

Integrated Solutions for Fixed Gas Detection

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1.0 Preface

Over the years, a variety of gas detection technologies have been developed for the oil, gas, and chemical process industries. The advent of embedded electronics, sophisticated firmware, new materials, and spectral techniques has prompted remarkable improvements in detection. In many cases, technology development proceeds through parallel routes with each technology staking its own specialist market. Catalytic bead sensors and infrared detectors are two examples of conventional sensing methods with wide customer acceptance. Likewise, comparatively newer technologies like open path, gas cloud imaging, and ultrasonic¹ gas leak detection have made inroads into the safety instrumentation market, not due to their novelty, but because they solve customers' problems like no technology before them.

In such a world of competing solutions, it is tempting to think single technologies will provide answers to most industry challenges. Offshore platforms, onshore terminals, gas compressor stations, and other facilities, however, are complex environments no single type of detector is bound to cover completely. Experience has shown it is in fact the combination of gas detection schemes that provide the enhanced level of safety that customers demand.

Take the combination of ultrasonic and conventional detection as an example. Ultrasonic detectors can be deployed along pressurized vessels or pipes, while open path instruments are installed along perimeters to detect low concentration gas leaks in wide open areas. Similarly, fixed point and ultrasonic detectors can be placed throughout a facility to improve detection. Fixed point detectors can tackle the monitoring of areas protected from air drafts, providing protection against small quantities of gas and low pressure leaks. Ultrasonic gas leak detectors could be placed in high pressure (≥ 145 psi) offshore and onshore gas facilities that may be exposed to high winds or where gas clouds can easily disperse. Taken together, these detectors enhance the protection of the area as a whole.

The ability of detection technologies to work together, thereby mitigating the limitations of single technologies, is one of the benefits of a new outlook in fixed gas detection systems. Ultrasonic gas leak detectors alarm as they "hear" the ultrasonic sound from a gas leak, whereas other methods rely on imaging or "seeing" a gas cloud, or "smelling" trace amounts of a toxic or combustible vapor. These different methods of detection may be equally compelling tools. Such diversification in the field leads to a more robust coverage of monitored areas.

At General Monitors, our vision is to be a total solution provider for our customers by offering integrated, scaleable systems that offer such diverse layers of protection. Effectiveness in detection is achieved by integrating the sensing equivalents of smelling, seeing, and hearing to detect gas leaks, flames, and other hazardous conditions. Each technology has its strengths and weaknesses and there is no one perfect solution. But by integrating a variety of passive and active sensing technologies into a comprehensive safety system, companies can better protect their plant assets.

This document describes the role of integrated solutions in enhancing total safety. An overview introduces General Monitors' vision of being a total solution provider and the approach to fulfilling such vision through a broad range of detection technologies. The next section describes the physical principles behind ultrasonic gas leak detection, infrared gas cloud imaging, and conventional gas detection methods; strengths and weaknesses of each are covered in detail. Having reviewed each technology individually, the next section addresses the combination of ultrasonic, gas cloud imaging,

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¹ Ultrasonic gas leak detection is sometimes also referred to as acoustic gas leak detection.

open path, and fixed point gas detection and explores their use through several application examples. A final section is devoted to detector selection. A decision tree and a selection matrix illustrate the key elements of each detection method, providing the reader with a quick reference for choosing a detector within the General Monitors family of products.

2.0 Overview

The modern industrial site is a complex environment for safety monitoring. The topology of the land, construction, type of risk, placement, size, and shape of equipment can influence the choice of detection devices sized for particular applications. Power generation stations, for example, can employ several varieties of gas monitoring equipment depending on temperature and selectivity requirements.

Variety of gas detection equipment is often prompted by changes in gas detection technology. So that as new detection methods replace old ones, several “generations” of gas detection devices are deployed at a single facility. The use of different instruments may also reflect changing preferences or a desire to take advantage of innovative features in products newly introduced to the market. Implicit in this variety is the need to find solutions tailored for specific applications.

Advantages of standardization alone, like reduced specialized training or volume purchasing, would tend to tilt balances in favor of few product types. Detectors that could be used in several applications become the chosen few. Nevertheless, in a time of increased emphasis on safety, companies have discovered product versatility is not enough. Systems that use the same method of detection to give warning of any potential gas clouds expose monitored areas to risk. These instruments share common failure modes that can compromise safety. Were a device to fail to detect a gas release, others might follow in tandem. As a result, some of the best and most redundant safety measures can be defeated by weaknesses that allow a loss of containment to propagate undetected.

In order to mitigate the potential spread of hazardous events, General Monitors is recommending the use of *technology diversification*. The term “diversification” is commonly used in the fire, gas, and safety industry to describe the principle behind protection layers; whereby safety layers that don’t share common failures are designed to reduce the probability and severity of hazardous events². Similarly, technology diversification refers to the various means of detection that when layered reduce the likelihood that detectors will fail to detect a hazard. Just like no single layer, however good, can eliminate risks inherent in a process, no single detection technology can reduce the risk of failure to detect loss of containment to a vanishingly small number. Nevertheless, an array of detectors that integrates diverse sensing technologies can make common cause failures more unlikely.

An effective approach for technology diversity is to use the human sensory model. Like a person who is able to assess danger through his senses, fire and gas systems that rely on a combination of ultrasonic, optical, and conventional detection can provide a better picture of overall plant safety. The picture is richer because the system does not rely on a single point response alone, but can undertake, based on the response of the end devices, an appropriate action based on the type and magnitude of a hazard. Two or more detectors that use different sensing technologies can complement one another by suppressing the disadvantages of each or can reinforce detection by providing safeguards in case one were not to detect gas.

This is not to say that technology diversification alone can reduce all risks. As a working group for the ISA Standards Panel 84 observes, “system effectiveness’...is dependent on a number of factors associated with design, installation, site-specific operating conditions, and maintenance”³. In particular, reliability, number, and location of sensors play essential roles in ensuring fire and gas systems function

² Paul Gruhn and Harry L. Cheddie, *Safety Instrumented Systems: Design, Analysis and Justification*, Second edition, Research Triangle Park, North Carolina, ISA Press, 2006.

³ Fire and Gas Systems Technical Report, ISA Standards Panel 84.

properly under demand conditions. Technology diversity enhances effectiveness, the ability to respond as intended to a hazard, by providing adequate detection for a wide range of potential process failures.

Advances in ultrasonic gas leak detection, remote gas cloud imaging, coupled with improvements in optical path monitoring and point gas detectors, allow users to apply this sensory model. As companies deploy these integrated technology systems, it is worth reviewing the different types of detectors, since a clear understanding of their strengths and weaknesses helps determine the design of systems that integrate sensing technologies.

3.0 Detection Technologies

3.1. Conventional Gas Detection

Conventional gas detection refers to those types of detectors that through extensive use are considered the norm in many applications. Far from ordinary or unexceptional, conventional gas detection methods have proven to solve some of the industry's most troublesome problems. In many instances their combination of performance, versatility, and cost is unmatched, as evidenced by their widespread deployment in refineries, chemical plants, compressor stations, and other facilities. Conventional detection comprise catalytic (or electrocatalytic), electrochemical cell, solid state, and infrared gas detection technologies. They include point detection as well as area and perimeter monitoring devices. Catalytic detectors are commonly employed as point instruments (though they can cover large areas if installed in a grid system), while IR detectors can be either point or perimeter monitors.

Catalytic detectors employ catalytic combustion to measure combustible gases in air at fine concentrations. As combustible gas oxidizes in the presence of a catalyst, it produces heat and the sensor converts the temperature rise to a change in electrical resistance, which is linearly proportional to gas concentration. A standard Wheatstone bridge circuit transforms the raw temperature change into a sensor signal.

The simplicity of catalytic detector design belies several strengths that have made them a mainstay of fire and gas safety applications for over 50 years. Catalytic detectors are robust, economical, reliable, and self-compensating to changes in the environment such as humidity, pressure, and temperature. They are also easy to install, calibrate, and use. Once in place, the detectors can operate for years with minimum maintenance, requiring only periodic gas calibrations to verify operation. Because the catalytic combustion reaction is non-selective, catalytic detectors can be used for monitoring several target gases across a wide range of applications. Such flexibility is virtually unmatched by other types of detection means.

Advances in material processing have yielded measurable improvements in the tolerance of catalytic detectors to high temperatures. Some detectors produced by General Monitors, for example, can operate continuously at 200°C. These devices are well suited for monitoring combustible gases or vapors in turbines, compressor stations, engine rooms, and other applications.

Despite the many strengths of catalytic gas sensing, the technology has its limitations. A main weakness is that catalytic gas detectors require oxygen for detection. Since the catalysis requires efficient oxidation of hydrocarbon gas, oxygen levels affect oxidation efficiency, and as a result, sensor accuracy. Another limitation is the possibility the catalyst may be poisoned or become inactive due to exposure to silicones, chlorine, heavy metals, or sulfur compounds. Agents such as halogen compounds will inhibit the catalytic sensor and curtail its ability to function. Entrapment of dust in the flame arrestor

or exposure to heavy oils and greases can also impair the sensor. Figure 1 provides a summary of main advantages and disadvantages of catalytic detectors.

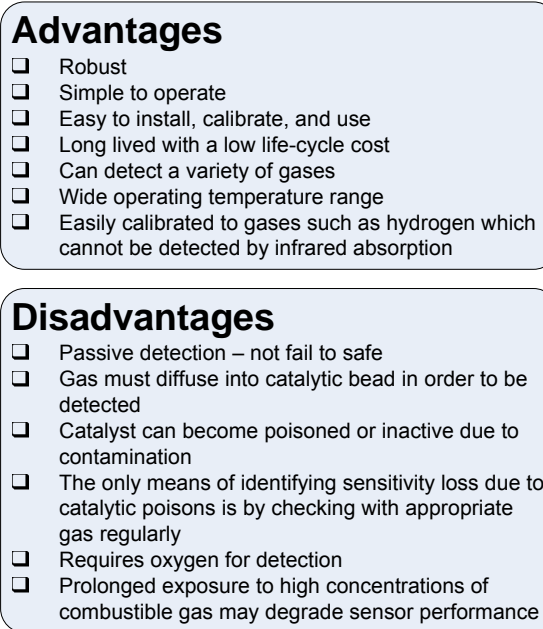


Figure 1. Advantages and Disadvantages of Catalytic and Electrocatalytic Gas Detection.

Like catalytic detectors, electrochemical cell devices are some of the most widely applied detector technologies in the market today. They respond quickly to a variety of gases like carbon monoxide, hydrogen sulfide, and hydrogen chloride and are highly accurate. Current designs have all but eliminated the propensity of earlier detectors to become obstructed by airborne contaminants such as dust. See Figure 2 for a summary of key advantages and limitations of electrochemical detection.

Electrochemical detectors can be considered as transducers that convert gas concentration to an electrical current. Molecules of the target gas react on the sensing electrode and generate a current. The amount of gas present in the atmosphere is linearly proportional to the current generated by the cell.

Most electrochemical cells consist of three electrodes – sensing, counter, and reference – sealed into a housing containing a small volume of conductive solution (electrolyte). A controlling circuit potentiostat maintains a stable electrochemical potential between the sensing and reference electrodes. For a gas to come into contact with the sensing electrode it must first pass through a capillary diffusion barrier before it reaches the electrode surfaces. This hydrophobic barrier allows the proper amount of gas to react at the sensing electrode, while preventing the electrolyte solution from leaking out of the housing.

A reference electrode anchors the sensing electrode potential to ensure that is always stable and constant^{4,5}. Without the aid of the reference electrode, the sensor output

⁴ Hazardous Gas Monitors, Chapter 2, "Electrochemical Sensors."

⁵ Alphasense Application Note AAN 104, "How Electrochemical Gas Sensors Work."

would drift and performance deteriorate over time. This is because the working electrode that is catalyzing the oxidation (or reduction) of the target gas starts to polarize away from the optimum working potential. After the electrode has drifted sufficiently away from a stable potential, its capacity to catalyze the reaction is greatly impaired. A reference electrode with stable potential keeps the working electrode at its optimum electrochemical potential, enhances the speed of response of the sensor, and maintains the sensor at constant sensitivity and good linearity.

Because the electrodes act as a catalyst for the electrochemical reaction, they are not consumed by exposure to the target gas⁶. Rather, they speed the electrochemical reaction while remaining unaffected by the conversion of gas molecules into other species. (Nevertheless, small amounts of impurity gases and other species can poison the electrodes over time, reducing their activity and hence the detector sensitivity.)

Most of the drawbacks of electrochemical gas detection stem from the factors affecting the chemical reaction. The speed of reaction, for example, decreases with decreasing temperature. As a result, the temperature range of electrochemical cells tends to be narrower than those of other types of detectors. Similarly, electrochemical cells have a working pressure range of 10% within atmospheric pressure. Pressures outside this range affect the accuracy of the gas measurement.

Advantages

- Fast response
- High accuracy
- Versatile - responds to wide range of toxic gases
- Low power consumption

Disadvantages

- Limited at low ambient temperatures ($\leq -40^{\circ}\text{C}$)
- Unsuitable for use in dry environments ($< 15\% \text{ RH}$) over several months
- Operates in a narrow range of pressures ($1 \pm 0.1 \text{ atm}$)
- Not fail safe

Figure 2. Advantages and Disadvantages of Electrochemical Cell Sensors.

Another technology of toxic gas detection is solid state sensing. Solid state sensors consist of one or more metal oxides from the transition metals, such as tin oxide or tungsten oxide. These metal oxides are prepared and processed into a paste to form thick films or deposited as thin films through vacuum deposition onto a silica or aluminum oxide substrate. This latter process is similar to that used for fabricating semiconductors; hence the name metal oxide semiconductor (MOS) for which they are commonly known.

A heating element is used to regulate the sensor temperature, since the sensors exhibit different gas response characteristics at different temperature ranges. This heating element can be a platinum or platinum alloy wire, a resistive metal oxide, or a thin layer of deposited platinum.

⁶ An exception is electrochemical cell sensors for oxygen deficiency. For these devices, the lead electrode takes part in the reaction and is consumed over time.

When exposed to gas, gas molecules react on the metal oxide surface and dissociate into charged ions or complexes that alter the resistance of the film⁷. This change is dependent on the physical properties of the metal oxide film as well as the morphology and geometric characteristics of the sensing layer and the temperature at which the reaction takes place. A heater circuit raises the temperature of the film to a range that yields optimal sensitivity and response time to the gas to be detected. Additionally, a pair of biased electrodes is imbedded into the metal oxide to measure the change in resistance. This variation of the sensor that results from the interaction of the gas molecules with the film is measured as a signal and is completely reversible. This signal is then converted to a gas concentration.

Solid state sensors offer many advantages over other types of sensing technologies (see Figure 3). They are versatile and long lived. Typical semiconductor sensors can detect a wide variety of gases and can be used in many different applications. Furthermore, they can do so over 10 years, making their life expectancy among the longest of any detection technology available. Solid state sensors are also robust. They have high tolerance to extreme ambient conditions and corrosive environments. Since a heater regulates the temperature of the MOS film, the response of solid state sensors is unaffected by ambient temperatures. Indeed, these sensors can operate at ambient temperatures as high as 90°C. High tolerance also extends to humidity. Unlike electrochemical cells, semiconductor sensors can operate over several years in low humidity environments. Operating ranges for humidity commonly span 5% to 95% RH, non-condensing.

One of the advantages of solid state sensors is their capacity to detect low and high concentrations of gas⁸. This makes them uniquely suited for monitoring simultaneously toxic and explosive concentrations of the same gas. Acetone, benzene, and ethanol are three substances that semiconductor sensors can detect in a full scale at 100 ppm or in an LEL range. Such versatility makes solid state sensors an ideal choice in many installations, where a single type of detector is required for many applications.

Solid state sensors, however, have many disadvantages. A weakness of this detection technology is poor selectivity toward a gas to be detected or high cross-sensitivity toward other gases⁹. Many solid state sensors, for instance, are affected by methyl mercaptan, chlorine gas, NO_x compounds, and other interference gases which alter the reading of the gas to be detected. This makes the sensor output unreliable and could lead the instrument to trigger false alarms. To overcome this limitation, many developers of solid state sensors have equipped them with filters to block cross-contaminants or developed sophisticated algorithms that take into account the cross-response of various gases. General Monitors, in particular, has developed a line of hydrogen sulfide sensors that are highly selective toward the monitored gas. Such high selectivity is achieved by a combination of the fabrication process and composition of the thin MOS film.

Another drawback of solid state sensors is their high power consumption. As noted earlier, these devices rely on a heater to regulate the temperature of the MOS film. High temperatures are required because the gas response (or gas sensitivity) of metal oxide films reach a maximum between 100 and 500°C, depending on the composition of the

⁷ Gas detection reactions may employ different mechanisms, including chemisorption and redox reactions. These reactions vary depending on the type on the composition of the MOS film and the gas. Ref. G. Korotcenkov, "Gas Response Control Through Structural and Chemical Modification of Metal Oxide Films: State of Art and Approaches, *Sensors and Actuators B*, 2005, Vol. 107, 209 – 232.

⁸ Hazardous Gas Monitors, Chapter 4, "Solid-State Gas Sensors."

⁹ G. Korotcenkov, "Gas Response Control Through Structural and Chemical Modification of Metal Oxide Films: State of Art and Approaches, *Sensors and Actuators B*, 2005, Vol. 107, 209 – 232.

film and the adsorption and desorption characteristics of the gas on the metal oxide surface. The penalty for such high temperature is the need for a large and constant supply of energy. Typical specifications for power consumption are about 1 W.

Advantages

- Robust
- Versatile – able to detect broad range of gases
- Wide operating temperature range
- Resistant to corrosive environments and low humidity
- Long operating life (2 – 10 years)

Disadvantages

- Commonly not selective (although some devices have overcome this limitation)
- High power consumption
- Not fail safe

Figure 3. Advantages and Disadvantages of Solid State Sensors.

Infrared gas detectors have been in use for almost as long as catalytic detectors. Such instruments use two wavelengths, one at the gas absorbing wavelength and the other at a wavelength not absorbed by the gas; neither wavelength is absorbed by other common atmospheric constituents such as water vapor, nitrogen, oxygen, or carbon dioxide. The IR hydrocarbon gas detector can be classified into point detectors and open path detectors.

In the point IR detector, the concentration of hydrocarbon gas is measured via the infrared absorption of an optical beam known as the active beam. A second optical beam, known as the reference, follows the same optical path as the active but contains radiation at a wavelength not absorbed by the gas.

In open path IR gas detectors, the sampling path of the IR beam is expanded from less than 10 centimeters, typical of point IR detectors, to greater than 100 meters. These devices can use a retro-reflector or separate IR transmitters and receivers housed in different enclosures. Open path IR detectors offer many of the same advantages of point IR detectors such as immunity to poisons, high sensitivity leak detection, low maintenance, fail-to-safe operation, and easy installation.

Hydrocarbon sensors based on infrared (IR) absorption are not subject to the same limitations of catalytic bead detectors. They provide for fail-to-safe operation since optical sensing is an active technology, which continuously monitors for sensor faults and conveys them to the user. This is achieved through the use of the second or reference wavelength. Since no chemical reaction is required for operation, IR detectors are also immune to poisoning, resistant to corrosion, can operate in oxygen deficient or oxygen rich atmospheres, and have no reduction in sensor life from repeated exposure to gas. As a result, they tend to have long lives and greater stability over time. Further, IR detectors require no routine calibration.

One particular advantage of open path detectors is that they are able to cover large open areas, along a line of several potential leak sources such as a row of valves or pumps and also for perimeter monitoring of leaks. A mirror can also be used to deflect the optical beam around a corner to the receiver.

Despite their reliability and low maintenance, IR detectors can only detect gases that are strongly absorbent in the infrared spectrum. Additionally, IR detectors require large sample volumes to detect the presence of gas, and consequently, may not respond to a leak if the gas does not accumulate in the sampling chamber. Finally, the detectors are limited to a comparatively narrow range of ambient conditions. Dusty environments, high humidity, and high temperature can cause performance to degrade over time, leading to higher maintenance costs.

A list of strengths and limiting factors of infrared gas detectors is summarized in Figure 4.

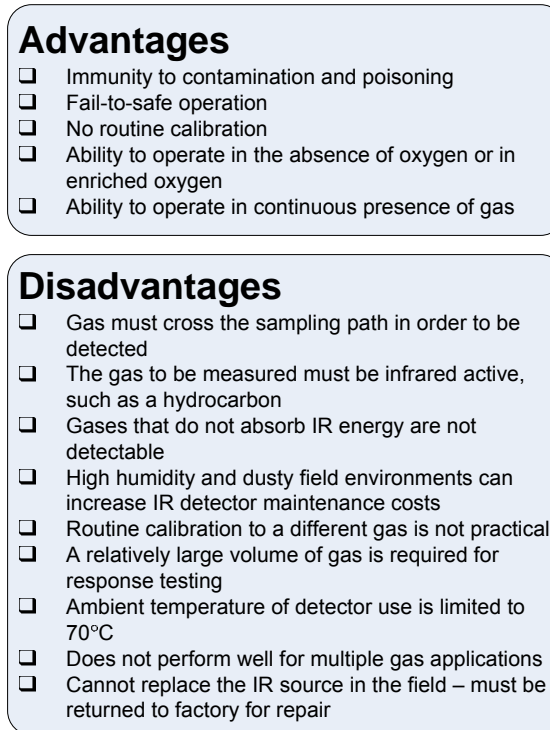


Figure 4. Advantages and Disadvantages of Infrared Gas Detection.

3.2. Ultrasonic Gas Leak Detection

Acoustic monitoring techniques use ultrasonic sensors to detect leaks based on changes in the background noise pattern. These sensors respond to the sound generated by escaping gas at ultrasonic frequencies. The ultrasonic sound level is directly proportional to the mass flow rate (leak rate) at a given distance. The leak rate in turn is mainly dependent on the size of the leak and the gas pressure.

What makes airborne ultrasound effective at detecting escaping gas? Most gas leaks – as well as operating mechanical equipment and electrical emissions – produce a broad range of sound that span from the audible to the ultrasonic range (approx. 20 Hz – 10 MHz). The ultrasonic range itself ranges from 25 kHz to 10 MHz. Ultrasound generates high energy, short wave signals that are directional and localized. As waves propagate, they segregate according to wavelength and speed, and are thus, readily discerned from ambient noise. Ultrasonic gas leak detectors respond to deviations from this normal or baseline condition to produce an alarm.

Unlike other detection technologies, ultrasonic gas leak detection does not measure gas concentration (ex. %LEL or ppm) or a concentration over a sampling distance (ex. LEL-m or ppm-m). Rather, it defines gas leaks in terms of the sound pressure level (SPL). In general, the greater the leak rate, the larger the sound pressure level emitted by the escaping gas.

Leak rates can be divided into three categories according to dispersion models employed in the oil and gas industry¹⁰:

Minor leak	< 0.1 kg/s
Significant leak	0.1 – 2.0 kg/s
Major leak	> 2.0 kg/s

These categories have been defined based on the speed of a gas cloud to accumulate into an explosive gas concentration. According to the above categorization, the performance standard of ultrasonic gas leak detectors for typical applications is based on gas leaks of 0.1 kg/s. For reference, a methane leak of this flow rate can be generated with gas pressurized to 650 psi (45 bar) and expelled through a hole measuring 4 mm in diameter. At 0.1 kg/s in average background noise conditions the ultrasonic gas leak detector detects hydrocarbon leaks in a radius of 8 – 12 m.

For special applications the performance standard of the ultrasonic gas leak detectors may be changed in order to detect even smaller leaks. This is possible without increasing the risk of false alarms. For example, an ultrasonic gas leak detector can respond to a leak rate of 0.03 kg/s if the detection coverage is decreased to 4 – 8 m.

Ultrasonic noise, of course, can be generated by sources other than streams of jetting gas. Compressors, turbines, large fans, electric motors, for example, produce high levels of sound, which include frequencies in the ultrasonic range that can be detected by ultrasonic gas leak devices. In order to enhance immunity to these potential false signals, ultrasonic gas leak detectors are equipped with high pass electronic filters that screen frequencies from many man-made and natural sources. An alarm trigger level for the ultrasonic gas leak detector is set at least 6 dB above the ultrasonic background noise. Such margin reduces the likelihood that fluctuations in background noise cause the detector to alarm. Lastly, detectors are supplied with a built-in delay function that can be adjusted by users to screen controlled releases of pressurized air at a facility. Most air releases last a few seconds, whereas the ultrasound emitted from a gas leak lasts much longer. A practical example of the difference between audible and ultrasonic sound levels emitted from machinery can be found in a survey performed on a platform in the North Sea¹¹. A test installation was set up next to a turbo expander unit and sound measurements were taken. The audible (20Hz – 25 kHz) sound level was 100 dB, but the ultrasonic level (> 25 kHz) was less than 78 dB. This resulted in setting the trigger level of the ultrasonic gas leak detector at 84 dB with a delay time of 15 seconds. These settings proved to be sufficient to mask out the ultrasonic sound levels and prevent spurious alarms.

The advantages of the system include instant detection of pressurized gas leaks and imperviousness to changes in wind direction or gas dilution. Ultrasonic detection applies

¹⁰ Health and Safety Executive (HSE) Report, *OSD Hydrocarbon Release Reduction Campaign, Report on the Hydrocarbon Release Investigation Project ~ 1/4/2000 to 31/3/2001*, 2001.

¹¹ Gregory A. Neethling and Martin T. Olesen (Innova AirTech Instruments), Nitrogen Leak Tests on SLEIPNER A and SLEIPNER T.

to all types of gas, whether combustible, toxic, or inert, and it is thus, quite versatile on many applications.

Another advantage of ultrasonic gas leak detectors is that their performance can be verified with live gas leaks during commissioning. Using an inert gas, operators can carry out simulations of gas releases of a known leak rate and test the response of the detectors in potential locations.

Despite these advantages, the technology is unable to detect low pressure leaks (< 10 bar or 145 psi) that do not produce acoustic emissions at levels substantially higher than the background noise. Attempts to detect small leaks can be accomplished but it requires that the detector is placed closer to potential leak sources. Otherwise it may result in false alarms.

It should also be noted that the correct positioning of the ultrasonic gas leak detectors in the gas facility is important to ensure optimal performance. As a result, qualified personnel should be consulted during the implementation of these detectors. Gassonic or General Monitors have trained and experienced engineers, who can assist facility managers in the survey, installation, and implementation phases of these detectors.

Advantages

- Instant detection of pressurized gas leaks
- Versatile – detects pressurized leaks regardless of type of gas
- Not influenced by fog, heavy rain, or other ambient conditions
- Minimal maintenance and no consumable parts
- Robust, fail safe operation
- Not sensitive to changing wind direction and gas dilution

Disadvantages

- Not suitable for low pressure leaks
- Under certain conditions affected by man-made or natural ultrasonic sources
- Background noise levels need to be estimated prior to installation
- Unable to determine concentration of gas

Figure 5. Advantages and Disadvantages of Ultrasonic Gas Leak Detection.

3.3. IR Gas Cloud Imaging

IR gas cloud imaging is a comparatively new means of gas detection with potential for widespread application¹². Surveillance for large gas clouds in chemical installations, petrochemical plants, tank farms, and pipelines can greatly enhance safety, particularly when used in combination with other gas detection technologies. Gas imaging employs an absorption gas imaging technique in which a scene, either illuminated by infrared laser radiation or infrared radiation that emanates from the sun and other natural IR sources, is imaged using an infrared camera. Gas present in the imaged area that absorbs at the

¹² J. Hodgkinson and R. D. Pride, "Gas Leak Imaging," In *Business Briefing: Exploration & Production: The Oil & Gas Review 2005*, Issue 2.

laser wavelength or the wavelength of the IR radiation from the sun appear as dark clouds in the generated video image, which allows increased rapid identification of gas leaks.

IR gas cloud imaging is divided into active and passive detection. Active imaging uses different types of laser techniques such as lidar to detect gas clouds¹³. Infrared laser sources are necessarily intense and the lasers must be selected for a spectral line specific for the gas to be detected (ex. 1.651 microns for methane). Backscatter light is received by the detector to give a reading of the amount of light absorbed by the gas, and as a result, the concentration along the path of the beam. Like open path detectors, the technique is self-referencing in that it can adjust to changes in the level of reflected light without introducing systematic errors in the measurement.

Passive imaging is based upon a differential imaging radiometry technique that resolves the image of a gas cloud based on the difference in temperature between the target gas and the background. The image of the field acting as an infrared complex source is resolved through a set of band pass filters. One filter known as a “reference” excludes transmission or absorption of IR radiation of the gas of interest. In contrast, “active” filters bracket the absorption or emission bands of the gas of interest at the exclusion of the broader IR spectrum. The difference in signals produced by the reference and active filters allows the instrument to produce an image of the gas. Such comparison of the contrast signals gives a quantitative measurement of gas concentration of the cloud along the line of sight, irrespective of the temperatures of the gas cloud or the background.

IR gas imaging offers several benefits that complement conventional and ultrasonic gas detection methods. First, IR gas imaging provides continuous wide area coverage per device, with typical spans of a few hundred meters to one or two kilometers. With fields of view of 15° to 60°, IR cameras can supervise entire sectors of a plant with detailed spatial resolution. Second, IR imaging conveys a rich stream of information: The dynamic representation of gas flux allows users to identify not only the specific zones from which gas plumes originate, but also the direction of dispersal, leading to efficient responses to hazardous events. Finally, imaging is immune to major sources of false alarms. Due to the characteristics of the absorption bands for most hydrocarbon gases, IR imaging is unaffected by the absorption of water, carbon dioxide, and other atmospheric constituents present in a plant atmosphere.

Like other detection techniques, IR gas imaging also has its drawbacks¹⁴. Passive gas imaging requires a temperature difference between the background and the gas in order to produce an image. As this difference becomes smaller, the detected gas loses contrast against surrounding objects and becomes difficult to visualize. Thus, passive imaging is not suited for low-pressure leaks, small fugitive leaks, and leaks from buried pipes for which large temperature differences are unusual. Active gas imaging is limited by distance and the strength of the laser to be used is restricted by eye safety regulations. Both techniques are affected by wind and humidity.

¹³ T. G. McRae and T. G. Kulp, “Backscatter Absorption Gas Imaging: A New Technique for Gas Visualization,” *Applied Optics*, 1993, Vol. 32, 4037 – 4050.

¹⁴ S.-A. Ljungberg and O. Jönsson, “Passive Gas Imaging – Preliminary Results from Gas Leak Simulations: A Field Study Performed During Real World Conditions,” *Thermosense XXIV* (2002).

Advantages

- ① Wide field of view and long detection range
- ① Requires no gas calibration in the field
- ① Highly immune to false alarm sources
- ① Detection of multiple gases at the same time

Disadvantages

- ① Has difficulty detecting gases when the contrast with the background is poor
- ① Heavy fog and rain attenuate detection range
- ① Only a gross leak detector (large leaks), not a small concentration detector

Figure 6. Advantages and Disadvantages of IR Gas Cloud Imaging.

4.0 Integration of Detection Technologies

Conventional, ultrasonic, and IR gas imaging are powerful detection technologies that, when properly used, allow fire and gas systems to mitigate the risks of hazards from propagating. Each has its own advantages and disadvantages depending on application specific requirements. Combined, they can be a formidable defense against developing hazards. The key to realizing this potential is understanding how these detector technologies complement one another.

Figure 1 – Figure 6 show the advantages and disadvantages of several types of detection technologies. As evident from these summaries, reliable application of these detector types depends on a system that pairs the detectors and sampling techniques to the target gas and ambient conditions of the monitored area. It is important to recognize that no single detection technology can provide the sensitivity and response time required for every gas.

Devices operate over different monitoring distances (Figure 7). Catalytic (or electrocatalytic) detectors and fixed point IR detectors are single point devices. Experience shows these detectors operate best at a monitoring radius of 0.5 to 2 meters. As a result, they are commonly placed near potential sources of gas leaks. Ultrasonic gas leak detectors, as opposed to point detectors, protect larger areas. While monitoring radii varies according to the required sensitivity, the devices have a radial coverage of about 452 m² or 12 meter radius. Open path IR detectors and IR gas cloud imaging cameras offer some of the longest monitoring distances. Open path IR detectors, for example, typically have sampling paths from 10 to 100 meters, while IR gas imaging cameras can cover spans from 100 to 2,000 meters.

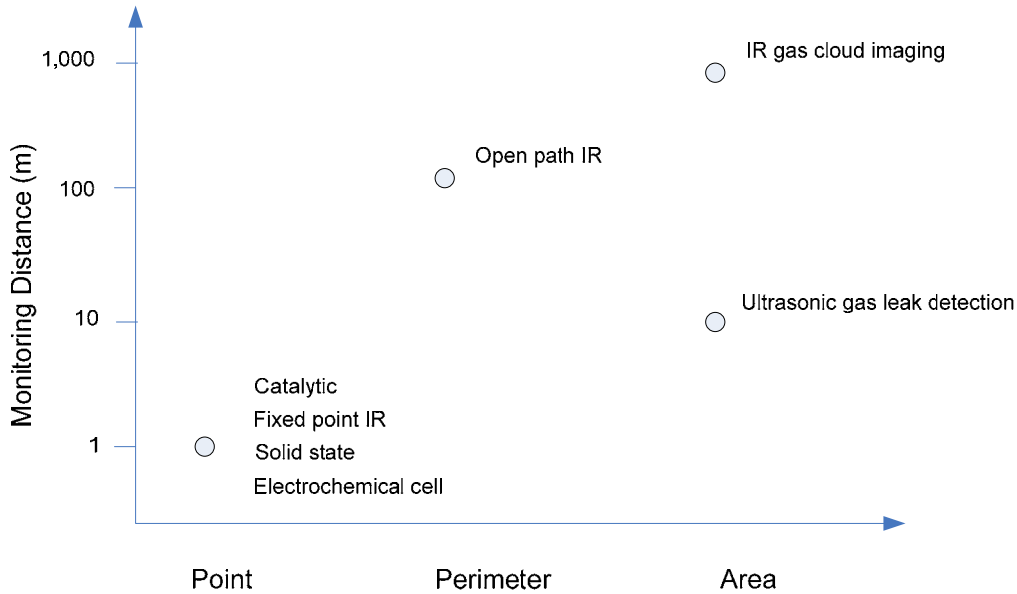


Figure 7. Approximate Detection Ranges of Point, Area, and Perimeter Detectors.

A human sensory model applied to fire and gas safety suggests detection technologies associated with the classical senses can be combined to provide superior protection than each technology alone. Devices that rely on ultrasonic, optics, or mass transport to trace gas are independent, since their methods of operation are based on different physical principles. Sound propagation, emission or absorption of light, or an exothermic chemical reaction can inform the presence of a gas under the right conditions but share few common elements; and as a result, few common failures. Table 1 shows a list of classical human senses and gas detection technologies that bear similarities to them.

Sense	Detection Technologies
Sight	Gas cloud imaging, UV/IR enabled flame detection
Smell	Fixed point IR gas detection, open path detection, catalytic, metal oxide semiconductor, electrochemical cell
Hearing	Ultrasonic gas leak detection

Table 1. Detection Technologies Classified According to Human Sensory Model.

5.0 Application Examples

One illustration of the human sensory model is presented in a two-stage hydrocracking operation (Figure 8). During hydrocracking, heavy aromatic feedstock is converted into lighter hydrocarbons under high pressures (6,900 – 13,700 kPa; 1,000 – 2,000 psi) and temperatures (400 – 816°C; 750 – 1,500°F) in the presence of hydrogen and special catalysts. Because of the high pressures and temperatures, there is potential for exposure to hydrocarbon gas and vapor emissions and hydrogen and hydrogen sulfide gas due to high pressure leaks. Large quantities of carbon monoxide may also be released during catalyst regeneration. In order to reduce the likelihood of hazardous events, ultrasonic gas leak detectors are installed near the two hydrocracker reactors and the hydrogen separator, around pumps, flanges, and valves. An open path detector provides perimeter monitoring across the tank, while the fractionator is protected by fixed point IR or catalytic detectors. For supervision of the distillation column and the storage tank for light end gas mixtures, a wide area monitoring system is developed with an IR imaging

camera. The monitoring scheme not only covers known gas leak sources, but also those that are difficult to identify due to the size and layout of the site.

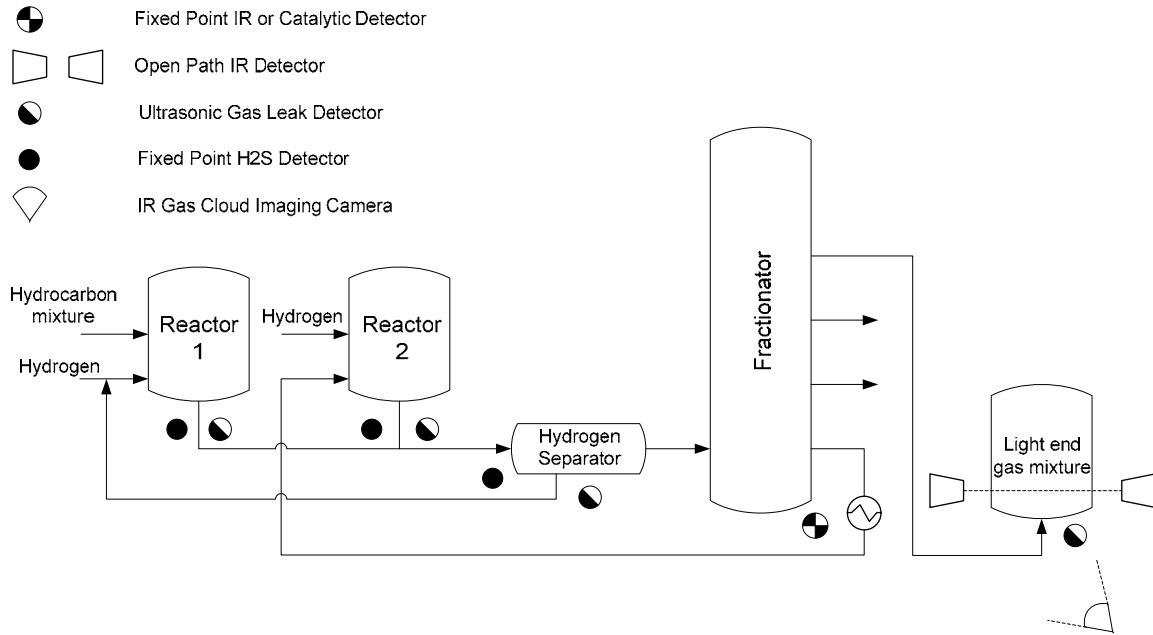


Figure 8. Schematic of Detector Placement in Section of Two Stage Hydrocracking Process.

The hydrodealkylation (HDA) of toluene to produce benzene at a chemical processing plant provides another illustration of the integration of detection technologies. A section of the HDA process is shown in Figure 9. A recycle column separates toluene from unwanted diphenyl, while benzene, and methane, – separated earlier – are stored in tanks. As with the previous example, fixed point or catalytic detectors are placed near pumps, valves, and flanges. Ultrasonic detectors are also placed close to the methane storage tank, as methane is lighter than air and may not accumulate. The ultrasonic detection devices act as an extra line of defense should small leaks erupt into large fluxes of gas. Overlooking the entire field, an IR imaging camera provides protection against the release of large methane clouds.

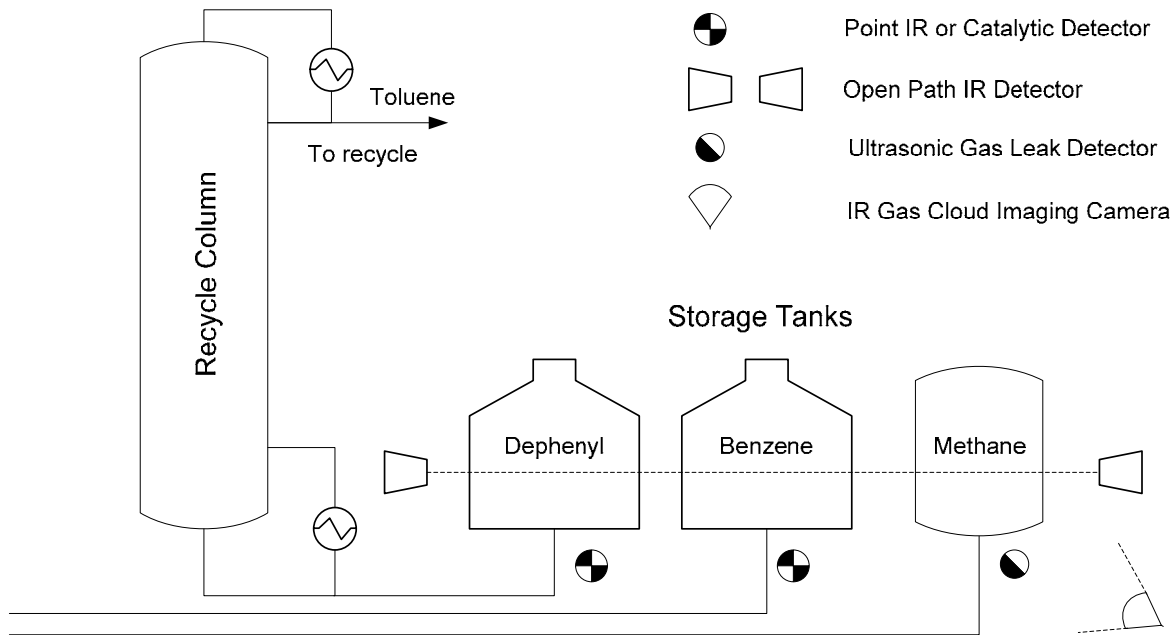


Figure 9. Installation of Detectors in Segment of HDA Process.

A third example of technology integration comes from the gas industry. Natural gas production facilities engage in the extraction of natural gas, which is obtained from natural wells. Natural gas pumped from a high pressure well is first sent through inlet separators to remove water, heavy hydrocarbons, brine, and particulate matter from the incoming natural gas. Natural gasoline, butane, and propane are usually present in the gas. The liquid and contaminants are stored in condensate tanks. The natural gas is sent to a compressor system to transport the gas through a pipeline. A sketch of a natural gas production facility is shown in Figure 10.

Potential sources of gas leaks at natural gas production facilities include wellheads, manifolds, separators, compressor engines, and the pipes and storage vessels for hydrocarbon condensate. In this instance, ultrasonic gas leak detectors are placed close to each of these units in the process. An open path detector provides further protection by monitoring the perimeter of the facility. Although most of the vessels in the plant are pressurized, processing units like the fuel gas skid and the storage tanks are not maintained at high pressure. For these, point IR or catalytic detectors are excellent choices for monitoring natural gas leaks. Finally, the facility as a whole is supervised with an IR gas cloud imaging camera.

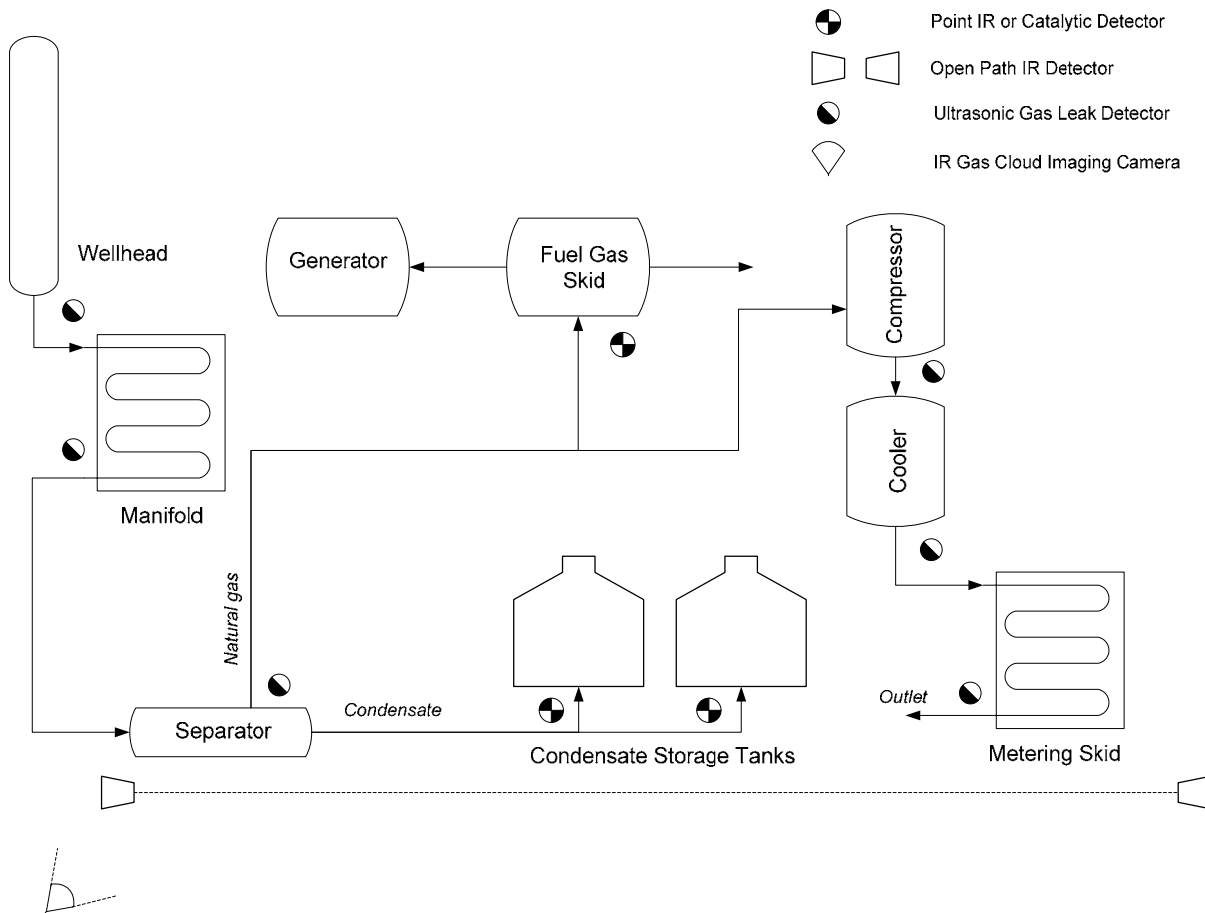


Figure 10. Schematic of Natural Gas Production Process.

Whether at a series of tanks near a rail terminal, a chemical processing plant, or a natural gas facility, the examples above show the human sensory model is a useful approach for applying technology diversification. The model is consistent with a philosophy of multiple, diverse, and independent safety layers. Sites are better protected since technology integration makes it harder for initiating events to culminate into hazardous events. Despite the benefits of combining different detection technologies, the effectiveness of the model depends on an adequate choice of detectors.

6.0 Detector Selection

Choosing the right detectors is an important part of mitigating incipient hazards. Adequate selection is based on a number of inputs: physical properties of target gases, ambient conditions, required sensitivity, maintenance cycle, and method of operations among others. Given the large number of variables, it is tempting to either oversimplify the selection process to a few rules of thumb or to treat it as something requiring such expertise only a few company employees or consultants can perform. The solution may lie somewhere in-between.

A comparison of detectors across several categories is presented in Table 2. The table shows that under many circumstances two or more detectors can fulfill the same requirements. In such cases, total cost of the device across its life-cycle may drive final selection.

In general, the decision diagram and table are useful guides for choosing a gas detector from General Monitors. There are important factors to consider when selecting the proper device – possibly prompting

further research into the application field environment or revisiting assumptions. A quick decision, based on a first pass glance at the diagram or table, may not always yield the correct detector choice. But a selection that follows careful review of requirements *after* perusal of these tools is likely to lead to the selection of detectors that best meet targets for optimal performance, safety, reliability, and cost.

Product Categories	Ultrasonic Detection			Combustibles					Hydrogen Sulfide				Toxics			
	Gassonic MM0100	Gassonic Surveyor	Gassonic Observer	Second Sight® TC	S4000C	S4100C	IR2100	IR5000	S4000T	S4100T	TS4000	TS400	TS4000	TS400	TS420	IR7000
Products																
Gas Characteristics																
Pressurized gas	X	X	X	X									X	X	X	X
Unpressurized gas				X	X	X	X	X	X	X	X	X	X	X	X	X
Toxic gas	X	X	X										X	X	X	X
Combustible gas	X	X	X	X	X	X	X	X								
Hydrogen	X	X	X		X	X										
Hydrogen sulfide	X	X	X						X	X	X	X				
Carbon dioxide	X	X	X													X
Oxygen (deficiency)															X	
High concentration	X	X	X	X	X	X	X	X								X
Low concentration	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Characteristics of Target Area of Protection																
Large coverage area	X	X	X	X												
Small coverage area (point)					X	X	X		X	X	X	X	X	X	X	X
Perimeter								X								
Ambient Factors																
High temperature (200 deg C)					X	X										
High humidity, corrosive field environments	X	X	X		X	X			X	X	X	X	X	X	X	X
High wind (> 50 km/h)	X	X	X	X	X*	X*			X*	X*	X*	X*	X*	X*	X*	
Low oxygen levels	X	X	X	X			X	X	X	X	X	X	X	X	X	X
Presence of contaminants**	X	X	X	X			X	X								X
Detector Characteristics																
Sensor Life Indicator					X	X			X	X	X		X			
Analog Output		X	X		X	X	X	X	X	X	X	X	X	X	X	X
Modbus		X	X		X	X	X	X	X	X	X	X	X	X	X	X
Full fail safe operation			X				X	X								

* Applicable only with the use of a sinter or dust guard

** Methyl mercaptan, ethyl mercaptan, chlorine, nitrogen, silicones

Table 2. Selection Table of General Monitors Gas Detectors.

7.0 Conclusion

Technology diversification can be achieved with detection methods readily available today. These comprise conventional gas detection (catalytic, point IR, open path IR, electrochemical, MOS), ultrasonic, and gas cloud imaging. Many of these technologies have long pedigrees and are commonly used in the oil and gas and chemical process industries. Others, like ultrasonic monitoring and IR gas cloud imaging, have gained wider acceptance in industrial markets in recent years and each has advantages and disadvantages. No one detection method is an encompassing answer to all gas detection. Indeed, successful diversification depends on matching the detection technologies so that the limitations of one are offset by the strengths of others.

Diversity of technology shares many common elements with the concept of diversity as applied to Safety Instrumented Systems (SIS). Just as protective layers of the SIS methodology reduce the risk of hazard propagation, sensing technologies that complement one another make it harder for a combination of events to result in an undetected gas leak. In addition, the performance of sensing technologies can be assessed and integrated into hazard and risk analyses, providing a more accurate picture of fire and gas system effectiveness.

Integration of diverse detection technologies is not without its risks. Used improperly it can lead to poor results. Diversity of detection technologies, for instance, cannot compensate for improper detector selection in the first place. When choosing a gas detection system, there are specific factors to consider including physical gas properties, concentrations, target coverage, ambient conditions, and regulatory compliance. An ultrasonic gas leak detector and an open path IR detector are ineffective at responding to gas if each is unsuitable to detect the hazard. A low pressure release of a gas that is not IR active will not be detected by either of these instruments. Similarly, the benefits of diversity are compromised if diversity is mistaken for redundancy. True enough, redundancy plays an important role in plant safety and can prevent an initiating event from propagating if a detector fails to function as intended. In such case, a second or third detector can compensate for the failure of the first. But multiple detectors subject to the same limitations may not detect gas at all. Two perfectly operational point detectors are not a match for a high pressure gas leak that jets downwind from the detection equipment.

A useful approach toward achieving meaningful diversification is to employ a model based on the classical human senses. Detection technologies that see, hear, and smell are inherently independent and complementary. Examples of hydrocracking and hydrodealkylation processes show how IR gas cloud imaging, ultrasonic, and conventional gas detectors can be used in combination to reduce the risk of potential hazards. Ultrasonic gas leak detectors protect high pressure gas processing facilities both offshore and onshore, compressor stations, and high pressure storage tanks, while conventional gas detectors provide coverage at critical points and perimeters in a grid system. Areas covered by ultrasonic gas leak and conventional detectors are in turn supervised by IR gas imaging cameras. Point detection, area monitoring, and IR imaging thus form a chain of defenses, each reinforcing the other to guard against the hazardous effects of a gas release.

The development of new detection technologies and advances in fire and gas safety methodologies have prompted a new thinking about the role of technology diversity in system effectiveness. Like adequate sensor coverage at a plant or proper functioning of component equipment, diversity of technology increases the likelihood the propagation of an accident sequence is halted and no hazard results. It does so by spreading the risk of detection failure across a larger number of sensing technologies; the greater the number of these independent and diverse technologies, in general, the greater their effectiveness toward safeguarding personnel, capital equipment, and the environment.

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