Gas Detection in Process Industry – The Practical Approach

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There are multiple gas detection mechanisms in the process industry. They have wide ranging applications from modeling gas releases to detecting an accidental release in a process facility and triggering a shutdown or mitigation function. This paper discusses various types of gas detectors from a functional perspective including installation and calibration procedures, cross measurement amongst various gases, response times, power requirements and measurement ranges. A comparative analysis of the various types of detectors is provided. The information presented has been obtained through extensive testing of a range of different hydrocarbon gas detection systems at an outdoor test facility with different types of gas detectors.

Keywords: Gas detection, point detectors, area detectors, catalytic, IR, line of sight, acoustic

Introduction

Gas detection systems have been deployed extensively in the process industry to detect and mitigate gas releases and minimize their potential consequences. The detection mechanisms differ between chemicals, and consideration has to be made to select the correct technology for each application, along with practical considerations of installation, commissioning, and maintenance. Most of the current applications trigger an alarm for the operator based on high readings from gas detectors. However, with the industry push to incorporate safety gas sensors into shutdown systems, the need to design, calibrate and commission these sensors correctly to minimize nuisance trips is increasing in importance.

Gas detection technologies

There are two broad categories of gas detectors: point detectors and area detectors. Point gas detectors have a single detector location requiring the gas cloud to interact with the sensor. Point detector types include catalytic, electrochemical, solid state, and infrared (IR). Catalytic and IR detectors are most widely used in the industry and are discussed in detail in the paper. Area detectors are able to detect a release without the gas cloud directly interacting with the detector. Area detector types include Open Path (Line of Sight - LOS) and Acoustic.

Point gas detectors

Catayltic gas detectors

Catalytic detectors (Figure 1) are point detectors that use a heated platinum resistor coated with a catalyst to react with a combustible gas. As the combustible gas interacts with the resistor the coating oxidizes, heating the coated resistor. The temperature rise of the coated resistor is compared against a control resistor to determine the %LFL.

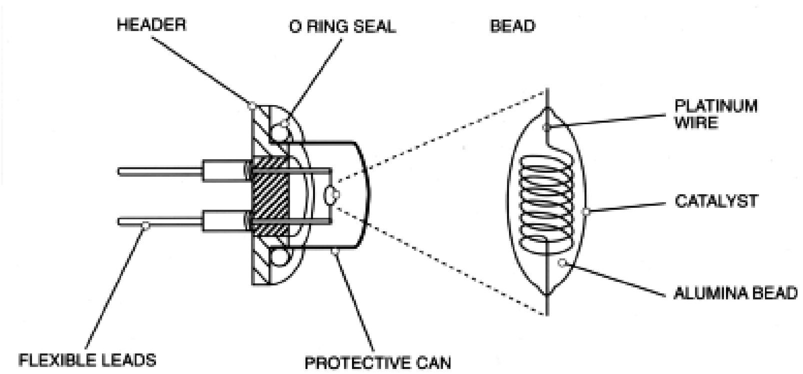

Figure 1 Internal diagram of catalytic sensor [Mohankumar 2012]

Advantages:

- Simple operation
- Robust and easy to use and calibrate
- Highly reliable
- Easily calibrated for individual gases such as hydrogen

Disadvantages:

- Frequent calibration required due to inactivity or contamination
- Prolonged exposure to flammable gas reduces sensitivity

Practical Considerations:

- Catalytic sensors are generally helpful to detect gases like hydrogen where other point gas detectors are not as responsive.
- Sensor beads might have to be replaced or sensors have to be calibrated frequently to maintain high reliability.
- Calibration kits are available from different vendors to allow remote calibration since sensors could be located at heights not easily accessible.
- Power requirement of the catalytic sensors is not very high and generally operates on loop power from controller.
- Accuracy ranges from 3-5% depending on the %LFL range.
- Typical response time to 50% LFL is 10 seconds and to 90% LFL is 30 seconds. This is the time it would take for the sensors to detect the correct gas concentration and provide a signal once the gas is in contact with the sensor.
- It can operate over a wide temperature range, -40 ^{o}C to +75 ^{o}C.
- Very high reliability in environments with extreme temperatures, humidity and vibrations.

InfraRed (IR) Gas Detectors

InfraRed detectors use the infrared absorption of hydrocarbon gases in the 3.4 micrometers wavelength to detect when a combustible gas is present. These detectors utilize an infrared light transmitter to detector at the target gas wavelength as well as control the wavelength. Complex algorithms are used to calculate the %LFL from measured transmittance.

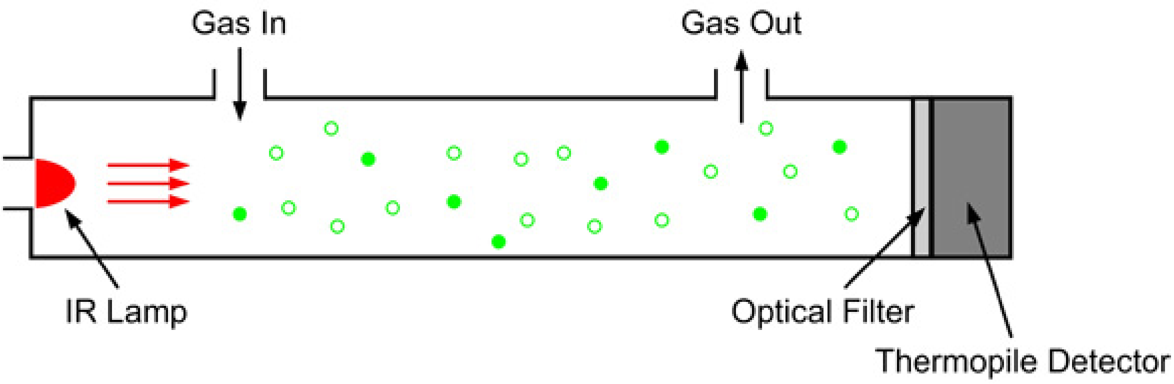

Figure 2 Schematic of IR sensor [Seitz 2012]

As shown in Figure 2, the source transmits an IR beam through a chamber filled with the sample gas. The reflected IR is correlated with the gas concentration. Optical filters may be used to measure only specific gases. With the filters removed, the sensor can measure a wide range of gases, but the response time is slower and needs more complicated algorithms.

Advantages:

- Most common gas detection system
- Wide choice of vendors and cost competitive
- Easy to setup and calibrate
- Calibration is not required as often as catalytic sensors
- Immunity to noise and contaminants
- Works continuously in presence of flammable gas without degradation

Disadvantages:

- Initial purchase and installation cost is high
- Gas has to be infrared active, such as hydrocarbons

- Not effective in extreme temperatures, humidity or high vibration environments
- Does not perform well for multiple gas applications

Practical Considerations:

- IR sensors are generally helpful to detect hydrocarbons.
- Power requirement of IR sensors ranges from 5-20W. IR sensors typically operate on loop power from the controller.
- Accuracy ranges from 1-5% depending on the %LFL range it's measuring.
- Typical response time to 50% LFL is 5 seconds and to 90% LFL is 10 seconds.
- IR sensors can operate over a wide temperature range of -40 ^{o}C to +75 ^{o}C.
- IR sensors are calibrated to a particular gas, example methane or propane. If other gases are measured using the same sensor, vendors must provide adjustment curves to determine the concentration. Accuracy of such corrected measurements is limited.
- If the gas sensor becomes "saturated", it may require significant time for the sensor value to reduce to normal level after it has come in contact with the gas. This is especially true if a hydrophobic filter or a weather baffle is used.
- Deviations in mounting from the manufacturer's recommended orientation may result in large errors in measured concentrations.

Area Detectors

Open Path Detectors

Open path area detectors are of two types: IR and Laser Spectroscopy. The IR open path utilizes the same technology as point IR detectors. The IR open path detector spaces the distance between the IR transmitter and receiver from 15 feet to 650 feet depending on detector capabilities. Laser spectroscopy open path measures several different wavelengths to identify a specific gas concentration. The current paper discusses the IR open path detectors as they are widely used in the industry.

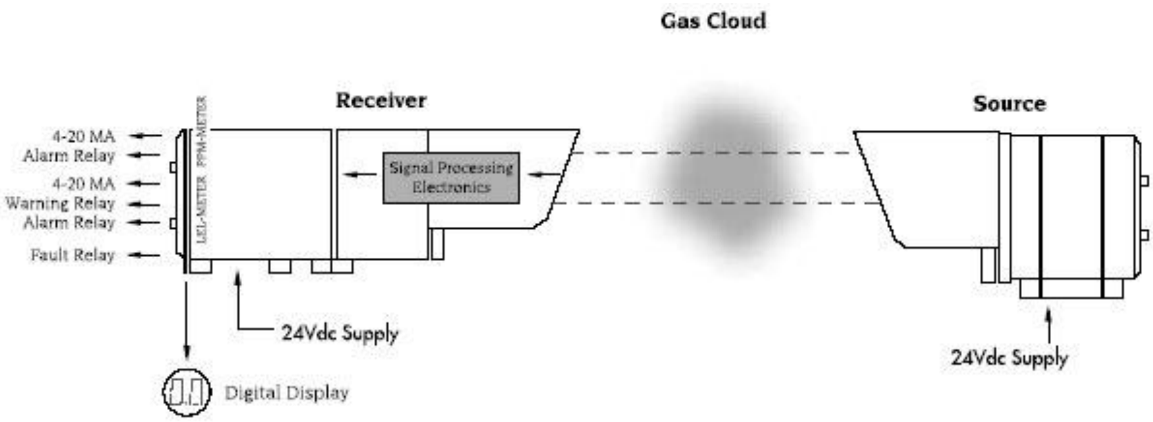

Figure 3 Schematic of Open Path IR Detector

As shown in Figure 3, a source transmits a beam of infrared light to the receiver unit. The degree of absorption of the beam is related to the total number of particles of gas within the path from transmitter to receiver. The output is therefore reported in terms of LFL-m (product of %LFL and width of the unit's path).

Advantages:

- Extensively used in offshore platforms and on-shore facilities to detect gas release in a wider area.
- Used both as early alarms as well as to trigger evacuations.
- Needs less installed equipment than point detectors if the purpose is to only detect gas release and not the concentration of gas.

Disadvantages:

- Open path detectors are extremely sensitive to maintaining line of sight between transmitter and receiver. This makes initial commissioning very difficult and time consuming. They are very susceptible to temporary obstructions like rail cars, scaffolds, other equipment or vehicles. Notorious for nuisance alarms or trips.

- Unit does not report the value of %LFL, only gives the value of LFL-m.
- Initial cost of the instrument and installation is significantly higher than point IR detectors.
- Vibrations may result in misalignment of the source and receiver units.

Practical Considerations:

- Line of Sight sensors are generally helpful to detect hydrocarbons. However, very few toxic units are available.
- Power requirements of the IR sensors range from 20-50W. Some units draw higher power if they don't need fine adjustments to ensure line of sight. These units constantly transmit IR beams over a wider area. If power is not an issue, these units could be considered to reduce calibration time.
- Accuracy ranges around 1% depending on the %LFL-m range it's measuring
- Typical response time to 90% LFL is 5 seconds.
- It can typically operate over a wide temperature range, -50 ^{o}C to +50^{o}C.
- Area detectors are not calibrated to a particular gas, so they can provide %LFL-m values for a range of hydrocarbon gases. Toxic detectors are calibrated to particular gases like hydrogen sulfide or ammonia and they should only be used in the applications for which they are designed.
- Alignment of the source/receiver requires significant time and effort. Units may become unaligned due to vibrations, weather, or accidental encounters.
- Even though these units do not need the gas to contact the sensors, correct placement is still critical for adequate detection. The gas cloud must still interact with the IR beam to trigger an alarm.

Acoustic Detectors

Acoustic gas detectors detect ultrasonic sound waves created by a leak. Acoustic detectors are able to detect a leak of any gaseous material under pressure. When a pressurized gas leak occurs, the frequency content of the sound being generated extends beyond the audible portion of the spectrum into the ultrasonic region (above 20kHz). The intensity of the sound generated by a leak is determined by several factors including pressure, leak rate, gas viscosity, and distance from leak source. [Det-Tronics 2014]

Advantages:

- Response time is negligible.
- Detects leaks independent of gas.
- Most acoustic units can be programmed to learn certain types of release gas based on historical data. This can help increase the accuracy of the measurement.

Disadvantages:

- Prone to nuisance alarms/trips if not configured correctly, since it can detect any leak. A nitrogen or instrument air leak in the area could trigger an alarm/trip.

Practical Considerations:

- Acoustic technology for gas detection has developed a lot over the last few years; however, additional work is ongoing to reduce nuisance alarms/trips.
- Acoustic detectors may be best used as a preliminary alarm, with point or area detectors deployed to trigger any type of shutdown (either automatic or by an operator).
- Most of the acoustic units are battery operated and require low power (1-2W).
- Installation is fairly simple and costs significantly less than gas detectors. Proper placement for leak detection not as critical as with gas detectors.
- It can typically operate over a wide temperature range, -50 ^{o}C to +75 ^{o}C.

Placement of Gas Detectors

History of Detection

Gas detection started as canaries in cages and has been evolving with technology. The petrochemical industry has adapted to utilize new technologies as they become reliable. In 1991, the American Petroleum Institute (API) published API 2031 "Combustible Gas Detector Systems and Environmental and Operational Factors Influencing Their Performance" to assist with the location and installation of gas detectors. The publication was withdrawn shortly after release to avoid potential issues in industry. There is no current governing standard on where to place gas detection in process areas, however most companies have internal standards that govern the placement of gas detectors. Traditional gas detector placement studies include experienced based location by experienced engineers. CFD modeling has also been utilized to assist in gas detector placement but it is cost prohibitive. The UK HSE has 8 years of offshore data showing that only 60% of known releases have been detected. The lack of reliable detection has pushed industry to a quantitative methodology regarding detector location. In 2010 ISA 84 TR 7 was released to assist in designing gas detection systems based on quantitative coverage.

Quantitative Detection Design

Geographic Coverage

ISA84 TR7 defines Geographic Coverage as: "The fraction of geometric area (at a given elevation of analysis) of a defined monitored process area that, if a release were to occur in a given geographic location, would be detected by the release detection equipment considering the defined voting arrangement." Geographic coverage is based on a defined hazard zone as shown in Figure 4. Gas detectors are assigned an effective volume and are placed in the defined hazard zone. An analysis is run to determine scenario coverage factor based on percentage of geographic area detected by the detectors.

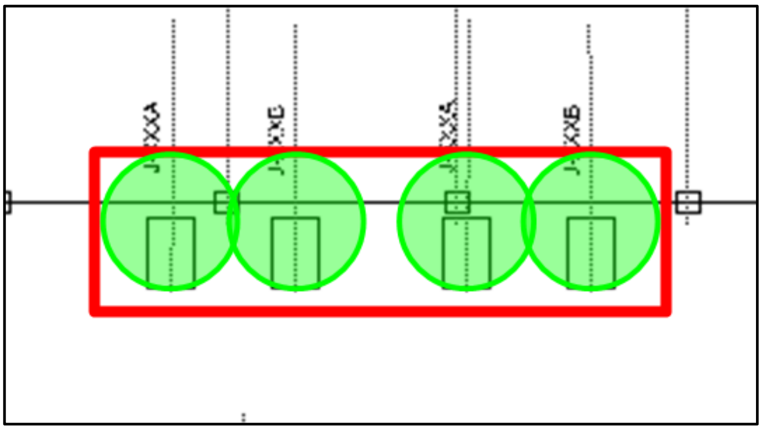

Figure 4 Geographic coverage with 4 point detectors

Advantages:

- Does not require any additional modeling.
- Accurately models acoustic coverage.

Disadvantages:

- Requires assumptions regarding detector effectiveness. For point and open path detectors this can be non-conservative as it requires the cloud to directly interact.

Scenario Coverage

ISA84 TR7 defines Scenario Coverage as: "The fraction of the release scenarios that would occur as a result of the loss of containment from items of equipment of a defined and monitored process area that can be detected by release detection equipment considering the frequency and magnitude of the release scenarios and the defined voting arrangement." Scenario coverage utilizes dispersion modeling software to predict plumes for potential releases. An example of scenario coverage is shown in Figure 5. An analysis is run to determine the coverage factor based on the number of scenarios detected by the detectors.

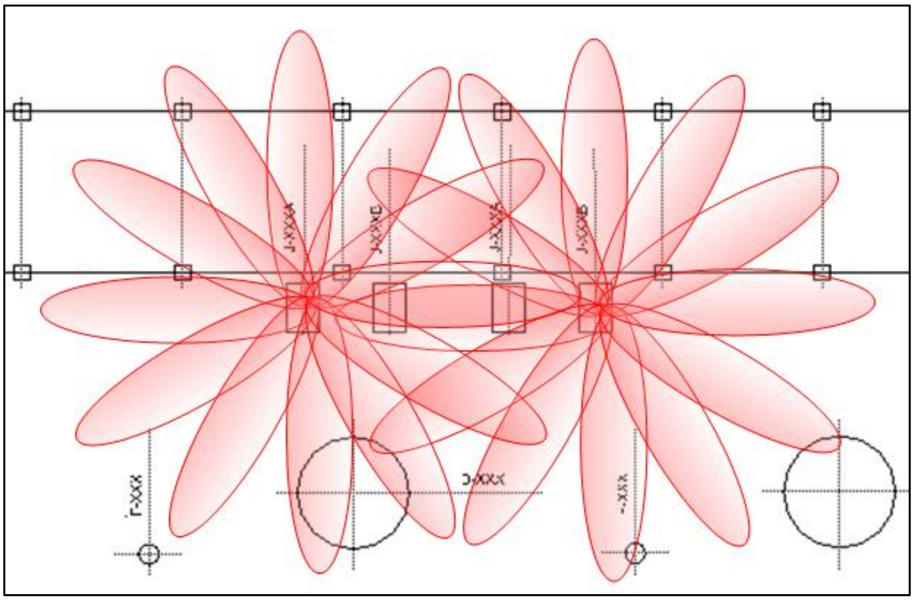

Figure 5 Scenario coverage

Advantages:

- Detectors can be placed appropriately depending on the actual process conditions in the equipment and piping
- Avoids putting detectors in less hazardous locations depending on release scenarios, wind and weather conditions, and process congestion in the area

Disadvantages:

- Needs detailed analysis of each release scenario. This effort could be expensive and time consuming. Most PSM sites would have undergone a facility siting study detailing scenarios possibly leading to loss of containment and gas release. That information could be used to determine the scenario coverage without much additional cost.

Case Study

This case study consists of four LPG pumps with four separate IR point gas detectors. The point detector locations are shown below in Figure 6.

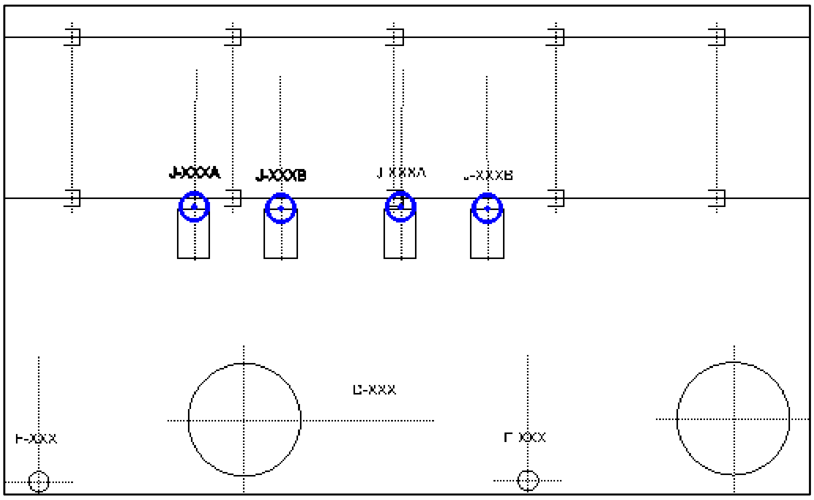

Figure 6 Point gas detector location

Geographic Coverage

The hazard zone is defined around the potential maintenance area for the four pumps. The IR point detectors were given an effective radius of 3 feet resulting in a coverage factor of 67.4%. Figure 7 shows the geographic coverage for four gas detectors. The green areas represent the effective coverage of the detectors and the yellow area shows the uncovered area.

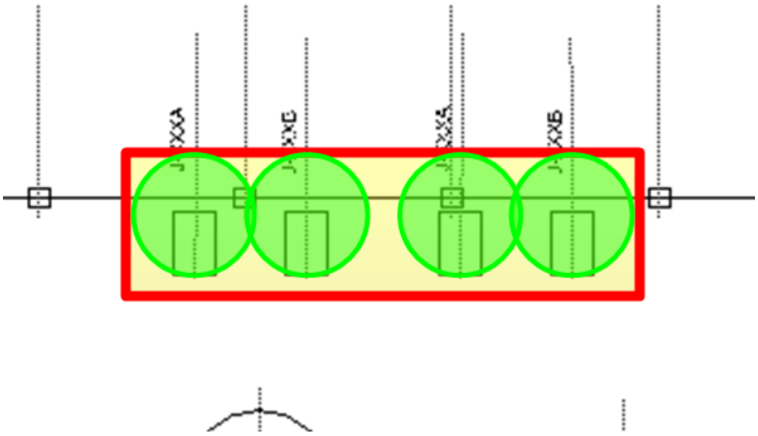

Figure 7 Geographic coverage with 4 point detectors

Scenario Coverage

Release scenarios are defined from process information. For this case study a release was defined for each of the four pumps. The release points are shown below in Figure 8.

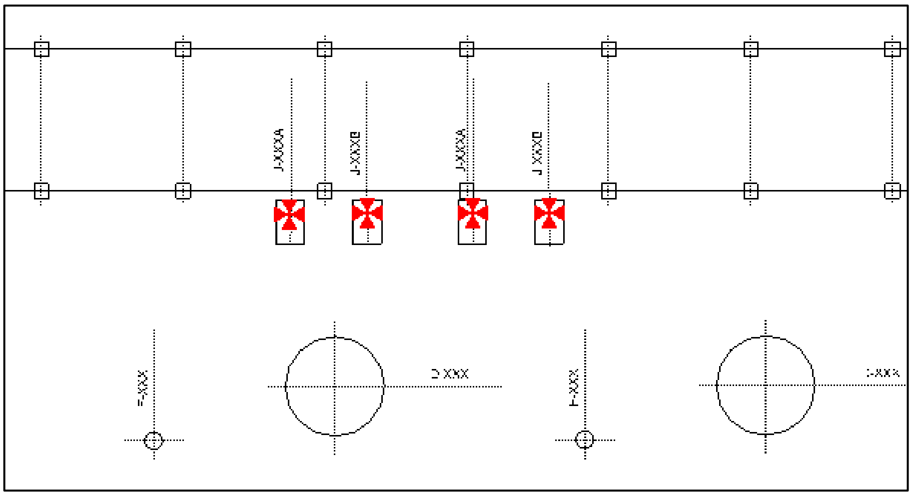

Figure 8 Case study release cases

The releases are modeled in dispersion software and rotated in 16 wind directions. The dispersions are interacted with the gas detectors as shown in Figure 9

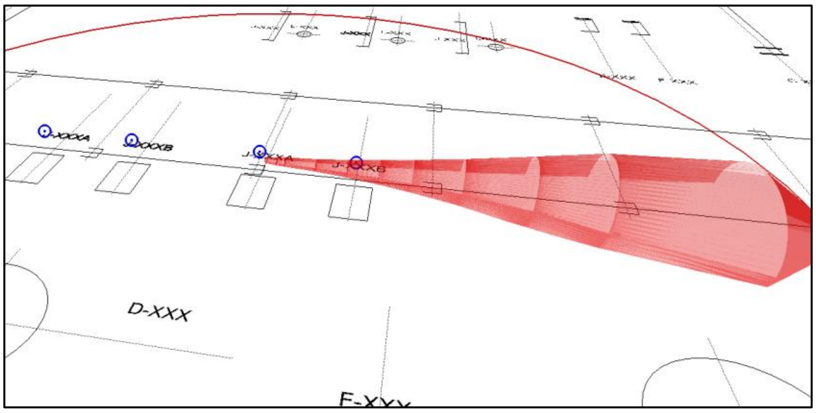

Figure 9 Case study release cases

An analysis is run to determine the percentage of the potential dispersions that are detected by the Point IR gas detectors. Example results of the analysis are shown below in Table 1.

Table 1 Example results

Source Name	Weather Name	Wind Direction	Detected by
J-XXXB - Propane-0.5	F1.9	247.5	J-XXXB
Exp-25-V125-0.51	F1.9	270	J-XXXB
Exp-25-V125-0.51	D7.2	270	J-XXXB
Exp-25-V125-0.51	D3.5	247.5	J-XXXB
Exp-25-V125-0.51	D3.5	270	J-XXXB
Exp-25-V125-0.51	B2.4	202.5	J-XXXA

The total scenario coverage for this example is 19.1%. This is significantly lower than the geographic coverage (67.4%). Geographic coverage as shown in this case study is non-conservative regarding point and open path gas detection.

Conclusions

There are many different types of industrial gas detectors and each has advantages and disadvantages. It is important to apply the correct technology for the selected application. Point detectors are the most common types and are widely used across industry. There are lots of manufacturers that manufacture these detectors and certify them to the various industry standards. It is important to consider the power requirements, mounting requirements, standoff distances from other units, operating temperature ranges, gas calibration limitations, accuracy, and the response time at different concentrations. Similarly, area LOS detectors are receiving increased attention from pipeline and offshore industry to detect leaks over longer distances without deploying multiple sensors. Area detectors typically draw significantly higher power and are susceptible to any interference. Acoustic detectors are fairly new in the process industry and present a lot of potential for early detection if installed correctly. With capabilities to adjust the algorithms over time based on recorded data, the acoustics could be a promising technology for early detection of major or minor releases in the future.

There is little general guidance regarding the design and placement of gas detection systems, and many facilities rely on experience-based designs. ISA 84 TR 7 recently provided some guidance for quantitative detection design, including both geographic and scenario coverage design schemes. However, it has been shown that designing detection systems based on geographic coverage may result in significant coverage gaps. An ideal quantitative detection design would be scenario-based, and examine such factors as release location, release orientation and wind direction, hole size, plume trajectory, detector elevation, detector uncertainty, and weather effects. Such an approach would require extensive dispersion modeling; therefore, designing or auditing gas detection systems in conjunction with a facility siting study or quantitative risk assessment is the practical approach

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