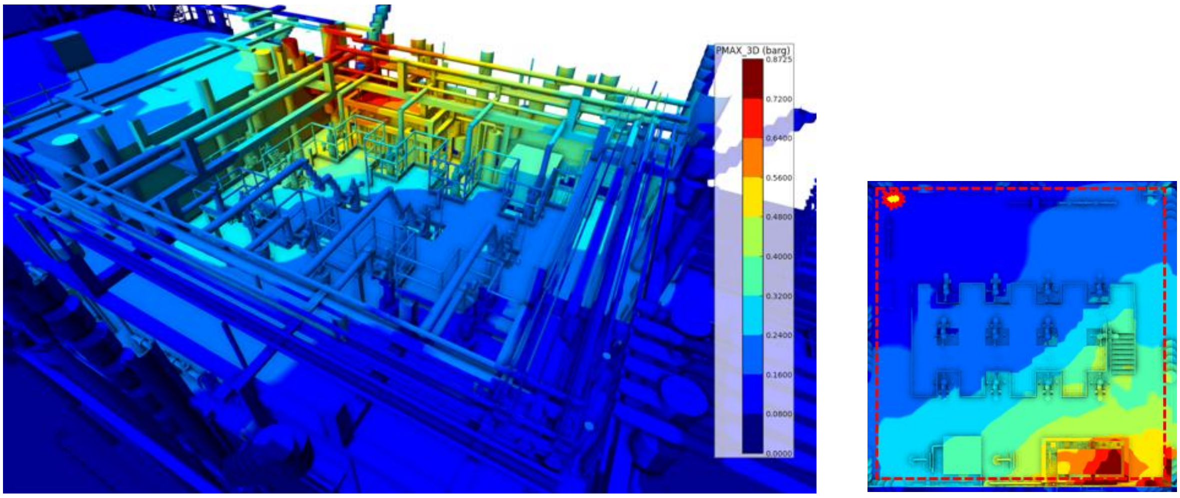


Figure 5. Pressure distribution in the wellhead area on the Drilling Platform. Right, the initial gas cloud size (red dashed line) and ignition location.

Figure 6 shows the flame development with time for an explosion scenario on the Drilling Platform. It is possible to see that the grated deck in the Drilling Platform allows the flames and pressure generated within the wellhead area to vent through it, thus reducing the overpressures achieved within the partially-confined area.

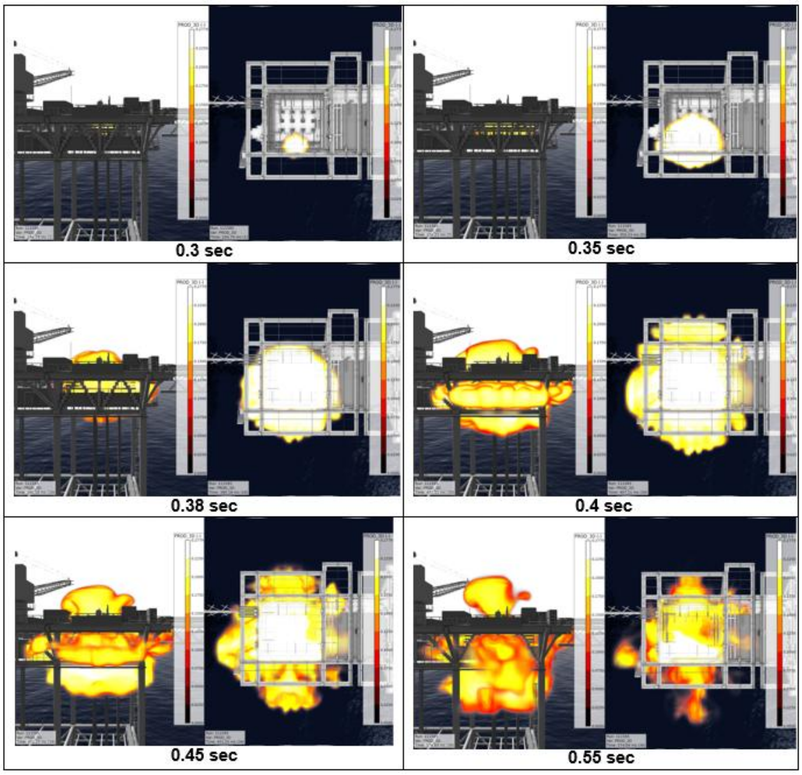


Figure 6. Images of flame path in the Drilling Platform at various times for an explosion scenario with an ignition location close to the WCP.

For the Production Platform, Figure 7 shows the pressure distribution resulting from the explosion of a gas cloud that fills the entire process area, with ignition in the centre of the cloud near the deck. Figure 8 presents a similar configuration, but with the gas cloud in the utility area. It is possible to see that the target buildings and piping on the platform experience low overpressures. This is mainly due to the fact that it is a largely open region (i.e. not confined) and also relatively uncongested, which allows pressure to vent outwards to the surroundings.

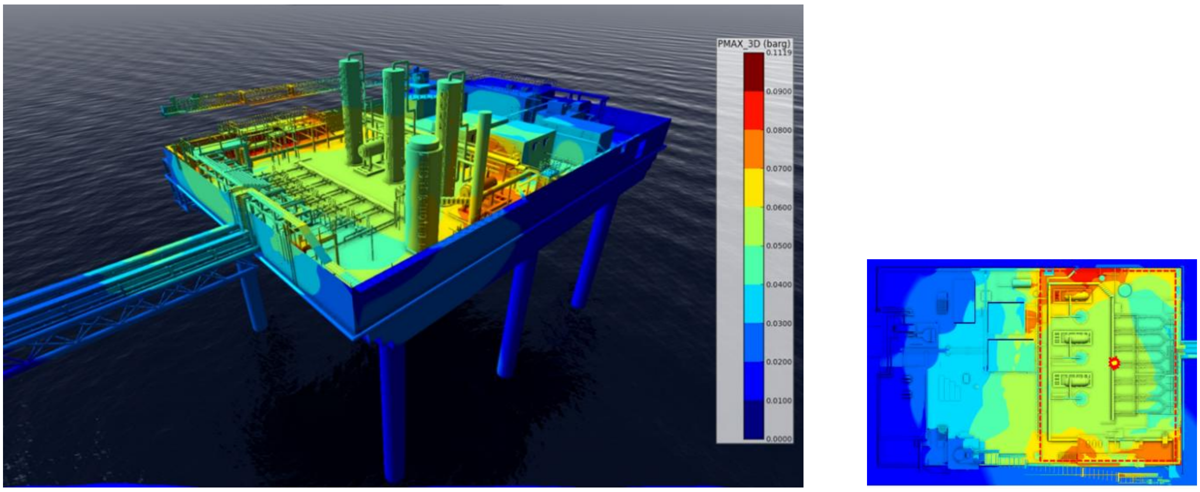


Figure 7. Pressure distribution in target areas in the process area of the Production Platform. Right, the initial gas cloud size (red dashed line) and ignition location.

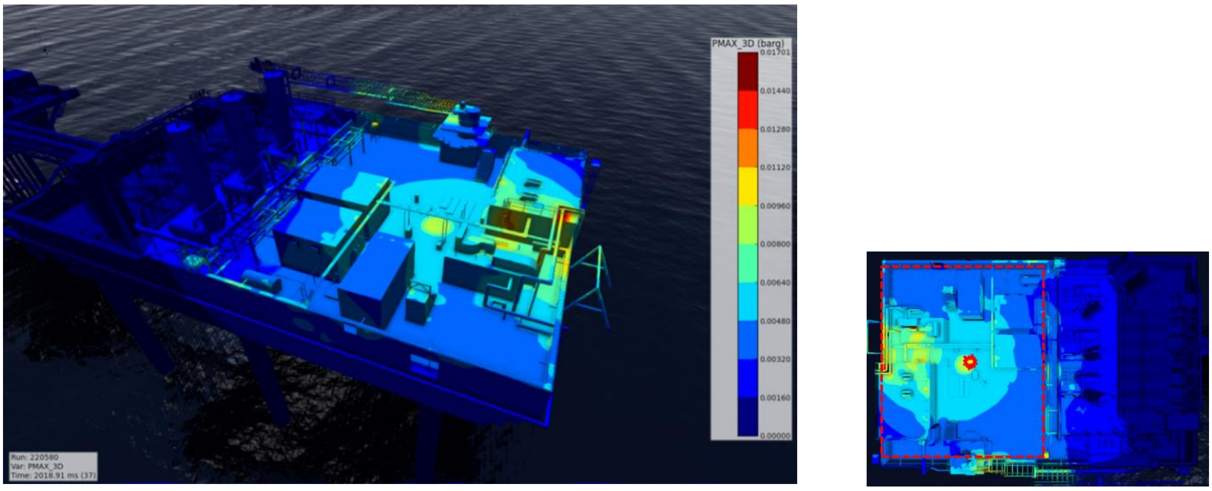


Figure 8. Pressure distribution in target areas in the utility area of the Production Platform. Right, the initial gas cloud size (red dashed line) and ignition location.

Ventilation Studies

Ventilation studies were carried out to determine detailed flow patterns within the process areas of each platform and help identify areas of stagnation or high wind speed. Air Changes per Hour (ACH), which depend not only on the meteorological conditions of the location but also on the geometrical configuration of the platform, were obtained in all areas of each platform. An extensive study was conducted, considering 8 cardinal and ordinal wind directions and the characteristic (most probable) flow speed taken from wind rose statistics (i.e. 8 m/s). For the purpose of the analysis, it was assumed that the ventilation rate scales linearly with wind speed.

It was possible to see that the Air Changes per Hour were quite high for both platforms, indicating they are both very well ventilated. Additional information that can be obtained from 3D CFD simulations are ventilations patterns, as shown in Figure 9 and Figure 10, which show details of the wind velocity vectors coming from two different cardinal directions for the Drilling Platform and Production Platform, respectively. It is possible to see that, if a gas leak occurs, the resulting wind flow patterns could cause the gas to migrate towards target buildings/areas. For example, for the particular scenario in Figure 9, if a leak were to occur in the wellhead area, the cloud could migrate towards the shelters and life boat regions, potentially resulting in an explosion near these areas.

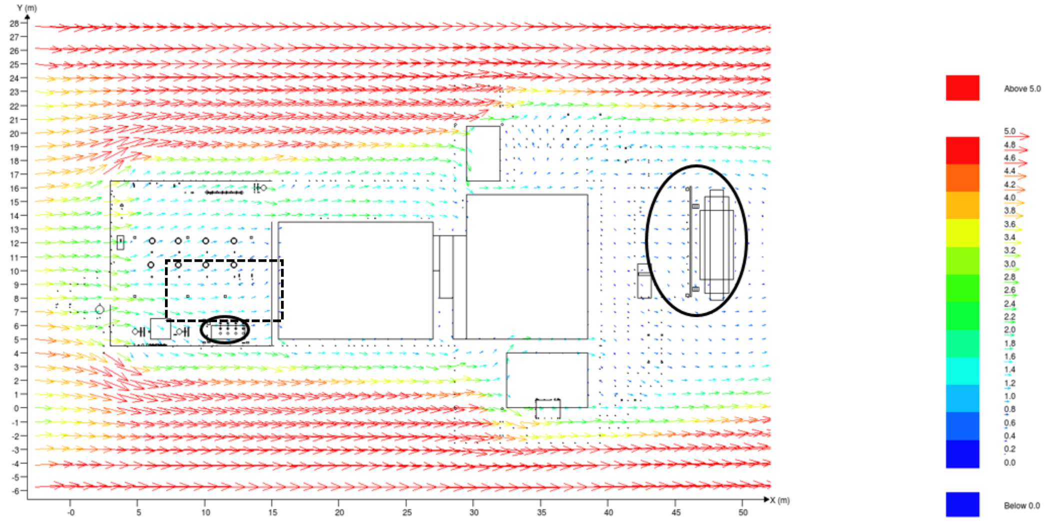


Figure 9. Velocity vectors within the wellhead area (dashed black) of the Drilling Platform for wind coming from the West (targets are circled in black).

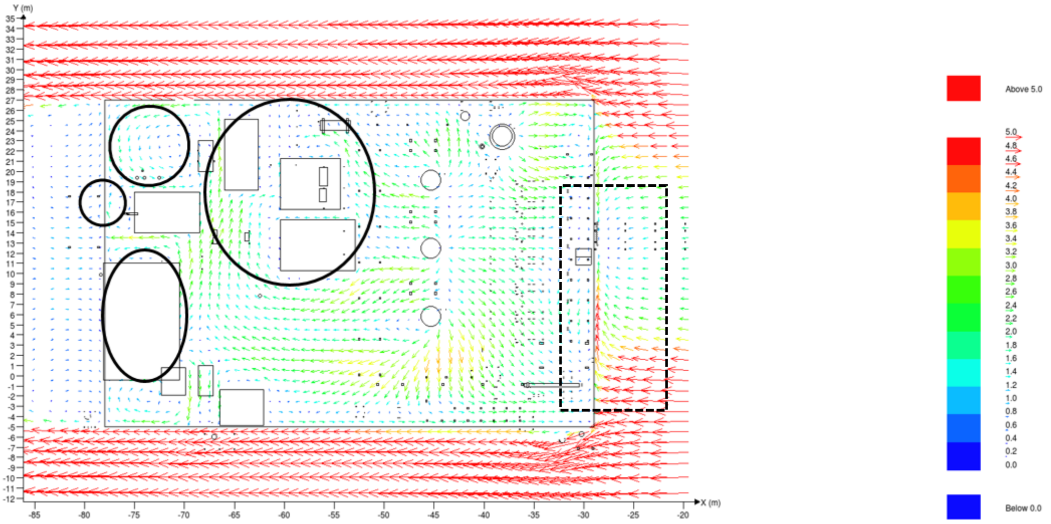


Figure 10. Velocity vectors in the Production Platform for wind coming from the East (targets are circled in black, pipework in dashed black).

Dispersion Studies

The objective of the dispersion studies was to simulate a number of accidental gas releases that would provide realistic and precise data on how gas disperses and accumulates in different areas of the platforms. The different gas detector layouts were tested against the data set obtained from this study. The dispersion study was carried out based on a "worst-case" approach, (i.e. we have aimed for "challenging" scenarios for the gas detection system), meaning no frequency/risk-based aspects have been considered.

As the number of potential gas leak scenarios is very large, there will always be leaks that can never be detected (e.g. very small leak rates, leaks pointing away from the facility, etc.) and leaks that will always be detected (e.g. very large leak rates, leaks adjacent to detectors, etc.). The key aspect of a CFD-based evaluation of a gas detection system is the selection of leak scenarios to be used for testing and challenging the detection system.

In addition to sonic jets (the most likely release scenario) the study accounted for diffusive leaks (low momentum gas leaks). A combination of leak locations, leak directions, leak rates and wind conditions were chosen so that the combination of all simulated gas clouds covers the most probable loss of containment scenarios, with a total of 560 FLACS simulations being performed.

Following the ventilation study in the previous section and based on the flow patterns obtained, Figure 11 shows the leak locations and directions defined for the dispersion analysis. The leak rates simulated were 1.5 kg/s, 6 kg/s, 24 kg/s and 96 kg/s in order to include a combination of small, medium, and large release rates. The wind speeds considered were "Calm" (0 m/s), "Light" (4.8 m/s), "Average" (8 m/s) and "Strong" (14.9 m/s). Calm conditions can allow the very smallest leaks to form significant gas clouds. However, high wind speeds could dilute rich gas clouds formed from very large leaks, resulting in large flammable gas clouds.

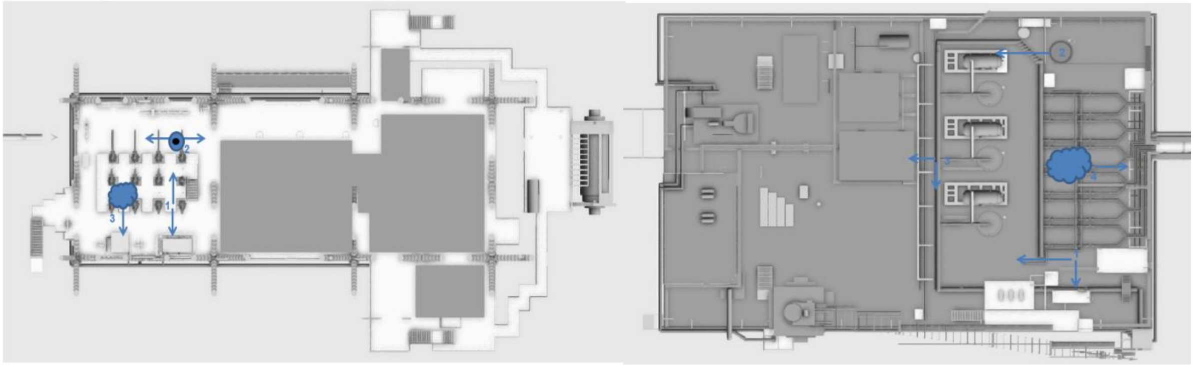


Figure 11. Location and direction of leaks (arrow represents a jet leak, cloud represents a diffusive leak and a black dot a jet leak pointing upwards) on the Drilling Platform (left) and Production Platform (right).

Based on the flow patterns and leak configurations that could generate "dangerous" clouds, various combinations of line and point detectors were defined. 16 different layouts were designed and analysed for the Drilling Platform and 27 for the Production Platform. Some of the designs considered can be seen in Figure 12 and Figure 13. A simplistic spherical point detection method was used to determine the Simplistic Analytical Method (SAM) gas detector layout for the Drilling platform. The SAM layout was also analysed and their performance compared to the different layouts proposed.

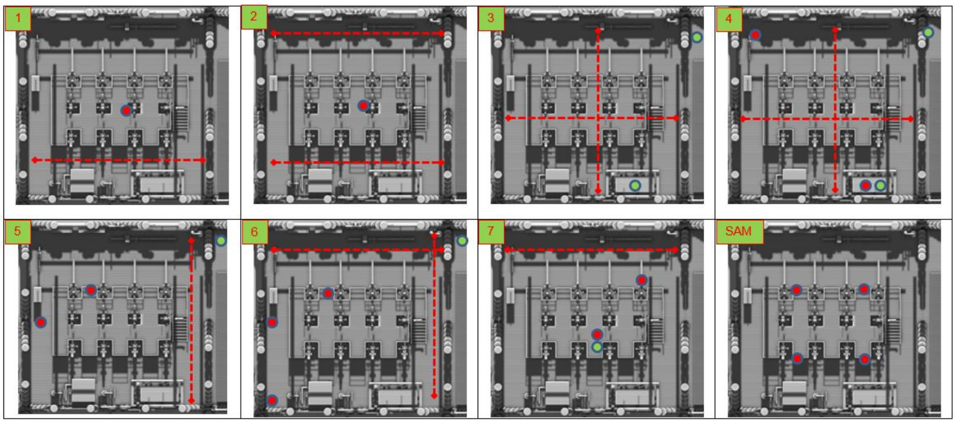


Figure 12. Gas detector layouts for the Drilling Platform: ---- = Line detector; Red dot= Point detector at 0.5 m height above the cellar deck; Green dot= Point detector at 2.5 m height above the cellar deck.

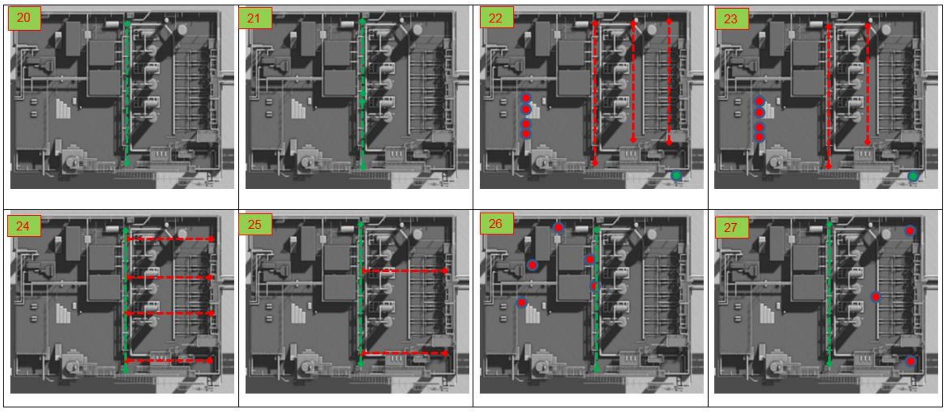


Figure 13. Gas detector layouts for the Production Platform: ---- = Line detector at 1 m height from weather deck; : ---- = Boundary detection made of line detectors at 1 m, 1.5 m, 2 m and 2.5 m height from weather deck; Red dot= Point detector at 0.5 m height above the deck; Green dot= Point detector at the ESDV cabinet.

Boundary Detection was also defined in many layouts for the Production Platform. This consists of line detectors at different heights to form a kind of line detector "barrier". The heights defined for each line detector were 1.0 m, 1.5 m, 2.0 m and 2.5 m above the weather deck.

For detection in terms of gas concentration, the performance of the detector layouts was evaluated based on Low Alarm (1oon) and High Alarm (2oon) coverage. Monitor points were defined around the targets of interest in order to continuously monitor gas concentration at these areas (see impairment criteria in Table 1). Figure 14 provides details of the location of the monitor points around the target buildings that were considered, so as to evaluate the detection performance of the different layouts. Furthermore, voting criteria were employed that considered when the alarm would occur, based not only on the gas concentration detected but also on how many detectors reached those values.

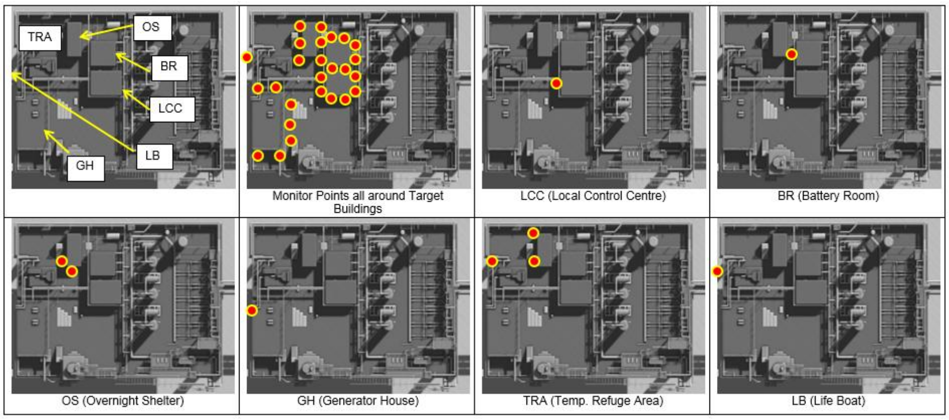


Figure 14. Monitor points distribution: All around target buildings and in HVAC inlets on the platform North side of each building

Figure 15 shows the percentage of scenarios that were detected for each detector layout from all the dispersion scenarios simulated on the Drilling Platform. It can be seen that layouts 4, 5, 6, 9, 10 and 16 performed the best. Layouts 9 and 10 detected every dispersion scenario that was considered, however these layouts were extreme cases that contained many detectors: 16 point detectors distributed in a 4 x 4 uniform arrangement on a single plane (L9 at 0.5 m height, L10 at 2.5 m height). This result was therefore expected and these layouts were set up so as to have reference layouts with which to compare the different proposed designs to. Layouts 4, 5, 6 or 16 would therefore be preferable as they required far fewer detectors and yet detected very high percentages of the 336 leak scenarios modelled for the Drilling Platform. The SAM layout detected every scenario at low alarm but it was outperformed by the proposed designs for high alarm detection.

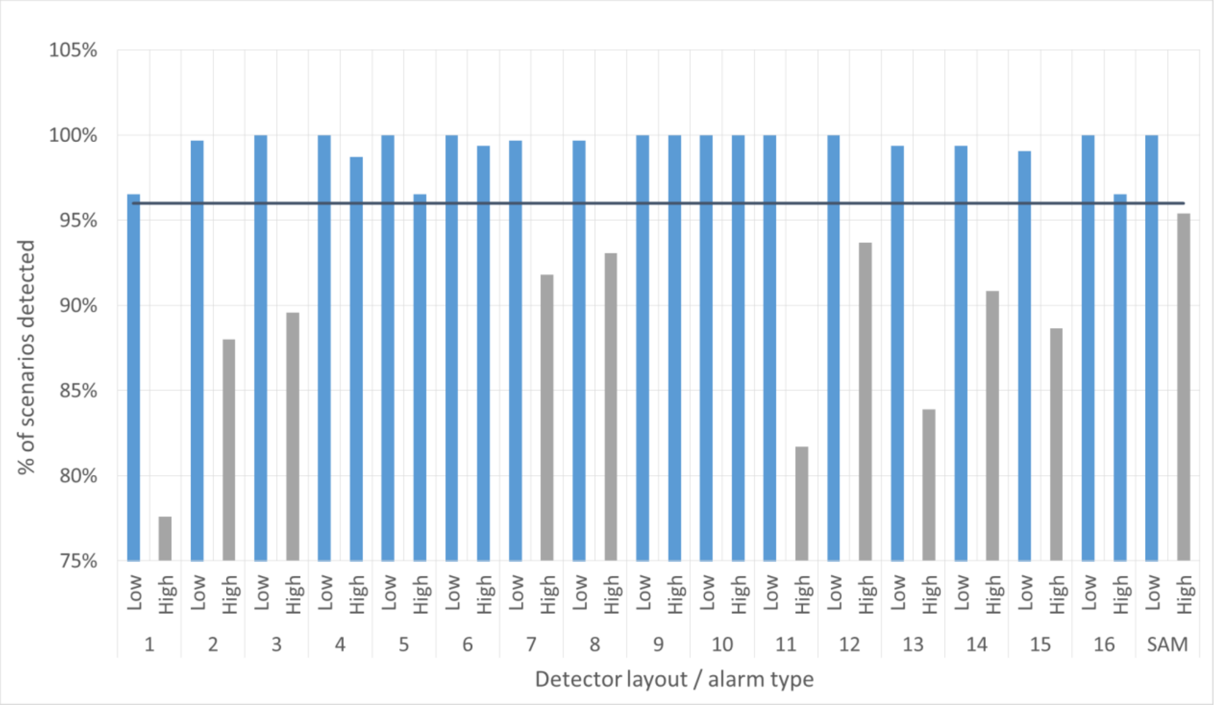


Figure 15. Percentage of leak scenarios modelled that were not detected, for all detector layouts analysed on the Drilling Platform

Table 3 summarises the results of the best performing detector layouts along with the SAM layout. Each layout is coloured by a different shade of red: The darker the colour, the worse the layout performed compared to the others for that particular criterion. For example, detector layouts 9 and 10 performed the best, as expected, in terms of the percentage of scenarios detected to both low and high alarm, as well as the percentage of scenarios detected with respect to both low and high alarm before the dangerous cloud volume was reached (264 m^3), however, these layouts required the most detectors.

This table allows a comparison to be made between the best performing layouts, based on various criteria. It was suggested that detector layouts 4, 5 and 6 were the most preferable, as they all required few detectors and all detected a very high percentage of the leak scenarios modelled to high alarm before the dangerous cloud volume was reached (96%, 95% and 97%, respectively).

Table 3. Summary of results for best performing detector layouts for the Drilling Platform

Detector layout no.	No. of point detectors	No. of line detectors	Total no. of detectors	% of scenarios detected to low alarm	% of scenarios detected to high alarm	Max. detection time to low alarm for all scenarios detected (s)	Max. detection time to high alarm for all scenarios detected (s)	% of scenarios detected to low alarm before dangerous cloud volume reached	% of scenarios detected to high alarm before dangerous cloud volume reached
4	4	2	6	100%	99%	15.0	53.5	99%	96%
5	3	1	4	100%	97%	18.3	34.5	99%	95%
6	4	2	6	100%	99%	18.3	31.7	99%	97%
9	16	0	16	100%	100%	11.6	12.8	99%	99%
10	16	0	16	100%	100%	15.0	15.8	99%	99%
16	9	0	9	100%	97%	30.7	201.2	98%	91%
SAM	4	0	4	100%	95%	31.2	40.9	99%	93%

Figure 16 shows the percentage of scenarios that were detected for each detector layout from all the dispersion scenarios simulated on the Production Platform. Layout 11, a reference layout with which to compare all the proposed designs to, detected every dispersion scenario that was considered. Several of the other layouts performed well with respect to low alarm, but did not reach the same performance for high alarm.

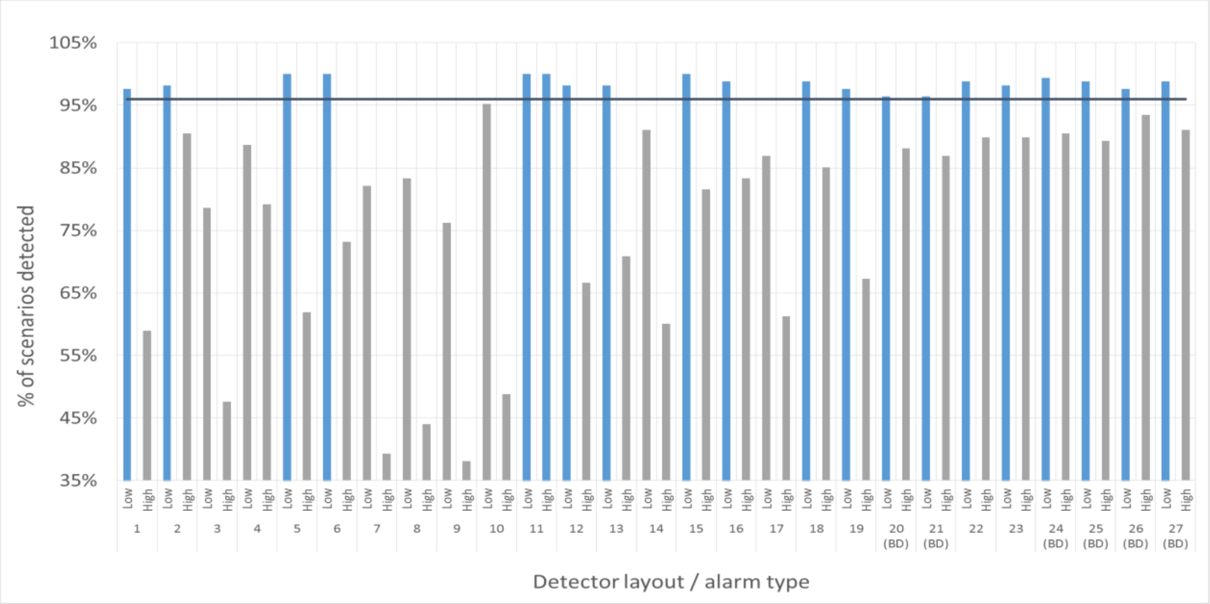


Figure 16. Percentage of leak scenarios modelled that were not detected, for all detector layouts analysed on the Production Platform

As mentioned previously, monitor points to detect gas ingress in buildings were defined on the North side of the target buildings. These were used to determine the time at which the impairment criteria for gas concentration were exceeded at these targets (see Figure 10 for references). The minimum time considered for the criteria to be exceeded at any of the targets was the time by which each detector layout reached at least low alarm. The reason for this was that gas ingress at any of these targets could result in a subsequent fire or explosion; therefore the first detection of gas at any of these targets was considered a risk.

Table **4** summarises the performance of each layout in terms of time to detection at low and high alarm. The times to detection are considered for both the 10% LEL criteria (referred to as "min. conc.") and 25% LEL criteria (referred to as "max. conc.") defined for the targets on this platform. The "No. of Fails" column shows the number of scenarios that did not reach low or high alarm before the impairment criteria was reached at any of the target buildings/equipment. It can be seen that the detection performance was generally poor for all layouts.

Table 4. Gas detector layout performance for every leak scenario, based on time to detection compared to time at which impairment criteria is exceeded at targets (LA: low alarm, HA: High alarm, min. conc.: 10% LEL, max. conc.: 25% LEL).

		Minimum time	
Layout #	**Alarm type**	**No. of Fails**	**% of Fails**
1	LA, min. conc.	63	28%
	LA, max. conc.	60	27%
	HA, min. conc.	138	62%
	HA, max. conc.	133	59%
2	LA, min. conc.	28	13%
	LA, max. conc.	26	12%
	HA, min. conc.	70	31%
	HA, max. conc.	65	29%
3	LA, min. conc.	81	36%
	LA, max. conc.	76	34%
	HA, min. conc.	124	55%
	HA, max. conc.	120	54%
4	LA, min. conc.	40	18%
	LA, max. conc.	40	18%
	HA, min. conc.	69	31%
	HA, max. conc.	67	30%
5	LA, min. conc.	25	11%
	LA, max. conc.	25	11%
	HA, min. conc.	104	46%
	HA, max. conc.	97	43%
6	LA, min. conc.	25	11%
	LA, max. conc.	25	11%
	HA, min. conc.	74	33%
	HA, max. conc.	67	30%
7	LA, min. conc.	60	27%
	LA, max. conc.	57	25%
	HA, min. conc.	144	64%
	HA, max. conc.	137	61%
8	LA, min. conc.	60	27%
	LA, max. conc.	57	25%
	HA, min. conc.	137	61%
	HA, max. conc.	131	58%
9	LA, min. conc.	86	38%
	LA, max. conc.	81	36%
	HA, min. conc.	142	63%
	HA, max. conc.	136	61%
10	LA, min. conc.	16	7%
	LA, max. conc.	14	6%
	HA, min. conc.	140	63%
	HA, max. conc.	136	61%
11	LA, min. conc.	0	0%
	LA, max. conc.	0	0%
	HA, min. conc.	2	1%
	HA, max. conc.	2	1%
12	LA, min. conc.	28	13%
	LA, max. conc.	26	12%
	HA, min. conc.	83	37%
	HA, max. conc.	76	34%
13	LA, min. conc.	28	13%
	LA, max. conc.	26	12%
	HA, min. conc.	81	36%
	HA, max. conc.	74	33%
14	LA, min. conc.	43	19%
	LA, max. conc.	42	19%
	HA, min. conc.	104	46%
	HA, max. conc.	100	45%
15	LA, min. conc.	25	11%
	LA, max. conc.	25	11%
	HA, min. conc.	54	24%
	HA, max. conc.	50	22%
16	LA, min. conc.	6	3%
	LA, max. conc.	5	2%
	HA, min. conc.	105	47%
	HA, max. conc.	97	43%
17	LA, min. conc.	79	35%
	LA, max. conc.	73	33%
	HA, min. conc.	149	67%
	HA, max. conc.	142	63%
18	LA, min. conc.	9	4%
	LA, max. conc.	8	4%
	HA, min. conc.	127	57%
	HA, max. conc.	110	49%
19	LA, min. conc.	5	2%
	LA, max. conc.	4	2%
	HA, min. conc.	110	49%
	HA, max. conc.	105	47%
20 (B.D.)	LA, min. conc.	32	14%
	LA, max. conc.	28	13%
	HA, min. conc.	50	22%
	HA, max. conc.	43	19%
21 (20 half width)	LA, min. conc.	32	14%
	LA, max. conc.	27	12%
	HA, min. conc.	54	24%
	HA, max. conc.	48	21%
22	LA, min. conc.	26	12%
	LA, max. conc.	25	11%
	HA, min. conc.	56	25%
	HA, max. conc.	48	21%
23 (L.22 simplified)	LA, min. conc.	27	12%
	LA, max. conc.	26	12%
	HA, min. conc.	61	27%
	HA, max. conc.	48	21%
24 (B.D. + L.14)	LA, min. conc.	26	12%
	LA, max. conc.	25	11%
	HA, min. conc.	42	19%
	HA, max. conc.	38	17%
25 (B.D. + L.14 simpl.)	LA, min. conc.	27	12%
	LA, max. conc.	26	12%
	HA, min. conc.	44	20%
	HA, max. conc.	39	17%
26 (B.D. + L.16)	LA, min. conc.	4	2%
	LA, max. conc.	3	1%
	HA, min. conc.	35	16%
	HA, max. conc.	30	13%
27 (B.D. + L.10 simpl.)	LA, min. conc.	27	12%
	LA, max. conc.	26	12%
	HA, min. conc.	43	19%
	HA, max. conc.	39	17%

It is possible to see that Boundary Detection (B.D.) generally greatly improved performance for high alarm detection criteria. With the possibility of easily testing slight variations in layouts, Layout 23 was designed as a simplification of Layout 22. Comparing the two layouts it is evident that there is only a marginal increase in performance with the addition of an extra line detector in Layout 22. Nevertheless, as with the rest of the layouts studied (besides reference layout 11, consisting of 30 point detectors distributed in a 6 x 5 uniform arrangement on a single plane at 3 m height), the performance for gas detection is not satisfactory.

Detector layout 26 (which consisted of 3 line detectors forming a B.D. and 5 point detectors) was the best performing layout detecting 98% of all leak scenarios modelled to low alarm before the impairment criteria was exceeded at the target buildings. This layout also achieved the best performance in detection to high alarm (excluding reference layout 11) with nearly 85% of leak scenarios detected to high alarm before the impairment criteria was exceeded at the target buildings.

Conclusions

304 dispersion simulations were undertaken for the Drilling Platform, considering various leak locations, leak directions, leak types, leak rates, wind speeds and wind directions. The performance of the detector layout designed using a Simplistic Analytical Method (SAM) was compared to the 16 gas detector layouts proposed. Each layout was tested against every dispersion simulation performed. The ability to detect gas clouds, the time to detection and the flammable volume at detection were all recorded for each point detector and then compared to one another based on their ability to detect clouds before the "dangerous cloud" volume was reached, time to detection and the number of detectors required. The maximum time to detection at high alarm was 6 seconds longer for the SAM layout than the proposed layout 5. Similarly, compared to layout 6, the maximum time to detection at high alarm was 9 seconds longer for the SAM layout, although layout 6 required 2 more detectors. Finally, the SAM layout detected a lower percentage of scenarios to high alarm before the "dangerous cloud" size was reached when compared to layout 5. The scenarios not detected to high alarm were almost all from small leak rates combined with high wind speeds. Such leak scenarios will always be difficult to detect, and will also typically not result in flammable clouds large enough to be considered "dangerous".

224 dispersion simulations were then undertaken for the Production Platform, with a similar philosophy as for the Drilling platform. The SAM layout performance was compared to the 26 gas detector layouts proposed and tested against every dispersion simulation performed. Monitor points were placed around the target buildings/equipment to determine the time at which the impairment criteria in terms of gas concentration were exceeded. It was possible to see that some detector layouts

performed well in terms of detecting clouds, but the same performance was not achieved in detecting clouds before the impairment criteria were exceeded at the targets. Detector layout 11 performed well in terms of leak detection (detecting every leak to low and high alarm before the impairment criteria were exceeded at the targets), however this layout required 30 detectors. Many of the other layouts performed well for low alarm but failed to detect leaks at high alarm.

One reason for the difficulty in detecting gas clouds before the impairment criteria were exceeded at the targets were due to the proximity of many of the targets to potential leak sources. It would be worthwhile to place some detectors at various points in the process area in order to detect gas leaks that would take longer to reach the targets, and would hence be detected (such as leaks pointing away from the utility area and being blown by wind pointing in the same direction). However, gas detectors should be placed directly on or close to the target buildings/equipment on this platform in order to detect potential gas ingress (if buildings are gas tight, the only areas of concern would be the HVAC inlet/outlet).

Throughout the study, the benefits of using CFD when designing a gas detection system have been evident. From ventilation simulations to determine real wind flow patterns in the facility, to dispersion simulations to provide realistic and precise data on how gas disperses and accumulates in different areas of the platforms. These help to optimise the placement of detectors, providing a cost-effective reduction in detection times and total risk, thereby improving the performance of a layout design. It was shown that the number of detectors could be reduced without affecting the general performance of the gas detector layout, resulting in a lower CAPEX. Reducing the number of detectors also results in a reduction in the subsequent operating and maintenance costs over the entire operating lifetime of the detectors, giving a potentially significant reduction in OPEX.

Future work

An additional analysis could be carried out in a “risk-based” manner where the leak frequency, leak sizes/types, wind probability, etc. are also considered in order to define more realistic leak sources to determine the failure frequency of the gas detection system and compare that to the performance criteria.

Furthermore, many questions arise at the time of designing a gas detection system: What type of sensors should I use? Where should I locate them? Could a different layout perform any better? Existing practices are based on heuristics or analyses using a small number of scenarios. The present study shows that CFD-based dispersion simulations provided a considerable amount of information from which we are not taking full advantage. It would be beneficial to have an improved quantitative approach based on “optimization” that considers uncertainties and makes use of the valuable plant information provided from rigorous gas dispersion simulations for detector placement.

In the EC-funded Horizon 2020 project Fortissimo II, Gexcon are working together with Micropack (validation) and EPCC (implementation as an HPC service) on an advanced optimization framework for CFD-based gas detector mapping using FLACS. This approach constitutes a vast improvement over the capabilities of current ‘mapping programs’ and will provide improved safety and reduced detector installation and operating costs in many industrial/manufacturing facilities that incur risks of gas releases, explosions and fires.

References

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