

GAS DETECTOR LOCATION

Ø.Strøm and J.R. Bakke, GexCon AS, Norway

AUTHOR BIOGRAPHICAL NOTES

Øyvind Strøm graduated in 1996 from Stavanger University College with a M.Sc. degree in Offshore Safety Technology. Before he joined GexCon AS he worked as a safety engineer in Halliburton AS. He currently works as a consultant i GexCon, performing ventilation, dispersion and explosion analysis using the CFD program FLACS.

Jan Roar Bakke has a Ph.d. in applied mathematics (i.e. gas explosion modelling) from the University of Bergen in 1986. He has worked 12 years at Christian Michelsen Research (CMR) with gas explosion research, followed by 6 years in Statoil's Safety Technology department. Since November 1998 he has held the position of Technical Director in GexCon, a consultancy company owned by CMR. He is also Visiting Professor of Safety Technology at the Stavanger University College.

ABSTRACT

Experience has shown that many gas leaks on offshore installations remain undetected by the platform gas detection systems. Through a more detailed study of how gas is dispersed in complex offshore modules, taking into account ventilation conditions, gas properties, leak characteristics and locations and other unique variables for the actual installation, the system design can be improved. The paper describes how the CFD program FLACS can be used as a tool to determine the number, type and location of gas detectors, taking all these variables into account.

The paper will describe the methodology by presenting a study for an actual platform geometry, and will focus on these main elements:

- Geometry representation
- Type, number and location of detectors involved in the study
- Description of scenarios (leak points, leak rates, ventilation conditions etc.)
- Method of ranking the detectors based on their efficiency in the simulations performed
- Conclusions / recommendations for further work

INTRODUCTION

The main purpose of the case study presented in this paper was to develop a methodology for evaluation of different gas detector locations. The overall object is to improve the gas detection system ability to detect gas in the most frequent release scenarios with a potential to cause unacceptable consequences.

The study may be performed separately or as an integrated part of a probabilistic explosion study where FLACS is used. A probabilistic explosion study involves a significant number of

computational fluid dynamics (CFD) dispersion simulations. Including an evaluation of possible detector locations in the probabilistic explosion study will require a limited amount of additional work. The additional work will mainly be the definition of detector locations to be evaluated, and the treatment of the output data for these detectors for the simulations carried out. It is believed to increase the cost benefit value of performing a large number of CFD simulations.

The results from a gas detector study may be used to answer typical questions like:

- What is the most efficient location of 10 detectors in the actual module?
- How many detectors are required to ensure detection of 95% of all leaks larger than 5 kg/s within 30 seconds?
- What will be the most cost efficient combination of a given number of line and point detectors?

The paper will not describe the computer model FLACS in any detail.

1 STATUTORY REQUIREMENTS AND STANDARDS

All installations in the Norwegian sector of the North Sea have to comply with the NPD (Norwegian Petroleum Directorate) regulations. Regarding location of gas detectors the following requirements apply:

“In order to ensure quick and reliable detection of a fire or an incipient fire, as well as accidental gas discharge, fire and gas detectors shall be fitted and arranged in a suitable manner and in adequate numbers, i.e. that gas detectors are located based on an evaluation of possible leakage sources, gas propagation conditions, ventilation conditions, the specific density of the gas etc.”

NORSOK (norsk sokkels konkuransesjjon or in English the competitive standing of the Norwegian offshore sector) is the Norwegian initiative to reduce development and operation cost for the offshore oil and gas industry. An important part of this effort is to develop cost efficient standards to replace individual oil company specifications and now also NPD's technical guidelines. The following requirements related to location of gas detectors may be found in the NORSOK standard for Technical Safety:

“Location, type and number of gas detectors shall take into account: leakage sources within the area, borders between non-hazardous and hazardous areas, gas density relative to air, detection principles and voting logic, ventilation air flow patterns, wind-direction and velocity, critical reaction time/detector response time, size of the area and criticality of the area with regard to safety.”

The first edition of ISO 13702, “Control and mitigation of fires and explosions on offshore production installations”, was issued 15.03.99. With respect to gas detection the following requirements are defined in the standard:

“The FES (Fire and Explosion Strategy) shall describe the basis for determining the location, number and types of detectors. This requires a process of identifying and assessing the possible fire and gas (F&G) hazardous events in each area and evaluating the requirements to reliably detect these events.”

With FLACS and the study methodology presented in this paper, all these requirements can be addressed.

2 GEOMETRY

The geometry used as a basis for the study, was the wellhead area on a small jacket platform. The area was about 20m wide and 40m long. The longest walls were firewalls separating the wellhead area from the process areas in east and the utility areas in west. The south end of the module was open, and the north end partly covered with louver panels (1/16) and explosion panels (9/16).

The wellhead area is located between the plated cellar deck at 28.5m above sea level, and the plated main deck at a height of 43m above sea level. Between these deck levels, two grated mezzanine decks are located at 34.2m and 36.9m above sea level.

The quality of the geometry representation has a significant effect on the results of the simulations. Although it may be more critical for simulations of explosions, it is also important for simulations of leaks and dispersion. Even smaller objects are of importance. If a high momentum jet from the gas leak hits some of these smaller objects, it will result in a better mixing of gas with air.

Some simpler models for gas dispersion simulations used today do not account for geometry details to the same extent as FLACS. It is obvious that some of the trends (e.g. degree of mixing) predicted from such models could be wrong. To generate validation data for FLACS with regard to dispersion in typical offshore modules, experiments were carried out at Christian Michelsen Research (CMR). For more information about these experiments, reference is made to paper¹ by Olav Hansen.

3 SCENARIO DEFINITION

The process of selecting the scenarios to be simulated starts with a study to investigate the natural ventilation conditions in the wellhead area. Ventilation conditions within the module are one of many important parameters that influence the gas dispersion. It is therefore critical to establish a good picture of the likely ventilation conditions. The dispersion scenarios included in the study are summarized in Table 1.

First the wind rose was divided into 12 equal sectors. For each of these sectors ventilation simulations are carried out with the average wind speed (and for some sectors with weak or strong wind) from the actual sector, illustrated in Figure 1. Actual statistical weather data for the field is used to define the wind conditions to be simulated.

Based on the simulations performed, air exchange rates per unit wind speed is found for the wellhead area. Higher and lower air exchange rates may then be calculated based on the conversion factor defined from the simulated case. The next step is then to group the air exchange rates into 3 different categories; low ventilation rates (lower 25%), medium ventilation rates (25-75%) and high ventilation rates (upper 25%), in principle more categories can be used if required. Each of these groups will then be represented by a specific external

wind direction and external wind speed in the simulations. The external wind speeds are selected so that the ventilation rate through the module will be a weighted average for the group they are representing.

One leak point was defined in the study. Location of the leak was centrally in the module. For this leak point 6 different leak directions was defined; east, west, north, south, up and down. Only high momentum leaks was simulated. It is obvious that defining only one leak point represents a clear limitation to the study. As a result of this, it is likely that detectors located close to this leak point will prove to be most efficient for the simulations performed. The number and location of leak points included in a gas detector study should be based on an evaluation of likely leak locations in the actual module, and should correspond to leak locations defined in other risk assessment studies in the specific area.

In the platform QRA, 5 different leak rates were defined. As the smallest leak rate defined, 0.7 kg/s, was too small to create gas clouds large enough to cause unacceptable consequences, it was not included in the gas detector study. A few dispersion simulations were carried out with this leak rate, and they all showed that the leaked gas was rapidly dispersed to a concentration below lower explosion limit (LEL) even for cases with low ventilation rate. The 3 next leak rates from the QRA, 3.4 kg/s, 10.3 kg/s and 31.3 kg/s, were all included in the gas detector study. The largest leak rate, 324.9 kg/s was not simulated. It could be that the same trend with respect to gas detector efficiency are seen with the highest leak rate as for 31.3 kg/s, but this was not further investigated in the study performed.

To summarize; this gave 3 different wind conditions, 1 leak point, 6 different leak directions and 3 different leak rates, a total of 54 simulations.

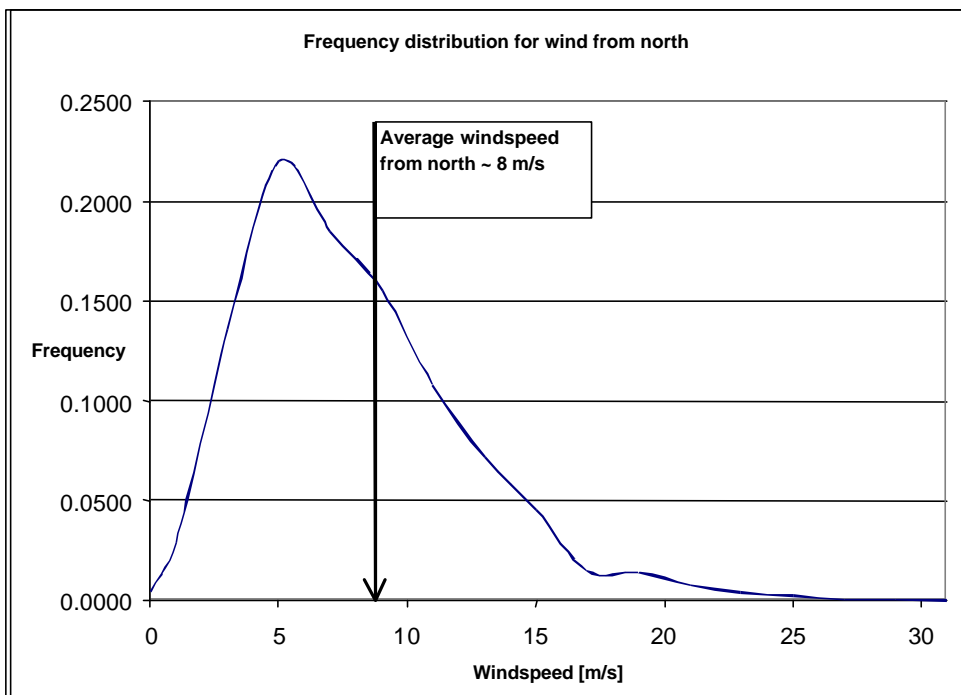


Figure 1, Illustration of wind speed frequency distribution and average wind speed from north

For each simulation (scenario) a frequency was calculated based on the frequency of ventilation conditions, leak rate and leak direction. The frequency of ventilation conditions was calculated based on statistical weather data, the leak rate frequencies was taken from the platform QRA and all 6 leak directions were given the same frequency.

A matrix of 24 point detectors was defined at three different levels within the wellhead area. This gave a total of 72 detectors included in the study. For all detectors and simulations %LEL as a function of time was recorded. No line detectors were defined in this study. This can be done if required, making it possible to evaluate effective combinations of the two detector principles. The lower detector matrix, i.e. detectors 1-24, is illustrated in Figure 2.

In all simulations the leakage, and subsequently the simulation itself, was stopped when the LEL reading for all detectors levelled out. Dependent of leak rate and ventilation rate, this required between 8 and 24 hours of computer processing time (CPU time). As several computers were utilized, all simulations were finalized in 8 days.

	Leak rate 3.4 kg/s			Leak rate 10.3 kg/s			Leak rate 31.3 kg/s		
	No.	Dir.	Frequency	No.	Dir.	Frequency	No.	Dir.	Frequency
Low ventilation	1	- X	0.00023963	19	- X	0.00012	37	- X	6.21E-05
	2	+ X	0.00023963	20	+ X	0.00012	38	+ X	6.21E-05
	3	+ Y	0.00023963	21	+ Y	0.00012	39	+ Y	6.21E-05
	4	- Y	0.00023963	22	- Y	0.00012	40	- Y	6.21E-05
	5	+ Z	0.00023963	23	+ Z	0.00012	41	+ Z	6.21E-05
	6	- Z	0.00023963	24	- Z	0.00012	42	- Z	6.21E-05
Medium ventilation	7	- X	0.00061787	25	- X	0.000311	43	- X	0.00016012
	8	+ X	0.00061787	26	+ X	0.000311	44	+ X	0.00016012
	9	+ Y	0.00061787	27	+ Y	0.000311	45	+ Y	0.00016012
	10	- Y	0.00061787	28	- Y	0.000311	46	- Y	0.00016012
	11	+ Z	0.00061787	29	+ Z	0.000311	47	+ Z	0.00016012
	12	- Z	0.00061787	30	- Z	0.000311	48	- Z	0.00016012
High ventilation	13	- X	0.0003282	31	- X	0.000165	49	- X	8.51E-05
	14	+ X	0.0003282	32	+ X	0.000165	50	+ X	8.51E-05
	15	+ Y	0.0003282	33	+ Y	0.000165	51	+ Y	8.51E-05
	16	- Y	0.0003282	34	- Y	0.000165	52	- Y	8.51E-05
	17	+ Z	0.0003282	35	+ Z	0.000165	53	+ Z	8.51E-05
	18	- Z	0.0003282	36	- Z	0.000165	54	- Z	8.51E-05

Table 1, Scenarios simulated

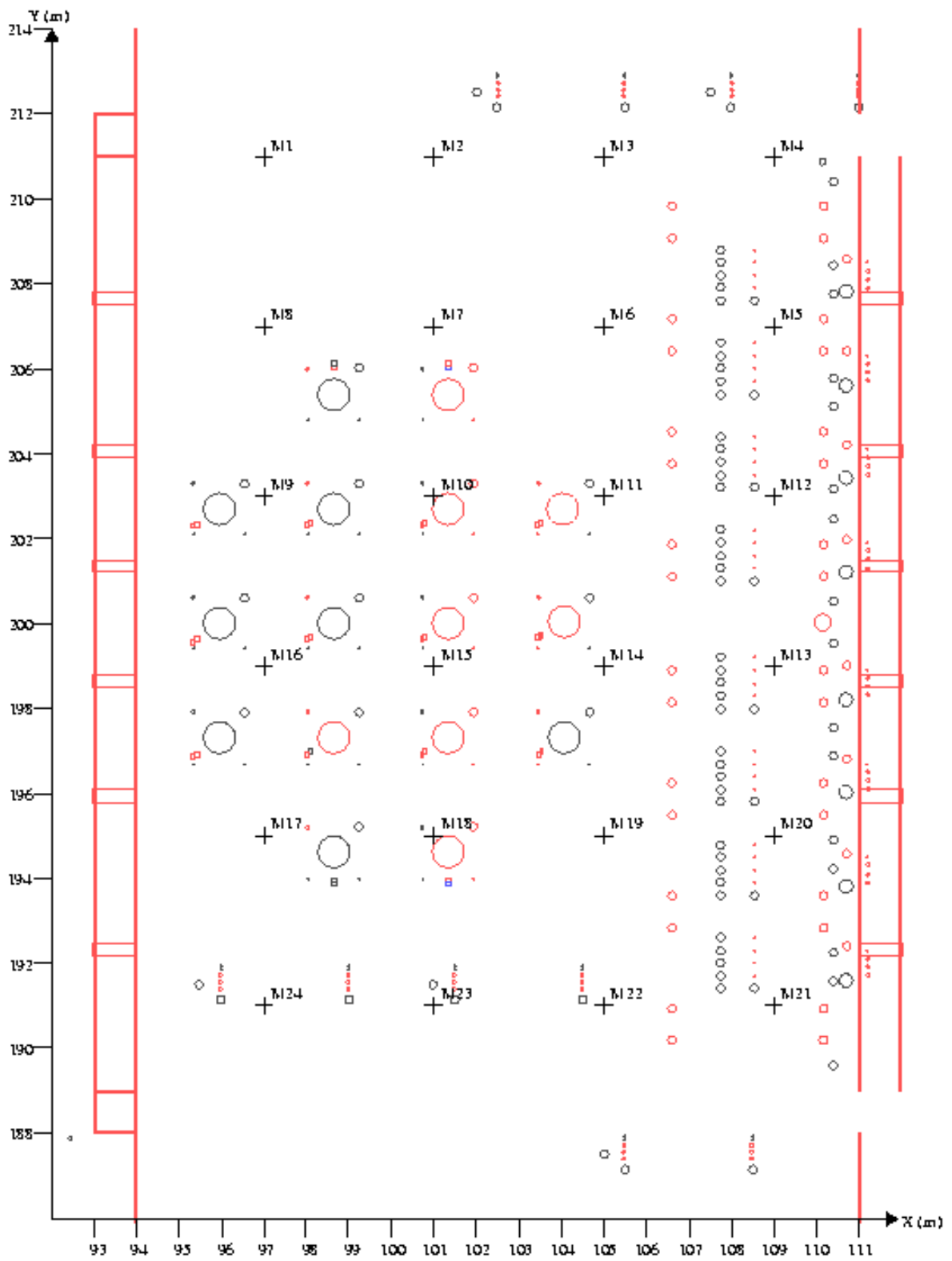


Figure 2, Lower detector matrix

4 SIMULATION RESULTS

The amount of output data from a study like this will be quite large. For example 100 simulations involving 100 detectors where time to detection of 20, 60 and 100% LEL is registered, would give 30 000 data values to be processed. GexCon has developed simple software tools that automatically extract the required data from standard FLACS result files, and organize these data in table's etc. suitable for further processing in standard spreadsheets like Microsoft Excel etc. To limit the extent of the paper, all results presented are based on the time to detection of 20% LEL. Table 2 illustrates how output data would look like. To limit the figure size, only 10 simulations and 10 detectors are shown.

Freq.	Sim.no.	Detectors									
		1	2	3	4	5	6	7	8	9	10
0.000311	460132	10.88	14.81	-	-	-	-	9.9	6.21	2.53	4.49
0.000311	460133	2.42	1.51	2.02	2.81	4.36	4.36	5.14	5.53	8.24	9.02
0.000618	460134	-	-	-	-	-	-	-	-	3.6	10.31
0.000618	460135	8.23	10.06	13.3	55.64	-	15.3	8.15	6.15	4.15	6.65
6.21E-05	460136	3.49	9.14	-	-	-	20.01	6.84	2.02	1.14	1.14
6.21E-05	460137	1.94	1.94	1.94	1.94	-	4.95	8.36	6.65	15.61	-
6.21E-05	460138	10.98	7.18	5.28	5.76	5.28	3.38	7.18	8.13	7.18	4.81
0.00016	460139	3.45	4.97	6.87	16.92	19.76	8.96	4.21	1.93	0.77	4.59
0.00012	460141	4	-	-	-	-	-	5.48	2.51	1.28	2.02

Table 2, Illustration of output data for detection of 20% LEL

In Table 2 the values are time (seconds) to detection of 20% LEL, empty cells means that the detector did not detect 20% LEL for the actual scenario.

As a large number of detector locations are evaluated in each simulation, a method of ranking the detectors after the simulations have been performed is required. As each simulation performed has its unique frequency, this frequency is used to define an efficiency value for each detector in each simulation. In this study the frequency was divided with time to detection to get the efficiency value (or criticality value). The efficiency value was then summarized for all scenarios to get an overall efficiency value for the specific detector. The higher the figure, the better the detector is and the higher the detector is placed on the ranking list. This way the best detector is the detector that rapidly detects gas in the most frequent leak scenarios. The formula for calculating the overall detector efficiency value is illustrated below.

$$E = \sum_1^n \frac{f}{T}, \text{ where}$$

E is the overall detector efficiency value, f is the frequency of the actual scenario, T is the time to detection of the specified level of LEL (e.g. 20/60/100 % LEL) and n is the number of scenarios (simulations).

Based on the time to detection of 20% LEL in the simulations, the detectors were ranked according to the method described above. Table 3 shows the detectors from Table 2 ranked. The table is included to illustrate the ranking methodology only.

Detector	9	10	8	2	1	3	7	6	4	5
Efficiency value	8.65 E-04	4.36 E-04	3.98 E-04	3.74 E-04	3.72 E-04	2.94 E-04	2.65 E-04	2.13 E-04	1.92 E-04	1.07 E-04

Table 3, Ranked detector list based on Table 2

Figure 3 illustrates average time to detection of 20% LEL dependent of the number of detectors installed. 1 means only the best detector from the ranking list is installed, 2 means the second best detector is included in addition to the best detector etc. Figure 3 is based on all detectors and simulations involved in this study.

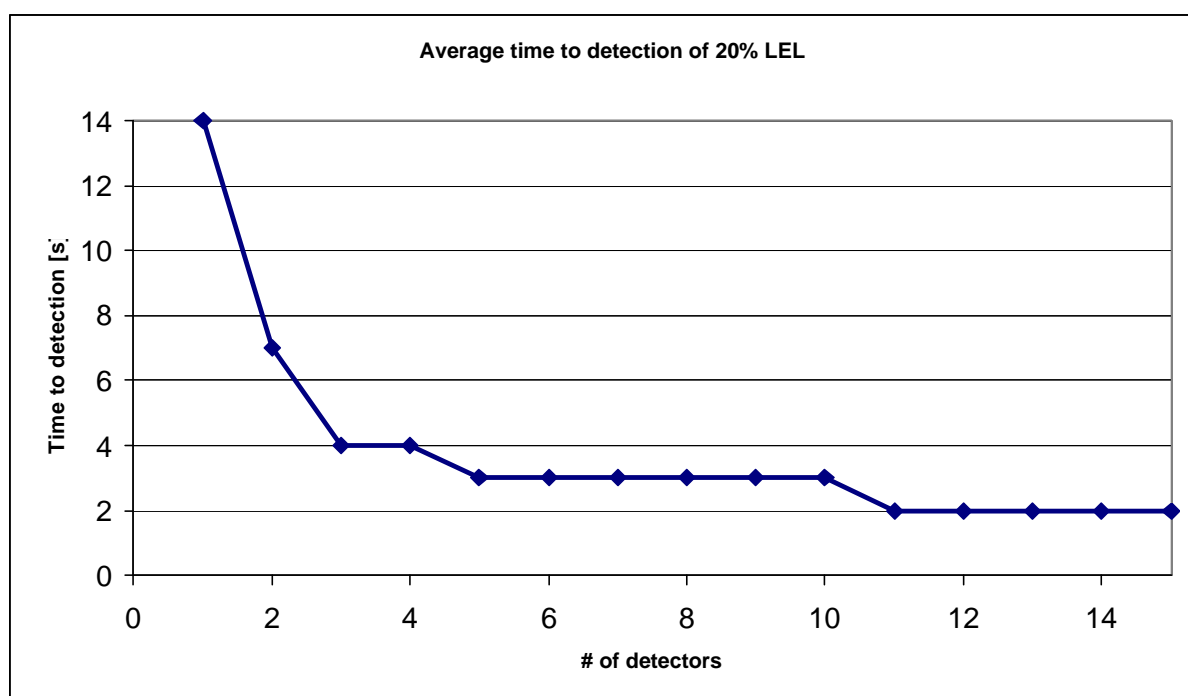


Figure 3, Average time to detection of 20% LEL

In Figure 3 the average time to detection is the average for all scenarios detected, i.e. the number of scenarios not detected is dependent of the number of detectors installed. This may be illustrated by a graph showing the percentage of the scenarios detected dependent of the number of detectors installed, ref. Figure 4. If the simulations carried out can be defined as a representative selection of all likely scenarios, this can be viewed as the overall likelihood of detecting gas leakages, i.e. the efficiency of the gas detection system.

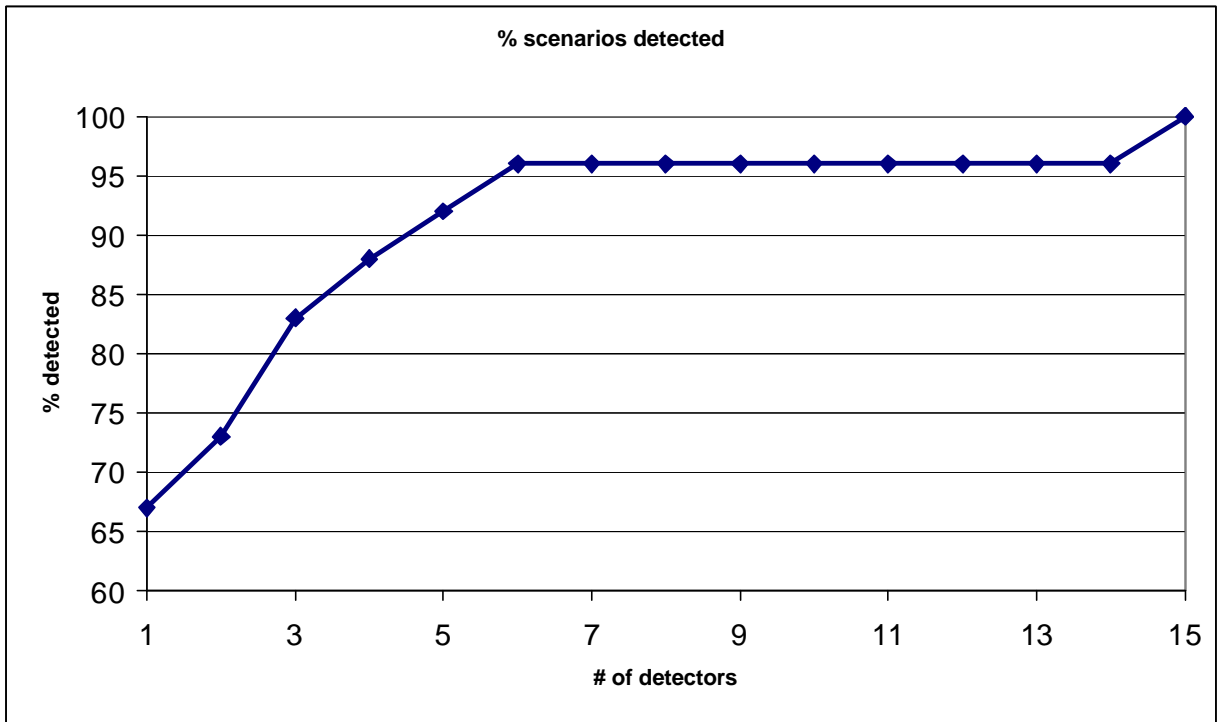


Figure 4, Percentage of scenarios detected

5 DISCUSSION

A total of 54 scenarios were simulated, and 72 detectors were included in all simulations. The detectors were ranked based on the methodology described in previous chapter. The ranking methodology proved to be easy to carry out using a Microsoft Excel spreadsheet model. If more scenarios are decided to be simulated, the results from these may easily be added to the spreadsheet model, new efficiency values calculated and a new ranking list produced.

In Figure 3 the results are presented as average time to detection dependent of the number of detectors installed. If a critical detection time is defined, this information can be used to decide the number and location of detectors to be installed. Critical detection time could depend on necessary time required from detection to consequence reducing measures (shut down, isolation of ignition sources etc.) are effective.

If there has been defined a minimum percentage of scenarios the gas detection system should detect, Figure 4 may be used to decide the number and location of detectors to be installed.

The two criteria's mentioned above may be combined. Consider the following system requirement: "The gas detection system shall, within 4 seconds, be able to detect at least 95% of all defined leaks." Based on Figure 3, the 5 best detectors from the ranking list would have to be installed to bring the average detection time below 4 seconds. Based on Figure 4, the 6 best detectors from the ranking list would have to be installed to ensure detection of at least 95% of the scenarios. To comply with the system requirement, the 6 best detectors from the ranking list would have to be installed. This illustrates how the results from the study may be used; although including voting logic etc. will further complicate it.

6 FUTURE METHODOLOGY DEVELOPMENT

As previously mentioned the number of variables to be handled in a study like this is quite high. It could therefore be interesting to find out how the ranking of the detectors is dependent of the leak rate. If the leak rate does not have a significant importance for the ranking of the detectors, the number of leak rates defined in the study could be limited to a few (1 or 2?), and thus being able to investigate other variables in more detail like leak locations, weather conditions etc. This could then be done without increasing the number of simulations to be performed beyond practical limits.

The ranking of the detectors will depend on which scenarios the ranking list is based on. In Table 4 the first column shows the 15 best detectors (of 72) from the ranking list based on all leak rates (i.e. all simulations). The second column shows the 15 best detectors from the ranking list based on simulations with leak rate 3.4 kg/s only (i.e. 18 of 54 simulations), the third column based on 10.3 kg/s and the fourth column based on 31.3 kg/s. The detector numbers are listed in ascending order in the table, and not according to the ranking list.

All rates	3.4 kg/s	10.3 kg/s	31.3 kg/s
9	2	2	9
11	3	3	11
13	9	10	12
14	13	11	13
15	14	13	14
16	15	14	30
31	16	15	31
33	18	33	33
34	31	34	34
35	33	35	35
36	35	36	36
38	36	38	37
39	40	40	38
40	46	46	39
46	47	47	40
# detectors also included in the ranking list based on all leak rates (column 1)	11	11	12

Table 4, 15 best detectors for different leak rates

Table 4 shows that the ranking lists based on only one leak rate (columns 2, 3 and 4) are not very different from the ranking list based on all leak rates (column 1). This indicates that it might not be necessary to include a range of leak rates in a gas detector study. This should be further evaluated through more detailed studies where several leak points are included.

As previously discussed, including more than one leak point is assumed to be important for the quality of the results. The number of leak points to be included will be dependent on the size of

the module and possible leak locations. Some of the possible leak points in a module may be disregarded, as they will not be able to cause unacceptable consequences.

The lowest ventilation conditions simulated in this study represented 41.5 airchanges per hour through the wellhead area. It is possible that calm wind situations (very low airchange rate) could give different results. This should be further investigated by defining a fourth ventilation condition; low-low ventilation.

7 CONCLUSIONS

The study methodology presented is still under development, but based on the case study performed it is believed to be a useful tool for evaluating and improving the design of gas detector systems.

Only minor additional efforts are required to include gas detector studies as described in this paper in probabilistic explosion risk analysis where several dispersion simulations are carried out with FLACS. This will further increase the cost-benefit value of performing a large number of detailed CFD simulations.

Simple software tools for extraction and treatment of output data from the simulations was developed by GexCon as part of the case study. These tools proved to be effective and necessary to be able to handle the large number of data produced.

Future development of software tools to help the user with setup and running of the simulations (run-managers), together with the development of faster computers, will increase the number of simulations possible to perform within a reasonable time. Introduction of embedded grid possibility in FLACS (currently under development) will reduce the number of control volumes included in the simulations, and further reduce the necessary simulation time.

8 REFERENCES

1. Hansen, O.R., van Wingerden, K., Pedersen, G., Wilkins, B., 1998, Studying gas leak, dispersion and following explosion after ignition in a congested environment subject to a predefined wind-field, experiments and FLACS simulations are compared, 7th annual conference on offshore installations, London 2nd december 1998, pp. 2.1.1-2.1.18