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Key Considerations When Designing a Gas Detection System…

When a plant decides to install a gas-detection system, any evaluation process should include the following five steps. Each is discussed below:

1. Understand the application
2. Identify potential danger points
3. Establish design goals
4. Determine gas characteristics
5. Profile the plant and potential release scenarios

1. Understand the application.

Before designing a detection system, the engineer must decide which gases the system should monitor. Legal requirements provide a good starting point for making this decision. Local and federal regulations, fire and building codes, and industry safety standards specify the use of gas detectors in certain types of facilities and for certain types of toxic and combustible gases. For example, in semiconductor- fabrication facilities, Uniform Fire Code (UFC) 5105.2.2 says: "[In semiconductor facilities] gas cabinets for [toxic and highly toxic] gases shall be provided with a

continuous gas detection system in accordance with 5103.5.3, regardless of whether dispensing occurs. Activation of the detection system shall automatically shut the valves on all hazardous-production material] gas lines from the cabinets and initiate an alarm to the emergency control station."

Similarly, in the U.S. Code of Federal Regulations, 49CFR 192.736 mandates the use of gas detectors in some natural gas-pipeline compressor stations: "...each compressor building in a [natural or other gas pipeline] compressor station must have a fixed gas-detection and alarm system, unless the building is constructed so that at least 50% of its upright side is permanently open; or located in an unattended field compressor station of 1,000 horsepower or less."

The local fire Marshall or a qualified safety engineer should be able to provide system designers with a comprehensive list of applicable regulations, codes and standards. Unfortunately, regulations, standards

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and codes, such as those shown in Table 1, only cover a small percentage of all applications in need of gas monitoring. In most cases, other criteria must also be used to decide which gases and equipment components to monitor. The most important consideration is the actual hazard posed by the gases. These hazards are driven by toxicity or explosion risk.

Since some toxic gases are more dangerous than others, engineers deciding what to monitor should evaluate the absolute toxicity of substances, based on factors such as LC_{50} (the median lethal concentration), short-term exposure limit (STEL), ceiling limit (the concentration that should not be exceeded), and IDLH (the concentration immediately dangerous to life and health). These factors are available from a variety of organizations, such as the U.S. Occupational Safety and Health Admin. (OSHA; Washington, D.C.), American Conference of Governmental

Industrial Hygienists (ACGIH; Cincinnati, Ohio) and National Inst. for Occupational Safety and Health (NIOSH; Cincinnati, Ohio) [2l. Physiological warning properties (such as odor threshold values) should also be considered. Substances with permissible exposure limits below their physiological warning levels (such as odor threshold values) should also be considered. Substances with permissible exposure limits below their physiological warning levels (such as arsine) are especially dangerous, since personnel will be unable to sense the hazard before a leak has begun to cause them harm [3]. It is also important to recognize that exposure limits and warning levels are only experimentally determined averages, and will vary somewhat across any group of people. System designers should therefore incorporate a wide margin of error in any decision based on these values. The primary hazard associated with handling flammable or combustible gases is the risk of explosion that could result from a leak or spill. As a rule of thumb, the lower the flashpoint or lower explosive limit (LEL) of a gas, the more important it is to monitor. System designers should install monitoring devices to detect leaks of any combustible and flammable substances whose flashpoint is below ambient temperatures, since these substances immediately give off vapors, which may be sufficient to form an ignitable mixture. Note that certain combustible gases are also toxic, with permissible exposure limits under their LELs.

Methanol, for example, has an STEL of about 250 ppm – well below its 6% (or 60,000-ppm) LEL. In areas where a leak could result in personnel exposure, these gases should generally be evaluated primarily as toxic hazards, rather than as explosion hazards. In some cases, even non-flammable or non-toxic gases (such as nitrogen) should be monitored. This is especially true when the potential exists for that gas to leak into an enclosed area. Such leakage would increase the risk of oxygen deficiency, which puts workers at risk of asphyxiation.

2. Identify potential danger points.

Site-specific danger points can be divided into two broad categories:

• Release points. Locations from which hazardous gas could be released.
• Receptor points. Locations where hazardous gases could pose a threat to personnel, property or equipment

In the case of flammable or combustible gases, the receptor point is specifically an ignition source – with no ignition, there is no threat to personnel, property, or equipment, except possibly through oxygen

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deprivation. In theory, all vessels, pipes and pieces of equipment containing hazardous substances, as well as all areas around these items, are potential danger points. In practice, however, it is generally prudent to focus on a smaller number of specific danger points to balance monitoring needs with capital and on- going maintenance costs. While most facilities have numerous release and receptor points, it is important to recognize that these two categories of dangers are not always located at the same site. For example, a potential release point may be located at an adjacent plant. To identify specific release points, the engineer should review all hazardous-area-classification drawings, which provide useful information on flammable- and combustible-gas danger points (e.g., they will indicate Class 1 areas, as defined by the National Electrical Code). Process-safety-management and risk-management plans can provide similar information for toxic gases handled onsite. Additional gas-release points and areas of potential gas buildup can be identified using process-and-instrumentation diagrams (P&IDs). Using such documents, the system designer should carefully evaluate the plant's gas-storage and inventory areas, as well as distribution, processing, ventilation, and waste/gas-treatment systems. Any transportation routes where gas or high-vapor-pressure liquids are transported (in trucks, railcars, cylinders and so on) should also be included in this evaluation.

In general, gas detectors used to monitor potential release points should be positioned close to the potential leak point, with consideration given to the likely mode of release. Common release points in process facilities include:

- Seals and flanges for pumps and compressors
- Valve-stem seals
- Expansion joints
- Gaskets
- Compression fittings
- Weld failures
- Loading and unloading areas
- Liquid- and gas-storage areas
- Sample points
- Battery rooms
- Runoff areas (such as sumps, oily water sewers and wastewater-treatment areas)
- Piping-distribution manifolds (such as valve-manifold boxes)
- Semiconductor tool processing and storage chambers

It is also a good idea to monitor certain locations where there is high potential for damage or injury to personnel – even if no specific release point exists nearby. These locations include areas where gases could potentially build up (e.g., cable vaults), as well as any areas where highly toxic or highly flammable combustible gases are stored, handled, transported or processed. Identifying receptor points should begin with a review of the facility's layout or floor plan, noting areas where personnel are likely to circulate or congregate on a regular basis (including evacuation and exit routes). P&IDs, as well as the plant's process-safety-management plan, can help determine potential ignition points. Gas detectors used to monitor receptor points should be positioned between release and receptor points. Common receptor points include:

- Analyzer shelters
- Facilities where plant personnel could be present

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- Switchgear shelters
- Internal combustion engine shelters
- Confined spaces
- Nearby communities and facilities

Facility-air intakes are also common locations for detectors monitoring receptor points in plants. While monitoring the air quality of the surrounding community is beyond the scope of this article, this type of detection is typically done at plant perimeters or in discharge stacks (e.g., by monitoring for scrubber break-through) [4]. Where leaks from surrounding plants are a concern, fence-line monitoring may be used to detect toxic and flammable or combustible gases coming into the plant [5,6]. Note that for fenceline monitoring, a signal from any one detection point provides a warning, but adds little additional information regarding the direction in which the gas is traveling. For this reason, fenceline monitoring systems typically use multiple detections in con- junction with a disperson-modeling program.

3. Establish design goals.

The purpose of all hazard-detection systems is to initiate a response based on an early warning of a potential problem. Once the potential danger points within a process plant have been identified, designers must decide how ”aggressive” the monitoring system should be.

In general, responses initiated by a gas-detection system follows a hierarchy of severity:

1. Notification or annunciation

2. Ventilation control

3. Process shutdown

4. Evacuation and emergency response

Typically, the desired severity of the response triggered by a gas-detection system determines the number of detectors needed, both for absolute measurement and for redundancy purposes. The severity of response depends on the danger posed by the potential leak and the amount of human intervention that is available or desirable.

For toxic gases, toxicity, as measured by the previously defined STEL, ceiling limit, or IDLH values, is the key factor determining the danger from a gas release. However, it is also important to consider other substances that may be present and any possible reaction by-products. For example, with adequate humidity, boron trifluoride (BF_3) will hydrolyze to hydrogen fluoride (HF), a slightly less harmful gas. Conversely, in some circumstances, reaction byproducts will be more toxic than the released gas.

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In areas containing high-value equipment or facilities, the chemical properties of the released gas should also be evaluated. Highly reactive gases, such as fluorine and HF, can cause significant property damage as well as bodilyharm. It is generally desirable to monitor these gases as close to the leak point as possible since they will quickly react with any surfaces they contact.

In some cases, little will be known or understood about some gases being monitored – this often occurs in the semi-conductor industry, where new process gases are continually being evaluated. In these situations, system designers should be as conservative as possible.

The problems caused by a flammable- or combustible-gas release generally come from the resulting fires and explosions, rather than from the gas leakage itself. For these problems to occur, the release must create a gas concentration greater than the LEL, which often occurs, and a source of ignition must be present. The timing of the ignition is quite important – immediate ignition typically results in a fire, while a delayed ignition allows for ignition of a fuel-air cloud, which typically results in a vapor-cloud explosion.

Since vapor-cloud explosions can result in more wide-ranging damage than fires, the potential loss from an explosion is a good measure of the danger from a flammable-combustible gas leak. The following four factors provide an indication of the potential damage from a vapor-cloud explosion:

1. Amount of confinement. In general, larger overpressure – and thus greater damage potential – results from explosions in confined areas than from explosions in unconfined areas

2. 2. Run-up distance. The more distance or area a flame front has to accelerate, the more damage it can cause. Experiments at the Christian Michelsen Institute in Norway have demonstrated that flame fronts need a run-up distance of about 18 ft to reach damaging speeds [7]. This reference provides additional guidance on detector spacing and positioning in critical areas. 3. Amount of congestion or obstacles. In general, small obstacles such as pipes, steel, structural steel, process equipment and so on promote turbulence in a burning vapor cloud, which increases over- pressure caused by an explosion and thereby increases the damage potential of the event. Note that an explosion can turn such obstacles into projectiles akin to shrapnel arid missiles, further threatening personnel and equipment.

4. Fuel quantity and mixing. The more fuel that is available and the better it is mixed with air, the more damage the flame front can cause. One researcher reports that a 220 lb ”minimum flammable mass” of flammable or combustible gas is required for a vapor-cloud explosion, and that overpressures that result in significant building damage (>0.2 bar) typically only occur when over 2,000 Ib is released [7]. The damage potential combined with the number of people potentially in the area and the value of property or equipment likely to be damaged indicates the total potential loss from an explosion. Note, however, that smaller releases can still result in fires with significant damage potential. In determining how much human intervention is desired, system designers should consider the consequences of not reacting quickly enough (e.g., the potential danger from a release), the cost of a false alarm and the availability of operators to monitor the instruments. Where rapid response is critical but false alarms are costly, many facilities use multiple detectors in a ”zoned” configuration, where all detectors in a pre-designated group must respond, or in a ”voting” configuration, where two out of three detectors in a group must respond. In remote facilities where human intervention is not possible, multiple detectors are often used to provide redundancy.

- Other factors to be considered during system design include:
- Margin of safety (the distance between leak points and receptors)

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- Plant safety policy
- Insurance requirements or incentives
- Regulatory and legal requirements or incentives

4. Determine gas characteristics.

The previous steps provide some guidance for engineers who are trying to develop a rough estimate of how many detectors are required and where they should be placed. The following evaluation of the physical characteristics of the substances being monitored enables engineers to refine their preliminary design outline.

Vapor density is a key criterion in positioning gas sensors. Heavier-than-air gases, including vapors from high vapor pressure liquids, tend to sink and flow in thermal layers along the ground, and will often accumulate in low places such as pits or ditches. Since they collect easily and are less likely to disperse, more sensors should be used to monitor these substances in unenclosed areas, compared with lighter-than-air gases.

Sensors for heavier-than-air compounds, such as hydrogen sulfide, should be located near ground level – typically about 18-24 in. above the ground – or in low-lying areas where the gas may gather. In contrast, sensors for lighter-than- air gases should generally be located above the danger point.

In enclosed facilities, it is typical to mount sensors for low-vapor-density gases on the ceiling.

Sensors for gases with the same density as air should generally be located at or near breathing level.

Note that when monitoring for oxygen deficiency, one should consider the density of the gas(es) that are displacing the oxygen. For example, in a helium cylinder storage room, the first indication of a leak will be seen by an oxygen sensor mounted close to the ceiling (helium will rise and “crowd-out” the oxygen near the ceiling).

Gas release temperature should not be ignored when evaluating vapor density. Liquefied, lighter-than-air gases, such as LNG, will generally behave like heavier- than-air gases immediately after a spill, but will soon begin to rise as the vapors become diluted and warm up to ambient temperatures. Similarly, some heated heavier-than-air gases, such as hydrogen sulfide, rise when first released, but will settle as they cool and their density increases above that of air.

It is important to recognize that factors such as ventilation and air currents, especially for gases whose densities are similar to air, may alter these general recommendations. Strong air- flow through a room, for example, may make an exhaust duct a better location than the ceiling for monitoring a lighter-than-air gas. Mode of storage and release can also affect the monitoring setup suggested by vapor density.

Liquefied gases and high-vapor-pressure liquids are typically released as liquid spills (or jets) that subsequently evaporate. The rate of evaporation varies positively with the surface area of the liquid pool (which is reduced by dikes or embankments), the boiling point or vapor pressure of the liquid, and the heat transferred from the ground and atmosphere.

In general, the slower the rate of evaporation or the denser the vapor, the more important it is to place sensors close to the location where the liquid accumulates. Meanwhile, prevailing air or ventilation currents become more important considerations as the rate of evaporation increases.

Gases stored or transported under, pressure are released as a gas (or two- phase, liquid-gas) jet. If a jet's release point or direction is predictable – for example, in a gas cabinet or by a valve where hoods or cones are used to direct the jet – it is generally desirable to place a detector in its path. Otherwise, detectors should be placed either in multiple locations around the danger

point or in areas where the gas is likely to travel or settle after being released (taking into consideration prevailing air or ventilation currents).

Note that lighter-than-air gases will often sink immediately after release due to the presence of aerosols in the jet, and the drop in temperature that accompanies a drop in gas pressure. Most gas jets experience substantial mixing, and, in the open can disperse below dangerous levels a short distance from the leak point. However, prolonged leaks and re- leases in confined or semi-confined areas still pose substantial threats.

5. Profile the plant and potential release scenarios.

This exercise will identify physical features of the area around the potential release points, such as obstacles (buildings and equipment), surface roughness, and ventilation, that are likely to impact the behavior of a gas cloud after it is released. Probably the most important of these features is the release area itself – whether it is enclosed or not enclosed.

Although indoor releases are often much more dangerous than outdoor ones – due to confinement or finite volume available for diffusion – their behavior is also more predictable. Studies have shown that in unexhausted rooms, gas tends to reach uniform concentration above (or below) the leak source very rapidly [8]. The more mixing that takes place through convection currents, ventilation and so on, the more quickly the gas will reach a uniform concentration.

In this application, "typical" sensor locations – those based primarily on vapor density and release mode) – can be used. Note that when very hot air exists near the ceiling, some thermal stratification may occur. For instance, warmer, lower-density air may slow the passage of a gas to the roof.

Since most indoor process facilities are exhausted, the effect of mechanical ventilation is important to consider.

Where ventilation rates are fairly rapid, such as Class 100 (or better) clean rooms, duct-mounted – or in the case of waffle-floor semiconductor facilities, sub-floor mounted – sensors often provide the best indications of air conditions in the room, chamber or cabinet. Note that in some cases, sensors may have to be mounted in several ducts, since code requirements require ventilation-system design to take gas density into account. For example, where mixtures of light and heavy gases exist, ventilation must capture gas at both high and low points.

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In situations where ventilation rates are slower, a smoke study should be per- formed to confirm that the sensor will ”see” a gas leak. In such a study, a puff of smoke or some other easy-to-see fume is released, and its behavior in the prevailing air currents is observed. If ventilation ducts are interconnected and a potential release point lies ”upstream,” or if air is drawn from the outside near a potential leak source, it may also be desirable to locate a sensor at or near the air-inflow duct. In certain cases, such as when highly toxic gases are being handled, it can be useful to monitor breathing zone locations as

well, for added safety.

Monitoring outdoor gas releases is significantly more complex, as gas behavior is impacted by many more variables. Numerous dispersion models are available to help designers predict gas-release plume sizes, shapes and concentrations. In addition to gas properties and leak kinetics, air dispersion models typically incorporate data such as surface roughness. Gas spreads faster over water, pavement, and grass than over cities, forests, and industrial complexes.

Meteorological conditions are also considered, because gas disperses most rapidly during sunny afternoons with light wind, and least rapidly during clear nights with light wind. For a comprehensive discussion of air-dispersion modeling [9].

In general, outdoor gas sensors should be located in such a way as to ensure that a quantity of gas greater than their limit of detection will pass by them in all normal release scenarios. Detection limits, specified by the vendor, are typically three times the signal-to-noise ratio.

It is important to note that predicted release behavior can be significantly altered by topographical characteristics created by buildings, process vessels, piping arrays and so on, since most dispersion models assume flat surfaces. For example, ”canyons” (i.e., the area between two large structures) tend to increase the concentration of a gas plume. Conversely, obstacles downwind of a release point will tend to dilute the gas plume through increased turbulence.

Gas-detection systems are important front-line watch dogs, and provide many process plants with early notification of dangerous releases. Proper design and layout is critical to the functionality of these systems, but poses a challenge for many users since little standardized guidance is available. A qualified safety professional should be involved in all ultimate design decisions. However, the five-step procedure discussed above will enable users to ”rough out” a preliminary installation on their own.

When designing a gas-detection installation, the engineer must remember that gas detection is only one part of a plant’s comprehensive process-safety- management plan. To be most useful during plant operation, monitoring system designers should address not only how many sensors are required and where they will go, but also how the real-time data provided by these devices can be used to improve the overall safety of the plant and its workers.

Gas Detection: Key Elements to Consider

In the rush to design and install a gas-detection system, certain practical considerations can be overlooked. Listed below are several issues that system designers should be sure to keep in mind.

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Accessibility. Like all instruments, gas detectors require periodic maintenance, although many new models enjoy significantly reduced maintenance requirements. Before making final placement and location decisions, it is important to make sure that adequate access to the instruments is provided for periodic maintenance and upkeep.

Wiring and installation. Poor installation is often to blame for system problems. Since wiring and installation are not cheap – one rule of thumb is to double the price of the instruments to arrive at a rough, "all-in" system cost – it is important to allow for these costs in the project budget, and to follow good instrument wiring and installation practices.

These include the use of drains, drip loops and so on. External factors. The best locations for gas detectors are sometimes susceptible to external factors that can cause serious difficulties. For instance, gas detectors installed near the ground can be damaged by plant vehicles or submerged by washdowns, while sensors mounted on exterior walls can be plugged by painting operations.

Environmental conditions. Ambient conditions can have a significant impact on detector performance. All gas-monitoring instruments have temperature limitations, so care must be taken to ensure that the installation remains within the specified range. Devices such as sunshields can be used to ensure transmitter temperature does not exceed this range. In locations where large amounts of dust or dirt fill the air, dust filters should be used to prevent sensors from becoming clogged.

EMI and RFI. Strong sources of electromagnetic interference (EMI) or radio-frequency interference (RFI), such as variable-frequency drives, located near transmitters or wiring can generate spurious alarms. To prevent this, shielded cable should always be used. In addition, in locations where EMI or RFI problems can exist, it is a good idea to specify transmitters with low susceptibility to interference, and to use conduits for all wiring.

Alarm levels. There is often a tradeoff between alarm setpoint and susceptibility to false alarms – the lower the setpoint (as a percent of full scale), the more likely a power surge, background noise or some other interference will trigger an alarm. In general, it is a good idea to keep low-level alarm setpoints at or above 10% of transmitter full scale (20% is preferable). If it is important to alarm at a lower level, users should consider changing the location of the transmitter – by moving it closer to the potential leak point, for in- stance – or specifying a transmitter with a lower full-scale range {e.g., 50 ppm versus 100 ppm).

Exposure limits. Alarm setpoints for toxic gas detectors are often based on permissible exposure limits. Since there are numerous ways of measuring these limits – such as recommended exposure limit [REL) from NIOSH, permissible exposure limit (PEL) from OSHA, time-weighted average (TWA) from ACGIH), short-term exposure limit {STEL) from ACGIH, or ceiling limit from ACGIH – it is important to ensure that the measurement used is appropriate for the application and that the definition of the measurement is fully understood by plant personnel (e.g., to not confuse time-weighted average with ceiling limit).