E-Book

Finding Gas Leaks in Urban Gas Distribution Networks

Technologies and Methods

Preface

Accurate leak detection is of great importance to the gas distribution industry. Gas leaks can cause explosions, are damaging to the environment, and waste natural resources. Utility companies put a great deal of resources into detecting leakage that is, to some extent, inevitable in an extensive network.

However, selecting the most appropriate technology for leak detection can be confusing. Different manufacturers use different technologies, with different capabilities and limitations. This paper explains these differences and the options that are available.

It is important for the utility company to select a technology that works well in their circumstances. Otherwise, the equipment may fail to detect gas that has escaped from the pipelines, giving a false sense of security and making the network survey a costly waste of time.

Introduction

A number of gas detection technologies have been devised over the years. Out of these, there are four that remain in widespread use for surveying gas network pipelines—semiconductor, laser spectroscopy, flame ionization, and infrared detectors. In addition, a number of other technologies exist aimed at specific applications.

Semiconductor detectors operate by detecting a change in resistance as gas molecules bond to the material. These detectors can be slow to react after high-concentration gas exposures, tend to lose sensitivity fairly quickly and are cross-sensitive to other gases. On the positive side, they are inexpensive and can be used in great numbers, enabling utilities to make detectors widely available.

Flame ionization detectors burn a sample of the gas and detect ions that are released in the process. These are accurate and robust, but can be cumbersome. This can sometimes reduce the mobility of the operator and have an adverse impact on productivity.

A type of laser spectroscopy, TDLAS (tunable diode laser absorption spectroscopy), can be used to measure the change in wavelength and light intensity of a laser beam as the atmosphere changes with the gas content. Using this technology, the concentration of gas and vapor can be measured from a distance in a remote detection device or built-in to an aspirated device used close to the leak. However, while this technology can accurately detect the presence of gas, it is typically tuned to identify only one type of gas, such as methane. The most advanced systems in the market are equipped with multiple sensor systems tuned for methane and ethane.

Infrared (IR) sensors work by passing infrared light through a tube containing gas. As the light

A flame ionization detector for finding natural gas leaks.

travels through, the gas absorbs a portion of the infrared energy. The reduction in light intensity corresponds to the concentration of the gas.

Both infrared and laser technology have a reputation for being costly, as it only used to be available in high-end equipment. However, the purchase price has come down considerably in recent years and, over time, costs tend to work out roughly the same as the cost for a semi-conductor system, as the IR system is cheaper to run and to operate. Laser-based systems are generally more expensive, but offer the highest sensitivity when it comes to handheld devices used close to the leak.

Successful gas detection also depends on the method by which the gas is picked up from the ground. The height needs to be as close to ground level as possible and remain consistent, as gas dissipates rapidly in the atmosphere. The tools used in the past frequently provided variable outcomes, but better designed implements available today can deliver substantially improved results.

Successful gas detection also depends on the method by which the gas is picked up from the ground.

Accurate gas detection—a matter of safety, and more

Tracing and eliminating gas leaks is an ongoing task for owners of gas distribution networks. Gas leaks can cause explosions. Prolonged exposure to leaking methane gas can also be a health hazard. Additionally, leaking gas represents a financial loss to operating companies and can cause reputational damage to utility companies as negative publicity appears in the press.

In recent years, yet another perspective has been added—the threat to the global climate of leaking methane gas, the main component in natural gas. In the short term, methane is a more powerful greenhouse gas than CO_2 and the world's attention is now switching to prioritize the tackling of methane emissions, to meet deadlines for environmental targets that loom in the coming years.

This means that utility companies need to keep one eye on the future when selecting leak detection technology. A solution that was chosen based on its track record and meeting current standards may not be able to meet the requirements of the next five to 10 years.

The gas industry is required to monitor natural gas emissions from the gas grid.

Safety

Utility companies undertake regular surveys of their gas networks to check for leaks. The primary objective of these surveys is to ensure safety. If leaking gas gathers in one place, or if dangerous concentration of gas occurs in the atmosphere, urgent attention is required. Emergency work means additional costs for the utility company and inconvenience for the general public. If the gas leak can be located before any hazardous accumulation builds up, the repairs can be planned and carried out in an orderly fashion and disruption can be minimized.

In addition, methane gas and chemicals added to detect leaks can be harmful to health. Every year, several accidents are reported around the world, resulting in injuries and, in the worst cases, fatalities.

Utility companies conduct regular surveys to ensure safety.

Environmental impact

Methane gas, the main component of natural gas, is very harmful to the environment, with a global warming potential more than 80 times that of CO_2 over a 20-year period.

Over the years, the debate on climate change has mainly focused on CO_2 emissions, but this is now beginning to change. Methane gas is more potent than CO_2 in the short term. However, it decays more rapidly and does not stay in the atmosphere as long as CO_2.

The warming of the planet can be tackled more quickly and efficiently by targeting methane. This can give a rapid boost to the effort to reduce greenhouse gas emissions.

Methane emissions from human activities are estimated to be responsible for up to 30 percent of global warming today.

Out of the total man-made methane emissions, about one-third of comes from the energy sector, the other two main sources being waste management and the farming industry.

Leaks in the energy sector can be tackled efficiently and cost-effectively—often at no net cost at all, as the gas prevented from escaping is a valuable commodity with a market value. According to the International Energy Agency (IEA), a significant share of methane emissions from fossil fuels could be avoided at no net cost, based on the average energy costs during the last years.[1]

Much of the leakage occurs in oil and gas production and upstream distribution. But coming legislation on methane gas emissions reduction will also affect downstream distribution and utility companies.

There are several powerful incentives to ensure that effective gas leak detection is applied across the energy sector. A new EU regulation targeting methane emissions, EU 2024/1787[2], has recently been adopted. But even if you operate elsewhere, and more stringent legislation has not yet arrived in the jurisdiction where you operate, there is no room for complacency. It will inevitably arrive, it is only a matter of time. More than 100 countries have signed the Global Methane Pledge[3], an agreement to reduce methane emissions by 30% below 2020 levels by 2030.

The changes will affect the whole industry from top to bottom. Utility companies, for instance, will require surveying companies to produce more reliable leak detection surveys to avoid fall. This means it is a good idea to stay on top of developments and prepare for the future, strive to meet stricter requirements and adapt to the new operational landscape in time.

Negative publicity

Irate customers are the last thing any organization wants. When emotions run high in the local community based on a genuine concern for health and safety, negative headlines in local newspapers are a near certainty.

As access to satellite imagery becomes widespread, this process can easily replicate on a national and global level. Once a company has been identified as a polluter in the media, finding a remedy to the problem becomes a matter of urgency. To avoid having to rush out solutions to a problem that should have been preventable, it is better to act in advance, take a lead in the green transition, and reap the benefits of positive publicity.

Financial loss

Loss of gas also represents a financial loss. This does not impact on utility companies directly, as it is regarded as part of the cost for doing business and passed on to customers. But the cost has to be picked up somewhere and higher costs make the provider less competitive.

[1] https://www.iea.org/reports/driving-down-methane-leaks-from-the-oil-and-gas-industry

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202401787

[3] https://www.iea.org/reports/global-methane-tracker-2022/the-global-methane-pledge

Pressure drop

Additionally, leakage can lead to pressure drop in the pipelines. Many networks already work to capacity. If the pressure drops as a result of leaks, this may mean insufficient supply at the consumer end, dissatisfied customers, and reduced revenues for the utility company.

Early leak detection is the key

To prevent leaks from causing problems, they need to be detected as early as possible. The most common causes of leaks in Europe are, in descending order, external influences, corrosion, manufacturing defects, and ground movements. Ground movement and external influences such as excavation increase the risk of larger holes or full pipe ruptures. Corrosion in older pipes and manufacturing defects, on the other hand, usually cause only pin-sized holes[4]. Early remediation will minimize disruption and safeguard reliable operation.

It is also worth keeping in mind that a small amount of gas on the surface does not necessarily indicate that the leak in the pipeline is small. Leaking gas can spread widely underground, with only a small amount being noticeable on the surface.

To detect small amounts of gas, the measuring equipment needs to be extremely sensitive and capable of measuring gas in low concentration. Not only will the amount of escaping gas be small, its concentration will be reduced on its journey from the pipeline to the surface and from the surface to the detection device.

Operators need to bear in mind that there is no single piece of equipment that will do all jobs and solve all problems. Successful leak detection results from using the right technology for each job; applying the right surveying techniques and methods; and staying up to date with developments, using training, and support from your chosen vendor.

Accurate leak detection is a matter of safety.

[4] 11th Report of the European Gas Pipeline Incident Data Group

History of gas detection

The first widely used gas detection device was the flame safety lamp. It consisted of an oil lamp with a glass sleeve and a mesh flame arrestor that protected the flame. This mesh prevented the ignition of flammable gas around the lamp. A high flame indicated the presence of methane, while a low flame indicated low levels of oxygen. Flame safety lamps were used throughout the 19th and 20th centuries. In addition, 20th-century coal miners used canaries in the tunnels to detect the presence of toxic carbon monoxide gas.

Modern gas detection arrived in the 1960s with the pellistor. This was the first solid state device used for flammable gas detection. Its name is based on a combination of the words "pellets" and "resistor." The device burns the target gas to produce heat. This causes a change in the electrical resistance of the ceramic pellets that are used to determine the gas concentration. Thanks to its simplicity, the pellistor is still very popular and used in many applications.

Natural gas is widely used to power home appliances efficiently.

Prevention is better than cure

Gas networks can be maintained by either reactive or preventive maintenance. With reactive maintenance, the gas utility relies on the general public to get in touch to say that they can smell gas (or, more correctly, the odorant additive in natural gas). With preventive maintenance, the operator undertakes network surveys, using staff or contractors to walk the route of the pipelines on a schedule, with detection equipment.

The sensors in the equipment can detect gas at far lower concentration than a human nose can detect gas odorant. Preventive efforts in Europe have significantly reduced the number of reported leaks, from approximately 0.75 leaks per 1000 km/year in 1970s to 0.15 leaks in 2010—five times fewer over the past 40 years.[1] This approach generally results in less leakage overall and a better maintained network. Such surveys are frequently carried out within a regulatory framework and may vary depending on the age and location of the network, type of pipes and the service pressure. Operators may be required to check network sections at specified intervals, such as annually or more frequently, based on regional or company regulations. These intervals can vary by grid section, depending on factors like system age, materials,

Operator walking the route of the pipelines.

[1] 11th Report of the European Gas Pipeline Incident Data Group (EGIG)

Surveys on foot provide access to all areas that require monitoring.

or surrounding conditions.

Surveys must be documented and traceable, with precise dating and location of every leak detected. This is normally documented in some sort of digitalized system (GIS) where leaks can be mapped on top of the gas grid. But paper map-based systems are still common in many parts of the world.

New regulations, such as those now coming into force in Europe, will shift more responsibility to grid owners to locate, quantify and document leaks as the basis for a continuous improvement plan to cut emissions.[2]

Modern leak detectors should be designed to comply with the recent proposal from the Pipeline and Hazardous Materials Safety Administration (PHMSA)[3], which mandates a minimum sensitivity of 5 parts per million (ppm) for leak detection equipment. This proposal aims to enhance safety by ensuring that leak detection systems can identify even the smallest gas leak.

[2] Regulation (EU) 2024/1787 of the European Parliament (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX-:32024R1787)

[3] Agency within the U.S. Department of Transportation (DOT) responsible for ensuring the safe transportation of energy and other hazardous materials through pipelines and other transportation systems.

Walking surveys vs. vehicle based

The aim of the survey is to measure presence of natural gas at ground level, as close to the pipes as possible. Surveys on foot provide the most accurate results as samples are taken directly on the ground, just above the pipe. This method also provides access to all areas that require monitoring. An operator can cover about 10 to 15 kilometers (6 to 9 miles) per day on foot. A vehicle-based system can cover greater distance in a day, 30 to 50 kilometers (18 to 30 miles), but will be less accurate and less able to get into areas that are difficult to reach, e.g., gas lines in frontyards. The system will also require a greater financial investment.

In many situations, surveys on foot are more cost effective, despite the lower speed of travel. If the objective is to cover the entire network in, for instance, four years, all that is needed is some forward planning; i.e., working out how many operators are needed to cover the network in the time available. The equipment is easy to operate and little training is required.

Surveys with vehicles can cover a large area, such as a neighborhood, in a short space of time. The equipment will detect everything in front of the vehicle and some of the area on the sides. Sophisticated software is used to take into account the vehicle speed, wind direction, temperature, air humidity, and other relevant factors to work out the most likely location of the leak.

In some situations, vehicle-based surveys can be particularly effective. This applies, for instance, if a gas main line located under the road is being traced or when looking for the origins of a leak in a busy city environment with many parked as well as moving vehicles. In such situations, a response team in a survey vehicle can quickly get an update of the situation and take a decision of whether further investigation is required.

Undertaking the survey

Using modern equipment, operators can find gas leaks with relative ease. The operator walks the route of the network. When a suspected leak is identified, the operator needs to pinpoint the location on a map, verify the presence of gas and measure the concentration.

The operator also needs to classify the leak with regards to its severity. This may depend on the size of the leak, but also factors such as distance to public areas and the condition of the pipework. This determines the urgency by which the leak will be dealt with by the utility company.

When a leak has been identified, further action becomes much simpler if the instrument has quick response and recovery times. The leak can then be recorded in an orderly fashion and the survey can continue. Instruments that react and recover slowly will disrupt the process and reduce efficiency.

Identifying natural gas

Natural gas mainly consists of methane, which also occurs naturally in the environment. To distinguish natural gas from other sources of methane, such as decomposing organic matter, the detection equipment needs to identify something that only occurs in natural gas. That component is ethane. The percentage of ethane in natural gas varies widely with the origins of the gas. North Sea gas, for instance, usually contains 6-8% ethane but globally the difference can be anywhere from 0.2 vol% to 15 vol% The typical ethane concentration in the gas grid is something that the gas companies want to know because a higher amount of ethane will change the calorific value of the natural gas, meaning it will have more energy per cubic meter compared to pure methane.

To find ethane and verify that the detected gas is actually natural gas, a gas chromatograph is normally used. Some models of detectors have this built-in, but stand-alone instruments are also used. Alternatively, a gas sample can be collected in a sample bag and sent to a lab for analysis; however, the result of the analysis takes on average a few days. The most advanced aspirated laser-based instruments on the market also have dual lasers: one tuned for methane and the other for ethane.

Pinpointing the exact location

When the presence of gas has been verified, a series of bar holes are drilled in a predetermined pattern around the site. Gas samples are collected from the holes to decide the location with the highest concentration of gas. This will indicate the spot to start excavation for repair work.

At this point, the network operator will want

Gas samples are taken from the holes to identify the highest concentration location.

to be reasonably certain that the location has been accurately pinpointed. Digging in the wrong place can be very costly and causes unnecessary disruption.

Some types of equipment can draw gas through the natural porosity of the road surfacing material, minimizing or eliminating the need for bar hole drilling—more on this later. If bar holes are needed for regulatory reasons, these can then be kept to an absolute minimum.

Rapid detection and remediation of gas leaks gives several advantages. Accurate detection means less damage to road surfaces, as it leads operators straight to the faulty pipework. Less excavation means less inconvenience for the general public. With a smaller operation overall, services can be restored to customers quickly. Cost savings can be passed back to customers.

Less excavation means less inconvenience for the general public.

Market drivers

Ensuring the safety of the public is the top priority behind all gas detection activities. This goes hand in hand with regulatory compliance. To fulfil these requirements, the organization needs equipment that indicates presence of gas accurately. But this is only one part of the equation. Utility companies also have other priorities that equipment manufacturers try to meet to varying degrees.

Productivity

Utilities want operators to efficiently cover their networks, carrying all necessary equipment without returning to the vehicle for missing pieces of kit.

Any indication of gas should relate only to natural gas, minimizing the occurrence of false alarms. The equipment needs to be fast reacting, so that the operator does not need to backtrack because the alarm sounded 15-20 seconds after the gas cloud was passed. The equipment also needs to recover quickly after the alarm so the survey can continue or provide an intuitive response behaviour when passing over a leak during pinpointing.

Accuracy

Operators and utilities need to feel confident that leaks along the route have been picked up. The technology needs to be sufficiently accurate to detect small amounts of gas and be able to tell the difference between natural gas and swamp gas.

Minimized disruption

If a gas leak can be identified while it is still small, thanks to accurate detection, less excavation will be required. This reduces costs, as well as disruption to the general public. Leaks that are left to expand over time may eventually require emergency repair, which increases disruption and costs.

Personal liability

In some markets, the operator is personally responsible for signing off the report saying that a particular stretch of pipeline is safe. This means the operator has a personal interest in ensuring that the measuring equipment operates accurately.

Corporate social responsibility

Inconveniencing the public, exposing people to hazards, and polluting the environment are not the behaviors expected by a socially responsible organization. The damage to the reputation of the company can be substantial and can take a long time to recover from.

Lower cost

More accurate detection reduces the need for bar hole drilling, the practice of drilling a series of holes in the surfacing material to pinpoint the source of a leak. If the location can be more accurately located before drilling starts, fewer holes need to be drilled. This saves time and reduces damage to road surfaces, cutting the cost for reinstatement—local authorities can levy substantial fines if road surfaces are not reinstated properly.

Ergonomics

Working conditions for the operator is another important factor. The equipment needs to be comfortable to carry during long days of survey work, to ensure the operator stays alert and efficient. Digital recording of the work means less disruption for the operator. If all the equipment needed during the survey can be carried comfortably, the survey work can easily be performed by a single operator.
In the future, the ergonomics of the equipment may become even more important. Enhanced environmental targets could lead to stricter regulations, requiring more surveys to be carried out and increasing the work load for leak detection operatives.

The equipment needs to be comfortable to carry during long days of survey work.

Technical developments

Several technical developments have been made by manufacturers in recent years to meet the requirements of utility companies.

Sample collection

To carry out a successful repair, it is necessary to pinpoint the source of the leak as accurately as possible and get up close. But for an initial investigation, gas detection from a distance can be used effectively to get an coverall view of the situation.

The greatest overview is provided from space, thanks to the new satellites MethaneSAT and Carbon Mapper[1] that were launched in 2024. The aim is to target hidden methane gas emission sources that companies and governments, until now, have been unaware about. Such leaks can be extremely harmful to the environment. For more information on satellite surveillance, see the section *Detection technologies—an overview*. Closer to earth, drones and aircraft can be used as platforms for laser-based systems that detect the presence of gas. Such systems are frequently used to monitor large installations such as oil fields and refineries.

With systems fitted to cars or quad bikes, utility companies can get an overview of the overall situation in an entire neighbourhood. The source of the leak can be traced using spectroscopy in combination with sophisticated software to calculate the impact of weather and the atmospheric conditions on the movement of the gas.

Hand-held laser pointers can be used to detect presence of gas in places that are inaccessible, for instance high up on exterior walls or behind fences.

But to pinpoint the location of a leak accurately and provide reliable data for repair work, the instrument needs to be at street level, as close as possible to the area in the ground where the gas emerges.

New sampling methods

Traditionally, gas detection instruments come with a ground probe that the operator holds near the ground to pick up gas. But new accessories have been developed to pick up gas samples more effectively. For instance, some instruments can use a vacuum bell to draw gas through the natural porosity of the road surfacing material, eliminating the need for drilling bar holes.

A vacuum bell forms an airtight seal when pressed against the surface material. A pump

[1] https://www.methanesat.org/ and https://carbonmapper.org/

in the instrument creates a vacuum sufficiently powerful to pull the gas through the road surface and delivers it to the gas sensor. This whole process takes 10 to 20 seconds—far quicker than drilling a hole through the pavement and without damaging the road surface.
However, not all instruments are suitable for this sampling method, primarily due to the capacity of the instrument's main pump. Most instruments will trigger a blocked flow alarm and turn off the pump to protect the system. The second important reason is that high gas concentrations are fairly normal with this method, even on challenging materials such as cement tiles or asphalt roads. Some sensor technologies, such as semiconductor-based instruments, may be affected by the high concentration and become slow or lose sensitivity over time.

Easier analysis

Some instruments now have a built-in a gas chromatograph. This enables the operator to make the analysis on site and determine if the gas is coming from a pipe or is just naturally occurring.

Easier positioning

Instruments often come with a built-in GNSS (Global Navigation Satellite System) chip, supporting systems like GPS, GLONASS, Galileo,

Built-in gas chromatograph allows for on-site gas analysis.

and BeiDou, which enables easy tracking of routes and precise pinpointing of leaks for later follow-up.

Improved sensor technology

Non-dispersive infrared (NDIR) detection, once limited to high-end equipment due to cost, has become more affordable in recent years, making it accessible to all operators if the utility company chooses to implement it.

Reduced cross sensitivity to other gases

Low cross sensitivity means that the instrument only raises the alarm if the target gas is detected—not, for instance, uncombusted fuel in the exhaust fumes of passing vehicles.

Ease of handling

Modern equipment is easy to carry. The instrument and all necessary accessories can be with the operator at all times.

Modern instruments can be controlled from the user interface on a tablet or phone.

Higher productivity

Faster reaction and recovery time of instruments reduce waiting times for operators.

Wider range

A measurement range from 1 ppm to 100% methane for some equipment also helps improve productivity. This means the operator can make all measurements with one instrument.

Single person use

Today's equipment can usually be managed by a single person. Older systems required one dedicated person to handle the instrument while another focused on collecting and recording the data. A modern instrument can be controlled from the user interface on a tablet or cell phone that the operator carries at the front. This also displays a map. The tablet is connected to the instrument using Bluetooth technology or a wired connection.

Electronic documentation of work

Survey results, including positioning data from satellites, can be downloaded to a Geographic Information System (GIS) for easy documentation of work. Survey results can also be streamed to a computer in real time, using Bluetooth technology or a wired connection.

Multifunction vs. single function

When gas has been detected, the operator needs to verify that the gas is actually natural gas. Here, a gas chromatograph is normally used. Traditionally, stand-alone instruments were used, but multifunction instruments are becoming more commonplace. This means that the instrument has more than one sensor and can be used for several different tasks. For instance, it may contain an IR sensor to detect gas leaks, plus a gas chromatograph to analyze the samples of gas.

Having several sensors in one instrument improves productivity by reducing trips to the service vehicle and the need for laboratory testing. However, instruments with multiple sensors are more expensive and require more calibration. Overall, utility companies appreciate the increased flexibility these instruments offer.

A built-in gas chromatograph can identify methane or ethane in just over a minute and differentiate between swamp gas and natural gas with ethane levels as low as 0.5%. Samples can be as low as 0.1% natural gas. The analysis can be carried out on the spot, saving significant time.

Some instruments have sensors that detect low levels of oxygen, as well as toxic gases such as carbon monoxide and hydrogen sulfide. This protects operators working in an indoor environment or down a manhole.

In the coming years, utilities may start mixing natural gas with hydrogen—more on this under the section *Outlook: the future of gas distribution and detection*. Hydrogen has different properties than hydrocarbon gases, such as methane and ethane, and requires different sensors for its detection. If and when this happens, multisensor instruments may become the norm.

Remote sensing

Remote sensing has become increasingly popular in recent years. This enables the operator to scan areas for gas leaks from a distance, especially in hard-to-access locations like fenced-off areas or high installations.

Remote sensing can be achieved either with a laser tuned to identify the target gas, or with infrared image sensors—more about these technologies in the next section.

However, once a gas leak has been detected from a distance, it is still necessary for the operator to move closer and to use one of the more common techniques to pinpoint its exact location, before remedial work can begin.

Detection technologies—an overview

Several methods to detect gas have been developed over the years. Over time, technology has become less costly and easier to use. The three current technologies mainly used to detect gas in low concentrations during gas network surveys are infrared detectors, semiconductor sensors and laser spectroscopy. A fourth common technology still in use in many organizations is flame ionization detection. This, however, is an older type of technology that is currently being superseded by the other three. The various technologies have fundamentally different ways to detect the presence of gas in the atmosphere.

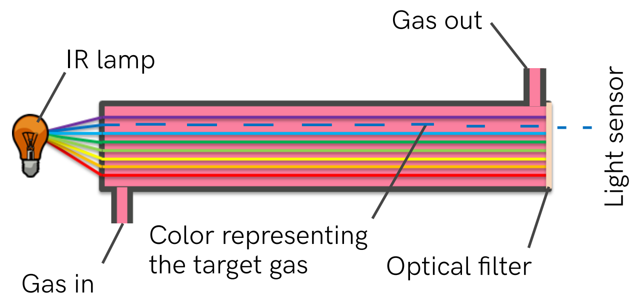
This section outlines details for these technologies. It also briefly touches on some other technologies that are used in this field and in adjacent areas. Each method has its drawbacks and benefits. The network surveyor will need to choose technology based on the circumstances that apply.

Different technologies to detect the presence of gas

- **Infrared (IR) sensors** use infrared light passing through a tube with gas. The gas will absorb some of the energy of the infrared light beam. The loss of light intensity indicates the concentration of gas.
- **A semiconductor sensor** changes its resistance depending on the concentration of gas present. To make the sensor responsive and sensitive, the substrate is heated to a high temperature.
- **Tunable diode laser absorption spectroscopy (TDLAS)** emits specific wavelengths of a laser beam and measures the wavelength and intensity of the light that is reflected back.
- **Flame ionization detection (FID)** is based on the detection of ions formed during combustion of gas in a hydrogen flame.

Infrared (IR) sensor

The type of infrared sensor used in gas detection is called nondispersive infrared, or NDIR for short. It consists of an infrared light source, a sample chamber, and an infrared detector.
The infrared light is aimed at the detector at the end of the sample chamber. An optical filter in front of the sensor is tuned to the infrared wavelength that is sensitive to the target gas. When gas enters the chamber, some of the light will be absorbed by the gas. Less light reaches the sensor and the concentration of gas in the atmosphere can be determined.
The main advantages of the IR technology are speed and stability. This is especially noticeable during and after high exposure. The sensing principle is entirely based on light passing through a sample from the atmosphere and involves no chemical reactions. Reaction and recovery only depend on the time needed for replacing the gas in the sample chamber. It recovers fast after exposure and is ready for renewed use immediately after an alert. Other technologies may require several minutes of exposure to normal atmosphere before being ready to work again.
The most sensitive IR leak detectors on the market can detect a concentration of a few ppm within a couple of seconds.
One further advantage of the infrared sensor is that it is highly selective to hydrocarbons, the main components in natural gas. Some versions are even able to differentiate between swamp

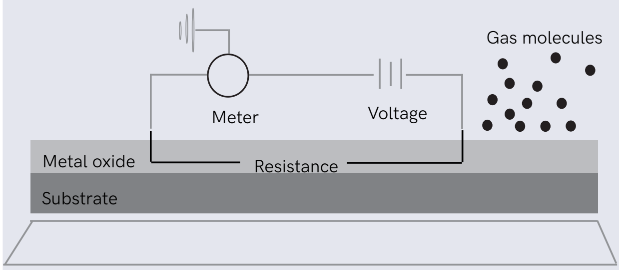


An infrared light is aimed at a light sensor at the end of the sample chamber. An optical filter in front of the sensor selects colours sensitive to the target gas.

gas and natural gas.
There are also detectors that entirely eliminate cross sensitivity from water vapor and from heavier and more reactive hydrocarbons, such as VOCs in polluted air or exhaust fumes. It is possible to combine the IR sensor in the instrument with other sensors, such as a gas chromatograph, to identify the type of gas that has been detected, as well as toxicity sensors to warn the operator of potentially dangerous atmospheres.
The drawback of IR sensors used to be their cost; however, this has come down considerably in recent years and the technology has become affordable for widespread use. The stability of the sensor gives an operational life of several thousand hours. This makes the lifecycle cost roughly similar to that of semiconductor technology while providing performance to rival the more costly laser systems.

Semiconductor sensor

Semiconductor sensors were introduced in the 1970s. These are based on semiconducting metal oxides, typically tin oxide. The sensors are small, inexpensive and easy to integrate into equipment.
The sensor material is made up of small particles just making contact with each other to form a thin semiconducting layer. In the presence of gas, the interfaces between these small



A semiconductor sensor is based on semiconducting metal oxide, normally tin oxide.

particles are affected. In ambient air, oxygen is absorbed on the surface of the particles. The oxygen traps conductive electrons close to the surface, creating a low conductance barrier between the particles. A reducing gas like methane can react with the oxygen, causing the trapped electrons to be released and lowering the barrier between the particles. This reduces the overall resistance of the semiconducting layer. The change in resistance is used to calculate the gas concentration. For methane, the resistance typically drops to a tenth in atmosphere with 1 Vol% concentration.
The semiconducting material is normally heated to between 150°C and 400°C to improve speed and sensitivity.
Reaction is typically fast but recovery can be very slow, especially after high concentration exposures. If the instrument is exposed to very high concentration, the semiconducting layer can become permanently damaged. This can

make the technology less useful in some leak survey applications.

The long recovery time also impacts on the efficiency of the survey work, as the operator has to wait while the instrument recovers. To reduce waiting times, operators sometimes have a backup instrument in the service vehicle. The backup instrument can also be used to verify the reading of the first instrument. However, having two instruments will add to the cost of the operation.

Semiconductor sensors are normally combined with a simple IR sensor in the same unit. The main reason for this is the limited measuring range of a semiconductor sensor as is saturates already at a few volume percent. A standard IR sensor overlaps this range and typically measures in the range between 1 vol% and 100 vol%. The IR system is also used to measure potentially explosive atmospheres, as semiconductor sensors are not considered sufficiently reliable for that type of measurement. This means this type of instrument actually combines two different sensor technologies to provide readings across the whole measuring range.

While the semiconductor sensor is highly sensitive, a major drawback is that it reacts to a wide range of combustible gases. This makes it difficult to know whether a reading is due to a leaking gas pipe, a nearby sewer, or uncombusted fuel in the exhaust fumes of a passing vehicle.

This sensor also reacts strongly to changes in ambient humidity. Nevertheless, this measuring method continues to be very popular, as it is less costly than FID and IR. However, its sensor degrades over time and it may also become permanently damaged by exposure, as described above. For these reasons, the sensor requires periodic replacement, adding to the cost of ownership. Over the course of the lifecycle, the cost for a semiconductor and an IR instrument will be similar, as the semiconductor sensor has a shorter service life.

As well as being used for gas detection, semiconductor sensors are also fitted in carbon monoxide alarms, breathalyzers, and environmental gas detectors.

Tunable diode laser absorption spectroscopy (TDLAS)

Spectroscopy is the method of analyzing various materials by studying a range of wavelengths of radiation emitted, reflected by, or transmitted through the material under study. The variant used in this context of gas detection is called TDLAS, tunable diode laser absorption spectroscopy. With this technology, gas content in the atmosphere is indicated by the change in wavelength and intensity of the light reflected from a surface back to the detector.

It works similarly to an NDIR instrument, in that it measures the reduction in light intensity as the light passes through the gas. Like NDIR, it also recovers quickly and reverts to normal as soon as the gas disappears. The technology tends to be more costly than NDIR.

The main advantage of TDLAS is that it works across a distance. Instruments with this technology are frequently used to detect gas leaks in areas that are difficult to reach, such as busy roads and fenced-off areas, where the laser beam is simply pointed at the suspected gas cloud. The tunable laser is adjusted to identify the target gas. As the laser beam passes through the gas, some of the light will be absorbed. The instrument will measure the light reflected back and calculate the concentration of gas.

The disadvantage is that it can be difficult to establish at which point, between the operator and the object at which the instrument is pointed, that the gas is present. The gas cloud can also be drifting sideways into the path of the laser beam.

The technology is frequently used in hand-held

An explosion at the gas pipeline caused by a leak.

detectors but can also be mounted on cars and quad bikes. In this case, the transmitter and receiver of the laser beam are parallel to the bumper of the car to register all the gas that the laser beam comes across as the vehicle moves. In addition, TDLAS sensors can also be fitted to drones and reach otherwise inaccessible areas.

TDLAS technology can also be used inside a hand-held instrument. In this application, the technology works similarly to an infrared analyzing system, albeit with a more powerful light source, providing very accurate measurement. Many laser instruments are large and heavy, though newer models are becoming more compact. It's important to consider local regulations and safety classifications of the instruments, including EX protection and laser beam intensity from the operator's perspective.

The major disadvantage with this technology is that a TDLAS instrument is typically configured to detect only methane. This can make it difficult to distinguish between, for instance, swamp gas and natural gas, as both contain methane. Laser instruments often lack safety sensors for toxic gases and don't display leaks as a percentage of the LEL (Lower Explosive Limit), making them less suitable for indoor or confined space use.

There are a few fairly expensive laser-based instruments available in the market that have two systems in parallel one for methane and one for ethane.

Flame ionization detection (FID)

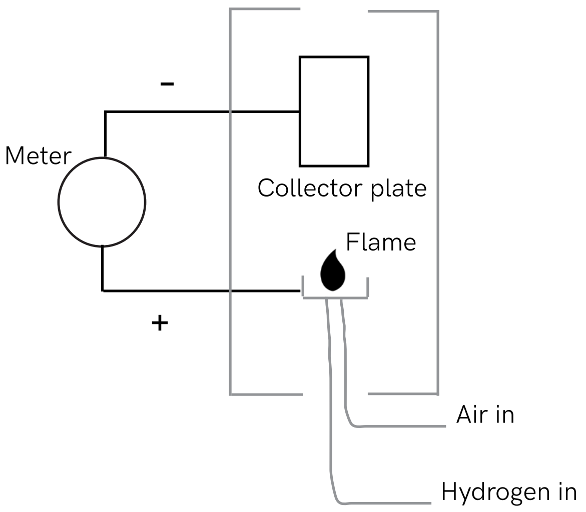
While flame ionization detection (FID) has been one of the most popular gas detection instruments in recent decades, it is now being superseded by more modern technologies. The equipment can be heavy and cumbersome, adversely affecting the efficiency of the operator over the course of the working day. More modern gas detection equipment is lighter and easier to work with. The inclusion of a flame in the system also makes the technology more challenging to use in the most demanding Ex environments.

With this said, this technology is still used in many organizations and provides accurate results in many applications. But very little new development is taking place and the current product ranges are likely to be the last of this type.

An FID system uses a hydrogen flame to burn the sample gas. When organic compounds such as methane are combusted, ions are released. Two electrodes, one positive and one negative, are used to create an electrostatic field around the flame to detect these ions. The positive electrode is typically in the nozzle where the flame is produced, while the negative electrode is made up by a plate or tube near the flame. Ions that are positively charged will be drawn to the negative electrode. The induced current is proportional to the concentration of hydrocarbon gas in the sample.

The instrument is very sensitive and reacts fast to the presence of gas. However, as mentioned previously, the FID equipment can be cumbersome, as it requires the operator to carry a hydrogen cylinder for the combustion, plus, frequently, a spare cylinder as backup.

Like a semiconductor sensor, it is unable to differentiate between different hydrocarbon gases, although it is considerably more sensitive and robust.



A flame ionization detector uses a hydrogen flame to burn the sample gas.

Another drawback is that the flame can be extinguished in high humidity or low oxygen conditions.

In the worst-case scenario, the instrument can cause a flame-out, where the gas from the cylinder ignites and burns with an open flame, outside the combustion chamber, which potentially could harm the operator.

Other detection methods

NDIR, semiconductor, TDLAS, and FID are the main technologies used for gas network surveys. In addition, a number of other gas detection technologies exist for use in specific applications.

Satellite surveillance is a new and promising technology to address methane emissions on a global scale. In 2024, two satellites for this purpose were launched—MethaneSAT and Carbon Mapper. Many companies and governments have, until now, underreported methane leakage due to a lack of reliable data, and previous earth observation satellites did not have adequate instruments to detect methane. The two new satellites use specially developed spectrometers to detect methane emissions from space. MethaneSAT provides a wide angle view, orbiting the earth every 90 minutes and targeting areas 200 by 200 km to give an overall view while still being able to see extremely small differences in methane concentration. Carbon Mapper, meanwhile, can zoom in to within 50 meters to focus on a specific area. Both satellites are operated by non-profit organizations that will make their data publicly available.

Aerial surveillance can be conducted using laser systems fitted to aircraft or drones that are able to sweep large areas in search of gas leaks. Such systems can also be equipped with sniffer systems that are able to distinguish several gases. These are often used to find leaks on large installations such as refineries and biogas plants.

Cavity ring-down spectroscopy is a method for detecting very low concentrations of substances, at levels as low as parts per trillion. It uses a laser beam inside an optical cavity, having two or more mirrors where the light bounces back and forth while gradually decaying. The rate of decay indicates the presence of absorbing gas in the atmosphere. Cavity Ring-Down Spectroscopy is sometimes used with a sampling technique where vehicles with the equipment drive through an area to take samples. Data indicating the presence of gas, wind, atmospheric conditions and geographical location is then used to calculate the likely locations of leaks.

This technology is very costly, but also very sensitive and is able to detect leaks even when traveling at considerable speeds.

High flow samplers use a fan to create a vacuum that draws air and gas into the sampling chamber, where it is analyzed using any suitable gas sensor. These are typically used for measuring individual emission points, such as valve and compressor seals. High flow samplers are increasingly recommended or mandated by regulations for quantifying and reporting the total emissions from a system or component.

Ultrasonic leak detectors are mainly used to detect leaks in equipment, for instance in compressor and metering stations. They operate by detecting sound in the ultrasonic range of 25 kHz to 10 MHz, indicating that high pressure gas is escaping into a low pressure atmosphere through a leak.

Optical gas imaging is very similar to thermal cameras where leaks or invisible gas flares are displayed as a colored image, with a more yellow or red colored image indicating a high concentration of methane. This type of technology is typically used for leak detection and emission monitoring of complex structures such as pipelines and large facilities like biomethane plants.

Dogs' acute sense of smell is sometimes used to detect gas with odorant, but they require a skilled handler. As living creatures, they need frequent breaks and may show inconsistent results, limiting their use for long term work.

Sampling methods

Successful gas detection depends not only on the sensitivity of the detection device. Equally important is the selection of an effective sampling method, ensuring that the sample reaching the sensor is a true representation of the atmosphere at ground level, where the gas collects.

Operators need to ensure they have a wide selection of probes to meet all scenarios. In most cases, a selection of complementary measuring technologies will be required; there is no one technology that can meet all the requirements in all situations.

A pipe connected to a hose is a basic mean of picking up samples from the ground.

Inspection with an aerial-shaped ground probe can lead to inconsistent results due to difficulty in maintaining a consistent height.

Gas dissipates rapidly in the atmosphere. Methods that collect samples away from ground level are far less effective and often fail to detect leaks altogether. The sample needs to be taken as close to the gas pipe as possible, on the ground.

A simple hand probe, or ground probe, is the most basic means of picking up samples from the surface. It consists of a metal pipe connected to a hose. Air is drawn by a pump inside the instrument, from the end of the pipe. The disadvantage of using a hand probe is that it only covers a very small area. However, it can be useful for pinpointing a leak, or for getting into corners and other tight spaces.

To cover a greater surface area, an aerial shaped ground probe is sometimes used. This has a wider footprint than the simple ground probe, and is typically pushed or dragged over the ground. However, the shape makes it more sensitive to wind and accurate placement throughout the day means that results may be less consistent.

A further development of this sampling method is the carpet probe. Here, the end of the probe rests on a wheeled support, covered by a rubber mat. The mat momentarily traps the air from across a relatively large area. The air is then analyzed by the sensor for presence of gas. This method ensures the distance to the ground remains consistent. The flexible mat can fold and can, for instance, follow the profile of the curb as it meets the road surface. The mat can also be flipped around and positioned to reach under obstacles such as parked vehicles.

Sometimes, a rubber bell is attached to the end of the probe to enable tapping against the ground. This enables the operator to swing the probe from side to side, touching the ground each time. This ensures that the height above

In a carpet probe, the end of the probe rests on a wheeled support, covered by a rubber mat.

Inspection with a rubber bell, holding the probe like a ski pole and tapping the ground while walking forward in a Nordic style.

ground is consistent on at least two occasions in this cycle. Alternatively, the operator can hold the probe in the style of a ski pole and tap the ground to the side, moving forward in the style of a Nordic walk.

A soft surface probe is designed to be dragged smoothly over the ground while walking, enabling continuous sample collection without interrupting the operator's pace.

The use of the soft surface probe allows to collect a sample while walking.

A vehicle-based leak survey system using sensors and equipment mounted on a vehicle to detect gas leaks.

Vehicle-based systems use a series of hoses suspended just above the ground, either from the front of the vehicle or along an open path laser. These systems are often equipped with auxiliary components such as GPS, anemometers, and analysis software to enhance performance and accuracy.

Pinpointing the location

Once the general area of interest has been located, a series of bar holes are normally drilled in a pattern. Samples are taken from the holes to close in on where the area of highest concentration is. In many cases, a change of instruments is required when taking measurements inside the hole. Some equipment allows users to use the same instrument throughout, saving time.

A further development of sampling through the road surface is the vacuum bell, which forms an airtight seal against the ground and draws air into the sampling chamber with help of a pump. The resulting vacuum inside the bell then forces air to rise through the road surface material, which can be tarmac or even concrete. This helps ensure gas leaks are pinpointed accurately. Gas can spread a long way underground and the point with the highest concentration above ground can be different to the highest concentration under ground, depending on where cracks are located. With a forced flow, gas is more likely to rise in a straight line.

By drawing air through the surface material, the need for drilling bar holes can be significantly reduced, or eliminated altogether.

The vacuum bell forms an airtight seal against the ground and forces air to rise through the road surface.

Inspection can be performed with help of bar holes in order to determine where the area of highest concentration is.

Outlook: the future of gas distribution and detection

Natural gas is an economical and easily manageable form of energy that looks set to remain with us far into the future. It is easy to distribute and simple to use. Very little equipment is needed to convert the fuel to heat in a gas-powered home. Gas is also a useful source of energy in the power industry, with gas fired turbines being able to ramp up quickly to provide effective backup power in cold climate zones, or as supplement for intermittent sources such as wind and solar power.

Substantial gas distribution infrastructure is in place in many countries, making it easy to continue current practices. Existing gas reserves are considerable and are expected to last for at least 60 years. The price of gas is affordable as well as relatively consistent over time. It is also a considerably cleaner fuel than the other two fossil fuels, oil and coal, emitting less carbon dioxide emissions per unit of energy.

However, the carbon dioxide emissions and their impact on the global climate are problematic. There are two main approaches to addressing the emissions problem. The first is replacing fossil gas with biogas or biomethane, which is produced through the digestion of materials like sewage sludge, food waste, and more, or by capturing gas from landfills. By-products such as carbon dioxide can be either captured and stored or converted into E-methane to further reduce emissions. As part of the broader green transition and efforts to strengthen energy system resilience, the share of biogas is expected to rise significantly in the coming years, even starting from a low base. The second key strategy for decarbonizing the gas industry is hydrogen. Trials are therefore underway at several locations around the world, exploring the viability of replacing natural gas with hydrogen.

Hydrogen burns without producing any emissions apart from water, making it ideal from an environmental point of view. It can also be used with the existing distribution system, which will only require modest modifications. Globally, a 5-20% blending of hydrogen into natural gas grids is considered to be in order, without the need to modify existing infrastructure components such as burners for water boilers, stoves, etc. Several small- and large-scale trials have been started around the world, mainly on blended gas networks but also on local grids with 100% hydrogen in the gas distribution pipelines. Only very small amounts of hydrogen exist naturally—it needs to be produced. Strictly speaking, hydrogen is not a fuel, but an energy carrier, like electricity. The energy content has to come from some other source.

The most abundant form of hydrogen is water, but to produce hydrogen from water requires substantial amounts of energy. If this could be produced sustainably, with wind or solar power for instance, this could form the basis for a low-carbon economy. To do this on an industrial scale may one day be possible, but it is a long way off.

A gas distribution center.

Today, the easiest way to produce hydrogen is to make it from natural gas using steam methane reforming (SMR). The carbon dioxide can then be separated out and stored in a carbon capture and storage (CCS) facility, for instance in depleted oil and gas fields.

Gas detection will still be necessary with hydrogen in the pipelines, as it leaks more easily than natural gas due to its smaller molecule size. Hydrogen also causes steel brittleness, prompting efforts to replace steel pipes with polyethylene. The risk of explosion remains in the event of a leak, though the risks to health and to the environment will be a thing of the past. Hydrogen in the gas grid may seem risk, but the fact is that it was a major component of town or coal gas, widely used before the transition to natural gas. Town gas is produced out of coal or naphtha and consists typically of 49% hydrogen, 29% methane, 19% carbon dioxide, and 3% carbon monoxide. Town gas is still common in some Asian countries.

Gas network surveys will remain necessary. Since hydrogen requires different sensors than those used for natural gas, new instruments will be developed over time. However, utilities will likely use a mix of natural gas and hydrogen in pipelines, meaning existing instruments will remain useful for many years.

But a note of caution may be in order. Instruments that have not been designed to work with hydrogen may give false readings with a mixed gas. Instruments may also lack Ex classification to operate in areas where high levels of hydrogen can be expected. Investing in instruments today that can meet tomorrow's requirements is a sound economic decision.

Conclusion

A large number of methods for gas detection have been developed over the years. Out of these, there are four that are mainly used in gas network surveys today. These are semiconductor, flame ionization, laser spectroscopy, and infrared detectors. The first two have been around for a long time and are based on chemical processes. Infrared and laser detection are non-contact technologies that do not process the gas as such; the gas sample is merely illuminated with light and the change in light intensity is picked up by a light sensor.

As no processing of gas is required with infrared and laser spectroscopy, the equipment is light and compact. This means that many of the requirements that the operators and the utility company have on the equipment are easy to meet. These requirements include ease of handling, portability, and convenience.

Systems based on infrared detection also have the ability to incorporate sensors to determine the type of gas, enabling the operator to carry out the entire process of surveying, detecting, for the full measurement range 0-100%, and reporting, with a single tool. This translates into higher efficiency and productivity in the surveying work.

The cost of IR has come down considerably in recent years. This technology used to be available only in high end equipment. While this is no longer the case, equipment with IR sensors is still unable to match the least costly gas detection devices on price. As a result, semiconductor sensors are often used in large numbers in organizations, while only a small number of infrared sensors may be available to operators.

This may well be false economy, as the running costs of an infrared system is lower, thanks to the much longer life of its sensor, resulting in a total cost over the life cycle that is much the same for an infrared or semiconductor instrument.

In addition, IR sensors can often detect gas in locations where a semiconductor sensor has shown no indication. A missed opportunity to find gas means higher costs for the utility company over time. This also wastes the resources that have been put into the surveying work, as operators walk the route without finding the leaks that exist.

While there may well be circumstances where semiconductor and FID detectors work just as well as IR, due to the individual circumstances on the site, utility companies would be well advised to look to the most up-to-date technology when it comes to general use.

All the current technologies have their place and there is no one technology that will solve all problems and be suitable for all situations.

About INFICON

INFICON is a leading company in development, production, and sales of instruments and equipment for leak detection. INFICON leak detection equipment is used in demanding industrial processes in production and quality control. INFICON leak detectors cover a wide variety of leak testing applications. The main customers of INFICON are manufacturers, as well as service companies for the RAC industry, the automotive industry, the semiconductor industry and manufacturers of leak testing systems. With its years of experience in leak testing and leak detection, INFICON also supports the public utilities market.

INFICON now looks back on more than 50 years of experience in leak detection technology. INFICON handles worldwide sales through production facilities in Cologne (Germany), Balzers (Liechtenstein), Linköping (Sweden), Syracuse (USA), and Shanghai (China), as well as sales offices in all the major industrialized countries and an expanded network of sales partners. In fiscal year 2023, INFICON AG and its approximately 1,600 employees achieved worldwide sales of approximately US$674 million. INFICON's registered shares (IFCN) are traded on the SIX Swiss Exchange.

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