8.16 Combustibles


Types:
A. Measurement of filament temperature or resistance in catalytic combustion sensors is most common. Thermal conductivity is used at higher concentrations. Electrochemical and semiconductor sensors can be used when hydrogen and other known gases are to be detected.
B. Flame ionization and photoionization with or without a chromatograph can be used for accurate hydrocarbon detection. Response varies and gases of concern need to be known in the design and selection phase of the project.
C. Infrared can be used for both point and area (open-path) applications. It cannot detect hydrogen.

Note: All three types are available as portable and fixed devices, and Type A is also frequently found in a personal (pocket) device version.

Materials of Construction:
Many choices exist and offer the opportunity to select an appropriate one for a given application. Stainless steel and polymer sensor heads with ceramic and metal sensors are usually offered. Various polymer and metal constructions with the appropriate optical window selections for photoionization and infrared applications are available.

Inaccuracy:
A. 5% of lower explosive limit (LEL); linearity and repeatability from 2 to 3% of LEL
B. ppm concentrations can be detected and monitored
C. ppm and low % LEL levels achievable, but vary dramatically and usually more a function of the application than the instrument

Drift:
A. 1 to 3% of LEL per month
B. No generally accepted drift range per value
C. No generally accepted drift range per value

Cost:
A battery-operated portable gas leak detector with sensing probe costs from $300 to $1000; a combined oxygen and combustibles sensor, microprocessor based, portable with diffusion sampling, costs $2500. For a permanently installed single-channel monitor with alarm or for a multichannel system, the cost per channel is $1000 to $2500. With sampled remote head installations, the installation cost of tubing can increase the per-channel cost to $3000 to $5000, and when a flame ionization or photoionization detector is used, the cost is more like $5000 to $10,000. A portable chromatograph with electrochemical detector and 50-ppb sensitivity costs about $15,000 to $20,000. Infrared systems cost about $1200 to $2700 for a point system and $7000 to $20,000 for an open-path system.

Partial List of Suppliers:
ABB (www.abb.com) (C)
American Gas and Chemical Co. Ltd. (www.amgas.com) (A, C)
Bacharach Inc. (www.bacharach-inc.com) (A)
Bascom-Turner Instruments (www.bascomturner.com) (A)
B W Technologies (www.bwtechnologies.nl or www.gasmonitors.com) (A)
Cole-Parmer Instrument Co. (www.coleparmer.com) (A)
Control Instruments Corp. (www.controlinstruments.com) (A, B)
Delphian Corp. (www.delphian.com) (A, C)
Detector Electronics Corp. (www.detronics.com) (A, C)
INTRODUCTION

The principles of operation and the applications of combustibles analyzers will be discussed in this section. These instruments are designed to detect the presence and measure the concentration of combustible gases and vapors on a continuous basis. The methods of detecting the presence of combustible gases and vapors can utilize the phenomena of catalytic combustion, electrical resistance, luminosity, thermal conductivity, infrared (IR) absorption, or gas ionization.

Of the above methods, the most widely used is catalytic combustion, where a change in the resistance or temperature of the sensing filament is caused by the catalytic combustion of the flammable gases, and this change is measured to detect the concentration of combustibles.

The second most widely used and a much newer technique is infrared. As will be seen, both techniques have both advantages and disadvantages. Most suppliers offer a variety of designs, so that the user might select the best choice for his application. The selection process usually considers cost, robustness, selectivity, poison resistance, speed of response, etc.

Selection Considerations

The most commonly used combustibles detectors are the catalytic filament units, which use a self-heated platinum wire as the catalytic surface to initiate combustion. A special portable variation of this unit is one that can be pinpointed at leaks by pointing a sample probe at the seals on manholes, tanks, or other containers that are likely to leak.

In some instruments, two filaments are provided: a catalytic combustion filament for low ranges, and a thermal conductivity filament for higher ranges. When the goal of the measurement is the detection of total hydrocarbons, or if the presence of lead, silicone, chlorinated compounds, or sulfur compounds could otherwise poison the catalytic filament, infrared and flame or photoionization analyzers should be considered.

Flame ionization instruments are discussed in Sections 8.12, 8.25, and 8.59 and involve the burning of the sample in a hydrogen flame. Since the flame of pure hydrogen contains practically no ions, even traces of organic material can be detected by the drastic rise in the number of ions in the flame.

Measuring circuits for catalytic bead-type sensors usually include the Wheatstone bridge for resistance and null-balance potentiometers with thermocouples for temperature measurements.

In addition to the discussion of the measuring means, complete loops consisting of measuring, readout, and alarm devices and their applicability are covered in the following paragraphs.

TERMINOLOGY, DEFINITIONS, AND BACKGROUND INFORMATION

In order to sustain combustion, each combustible gas or vapor requires a particular amount of oxygen. Some combustible gas mixtures ignite more easily than others (Table 8.16a). Additionally, the energy that is required to spark combustion also varies with the composition of mixtures.

Lower explosive limit (LEL): The lowest concentration of gas or vapor in air where, once ignition occurs, the gas or vapor will continue to burn after the source of ignition has been removed.

Upper explosive limit (UEL): The highest concentration of gas or vapor in air in which a flame will continue to burn after the source of ignition has been removed.

Flash point: The lowest temperature at which a flammable liquid gives off enough vapors to form a flammable or ignitable mixture with air near the surface of the liquid or within the container used. Many hazardous liquids have flash points at or below room temperatures. They are normally covered by a layer of flammable vapors that will ignite in the presence of a source of ignition.

The vaporization rates of the various liquids are a function of their vapor pressures, and vaporization rate increases with increased temperature. Flammable liquids are therefore more combustible at higher temperatures.

As can be seen from Table 8.16a, the ranges of air percentages within which some liquids and gases are flammable

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are extremely wide. In detecting the presence of such vapors or gases, their LELs are usually of most interest, and, in order to maintain safety, flammable gas and vapor concentrations must be kept below those limits.

Since air is usually the diluent and is almost always present, all concentrations above LEL are usually dangerous. Instruments are commonly calibrated with ranges in LEL units. LEL is selected as a limit on acceptable safety, because in order to reach a buildup of atmospheric concentration of flammables, which is above the UEL, the concentration must have necessarily passed through the full hazardous explosive range. Similarly, bringing the concentration back down to a safe level below the LEL, the concentration must pass again through the full hazardous explosive range.

**CATALYTIC COMBUSTION ON A HEATED FILAMENT**

When mixtures of flammable gases or vapors in air come in contact with a heated and catalytically treated, fine, uniform, homogeneous platinum filament, combustion is induced at a temperature considerably below the normal ignition temperature of the particular gas or vapor. The heat generated by the combustion is measured by sensing the change of temperature of the filament by using thermocouples or by measuring the change of resistance of the filament.

**Limitations**

One of the common limitations of catalytic combustion type analyzers is the poisoning of the filament by silicon, sulfur, chlorinated compounds, or lead compounds. When detecting the concentration of leaded gasoline vapors, which contain tetraethylead, a solid lead combustion product can form (by condensation) on the filament surface, which reduces its catalytic activity. One way to protect the filament against lead condensation is to maintain the filament at a temperature that is high enough to prevent this condensation. Compounds containing silicone can also poison the filaments.

These effects impair the life of the sensor to different extents, depending on sensor packaging. Specially packaged diffusion head sensors (to be discussed shortly) are more likely to last longer on such services than do the flowing sample type systems. Filament poisoning by chlorinated or sulfur compounds is also a serious problem.

In addition to special catalytic bead protective measures, ionization and infrared detectors should be considered as an alternate means of measurement where sensor poisoning is an issue.

A variety of filament protection means have been added to increase the poison resistance of the sensors. Figure 8.16b illustrates one such design, in which the catalyst support consists of a low-density macroporous structure that surrounds the platinum wire deep within the bead assembly. This provides both protection and an increased catalyst surface area. The reported result is a 10-fold or better increase in sensor life expectancy on such services as hexamethyldisiloxane (HMDS), leaded gasoline, Freon-12, ethyl mercaptan, and the like.

Life expectancies are usually defined in terms of exposure concentration hours. One high-concentration exposure of a poison has been known to knock out a sensor, and many do not respond in a fail-safe way. For this reason, nonpoisoning techniques should be considered, when poisoning is an issue.

---

**TABLE 8.16a**

*Properties of Some Flammable Liquids and Gases*

<table>
<thead>
<tr>
<th>Material</th>
<th>Chemical Formula</th>
<th>Specific Gravity Air = 1</th>
<th>Ignition Temperature in Air</th>
<th>Flammability Limits in Air (% vol.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(°F)</td>
<td>Lower</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(°C)</td>
<td>Upper</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>0.55</td>
<td>1193</td>
<td>645</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Blend</td>
<td>0.65</td>
<td>1163</td>
<td>628</td>
</tr>
<tr>
<td>Ethane</td>
<td>C₂H₆</td>
<td>1.04</td>
<td>993–1101</td>
<td>534–596</td>
</tr>
<tr>
<td>Propane</td>
<td>C₃H₈</td>
<td>1.56</td>
<td>957–1090</td>
<td>514–588</td>
</tr>
<tr>
<td>Butane</td>
<td>C₄H₁₀</td>
<td>2.01</td>
<td>912–1056</td>
<td>489–569</td>
</tr>
<tr>
<td>Toluene</td>
<td>C₆H₆</td>
<td>3.14</td>
<td>1026–1031</td>
<td>552–555</td>
</tr>
<tr>
<td>Gasoline A blend</td>
<td></td>
<td>3–4.00</td>
<td>632</td>
<td>333</td>
</tr>
<tr>
<td>Acetone</td>
<td>C₂H₅O</td>
<td>2.00</td>
<td>1042</td>
<td>561</td>
</tr>
<tr>
<td>Benzene</td>
<td>C₆H₆</td>
<td>2.77</td>
<td>968</td>
<td>520</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>CO</td>
<td>0.97</td>
<td>1191–1216</td>
<td>644–658</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>0.07</td>
<td>1076–1094</td>
<td>580–590</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>H₂S</td>
<td>1.18</td>
<td>655–714</td>
<td>346–379</td>
</tr>
</tbody>
</table>

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Whether the measurement is based on the change of temperature or resistance, it is convenient to use two filaments. One filament is constantly exposed to the sample (detector filament). The other is hermetically sealed in an inert atmosphere (reference filament). The reference filament is not activated with a catalyst, but its temperature resistance characteristics are similar to those of the detector filament. Its inert surface is usually exposed to the sample in a way that simplifies measurement compensation for changes in sample temperature, flow, and other potentially interfering characteristics.

The active detector filament and often the inert reference filament are mounted in a measuring chamber that is relatively large with respect to the size of the filaments. This permits a relatively large volume of sample to pass through the instrument, which ensures that the measurement filament is in contact with the sample and is measuring the current sample conditions. This design still only allows a relatively small portion of the sample to come in contact with the sensor, thereby increasing its useful life.

**Thermocouple Detector**  In this design two thermocouples are used. One thermocouple is bonded to the reference filament, the other to the detector filament. The two thermocouples are connected in series opposition, so that a differential electromotive force (emf) is developed and applied at the terminals of the potentiometric circuit (see Figure 8.16c).

When a combustible gas or vapor is admitted to the measuring chamber, combustion increases the temperature of the detector filament, resulting in an increased emf for the thermocouple bonded to it. The temperature of the reference filament remains the same as the sample temperature, since no combustion occurs on its bead. The potentiometric transmitter or the indicating, recording, and alarming instruments respond to the resultant differential emf.

**Wheatstone Bridge Detector**  A Wheatstone bridge is typically used for resistance measurement. Its operation is based on the comparison of an unknown resistance to a resistor of known value, as shown in Figure 8.16d.

In this figure,

\[
R_1 = R_2 = \text{constant} \\
R_3 = \text{reference} \\
R_4 = \text{sensor’s measured resistance (compared to } R_3) \\
\]

For current I to be zero,

\[
V_1 = V_2 \\
V_1 = \frac{R_3}{R_1 + R_3} V \\
V_2 = \frac{R_4}{R_2 + R_4} V \\
\frac{R_4}{R_1 + R_3} = \frac{R_4}{R_2 + R_4} \\
R_1 R_2 + R_3 R_4 = R_1 R_3 + R_4 R_3 \\
R_3 R_2 = R_1 R_4 \\
R_3 = R_4
\]

**FIG. 8.16b**  Porous bead construction provides poison resistance to catalytic combustion-type sensor.

**FIG. 8.16c**  Thermocouple detector.
In the catalytic bead-type combustibles detectors, \( R_3 \) is the reference filament and \( R_4 \) the detector filament. If the sample contains no combustibles, the bridge circuit remains in balance. If, however, there are combustibles in the sample, the combustion will cause heating of the detector filament. The change of resistance of the detector filament due to heating will result in unbalancing the bridge in proportion to the amount of additional heating caused by the combustible material in the sample. The output voltage of the bridge, which is in proportion to the concentration of combustibles in the sample, is detected by a transmitter or is used to operate indicating or recording instruments or to actuate alarms.

**Diffusion Head Analyzers**

In contrast to most analyzers, the diffusion head analyzer does not require a sampling pump or a controlled sample flow. Rather, the diffusion head type analyzer generates sample movement by diffusion, density difference, convection, or similar effects.

Diffusion-type catalytic bead sensors are available in poison-resistant designs and in intrinsically safe or explosion-proof construction. Figure 8.16e illustrates a conduit-mounted, diffusion type transmitter with 4- to 20-mADC output. This unit is provided with a stainless steel sensor head and a polyvinyl chloride (PVC)-coated anodized aluminum conduit. Diffusion sensors can be used in still air or provided with plant air aspirators or pumps to draw a sample flow over the sensor.

Semiconductor sensors are also available in diffusion head designs. Semiconductor sensors respond to a combustible (target) gas that has been absorbed onto the doped surface of a metal oxide semiconductor, by displaying a change in the resistance of the semiconductor surface. By varying the doping layer, the manufacturer can vary the responsiveness of the detector to various materials. As with the catalyst bead surface effect sensors, poisoning is an issue.

Diffusion type electrochemical and semiconductor sensors are also available to detect hydrogen, using a sensor that is not responsive to other hydrocarbons. This is desirable in semiconductor manufacturing plants, where it is a continual task to monitor for hydrogen leaks.

**Sampling System**

When diffusion-based systems are not adequate, active sampling systems may be required. The sampling systems should be carefully designed. Most importantly, the sample admitted into the analyzing cell should be wholly representative of the combustible components that are present in the monitored area. The sample should also be free of particulate matter and moisture.

In applications where the sample is at excessively high or low temperatures, it is advisable to use sample conditioners. This is particularly important if the sample is hot and humid and tends to cool while passing through the sampling line. The reason is that cooling would result in condensation,
which, in turn, could block the sample line or introduce a time lag in the analyzer response. The sampling system should permit transport of the sample to the analyzer cell at the proper rate and minimum transportation time lag.

Since the vapors of all flammable liquids are heavier than air, detection of such vapors requires that the probes be located near the ground. Gases like hydrogen are lighter than air and require elevated probe locations. In dealing with gases, their molecular weight (heavier or lighter than air) will decide whether sampling probes should be near the ground or the ceiling of the monitored area. This may seem trivial, but is still worth mentioning.

**Accessories**

It is important to make sure to avoid the propagation of flame when the sampled air containing an explosive mixture of gas is ignited on the detector filament. This is not a problem when the concentrations are low or below the LEL, but a leak or spill can result in concentrations exceeding the LEL (within the explosive concentration envelope), and this leak or spill can become a source of ignition in that area of the plant.

Flashback arrestors of coiled copper screen or sintered metal are usually provided at the inlets and outlets of filament chambers. These prevent the energy that is liberated by combustion from propagating to the outside.

Samples containing hydrogen or acetylene, with concentrations of oxygen in excess of that found in normal air, have high rates of flame propagation. In such mixtures, standard flame arrestors cannot dissipate the energy liberated by combustion and, therefore, special flame arrestors have to be used.

To ensure safe operation of the detectors, a variety of alarms are provided. These alarms can signal filament failure, power failure, alarm relay failure, and low sample flow rates (not available for diffusion head type designs). Many alarms do not detect sensor poisoning as a sensor failure. If in a particular application poisoning is likely, one should make sure to thoroughly understand the functioning of the alarms before issuing a purchase order.

To ensure that an adequate amount of sample passes through the measuring chamber, flow meters (rotameters) and needle valves can be provided for all except the diffusion head type of units.

**SELECTION OF COMPLETE INSTALLATION**

The selection is usually made from among three basic systems, and the choice is based on the plant layout, the required speed of response, and economic considerations. The three choices are 1) remote head (continuous measurement, continuous readout); 2) multiple head (continuous measurement, sequential readout); and 3) tube sampling system (sequential measurement, continuous readout).

**Remote Head System**

The remote head system offers the maximum application flexibility, but it does that at the highest initial cost. As shown in Figure 8.16f, this system typically consists of a number of locally mounted analyzer heads (suitable for hazardous areas) and an equal number of panel-mounted control and readout devices. The maximum number of areas monitored from one central panel is a function of the capacity of the sample pumps (or aspirators) and of the physical size of the panel. Because the analyzer heads are located in the monitored areas, the speed of response is fast.

Samples are continuously drawn, and the electrical signal corresponding to the measured combustible concentration is instantaneously transmitted to the control unit. The used sample is continuously withdrawn from the analyzer head through the tubing to the aspirator and is exhausted. Since the analyzer head is in the monitored area, it can be temperature controlled to prevent condensation. The remote head system should be selected where fast response is essential and justifies the cost.

**Multiple Head System**

Multiple head systems are used where at least four or more areas are monitored and a cyclic readout with the accompanying time delay can be tolerated. The multiple head system consists of a number of analyzer heads (one in each area to be monitored), one control unit with readout, and one or more
sample pumps. The electrical circuit incorporates a single readout device common to all analyzing cells.

A separate alarm unit is associated with each detecting unit. The sample is drawn continuously to each sample chamber. The pump continuously withdraws the expended sample. The electrical output of each unit is transmitted to the panel, where sequential readout is provided. The dwell time for each area is typically 10 sec; i.e., if four areas are being monitored, 40 sec elapse between subsequent readings for a given area.

This system is less costly than the remote head arrangement, but it can be used only where the combustible concentration buildup is likely to occur at a slow rate (see Figure 8.16g).

**Tube Sampling System**

The tube sampling system consists of one analyzer head, one readout device, and a sample pump. This may be the least expensive arrangement, but sometimes the tubing cost (purchase and installation) can exceed the amount saved on the instrumentation. Samples from different areas are sequentially admitted to the common analyzer head. The electrical signal is then transmitted to the readout device.

A sample selector unit, consisting of time-sequenced solenoid valves, is arranged to admit one sample to the detector and connect all other sample lines to the sample pump. The sample is drawn continuously through each line. The sample selector is located at the analyzer head; thus lag time between successive analysis and delay due to sample travel is minimized, since a fresh sample is always present at the sample selector.

One possible means of improving the system is to use separate pumps for the sample analyzed and for those that are bypassing the detector. A clean gas purge can be provided after each analysis to prevent an erroneous reading caused by residual carryover in this type of system (see Figure 8.16h).

In order to eliminate the problems associated with condensation in the sample tubes, these arrangements should be used only where true gases and vapors with boiling points well below ambient temperatures are to be detected.

Tube sampling systems usually have a 30-sec dwell time per hour. Therefore, they should be considered only if such slow response can be tolerated. For additional safety, readout devices can be calibrated with full-scale ranges as low as 0 to 20% LEL. The alarm switches contained in the measuring circuit are used to actuate alarms, start ventilation, shut down sparking devices, and so on.

These systems are found in coating ovens, solvent recovery, and soybean extraction plants, just to mention a few typical applications.

**CONCLUSIONS FOR CATALYTIC DETECTORS**

In the diffusion head type analyzer, the use of sample pump or aspirator is eliminated. Dispensing with any moving part increases reliability. Therefore, the use of a diffusion head analyzer is recommended wherever a flowing sample is not needed or where clean, dry samples are to be analyzed.

Large amounts of particular matter, moisture, and dust can and will cause plugging, which is difficult to detect in diffusion head analyzers since they cannot be furnished with low-sample-flow alarms.
In addition to the above, the selection parameters should include the considerations of plant layout, required speed of response, rate of gas buildup, and economy.

Comparing the Wheatstone and the thermocouple cells, the following should be considered. Whereas Wheatstone bridge cells use a fine, helical filament, the thermocouple cell uses a heavy, straight filament with a much longer useful life. Further, the evaporation on the exposed filament results in a constant change of base resistance of the filament.

In the Wheatstone bridge circuit, this change of base resistance produces a shifting of zero and requires frequent rebalancing of the bridge. The temperature change measured by the thermocouple is independent of filament deterioration. Thus, for the thermocouple detector, the zero drift is reduced by the thermocouple is independent of filament deterioration. Further, the evaporation on the exposed filament results in a constant change of base resistance of the filament.

In the Wheatstone bridge circuit, this change of base resistance produces a shifting of zero and requires frequent rebalancing of the bridge. The temperature change measured by the thermocouple is independent of filament deterioration. Thus, for the thermocouple detector, the zero drift is reduced by the thermocouple is independent of filament deterioration. Further, the evaporation on the exposed filament results in a constant change of base resistance of the filament.

### FLAME IONIZATION AND PHOTOIONIZATION DETECTORS

The theory and operation of flame ionization detectors (FIDs) and photoionization detectors (PIDs) are described in greater detail in the sections describing chromatography (Section 8.12), hydrocarbon analyzers (Section 8.25), and total carbon analyzers (Section 8.58). Both detectors are commonly used in chromatography and have been utilized for combustibles monitoring in both portable and fixed installation designs.

### Flame Ionization Detectors

The FID actually burns the sample in a hydrogen flame. In a simple combustibles application, no columns or carrier gases are used and the sample is used as an oxygen/air source. The sample is consumed during the combustion process. In a chromatography application, extremely clean air (as the source of oxygen) is introduced into the chromatographic column’s effluent (which contains the sample) and is sent into the flame.

In these configurations, the only variable sources for ion formation in the flame are the components of interest in the column effluent or combustible contaminants in the sample. The appropriate combustible materials in the sample form ions in the flame. An oxygen-rich hydrogen and air flame basically exhausts water, nitrogen, and unconsumed oxygen. None of these are ionic in nature.

A charged electrical field is positioned across the flame, and it can conduct a current utilizing available ions in the flame as its conductor. When most combustible materials are introduced into the flame, they produce ions in their combustion products, and these are detected by the increased flow of current across the electric field (flame).

This detection method has been called a carbon counter, because of its response profile. It essentially responds to each carbon atom in the sample that has been consumed and used to form an ion in the flame. For example, one molecule of ethane has nearly twice the response of one molecule of methane.

This has both advantages and disadvantages in combustibles monitoring applications. The sensor is very sensitive to larger organic molecules. Its response to a mixture that may vary in composition can be difficult to calibrate, since different components have different LEL concentrations (see Table 8.16.a) and different detector responses. Specific and unique calibrations may be needed for each sample or application.

The instrument cannot detect hydrogen (no ions are formed in the flame). These advantages and disadvantages are listed only as examples and are by no means exhaustive. Each application needs to be studied in full detail prior to selecting an appropriate measurement method.

### Photoionization Detectors

The PID utilizes a high-energy light source (normally ultraviolet (UV) radiation) as its source of ionization and measures the resulting flow of a current through the ionized sample, across a charged electric field. This detector also has several advantages and disadvantages.

It does not require auxiliary utilities (fuel gases). It can easily be made portable. It does not necessarily respond (depending on the ionization source chosen) to many potential components of interest. It requires frequent calibration and maintenance (as radiation sources deteriorate). Several different lamp strengths are available, and an appropriate one needs to be selected for a given sample. The ionization potential (IP) (eV) of each molecule needs to be matched to the strength of the ionization source being used.

For example, acetone has an IP of 9.71 and can be ionized by most common lamps having IPs of 9.8, 10.6, or 11.7 eV. Of course, each different lamp has a different response factor for acetone, while methanol has an IP of 10.85 and therefore responds only to the 11.7-eV lamp. Methane has an IP of 12.51 and would not respond to any of these lamps.

These advantages and disadvantages are only given as an example and by no means are exhaustive. As mentioned previously, each application needs to be fully studied prior to selecting an appropriate measurement method.

### INFRARED COMBUSTIBLES DETECTORS

Infrared combustibles monitors are primarily a simplified and special-purpose version of an infrared filter photometer. In cases of very simple applications, they have even been used as a substitute for an infrared photometer and actually used to monitor a process sample that was introduced to them. For this reason, they have sometimes been called the poor man’s IR analyzer.

Infrared photometers and spectrometers, and the technologies that they are based on, are discussed in great detail in Section 8.27, “Infrared and Near-Infrared Analyzers.”
Basically, an infrared beam of radiation that will excite the target gas molecules is used to measure the concentration of combustible gas molecules in the sample. For combustible gas monitoring, the radiation wavelength chosen is usually one that is absorbed by the C—H bond of most hydrocarbon molecules.

When the beam of radiation excites the molecules, a portion of its energy is absorbed and the amount of energy absorbed (lost to the beam) can be correlated to the amount of the target gas in the sample. Because many other factors could impact the intensity of the selected beam of IR radiation, these instruments usually also monitor a reference (another) wavelength of radiation that is not absorbed by the combustible gas, but is influenced by several of the other factors that could affect the measured beam’s intensity.

Infrared combustibles monitoring instruments are available as both point and open-path (area) monitors. Even the point monitors are sometimes called open, because the IR measurement cell is actually open to the atmosphere. They typically rely on atmospheric diffusion to supply the sample and, consequently, the cell must be open to allow the diffusion of sample into the measurement area to take place.

Open-path instruments, on the other hand, actually use a large, open atmospheric path as their measurement cell (tens to hundreds of meters). IR combustibles monitors are a relatively new innovation in the field of combustibles monitoring, but they have already gained wide acceptance as a niche technology. They perform well on many samples that other technologies have problems with. This is especially true for many gases that can poison other combustibles sensors and for monitoring requirements where the likely points of leakage are difficult or impossible to predict.

Diatomic molecules like hydrogen, oxygen, and nitrogen have no usable IR absorbance and cannot be detected by these IR monitors. Consequently, IR combustibles monitoring systems should not be used for hydrogen or hydrogen-containing combustibles mixtures. The response of each potential gas or mixture to the detection method needs to be considered when selecting a monitor.

---

**Point Infrared Systems**

Point IR systems monitor the sample at the measuring head, just like the other previously discussed point style combustibles monitors. If it is intended to monitor a sample that is not diffusing into the sensor head and is not located immediately adjacent to it, the sample must be transported to the sample head using a sample transport system. A couple of point IR designs are shown in Figures 8.16i and 8.16j.

Figure 8.16i depicts a reflector style point sensor design, where the IR source and detector are both located on the same side of the sample chamber. The measurement and reference IR beams are transmitted, reflected off of a mirrored reflector, and pass through the sample twice during the analysis. With this type of sensor there is no chemical reaction of the gas, and as such, the materials that poisoned catalytic beads cannot poison these sensors.

But nothing is perfect or without its own Achilles’ heel. For an IR point monitor to do its job, the IR radiation beam must pass through the sample and be partially absorbed by the sample of interest before reaching the detector. If the sample becomes opaque to the IR measurement beam or if the optical path is otherwise blocked (condensation or dirt on the windows, heavy fog, dust, etc.), the instrument can be rendered inoperable. Typically, the mirror and windowed instrument compartment are purged or maintained at

---

**FIG. 8.16i**

IR reflector style point sensor. (Courtesy of Draeger Safety Inc.)

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**FIG. 8.16j**

IR one-pass point sensor. (Courtesy of General Monitors Inc.)
a temperature that is intended to prevent condensation on either the window or mirror.

Figure 8.16j depicts a one-pass point IR sensor design, where the IR source and detector are located on opposite sides of the sample chamber. This analyzer is very much analogous to the reflector style sensor head depicted in Figure 8.16i, except that the beam of radiation only passes through the sample once.

In the reflector style, the beam has the opportunity to interact with the sample twice, and if all else was equal and good, the instrument should depict twice the sensitivity (or twice the interference to things like fog, dust, etc.). In real life, the sensitivities are usually not that different between the different designs, and the benefits are more often expressed in the form of a smaller sensor head or other geometric benefits.

Area (Open-Path) Infrared Systems

All of the previously covered combustibles monitoring technologies can be classified as point monitoring systems. They only measure the atmosphere at the points where they have been located (the gas of interest diffuses to a sensor) or sampled from. To monitor a large area, one would have to locate many monitors (points) and hope that they represent the area’s general atmosphere.

Open-path IR combustibles monitors project their IR beams in a path that is typically 10 to 200 m in length and monitor all of the combustibles in that path. This is not really an area (more of a line or path) detector, but the value it determines can be viewed as more representative of an area value, and few instruments could provide a value that more nearly represents an area than would be needed with point monitors.

Figure 8.16k depicts some of the conceptual differences between point and open-path applications. The figure shows examples of leak detection applications under both no-wind and mild wind conditions. It can be seen that the leak cloud shape varies as a function of atmospheric conditions. Leak cloud shapes also vary as a function of the composition and the conditions of the sample.

Lighter and hotter gases rise faster, and samples under different pressures produce different rates of release and dispersion. Therefore, it is very difficult to locate a sensor (point

![Fig. 8.16k](IR open-path vs. point monitoring concept. (Courtesy of General Monitors Inc.))
or open-path) in a way that will always accurately measure and detect a leak, unless it is located almost exactly at the source of the leak.

Both leak examples in Figure 8.16k show the use of both a point and an open-path monitor. It is easy to see the benefit one can gain by locating a good point monitor at a potential leak source. By so doing, one would get both an earlier and quicker detection, as the sample concentration is always higher closer to the leak.

It is also easy to see the benefits of locating a single open-path monitor along a pipeline that may contain many potential leak sources, as opposed to installing many point sensors, which would be very costly and impractical. Open-path sensors can also better cover a general area, where the positions of potential leak sources may be difficult to predict. Similar benefits can be visualized regarding other applications, like perimeter monitoring, room monitoring, fence line monitoring, or other general-area monitoring tasks.

It is important to note that the point and open-path techniques utilize different reporting values. Point techniques utilize parts per million (ppm) or percent LEL (%LEL) values, as described in the definitions at the beginning of this section and as listed in Table 8.16a. Open-path techniques utilize the units of parts per million or LEL meters (ppm.m or LEL.m). These will be discussed in more detail later in this section. It is fair to say that in most applications, open-path monitors are used more to detect leaks than to determine the absolute degree of hazard associated with the leak. This is because of the various leak cloud shapes that could exist and the way the instruments add or average the concentrations along their path.

**Hydrocarbon Gases in the Atmosphere**

Properly applied open-path monitors can be effective in monitoring combustible hydrocarbon gases in the atmosphere. Figure 8.16l shows an example of a typical open-path monitor. This installation involves installing two field devices. In this example, they are the source and the receiver or detector sections of the monitoring instrument. In other examples, they may consist of the instrument (source and detector) and a reflector.

In all cases, proper positioning and alignments are crucial to the success of the application. The beam must be positioned in a way that will enable it to detect the leaks of interest. The alignment is typically done with the aid of a vendor-supplied or recommended rifle scope that is mounted on one of the sections of the unit; using it helps in precisely aligning the beam, so that it properly hits the other unit.

The instrument needs to be located not only where it can make the best measurement of the leak, but also where it can perform. It must not be located where it can be exposed to shock or vibration, because this could make the alignment unstable or impossible. The monitor also must not be located where people, cars, or other equipment can block the beam.

Figure 8.16m depicts how an open-path instrument can compensate for partial blockages of its beam by light-obscuring interference, such as rain, fog, dust, etc. Essentially, it calculates the ratio of the measurement and the reference radiation signal. Most partially obscuring interferences will reduce both signals to the same extent. Therefore, the ratio of the signals is relatively unaffected by the interfering obstruction. On the other hand, the presence of a combustible gas will reduce only the measurement signal and therefore will result in a change in the ratio of the two radiation signals. This naturally is not the case if the signals are totally or nearly totally blocked. In that case, the instrument sensitivity and ability to detect a combustible gas are partially or completely lost.

Sunlight, flames, and many other light sources also produce infrared radiation. To reduce or eliminate their effects on the performance of IR instruments, choppers, filters, focusing optics, digital signal processing techniques, and other aids are utilized. In general, these miscellaneous IR sources do not interfere with the performance of today’s IR type combustibles monitors. Yet, under extreme situations, they can still reduce sensitivity, by swamping the detector with too much radiation, and consequently, they should be considered when designing the field installation.

**FIG. 8.16l**

A single-pass, open-path IR system. (Courtesy of General Monitors Inc.)
8.16 Combustibles

Point Measurement

The open-path IR systems monitor the concentration over the length of their optical path, but how can they be used to measure the concentration at any one point along this path? Do they operate like radar and actually monitor the concentrations at various points along the optical path? No, they do not. They essentially measure the number (concentration) of combustible gas molecules along the path in an integrated or cumulative fashion and report a number that incorporates the dimensions of both the concentration and distance.

Figure 8.16n illustrates how these instruments measure and report their readings. It should be kept in mind that the measurement is along a beam or path and, therefore, it is not detecting an area or a point. Percent or parts per million (ppm) readings are obtained by integrating the product of the concentration of the gas (along the length of the IR beam) by the length of the cloud (along the optical path).

In Figure 8.16n, there are three clouds in the optical path of the monitor. Each cloud has a different gas concentration and size, but all three are equal in LEL-meter units. In terms of their open-path reporting dimensions (100% × 1 m = 50% × 2 m = 10% × 10 m = 1 LEL·m each), if all three clouds were in the optical path simultaneously, the instrument would report the total presence of combustible gases as 3 LEL·m.

Clearly, the 1 m 100% LEL cloud is potentially explosive and the most dangerous of the three, but this method of monitoring does allow one to distinguishing between them. It cannot distinguish between small clouds of high concentration and large clouds of low concentration. It simply measures the total amount of target gas in its optical path. For this reason, the use and applicability of open-path IR combustibles monitoring is limited. Yet, this sensor still fills a niche market, and it can make some difficult monitoring applications feasible and practical.

All of the combustibles monitoring technologies reviewed in this section have strengths and weaknesses. Each has some advantages and disadvantages relative to the others. It is up to the user and the supplier to work together in evaluating these differences and picking the most appropriate technology for a given application.

Bibliography


