

Using CFD to Analyze Gas Detector Placement in Process Facilities

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Abstract

Gas detectors are used in process facilities to automatically alarm and initiate safety measures in response to hazardous leaks. Safety measures can include emergency system shutdown (ESD), evacuation of personnel, system isolation and venting of the affected area. In the absence of effective leak detection, facilities are susceptible to a potentially significant and disproportional increase of two main hazards: (1) accumulation of toxic gases to levels that exceed given exposure threshold limits, which can cause injury or even death, and (2) accumulation of flammable gases to levels that can cause a fire or explosion. Fires and explosions can cause injury to personnel and have the potential to escalate the hazard to neighboring vessels, piping or equipment.

The areas that need gas detection coverage can be determined by modeling the dispersion of gases from potential leaks using CFD. Leak scenarios may involve gases, released at high or low pressure, or liquids, that either flash upon release and/or form a liquid pool in areas of the facility. The details of the facility geometry and of the flow patterns due to wind and mechanical ventilation will have significant effects on the migration of the gas cloud and need to be taken into account for proper detector placement. The CFD model FLACS was chosen in the present study because it allows (1) the simulation of both gaseous and liquid releases, (2) the modeling of the detailed geometry within the facility, (3) the simulation of both natural and forced ventilation within the facility, (4) the evaluation of gas concentration measured by line and point detectors, (5) the evaluation of danger potential for the dispersion cloud, and (6) the ability to perform parametric sensitivity and optimization studies.

In this paper, a method is presented that utilizes FLACS simulations to optimize gas sensor locations in order to maximize the likelihood of early detection of gas clouds that are at levels of concern. The method employed herein will include expected ventilation patterns within the facility, a probabilistic distribution of leaks, and redundancy of sensors. The present study concerns releases of flammable hydrocarbons but similar principles can be applied considering releases of toxic substances.

1 Introduction

Risk is defined as the frequency or probability of a given event occurring multiplied by the severity of such an event. Significant effort is performed at process facilities to help restrict or minimize the risk to tolerable levels. This can be accomplished by: (1) controlling the threats of a given hazard by putting into place protective measures that form barriers between the possible threats and hazard, thereby reducing the likelihood of the hazard occurring or (2) mitigation measures that form barriers between the top level event or hazard and the consequences of such an event, thereby limiting the chain of consequences or severity of the originating event. For loss of containment or accidental hazardous releases of a flammable substance, the Gas Detection System (GDS) is the key barrier for triggering mitigation measures to limit the consequences and severity of a given event, which can include:

- activation of Emergency Shutdown (ESD) or Blowdown (BD) – isolating the inventory and limiting the size of the accidental release
- activation of Ignition Source Control (ISC) – minimize the likelihood of ignition of flammable gases or liquids following a loss of containment
- shut down of ventilation in HVAC inlets
- activation of fire water pump and deluge
- activation of PA/alarms to alert personnel

While the GDS is a critical part of a facility's safety system, the GDS' design coverage and layout can be extremely complex due to the intricate coupling of the various parameters involved in gas dispersion and those that are specific to a facility. In fact, ANSI/ISA-RP12.13.02 *Recommended Practice for the Installation, Operation, and Maintenance of Combustible Detection Instruments* [1] specifically warns that sensors should be located in positions determined by those who specialize in gas dispersion, and those who have a knowledge of the process plant. Some of these parameters include:

- Potential inventories – pressure, temperature, isolatable volume of the potential vapor or liquid sources, their associated location and placement within the facility
- Type of releases – high pressure momentum driven jets, flashing releases, liquid spills, low pressure releases, lighter or heavier than air gases
- Air movement and ventilation patterns in a given area. Open areas can increase ventilation and flammable atmospheres may be reduced. Areas congested with equipment and obstacles can impede ventilation. Regions of poor air movement or “dead zones” are volumes where gas can accumulate and not be diluted.
- Topography, cavities and geometric details of a given area

The goal of the GDS is to provide reliable and fast detection of flammable and toxic leaks before a gas cloud reaches a concentration and size, which could cause risk to personnel and installation [2]. For flammable gas detection, this would be the smallest gas cloud that has the potential for unacceptable consequences or a significant hazard. Currently, there are several industry and company specific standards that provide varying level of detail regarding “prescriptive” and “performance” recommendations for detector layout. These may include determining the number of detectors and maximum spacing of the detectors from volumetric arguments of the size cloud they wish to detect and the volumetric fraction the cloud occupies in a given process area. There is a lot of valuable information that can be extracted from these standards and used by an experienced engineer to develop an adequate design. However, more conservative decisions should be made when basing the design on less precise methods. Typically, one must also apply fundamental gas dispersion logic to the guidance in the standards before deciding on a site specific GDS.

GexCon's extensive work with gas explosion safety and fluid flow has shown that gas dispersion in complex geometries (i.e., production platforms) can at times show a behavior that is virtually impossible to anticipate based on qualitative assessments and previous experience. Thus for understanding the flow pattern, there is no substitute for CFD modeling that takes into account the effect of physical elements

such as congestion, confinement, ventilation, etc. Performing prescriptive, non-optimized detector layouts can lead to certain areas of a plant with a large number of detectors having little to no value in mitigating the consequences of a release, while other areas having insufficient detector coverage. In fact, a recent technical report [3] supports our position that many existing GDS provide poor risk reduction in the operating environment due to inadequate detector coverage, low effective detection rates, and longer than expected detection times.

Realizing the limitations in qualitative assessment, certain standards require that effective detection is also provided for smaller leak rates (i.e., 0.1 kg/s) and allow for “performance” based methods. More specifically, gas dispersion studies may be used to optimize the number, location and type (line vs. point) of detector used. While many studies have employed prescriptive methods and other engineering recommendations, there has in general been very little attention and resources used to evaluate the complex coupling to gas dispersion as it relates to ensuring a robust design of a GDS. To put this into perspective, the rule of thumb regarding the cost of adding a gas detector on an existing installation in the North Sea is approximately \$100,000.

In order to properly evaluate the performance of a given GDS, a quantitative computational fluid dynamic (CFD) tool is required to model all the parameters affecting hydrocarbon releases and gas dispersion. The CFD model FLACS was chosen in the present study because it not only allows for the simulation of the complex nature of the release, geometry and environment, but also has the ability to perform parametric sensitivity and optimization studies. While modeling such gas dispersion scenarios is complicated, it provides a repeatable screening tool able to test a given configuration and any alternate configurations against a consistent set of design criteria.

Gas detection is a vast topic, thus in this paper we will focus on hydrocarbon (HC) releases in medium scale process plants and typical offshore facilities. The same principles can be applied to other fields but the focus is shifted depending on the case. For example, the evaluation of a toxic release from a large process plant towards an inhabited area will entail very different criteria’s with respects to detector density and detection criteria compared to HC leak on an offshore production platform.

The first section of this paper will describe the general principles associated with HC gas detection. Next, we will describe the general methodology used by GexCon for gas detection optimization studies. Finally, we will present certain case studies to illustrate the capability of using CFD to evaluate GDS.

2 General principles of gas detection

The purpose of the GDS is to identify accidental releases as quickly as possible so that appropriate countermeasures can be initiated. The GDS consists of a given number of different types of detectors placed at different locations with different set points and associated alarm logics. Thus when designing a GDS the following issues must be addressed: number of detectors; type of detectors; placement of detectors; set point for detectors; and alarm logic. In order to evaluate the performance of a given GDS, various design criteria must be established. The design criteria include leak scenarios to be detected and the physical environment of the release (gas type, geometry, ventilation, etc.). The purpose of this section is to provide a brief overview of the principles of gas detection and is not intended to be all inclusive.

Principal methods of HC detection

One of the most commonly used methods of measuring HC concentration is based on absorption of infrared (IR) radiation at certain wavelengths as it passes through a volume of gas. IR gas detectors can be used for point (single location) or open path (line of sight) applications. The catalytic single-point detector and acoustic gas detectors are also used to detect leaks of combustible gas.

IR point detectors give a direct measurement of local gas concentration, which is typically in percent of lower flammability limit (% LEL). Detectors are then programmed to send signals when the measurement gas concentration exceeds a given threshold or set point (e.g., 20% LEL). Therefore, a system of IR point detectors may provide an estimate of the cloud volume that is above the set point. The volume of detectable gas, or otherwise stated the volume “seen” by the system of IR point detectors, would increase when the set point is lowered (see Figure 2.1). The relationship between the set point of a system of IR point detectors and detectable volume may be complex, and is related to the type of release and ventilation conditions. For instance, a small change in the set point of a system of IR point detectors may have a large effect on the detectable volume or virtually no effect.

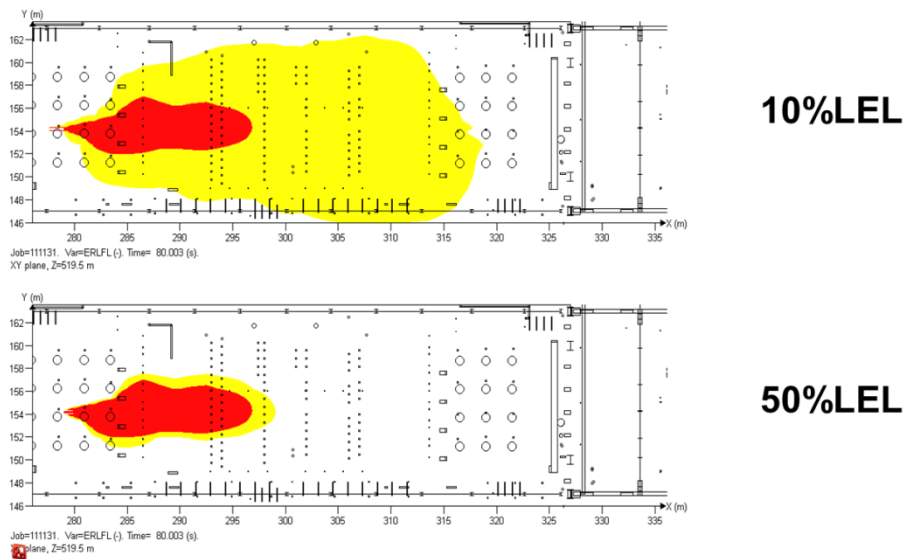


Figure 2.1: Variation in detectable volume of gas as the gas detector set point is changed from 10% LEL (top) to 50% LEL (bottom). Note red and yellow denote gas concentration within the specified range.

For IR line of sight detectors (line detectors) there is no direct relationship between set point and the volume of detectable gas, as the measurement is the concentration of gas integrated in space along the straight line between the source and the receiver, which is simply related to the product of the average gas concentration and the length of the gas cloud passing through the beam. This means that a small cloud at high gas concentrations could give the same output signal as a large cloud at low concentrations, if the product of the concentration of the leak and the path length are the same. The gas concentration output is given in LEL*meters (LELm) and this signal increases when the volume of gas passing between the source and receiver increases or the gas concentration increases.

Gas sensors used to detect HC leaks have generally advanced from catalytic sensors, to IR point detectors, to IR line of sight detectors, to acoustic detectors. While the newer detector types have very attractive features, they cannot fully replace the older detectors. Here are a few examples to illustrate this point:

- IR detection technology is superior to catalytic detection in almost all areas except for the fact that IR technology cannot detect hydrogen leaks
- Line detectors have a much better coverage than point detectors, but are prone to issues such as misalignment and beam blockage (due to contamination on the lenses, by personnel or temporary equipment)
- Acoustic detectors have an enormous coverage, but can also give false alarms (e.g., pneumatic systems) and will not detect low velocity leaks, such as gas evaporating from a pool of condensate.

When choosing the detector types the ability to detect should be balanced against operational issues, like maintenance and redundancy. The detection study can be used to quantify the effect of the different constraints specified by operations (e.g., how many extra detectors are needed if it's not possible to place detectors at the vent openings, is the response of the system not greatly reduced if one detector is failing or removed for service).

GDS - Gas detection system

The GDS refers to a detector layout consisting of a number of different types of detectors placed throughout an area of interest (such as an offshore module or a process area that has a strong likelihood of having explosive atmospheres). The GDS also includes a detection philosophy – the set point and voting configurations of detectors – as well as the actions to be performed upon gas alarm

The different attributes must be viewed as a whole when considering the design and performance of the GDS. Some of the factors and practices in the industry include:

- Number of detectors
 - Regulations vs. operator-specific practices
 - Proportional to module volume
- Layout of detectors (see Figure 2.2)
 - Clustering around likely leak sources (not recommended)
 - Equal-spaced grid vs. staggered grid (given cloud size)
 - Distribution according to ventilation patterns in the module or area.
 - Number of point versus line detectors
- Set points and voting
 - Set points for point detectors can range from 10%-25% on low alarm and 30%-60% on high alarm, set points for line detectors are in the 1 or 2 LELm range
 - 2ooN (2 out of N detectors)/ 3ooN (3 out of N detectors)
- Measures to be taken
 - Low Alarm:
 - Signal to the central control room and operating personnel
 - Ignition source control and isolation
 - Initiate deluge pump
 - High Alarm:
 - Initiate ESD or blowdown

The GDS will not address gas detection by indirect means, such as system alarms (e.g., loss of process pressure) or reported by personnel.

An example of a real detector layout is illustrated in Figure 2.2.

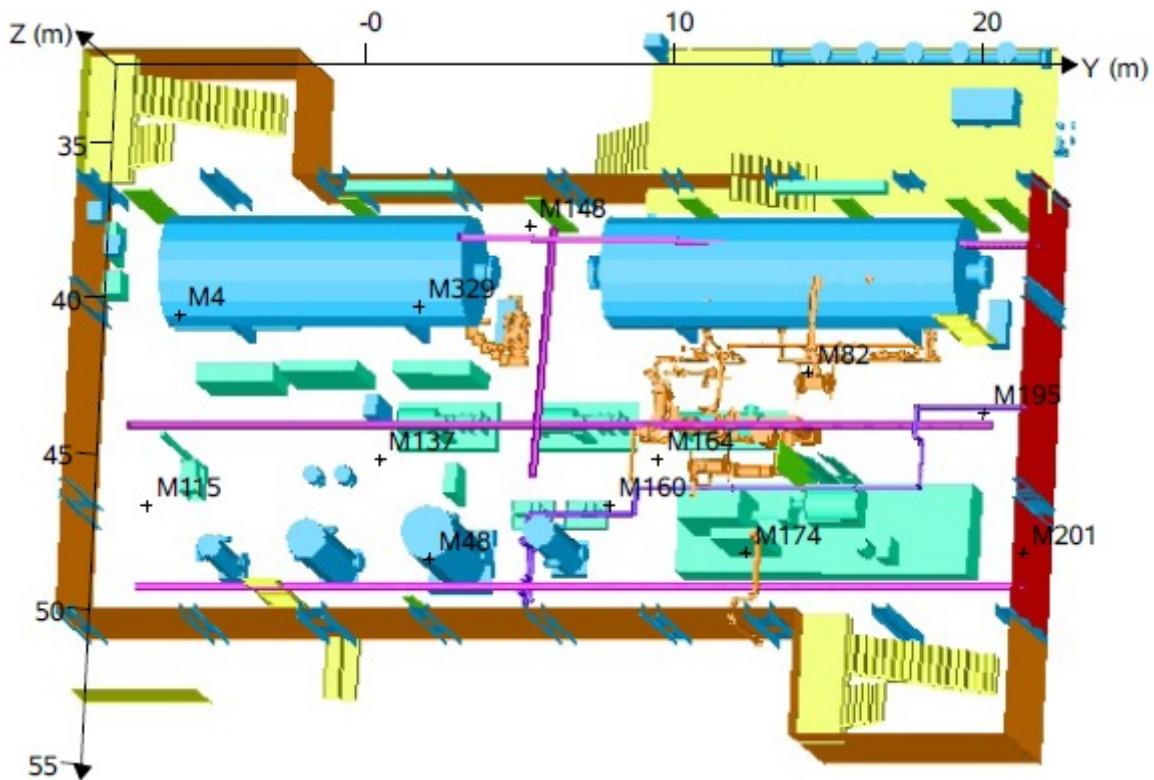


Figure 2.2: FLACS model of an offshore module with line (pink) and point detectors (+)

Detection criteria

Both leak rate and cloud size are key factors that are generally used to determine the potential danger from a gas leak and the criteria for gas detection. In order to detect the actual leak, acoustic detectors must be used; otherwise strategies need to be employed to detect the resulting gas cloud. The hazards associated with HC leaks are fires and explosions. Regarding hazard potential, cloud size is used to assess explosion hazards, while the leak rate is used to assess fire hazards (although it is obvious that the two are closely related). From a risk management point of view, the cloud size is the most relevant parameter since it directly affects the probability of ignition.

With regards to assessing the cloud size, it is important to understand the cloud size associated with detection (related to the set point, i.e., 10% or 50% of the LEL) is larger than that associated with the fire/explosion hazard, which is related to the flammable region of the cloud (between the LEL and UEL). Figure 2.3 shows a relative comparison of the detectable gas cloud size (10%LEL and 50%LEL) and the flammable cloud (between the LEL-UEL) at a given time for the same leak. For HC releases that result in gas explosions, the detection criteria should be based upon a predetermined “dangerous” cloud size. A dangerous cloud refers to a cloud that, if ignited, will yield unacceptable consequences. The dangerous cloud is deduced by determining a threshold for unacceptable explosion loads. These will typically be loads that lead to escalation of the initiating event and are often referred to as the Design Accidental Loads (DAL). The size of the “dangerous” cloud is determined by simulating gas explosions to establish a relationship between stoichiometric gas cloud size and explosion loads on critical equipment. These results are then compared to the minimum cloud size that can lead to escalation. This cloud size is referred to as the dimensioning gas cloud.

The dimensioning gas cloud determined from the explosion simulations is an ideal, homogeneous gas cloud at stoichiometric or most reactive concentration. Mapping is therefore needed to couple the dimensioning cloud to the realistic inhomogeneous gas clouds from the dispersion simulations, and thus obtain a criterion to determine when dispersed inhomogeneous clouds are “dangerous”. This mapping is

referred to as the Equivalent Stoichiometric Cloud (ESC). The ESC mapping can be based on the Q9 cloud criterion developed by GexCon [REF4], which assumes that only the flammable region of the dispersed cloud can participate in the explosion (between the LEL and UEL) and preferentially weighs concentrations near stoichiometric higher than those near the flammability limits (see Figure 2.4). Explosion consequences determined using Q9 clouds have been shown to correlate fairly well with those determined using the actual inhomogeneous gas clouds. Additional conservatism can be included in the mapping scheme, for example, by considering the entire flammable volume in the ESC mapping.

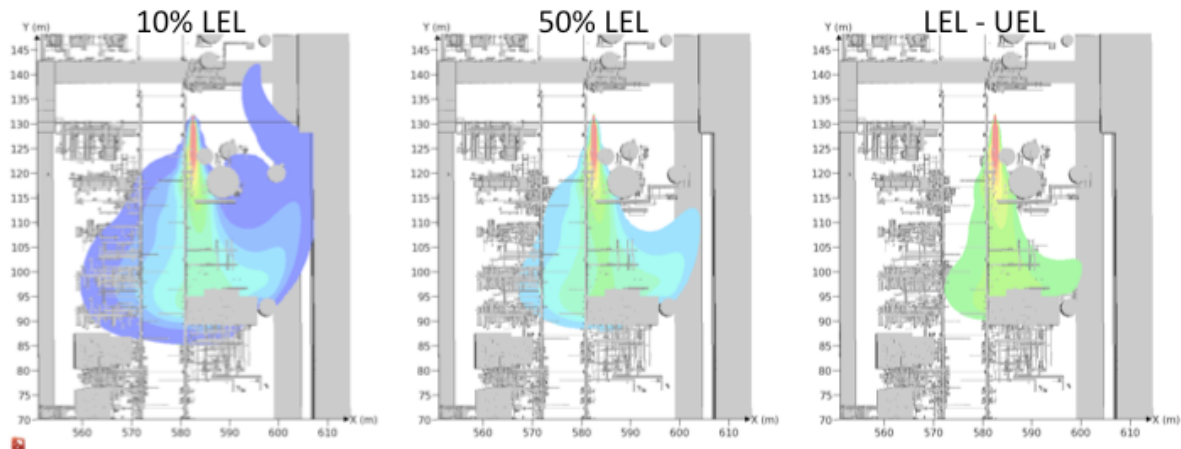


Figure 2.3: Comparison of cloud size for 10% LEL (left), 50% LEL (middle) and LEL at the same time for a given release

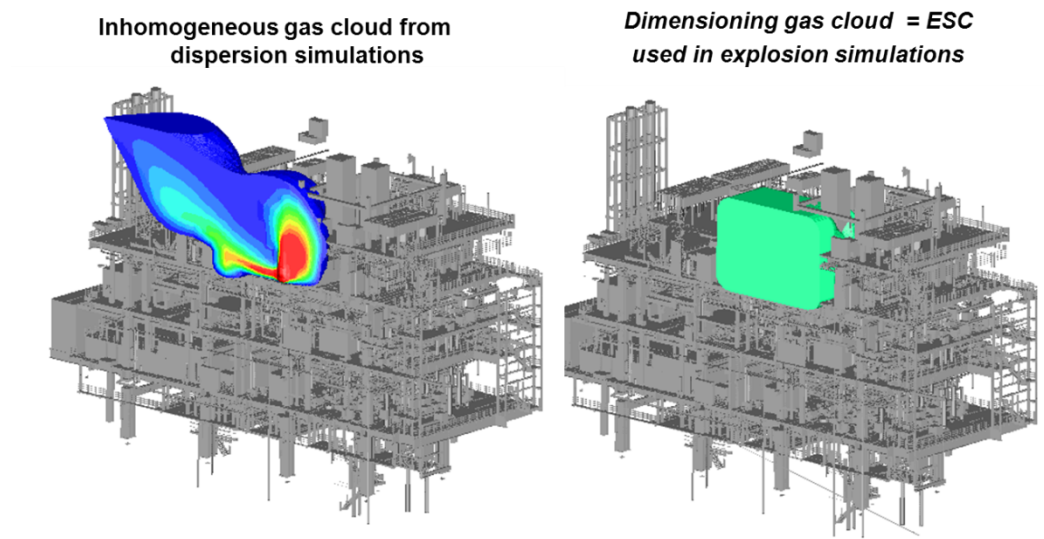


Figure 2.4: Equivalent Stoichiometric Cloud mapping of resulting inhomogeneous clouds determined from gas dispersions

The volume of the ESC determined from the mapping of the inhomogeneous cloud and used to determine the hazard potential will always be smaller than gas clouds that use %LEL for detection criteria. For 100 release scenarios at a given leak rate, Figure 2.5 shows the maximum cloud size for different detection criteria (10%, 20% and 30% LEL) as well as hazard potential Q9, versus 20% LEL maximum flammable volume.

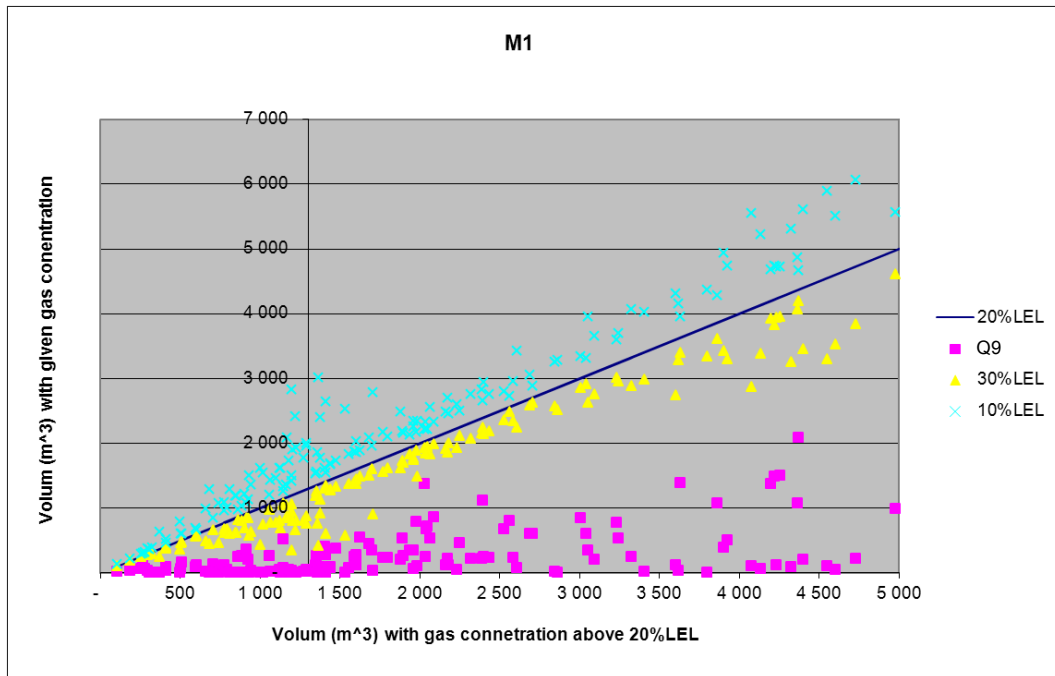


Figure 2.5: Maximum detectable gas cloud volumes (10%, 20% and 30% LEL) and ESC (Q9)

Theoretically, one would like to detect all accidental leaks. However, it is unrealistic and not economically viable to design a GDS that will detect every possible leak. This principle can be illustrated in the following example. A 0.1 kg/s leak in a semi-confined process module with natural ventilation may lead to a detectable cloud having a volume less than 1m³. Assuming the size of the module is 15x8x40m, thousands of detectors would be needed to ensure 100% detection. Relying on other means of detection such as acoustic detectors may of course reduce the number of detectors to a manageable level. Thus assuming that the GDS depends on point or line detectors, more precise detection criteria must be given. When deciding on criteria for detection, care should be taken when evaluating the difference between what we would like to detect and what must be detected.

The detection of dangerous clouds is typically a fairly relaxed requirement, as the minimum cloud size to be detected is relatively large. In this case, it can be sensible to use the ALARP principle to further optimize the GDS. One such approach is to optimize detection for small leaks, for example at the 0.1 kg/s leak rate. It should be noted that it is typically not feasible to detect all such leaks, but it is nevertheless a sound principle to try to detect as many leaks as possible in the shortest amount of time. In addition, it is an equally sound criterion that all “dangerous leaks” must be detected.

Leak points

It is primarily the gas cloud, not the actual leak, which is detected using IR systems. Thus placing the detectors according to potential leak points is not a productive approach. This is a common mistake that has led to poor design of many GDS. Detectors should instead be placed and optimized according to areas containing leak sources. For example, Figure 2.6 shows that, even with a dense detector arrangement around pressurized leak sources, there is a strong likelihood that the leak may go undetected. In addition, placing detectors immediately adjacent to equipment can lead to nuisance alarms due to inconsequential leakage during normal operation.

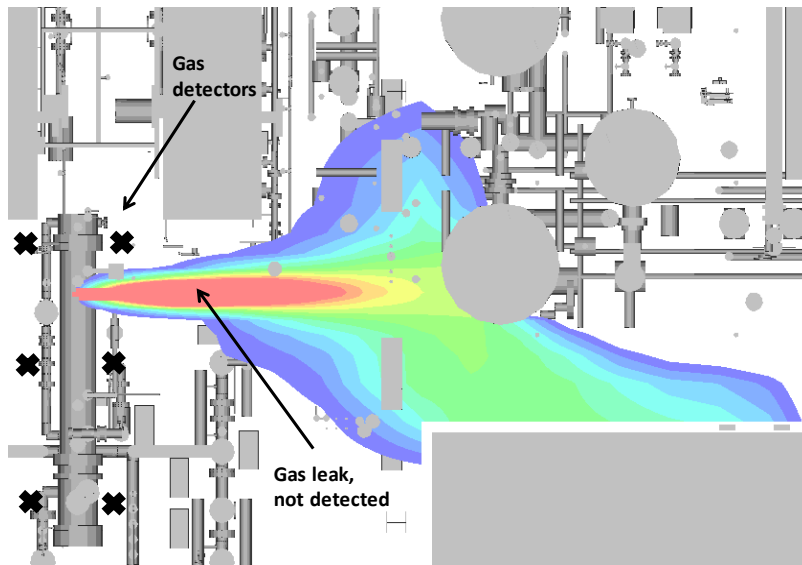


Figure 2.6: Pressurized gas leak flowing past detectors into an open area of the facility.

Practical limitations such as access and maintenance

In a detection study it is important to consider practical aspects such as access and maintenance. For example an operator in the North Sea has a requirement that inspections of equipment above 3m require fixed access such as a ladder. Thus there is potentially extra cost in having a detector at 3.5m compared to one at 2.8m. It is therefore quite important to know if lowering the height of the detectors by 0.7m in the present example has an effect on the GDS response. If these types of issues are not addressed, incorrect conclusions may be drawn from the analyses.

Time to detection

Time to detection is an important parameter in evaluating the effectiveness of the GDS; however, time to detection is also relative to the leak rate. Many reasonably designed GDS will eventually detect a leak that could lead to unacceptable consequences or escalation, but minimizing the time to detection can play a crucial role in allowing sufficient time to initiate automatic corrective actions (ignition source control, emergency shutdown or deluge).

False alarms

Due to signal drifting, a detector may give a false signal, that is, it will signal that there is a gas concentration exceeding the detector set point. A common approach to reduce the effect of false alarms is to implement “voting”, where 2 or more detectors must give alarm before executing automatic mitigation measures (i.e., shutdown).

Redundancy

For a given GDS there may be individual detectors that have a particular large spatial coverage, and hence there may be large areas only protected by a single detector. Such a design will have a low redundancy and may yield unacceptable GDS performance in the event that these detectors malfunction or are removed for service. Different strategies can be implemented to help resolve this issue. Extra detectors can be added so that the loss of any one detector, while reducing the overall system performance, still results in acceptable coverage. Alternatively, acoustic detectors may be installed and can be used to trigger automatic measures in the event a critical detector fails. Many operators however are reluctant to invoke automatic actions on acoustic alarm due to the previously mentioned issues regarding false alarms.

Other guidance

There are a number of simple and quite often obvious considerations that help to determine detector location. As this is beyond the scope of the present paper, the reader is referred to other references on the topic.

3 CFD based analyses of gas detection systems

3.1 Approach for a HC leak in a semi-confined area

The principal idea of using CFD to evaluate the performance of a gas detection system is: the direct assessment of the gas detection system's ability to detect gas clouds generated by a series of simulated realistic gas leaks. From a practical point of view, there will be leaks that can never be detected (small leak rates, leaks pointing away from the facility) and leaks that will always be detected (large leak rates, leaks adjacent to and directed towards detectors). There are essentially infinitely many leak scenarios that can occur. Thus, the key to a successful CFD based evaluation of the gas detection system is the selection of leak scenarios to be used for testing and evaluating the detection system.

The approach presented here is in line with that outlined in the Norsok S-001 [2] standard regarding criteria for detection. The proposed approach pertains to detection of HC leaks in semi-confined naturally ventilated areas. The following two criteria are specified in Norsok S-001: (1) all dangerous clouds must be detected; and (2) the GDS will be optimized based on clouds resulting from small, more frequently occurring leaks (typically 0.1kg/s leaks). Therefore a typical study is divided into "dangerous" cloud detection, which involves the analysis of larger leak rates, and "typical" cloud detection, which involves the analysis of small more frequently occurring leaks.

The key to the CFD study is determining what scenarios should be considered. If the scenarios result in large gas clouds then even simple detector layouts will yield detection and the study will not yield any useful information. On the other hand, if the simulated gas clouds are too small the study will result in an unrealistic number of detectors.

3.2 Optimization of a gas detection system

In general a GDS is developed based on the following elements:

1. The need to detect all potentially dangerous leaks.
2. Optimize detection of typical, small leaks.
3. Practical aspects such as installation, inspection and maintenance.
4. Robustness/Redundancy.

The primary scope of the study is to verify the performance of the GDS in detecting all potentially dangerous leaks (Item #1) and optimizing the GDS for typical leaks (Item #2). Item #3 is primarily for the client to evaluate, however the consequence of different approaches can be quantified in the study. Robustness and redundancy are related to the effect of losing a detector (e.g., if the gas detection system consisted of only a single line detector, then the loss of that detector would take down the entire detection system).

The main task of the study is to simulate a set of "dangerous leaks" and a set of "small leaks" to be used to assess the behavior of the GDS. The optimization of the gas detector layout is essentially to propose a series of detection layouts and test their performance against the simulated data set. The different layouts will consist of the following:

- variation in the number of detectors
- variation in type of detectors
- different detection strategies (boxing in area, staggered grid of detectors, ...)

The optimum system is derived through iterations with the client. A viable solution requires that the client survey the area and advise on where it is possible/practical to install detectors. Alternatively, the client can propose one or more detection layouts, which can be evaluated and approved, or modified based on the evaluation. The key to a successful evaluation is to ensure that all the elements for optimizing the detection system are accounted for. In order to do this, it is necessary to integrate the competence and tasks between those who have knowledge of the process plant systems and equipment involved, safety and engineering, and those with a knowledge of gas dispersion. Note that this is consistent with the recommendations in ANSI/ISA-RP12.13.02 [1].

3.3 Geometry model and visualization of detectors

One of the main reasons for using CFD is to predict flow phenomena within a complex geometry. As previously mentioned, it is at times not possible to predict how a gas will migrate using qualitative or simple tools that neglect flow patterns through actual complex geometries. As an example, Figure 3.1 shows a comparison of the flammable cloud (50% LEL) from a high momentum release in the +Y direction (left to right) with wind blowing opposite the release in the -Y direction (right to left), where the details of the geometry are included (upper image) and not considered (lower image). The release in the actual geometry impinges on a structure, loses momentum and is subsequently entrained by the wind and disperses upstream of the release location. On the other hand, the release without considering the details of the geometry remains a high momentum jet, which continues a significant distance in the direction of the release before being diluted by the wind.

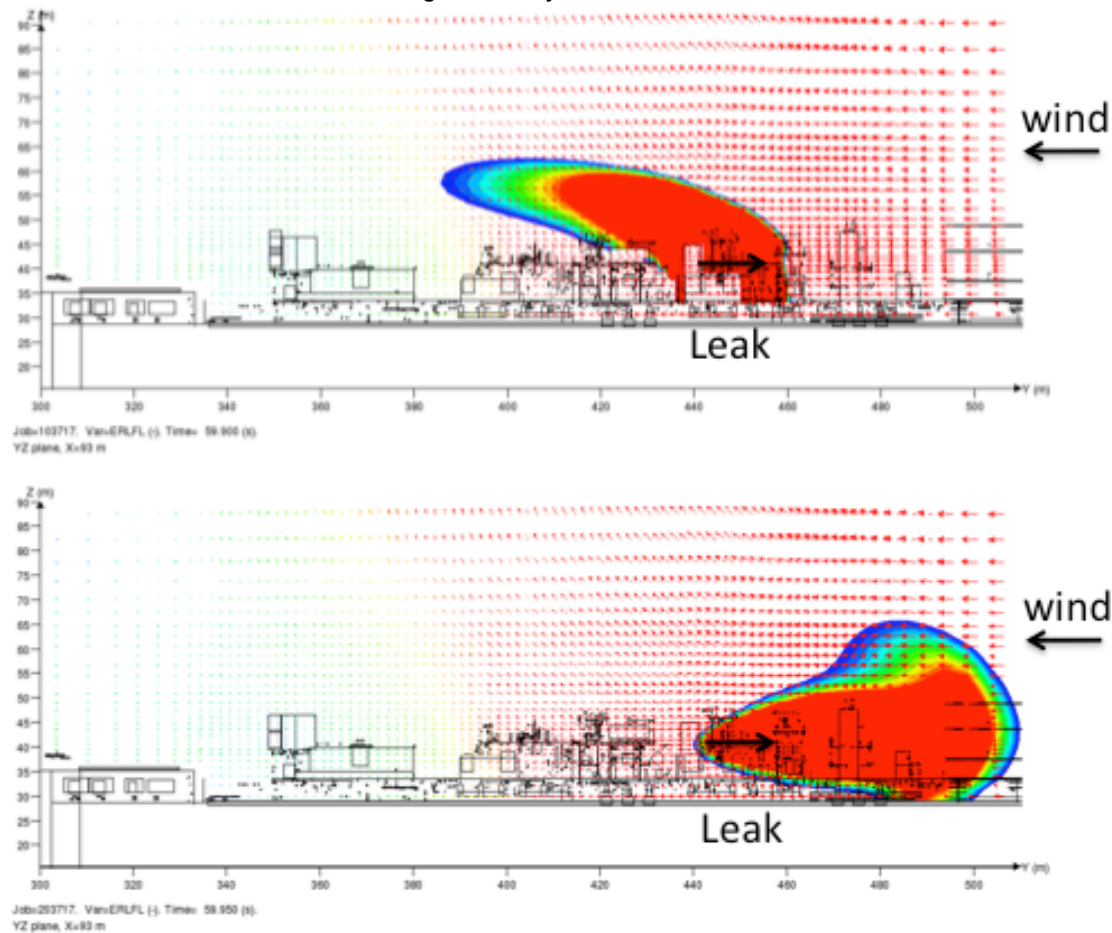


Figure 3.1: Gas dispersion results for a high momentum release in complex geometry (upper) and not accounting for the details of the geometry (lower).

It is therefore important to have a detailed geometry model that adequately represents a given process area. In early design models, it is sometimes necessary to supplement the geometry with Anticipated Congestion to more accurately account for typical equipment density. It should be noted that for new builds it has become increasingly common to have a 3D CAD model, which seriously reduces the resources needed for performing a dispersion study with FLACS.

When working with the gas detector layout it is GexCon experience that visualizing the layout is vital for ensuring success. A good visualization allows one to apply a qualitative understanding of gas dispersion, an evaluation of qualitative guidelines, efficient communication both internally and with the other involved disciplines, and an evaluation of practical aspects regarding layout. An artificial version of the FLACS geometry can be made in order to facilitate detector visualization, as shown in Figure 3.2. The proposed gas detection systems will be visualized in the artificial geometry.

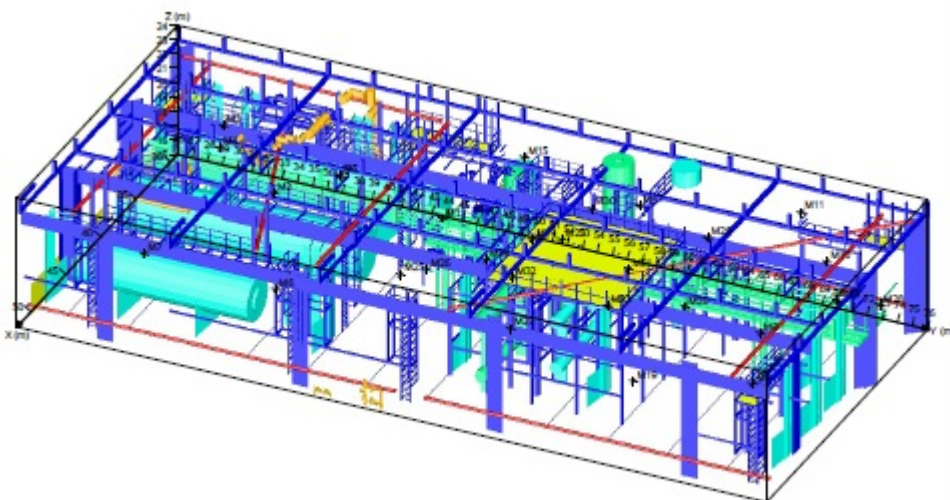


Figure 3.2: Illustration of point and line detectors in a typical process module

3.4 CFD based dispersion study

Dispersion modeling is performed with a combination of wind conditions and leak characteristics that represent challenging conditions for the GDS. The GDS will be reviewed against the dispersion results. Typically 100-600 FLACS simulations are performed for each area. The scenario parameters, such as: leak points and leak directions; wind speed and wind frequency; are chosen so that the union of all simulated gas clouds covers all relevant areas. Note that the leak cases are chosen generically within all areas that contain credible leaks sources (typically all areas that contain HCs). In addition to sonic jets, the study also includes diffusive leaks from, for example, open drain systems (gas flashing from oil leaks). Combination of oil mist/gas leaks is also assessed but not simulated directly, because the standard version of FLACS is currently not capable of simulating aerosol releases.

Of all the gas characteristics, the density of the gas is most relevant with respect to gas detection. If a given area contains significant quantities of two different gases having a large difference in density (e.g., both a lighter and heavier than air gas), then both gases should be simulated for the study. For each dispersion simulation in FLACS, the concentration versus time is recorded at more than a 1000 potential detector positions (see Figure 3.3 as an example for one detector). In addition, the gas cloud size (determined from any set point, such as 20% LEL) is also recorded at intervals of less than 1 s. This data can be post-processed to form a basis for evaluating the performance of any combination of considered detectors, variation in set point and detection philosophy. Also, a 3D array of gas concentration values is

stored for each scenario at intervals of 5-30 s. These 3D gas concentrations maps can be used to perform qualitative evaluations.

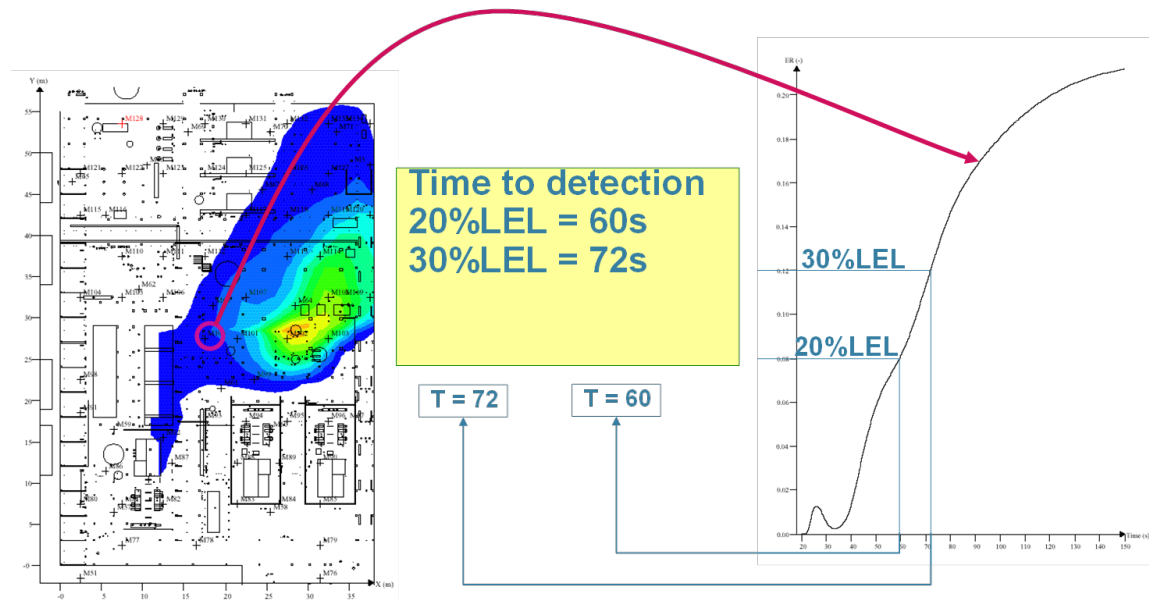


Figure 3.3: Illustration of dispersion output from FLACS simulations

As only a limited set of simulations are used to represent a potentially infinite number of possible scenarios, certain qualitative assessments are applied with respect to effects such as: flow patterns; symmetry assumptions; and relevance of scenarios relative to the selected detection criteria. These qualitative assessments are documented in order to allow for transparency.

3.5 Detection of dangerous clouds

The term “dangerous” cloud has been defined in the previous section and refers to a cloud that, if ignited, will yield unacceptable consequences. In order to determine the “dangerous” cloud size, the equivalent stoichiometric cloud (ESC) must be estimated by mapping of the flammable region of the inhomogeneous cloud determined from gas dispersion simulation. When the volume of the ESC is larger than the volume of the dimensioning gas cloud, the cloud is labeled “dangerous”. Recall, the dimensioning gas cloud is the smallest stoichiometric gas cloud that can result in explosion loads exceeding the DAL. An explosion study should first be performed in order to establish explosion pressure versus gas cloud size (see Figure 3.4); next, this analysis should be compared with the DAL specification in order to determine the size of the dimensioning gas cloud.

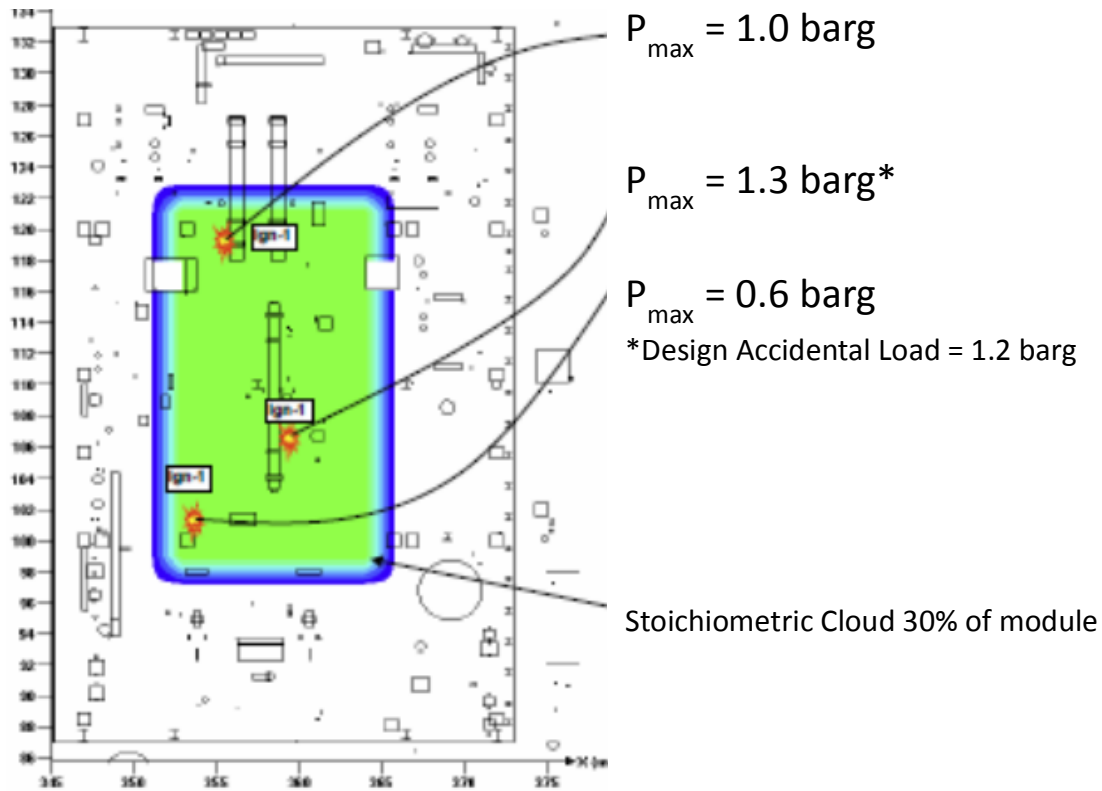


Figure 3.4: Example of explosion study to determine the dimensioning gas cloud

The GDS is coupled with the dispersion results to verify that all dangerous clouds are detected. If the GDS does not meet this criterion then the simulation results are evaluated qualitatively to reveal potential pitfalls or other information that can be used to enhance the GDS design. Figure 3.5 shows a comparison of the cloud size (flammable volume) at the time of detection versus the maximum possible cloud size (flammable volume) had no protection been present (e.g., no GDS) for different detector layouts. The dimensioning cloud was determined to be 4000m^3 , and all detector layouts were capable of detecting cloud sizes before they reached the dimensioning size, except for layout 3 (L3) where there is one cloud that was not detected until almost reaching 5000m^3 .

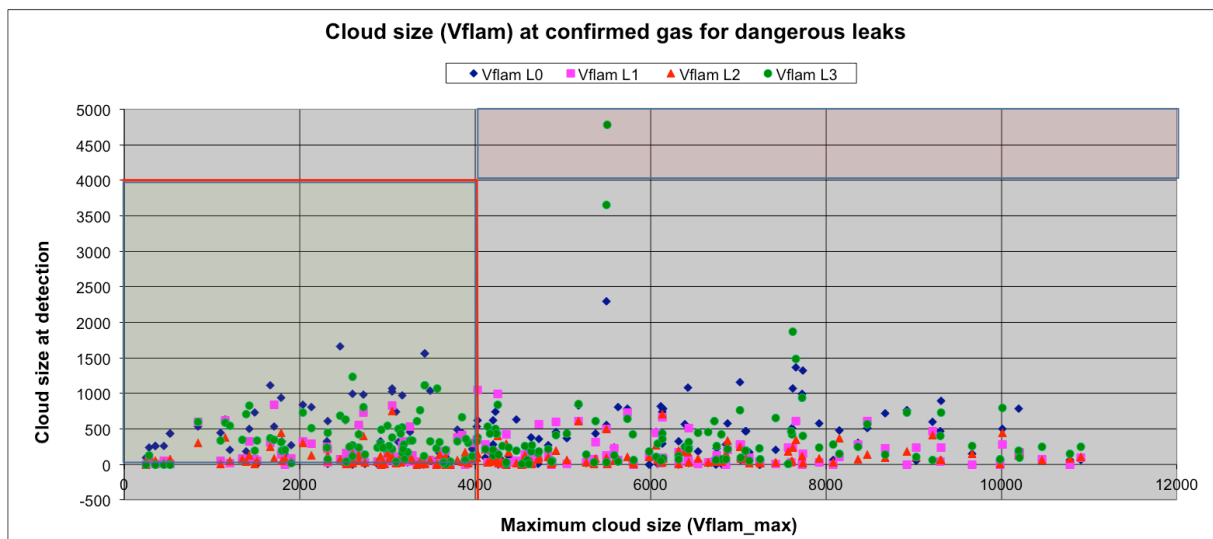


Figure 3.5: Cloud size at detection versus maximum cloud size

Time to detection can also be evaluated to compare relative performance of two different detector layouts or voting schemes. For example, the operator of an offshore production platform wanted to introduce voting in order to avoid false alarm. Yearly costs associated with false alarm costs were in the range of millions of dollars. A detection study was performed in order to quantify the effect of changing the GDS from 1x60%LEL to 2x20%LEL before shutting down the process.

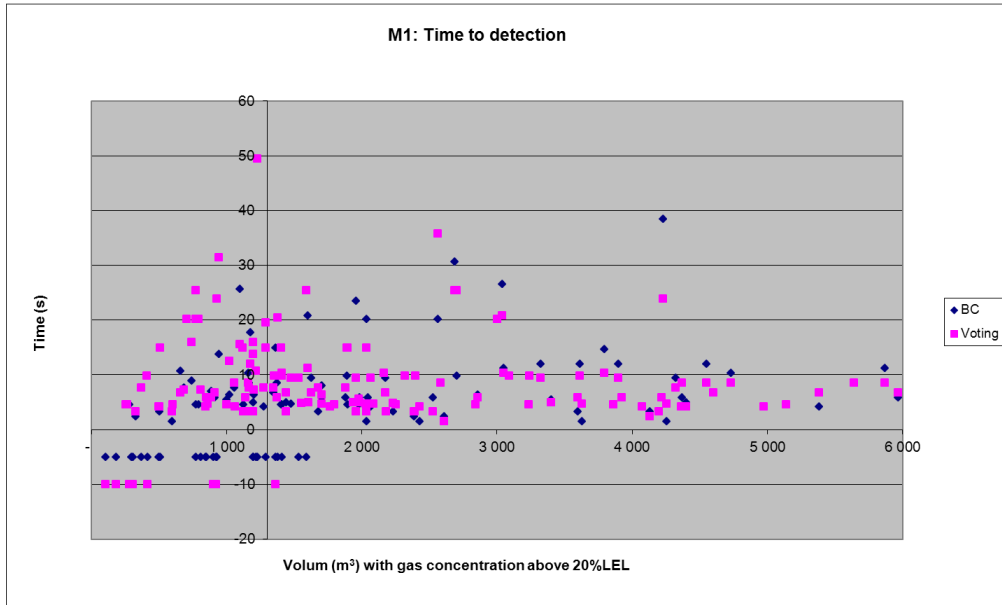


Figure 3.6: Time to detection comparison for two GDS, base case BC and with voting

Figure 3.6 shows that the performance of GDS after introduction of the 2x20%LEL voting remained essentially unchanged. The results were very convincing and it became clear that there was practically no loss in safety performance due to the modification that gave a yearly savings of approximately 4-8 million dollars.

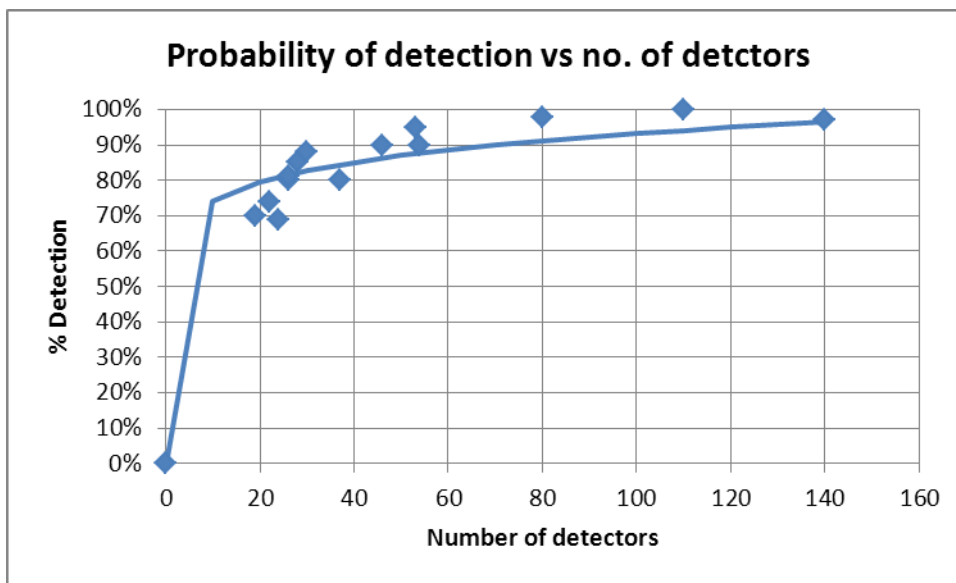


Figure 3.7: Probability of detection vs. number of detectors

The results of CFD studies will contain data, such as time to detection, probability of detection and cloud size at the time of detection. These studies can be used to help qualitatively assess the GDS as well as help optimize the system. Figure 3.7 shows that, for a given process area, when the number of detectors falls below approximately 20, the probability of detection drops considerably. Increasing the detector density beyond this minimum value results in marginal increments in GDS performance. Further improvements in performance are possible through quantitative optimization of GDS. For example, the system had a 99% probability of detection when it was optimized with 50-80 detectors; the “rule of thumb” approach would have required approximately twice as many (140) detectors to achieve the same performance.

3.6 Optimization of small leaks

Leak rates on the order of 0.1kg/s typically never reach “dangerous” cloud sizes, except under the most extreme circumstances. Therefore, the dispersion study must first be used to determine a “characteristic” cloud for these small, typical leaks. First, multiple 0.1kg/s leaks are generically studied to determine the “characteristic” cloud size that will be used for optimizing the number and the location of the gas detectors. The “characteristic” cloud size is assessed from the maximum possible cloud size (flammable volume) had no protection been present in the system. A set of leak scenarios using a fixed leak rate and wind speed is conducted for each independent area. The resulting gas clouds are then compared against the “characteristic” cloud. Based on this comparison the scenarios are re-simulated with a modified ratio of leak rate to wind rate speed ratio so that the resulting cloud as close to the size of the “characteristic” cloud as possible without becoming smaller.

The simulation output is analyzed and provided to give output with respect to design or verification. Most commonly, the GDS is rated in terms of time to and probability of detection. Time to detection is very useful when comparing the performance of various GDS for similar leak rates. Figure 3.8 shows the performance results of four different GDS layouts, where the maximum time to detection and maximum fraction of scenarios detected is illustrated (when the values cross zero and become negative).

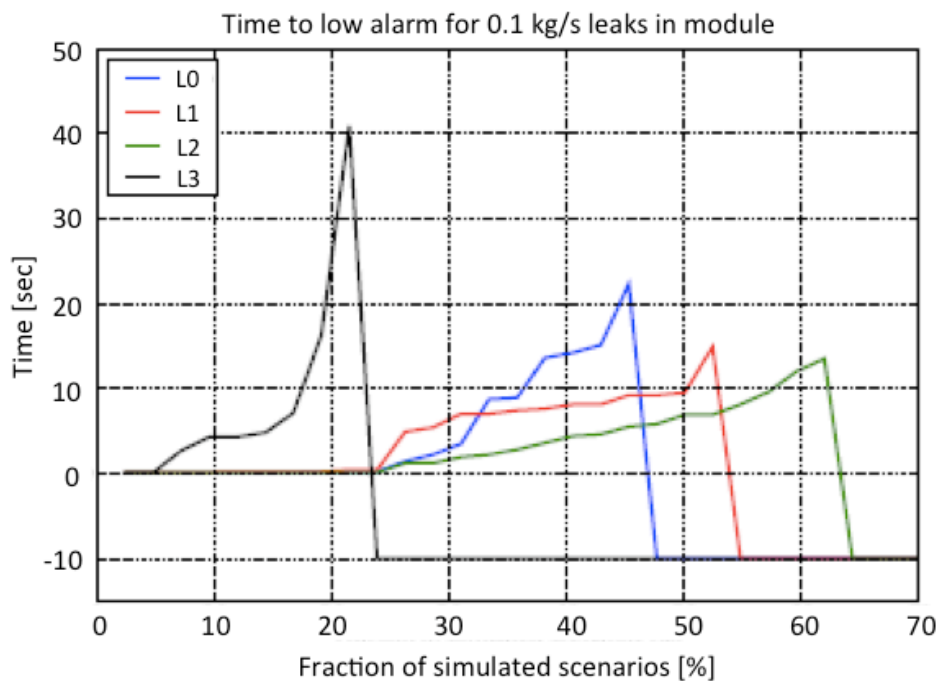


Figure 3.8: Time to and probability of detection for small 0.1 kg/s leaks

For this given system it can be seen that the time to detection for 40% of the scenarios had decreased by more than 10 seconds when initial layout (L0) was compared to second proposed layout (L2) and the maximum fraction of scenarios detected increased from 45% to over 60%.

It is also useful to evaluate GDS performance by reporting the size of the cloud (as determined from the detection criteria, i.e., 10% LEL) at the time of detection as compared to maximum potential size had detection not been present for each scenario. Figure 3.9 below shows such a comparison of the gas cloud size at 10%LEL, and shows how the detected gas cloud could be reduced when comparing the initial layout (L0) as compared to the first (L1) proposed layout for the GDS.

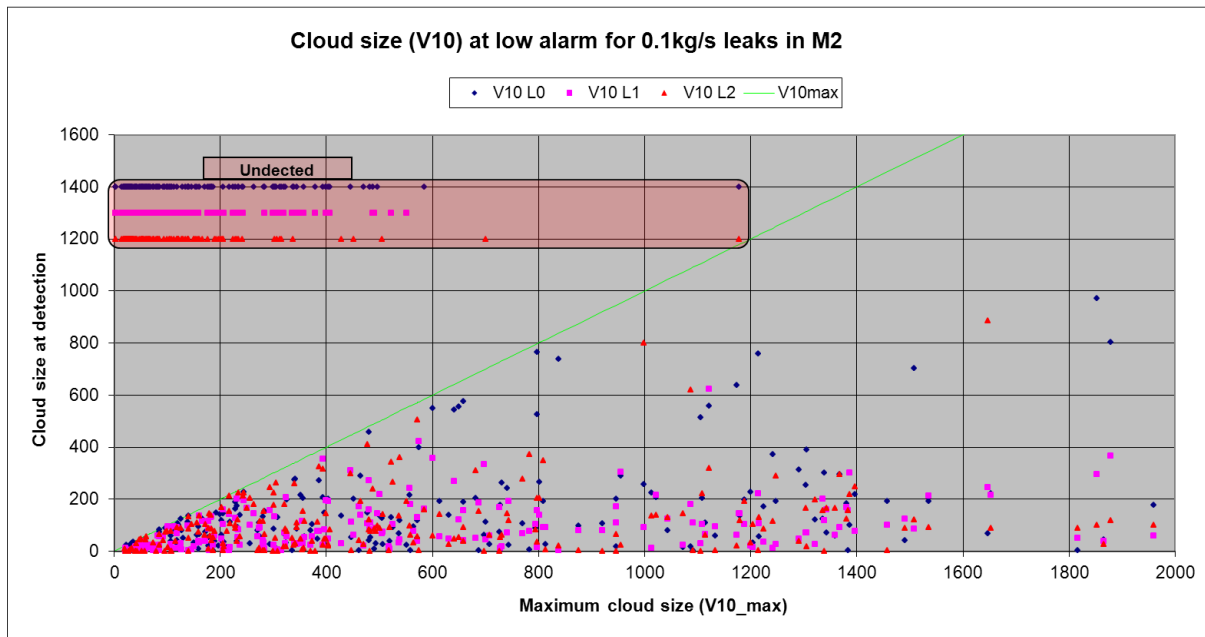


Figure 3.9: Cloud size at detection versus maximum potential cloud size (without protection)

3.7 Comments regarding CFD studies

The CFD part of a GDS is to quantify the detection versus the potential hazard. While the output can be provided in a number of ways, the performance of a GDS is typically rated in terms of time to and probability of detection. However, since the cloud buildup time depends of the leak rate, the relative effect of detection time will be different for small versus large leak rates. What is more important is that the results can be coupled to the measures initiated by detection (ignition source control, emergency shutdown, initiate deluge pumps). Improving performance of a GDS by a few seconds may not be relevant for initiating the closure of the ESD valves if the closing time is 30 seconds. In contrast, this same improvement may have a large effect regarding shutdown of ignition sources.

Since only a limited number of scenarios are simulated, an automatic routine for determining an optimum solution will be strongly correlated to the chosen leaks (position and leak direction). In other words, you will determine the “optimum detector layout” for the chosen scenarios. There are several ways to deal with this that include filters, choosing detector layouts prior to evaluating the dispersion results, and identifying direct correlations. In any event some degree of qualitative evaluation is needed.

When designing a GDS several disciplines need to be involved, such as instrumentation, safety, risk analysis and operations. The role of the CFD study is to quantify and verify solutions proposed in the design process. Also, the dispersion and ventilation results should be used to assess general ventilation and dispersion patterns and also be used as input to the design process. In addition, results showing

negative features can be used to avoid pitfalls in the design of the GDS. Since there are many potential leak scenarios, the choice of scenarios is critical for a successful study. In many process situations leak statistics show that the leak can occur virtually anywhere. In addition, as it's the resulting gas cloud (not the leak in itself) that is detected, detection should in general not be focused on a limited set of particular leaks, which will yield a poor GDS design.

The general philosophy should be to have the low and high alarm levels low as possible, while avoiding detector error and false alarms. The use of automatic actions upon confirmed gas alarm is preferred from a safety point of view.

4 Conclusion

The use of CFD is vital tool and critical supplement to ensure performance of a given GDS design. The CFD study is not a stand-alone solution but rather an integrated part of the design and verification of a GDS. CFD is a quantitative evaluation of the GDS. The results of a CFD analysis provide a firm and repeatable base upon which the complex reasoning used in the design of a GDS is anchored. Without such an anchoring point, one not only runs the risk of poor design but also may have a false perception of the quality of the design. Using CFD to quantify the behavior of a GDS should be supplemented with qualitative assessments due to the limitations in simulating leaks for every possible realistic leak scenario.

1 ANSI/ISA-RP12.13.02 *Recommended Practice for the Installation, Operation, and Maintenance of Combustible Detection Instruments* 2003.

2 NORSOK Standard S-001 Technical Safety – 4th edition 2008.

3 ISA-TR84.00.07-2010 – Technical Report – Guidance on the Evaluation of Fire, Combustible Gas and Toxic Gas System Effectiveness. January 2010

4 Hansen, O.R., Gavelli, F., Davis, S.G., and Middha, P. *Equivalent Cloud Methods used for Explosion Risk and Consequence Studies*, paper to be presented at Mary Kay O Connor Process Safety Symposium. October 2011, College Station, TX