CHAPTER 2

Gas Evolution and Measurement

The chapter covers issues relating to gas evolution and dispersion. It also describes the principles, uses and limitations of portable and fixed gas detection equipment and provides practical guidance for gas testing operations.

2.1 Hydrocarbon gas evolution and dispersion

2.1.1 Introduction

During cargo handling and associated operations, enough petroleum gas is often expelled from cargo tank vents to create flammable gas mixtures in the atmosphere outside the tanks. It is essential that these flammable gas mixtures are not exposed to a source of ignition. In most cases, this means eliminating the source of ignition or ensuring there are barriers, e.g. closed doors and ports, between the gas and potential sources of ignition.

A further safeguard should be introduced if operations can be arranged so that petroleum gas issuing from vents is dispersed well enough to prevent flammable gas mixtures reaching any areas where sources of ignition may exist.

Volatile cargoes with a high vapour pressure are most likely to result in flammable atmospheres outside the tanks. Examples are:

- Crude oil.
- Motor and aviation gasolines.
- Natural gasolines.
- Light distillate feedstocks and naphtha.

The gases from these petroleum liquids are denser than air, which has an important bearing on how they behave inside and outside the tanks (see section 1.3).

Gas will be evolved by loading, cargo standing in full tanks or part-filled tanks (including slop tanks), evaporation of tank residues after discharge and COW. Vented gas is evolved within the tanks and the way it evolves affects the concentration when vented and the time it takes for a high concentration to vent.

Whether air or IG, the initial tank atmosphere has no bearing on gas evolution or venting.

2.1.2 Gas evolution and venting

2.1.2.1 Evolution during loading

As a high vapour pressure petroleum cargo enters an empty gas free tank, the gas rapidly evolves. Because of its high density, the gas forms a layer at the bottom of the tank that rises with the oil surface as the tank is filled. Once it has been formed, the depth of the layer increases only slowly over the time it normally takes to fill a tank, although ultimately an equilibrium gas mixture is established throughout the vapour space.

The volume and concentration of gas forming this layer at the beginning of loading depends on many factors, including the:

- TVP of the cargo.
- Amount of splashing as the oil enters the tank.
- Time required to load the tank.
- Occurrence of a partial vacuum in the loading line.

The gas concentration in the layer varies with distance above the liquid surface. Close to the surface, its value closely relates to the TVP of the adjoining liquid. For example, if the TVP is 0.75 bar, the gas concentration just above the surface is about 75% by volume. If the tank was originally gas free, then the gas concentration well above the surface will be small. To consider further the influence of gas layer depth, it is necessary to define this layer.

When considering the dispersion of gases outside cargo tanks, only high hydrocarbon concentrations in the vented gas are relevant. For this purpose, the gas layer depth will be taken as the distance from the liquid surface to the level above it where the gas concentration is 50% by volume. Remember that hydrocarbon gas will still be detectable at heights above the liquid surface several times the layer depth defined in this way.

Most high vapour pressure cargoes give rise to a gas layer with a depth, in these terms, of less than one metre. The precise depth depends on the factors above and most of the advice on vented gas in this guide is intended for such cargoes. Gas layers greater than one metre in depth may be encountered if the cargo TVP is high enough. Cargoes that create these deeper gas layers may require special precautions (see sections 2.2.2 and 12.1.8).

2.1.2.2 Venting during the loading of cargo

As the liquid rises in the tank, the hydrocarbon gas layer rises with it. Above this layer, the atmosphere originally present in the tank remains almost unchanged. It is this gas that enters the venting system in the early stages of loading. In an initially gas free tank, the gas vented at first is mainly air (or IG) with a hydrocarbon concentration below the LFL. As loading proceeds, the hydrocarbon content of the vented gas increases.

Concentrations of 30–50% by volume of hydrocarbons are quite usual in the vented gas towards the end of loading, although the very high concentration immediately above the liquid surface remains in the final ullage space on completion of loading.

Evaporation then continues until an equilibrium hydrocarbon gas concentration is established throughout the ullage space. This may be very high, depending on the cargo composition and temperature. Values as high as 90–95% by volume have been seen with crude oils. However, this gas is only vented by breathing of the tank, and so intermittently. When the oil is discharged, this

very dense gas mixture travels to the bottom of the tank with the descending liquid surface and may contribute to the gas vented during the next operation in the tank. If the tank is not initially gas free, the hydrocarbon gas concentration in the vented gas during loading depends on the previous history of the tank. For example:

- In an unwashed crude oil tank that is to be loaded soon after discharge of a previous cargo, a layer of highly concentrated gas sits at the bottom of the tank, with hardly any hydrocarbon gas above it. This gas is expelled immediately ahead of the layer that is formed as fresh cargo enters the tank.
- In an unwashed crude oil tank after a long ballast voyage, a homogeneous hydrocarbon gas concentration of up to 10% by volume exists throughout the tank. When the tank is next loaded, this gas is expelled until the concentrated gas layer immediately above the liquid surface begins to exert its influence. This concentrated layer then dominates the composition of the vented gas.
- In a crude oil tank that has been crude oil washed but not then purged with IG or gas freed, a uniform gas concentration exists throughout the tank. Depending on the crude oil used and its temperature, this concentration is usually well above the flammable range and may be as high as 40% by volume. This mixture is displaced from the tank throughout the next loading until the, possibly even richer, gas next to the liquid surface approaches the top of the tank.
- Shortly after the discharge of a motor or aviation gasoline cargo, there is a layer at the bottom of the tank where concentrations of 30–40% by volume of hydrocarbons have been measured. If the tank is loaded at this stage, the gas enters the venting system immediately ahead of the concentrated layer formed by the next cargo.
- In motor or aviation gasoline tanks that have not been gas freed, uniform hydrocarbon gas concentrations as high as 40% by volume have been measured throughout the tanks. This concentration is expelled to the vent system throughout the next loading until the concentrated layer above the liquid surface approaches the top of the tank.

Note that in all loading operations, whether the tank is initially gas free or not, very high gas concentrations enter the venting system towards completion of loading.

2.1.2.3 Ballasting into a cargo tank

Where ballasting into cargo tanks is required (e.g. heavy weather ballast), the atmosphere will be similar to the atmosphere before loading an oil cargo, given a similar tank history. The gas concentration expected to enter the venting system during ballasting will compare to that in the examples in section 2.1.2.2. If it is necessary for tankers using COW to load ballast into a cargo tank before departure, some ports require controls on vapour emissions to the atmosphere. This is done by containing the vapour in empty cargo tanks, by simultaneous ballasting and cargo discharge, or by other approved means.

2.1.2.4 Inert Gas purging

If IG purging is carried out by the displacement method (see section 11.1.4), any dense concentrated hydrocarbon layer at the bottom of the tank is expelled in the early stages. The remainder of the tank atmosphere follows as it is pressed downwards by the IG. If there is a uniformly high concentration throughout the tank, e.g. after COW, the hydrocarbon concentration of the vented gas remains high throughout the purging process until the IG reaches the bottom of the tank.

If IG purging is being carried out by the dilution method (see section 11.1.4), the gas concentration at the outlet is highest at the beginning of the operation and falls continuously as it proceeds.

2.1.2.5 Gas freeing

In a gas freeing operation, air is delivered into the tank where it mixes with the existing tank atmosphere. It will also tend to mix together any layers. The resulting mixture is expelled to the outside atmosphere. Because the process is one of continuous dilution with the air, the highest hydrocarbon concentration is vented at the beginning of gas freeing and then decreases. For example, on a non-inerted tanker, gas freeing a motor gasoline tank can give initial concentrations as high as 40% by volume, although in most circumstances the concentration in the vented gas is much lower even at the start.

On inerted tankers, after purging to remove hydrocarbon vapour before gas freeing, the initial concentration will be less than 2% by volume (Marine Environment Protection Committee (MEPC) 250(66), Paragraph 6; *International Convention for the Safety of Life at Sea (SOLAS)* Chapter VIII-5).

2.1.3 Gas dispersion

Whether the hydrocarbon gas at the outlet is mixed with air or IG will have no bearing on the dispersion of the gas after it has left the outlet.

As the hydrocarbon gas displaced during loading, ballasting, gas freeing or purging emerges from the vent or vents on the tanker, it immediately starts to mix with the atmosphere.

The hydrocarbon concentration is progressively reduced until, at some distance from the vent, it passes below the LFL. At any point below the LFL, it is no longer a flammability hazard because it cannot be ignited. However, a flammable zone exists in the vicinity of any vent, where the gas concentration is above the LFL (see section 1.2).

Fire and explosion are potential dangers if this flammable zone reaches any area where sources of ignition may exist, e.g.:

- Superstructures and accommodation blocks where the gas can enter through doors, ports or ventilation intakes.
- The cargo deck and adjacent jetty, which are work areas even though they are usually regarded as free of sources of ignition.
- Adjacent vessels such as lightering tankers, bunker and stores craft, pilot and crew-transfer boats.

2.1.3.1 The dispersion process

A mixture of hydrocarbon gas and air (or IG), emerging vertically from an outlet, rises under its own momentum as a plume above the outlet. If there is no wind, the plume remains vertical, otherwise it is bent over in the downwind direction. The rise of the plume due to its momentum is opposed by a tendency to sink because its density is greater than that of the surrounding air.

The flow velocity of the issuing gas is at its maximum as it passes through the outlet and decreases as air is drawn into the plume. This air also reduces the hydrocarbon gas concentration and, therefore, the gas density in the plume. The progressive plume decreases in velocity, hydrocarbon concentration and density, together with the wind speed and other meteorological factors, determine the final shape of the plume and the flammable zone.

The type of vent used affects the dispersion of the plume. During normal loading operations, the venting will be either via:

- A high velocity vent installed at a minimum height of two metres above the deck, which causes the vapour to be vented at a speed of 30m/sec irrespective of the loading rate of the cargo.
- A vent riser with a minimum height of six metres above the deck.

These high velocity vents and risers may not be placed closer than ten metres to any accommodation block air intakes so that any vapours are safely dispersed before they reach them.

2.1.3.2 Wind speed

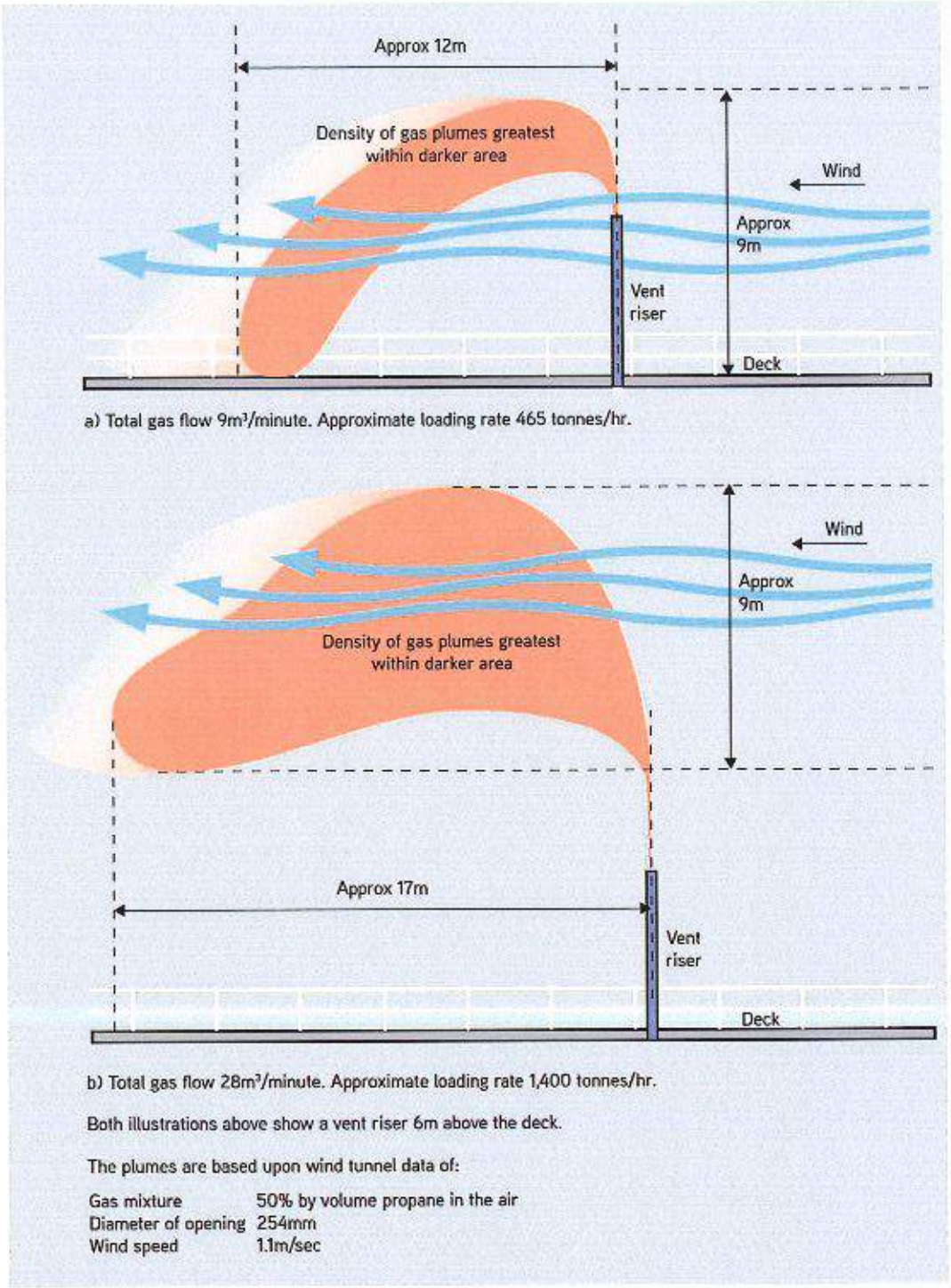
Low wind speeds inhibit the dispersion of hydrocarbon gas/air mixtures. This observation is based on experience on tankers, although little experimental work has been done to obtain quantitative information on the effect of wind speed. Much depends upon the quantity of gas being vented and how it is vented, but experience at terminals has shown that at wind speeds above 5m/sec (ten knots), dispersion is enough to minimise flammability risk. However, this wind speed is an indication only and each operation should be assessed on a case by case basis.

2.1.3.3 Rate of flow of gas

As the flow rate of a hydrocarbon gas/air mixture of fixed composition increases through a given opening, several effects come into play. First, the rate of emission of the hydrocarbon constituent increases in proportion to the total gas/airflow rate, so the distance the plume travels before it is diluted to the LFL should be greater. However, the higher the velocity, the more efficient the mixing of the initially hydrocarbon-rich gas with the air, which tends to counterbalance the first effect.

In addition, at low rates of total gas/airflow, the initial momentum of the plume may not be enough to counteract its tendency to sink because of the initially high density.

The results of the interaction of these different processes at low wind speeds are shown in figure 2.1. The gas mixture that these diagrams use is 50% by volume propane and 50% by volume air, which is typical of that expected when topping-off a crude oil cargo. At the lowest flow rate, figure 2.1 (a), the density effect predominates and the gas sinks back towards the deck. At the highest flow rate, figure 2.1 (c), mixing is far more efficient and there is no tendency for the plume to sink.



Figures 2.1 (a) and (b): Indicative effect of gas flow rate on flammable zone

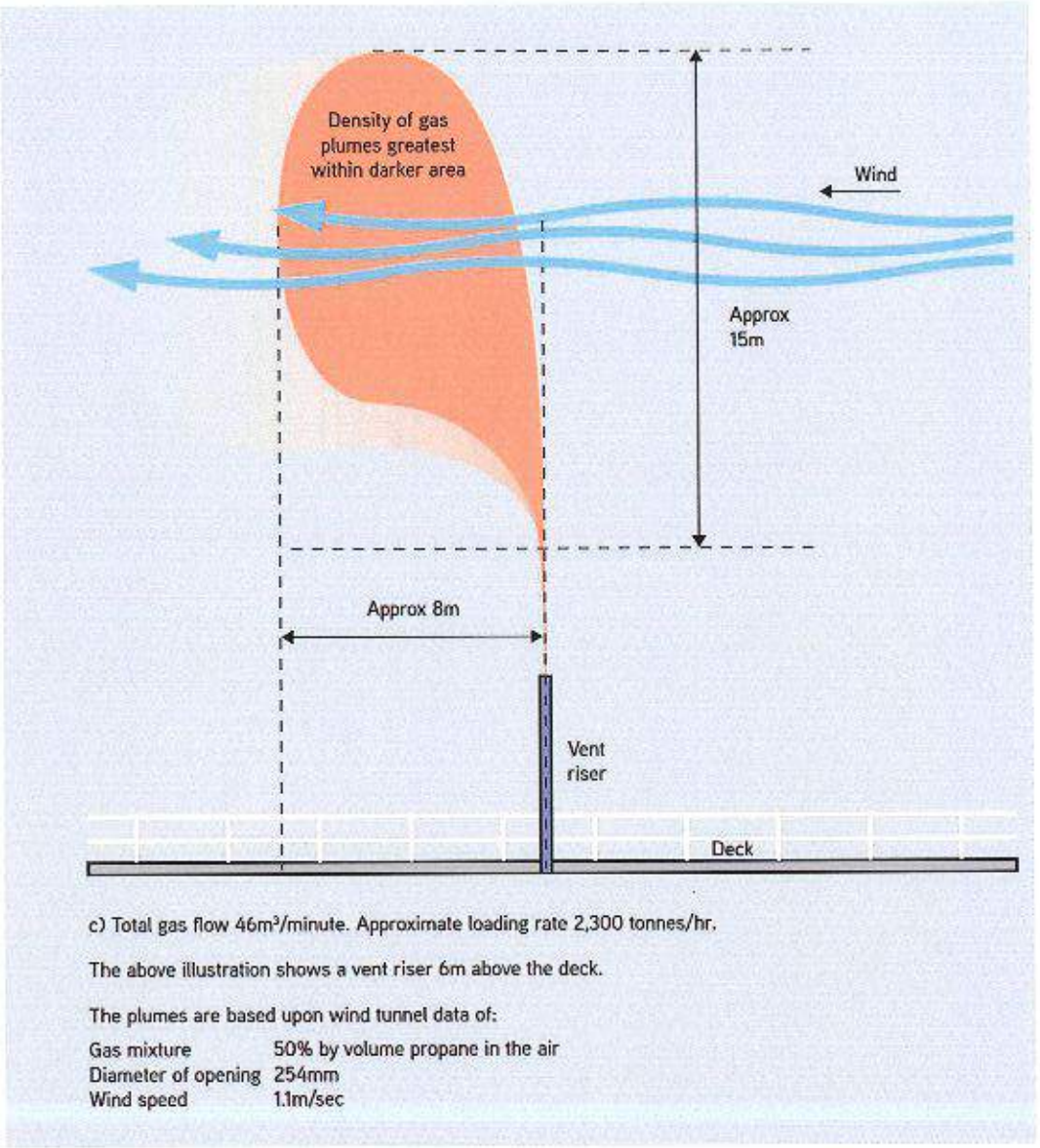


Figure 2.1 (c): Indicative effect of gas flow rate on flammable zone

The flammable zones generated by the same operations with motor or aviation gasolines would be similar but with a more pronounced density effect, which would be even more pronounced with a natural gasoline type cargo. The greater dilution required to reach the LFL with motor or aviation gasolines (see section 1.2.2) tends to make the flammable zones larger than for crude oils and the flammable zone for natural gasolines is even larger. Therefore, the dispersion problem gets progressively worse from crude oils to motor or aviation gasolines to natural gasoline type cargoes.

2.1.3.4 Concentration of hydrocarbon gas

With a constant total rate of flow of gas, changes in hydrocarbon concentration have two effects. The rate of emission of hydrocarbon gas increases in proportion to the concentration so that, other things being equal, the extent of the flammable zone increases. Also, the initial density of the gas mixture as it emerges from the opening becomes greater, so there is a greater tendency for the plume to sink.

At low concentrations a flammable zone similar in outline to that shown in figure 2.1 (c) is expected, but it is likely to be small because of the relatively small amount of hydrocarbon gas. As

the concentration increases, the flammable zone tends to assume the shapes in figures 2.1 (b) and 2.1 (a) as the increasing density exerts its influence. The overall size of the zone becomes greater due to the greater rate of emission of hydrocarbon gas.

2.1.3.5 Cross-sectional area of the opening

The area of the opening that the hydrocarbon gas/air mixture emerges from determines, for a given volumetric rate of flow, the linear flow velocity and so the efficiency of the mixing of the plume with the atmosphere. Effects of this kind occur during gas freeing, for example. If fixed turbo-blower fans are used, the mixture is usually vented through a standpipe with a cross-sectional area small enough to give a high velocity and encourage dispersion in the atmosphere. When using small portable blowers, which normally should be operated against a low back pressure, it is usual to exhaust the gas through an open tank hatch. The outflow velocity is then very low with the outlet close to the deck, which encourages the gas to remain close to the deck.

2.1.3.6 The design of the vent outlet

The design and position of a vent outlet must comply with current SOLAS requirements. For certain operations, such as gas freeing, vapour may be vented from the tank through apertures other than the designated tank vents.

2.1.3.7 Position of the vent outlet

If vent outlets are near structures such as accommodation blocks, the shape of the flammable zone is influenced by turbulence produced in the air as it passes over the superstructure. Figure 2.2 illustrates the kind of eddies formed. This shows how, on the upwind side, there are downward eddies below a level indicated by the line X-X and how, above and in the lee of the structure, turbulent air tends to form eddies close to the structure.

These movements can adversely affect the efficient dispersion of hydrocarbon gas.

If the exit velocity from an opening near a structure is high, it can overcome the influence of eddies.

For example, figure 2.3 (a) shows the flammable zone from a tank opening only about 1.5m upwind of an accommodation block. The plume is almost vertical and only just touches the accommodation block. However, a lower rate of venting would result in the zone coming into much wider contact with the accommodation block.

Figure 2.3 (b) shows the effect of an extra opening, which results in double the amount of gas being released. Partly as the result of eddies and partly due to the denser combined plume, the flammable zone is in close contact with the top of the accommodation block.

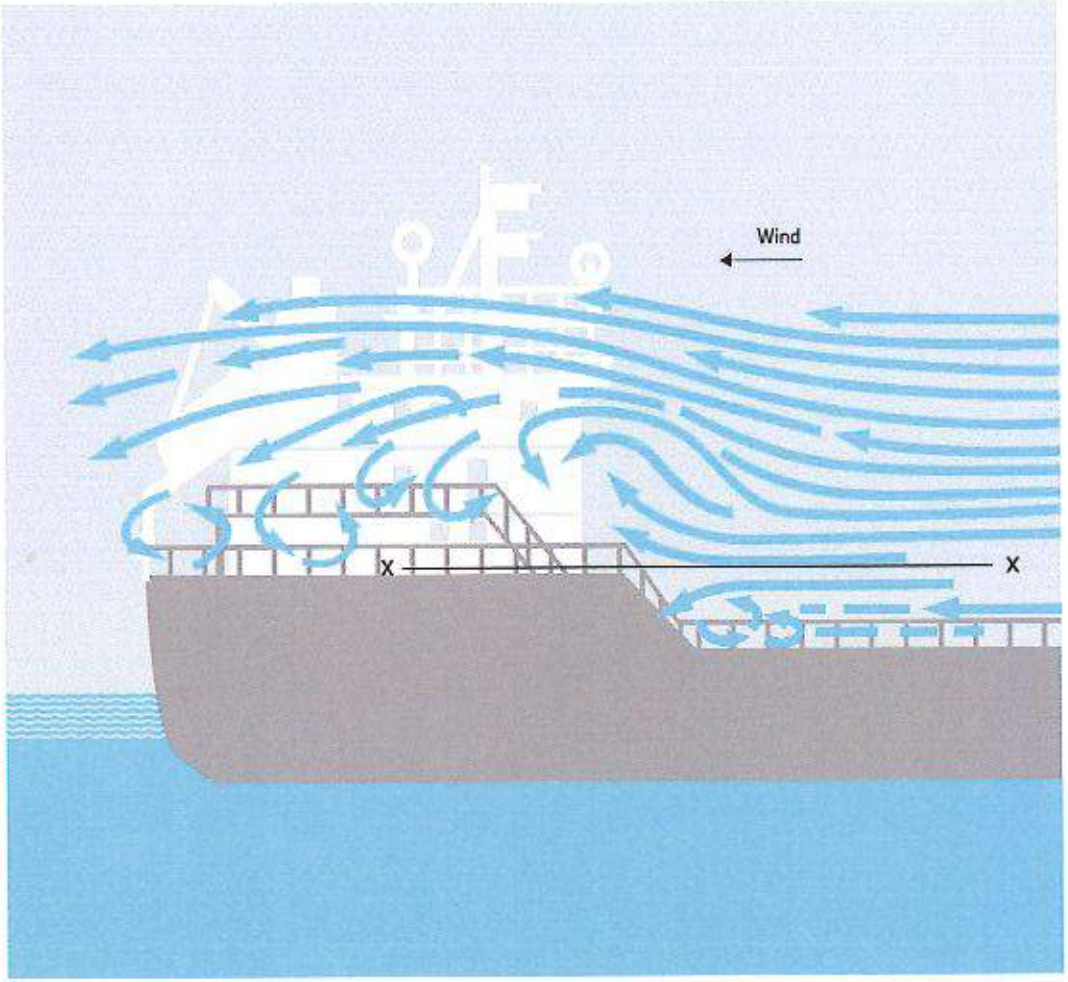


Figure 2.2: Typical pattern of airflow around an accommodation block

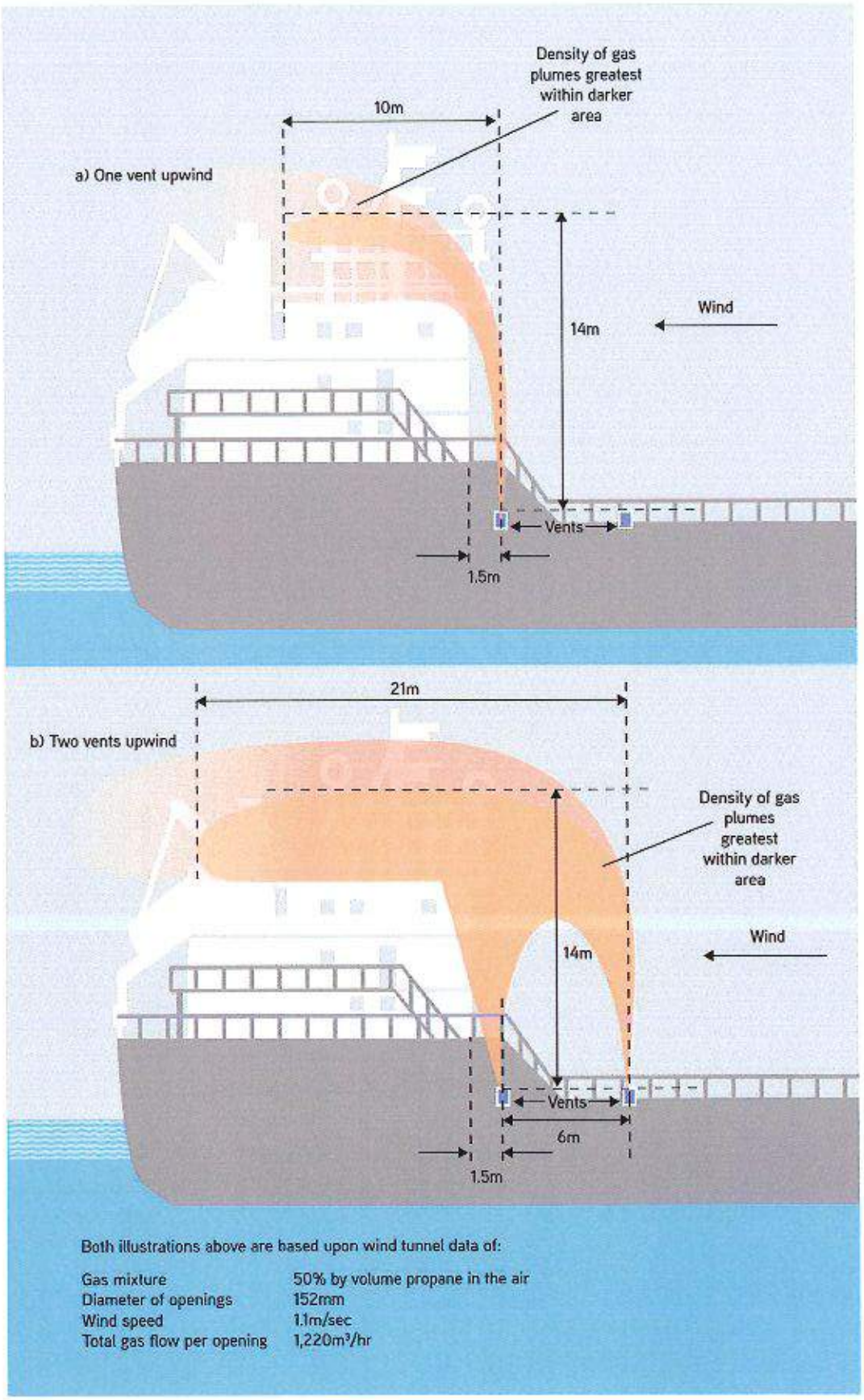
2.1.4 Minimising hazards from vented gas

The objective of venting arrangements and their operational control is to minimise the possibility of flammable gas concentrations entering enclosed spaces where there are sources of ignition, or reaching deck areas where, despite all other precautions, there might also be a source of ignition. Previous sections have described ways of promoting rapid dispersion of gas and minimising its tendency to sink to the deck. While this section is concerned with flammability, the same principles apply to the dispersion of gas down to hydrocarbon concentrations that are safe for personnel.

SOLAS requires the following conditions for any operation where flammable mixtures are displaced to the atmosphere or where displaced mixtures could become flammable on dilution with air, such as on inerted tankers:

- An unimpeded vertical discharge at a high efflux velocity.
- The outlet positioned sufficiently high above the deck.
- The outlet placed at an adequate distance from the superstructure and other enclosed spaces.

When using a vent outlet of fixed diameter, usually designed for 125% of the maximum cargo loading rate, the efflux velocity will drop at lower loading rates. Vent outlets with automatically variable areas (high velocity vent valves) may be fitted to maintain a high efflux velocity under all loading conditions. The permitted height of the outlet above deck depends on whether venting is through a mast riser or a high velocity vent valve.



Figures 2.3 (a) and (b): Flammable zone from apertures near an accommodation block

The designated venting arrangements should always be used during cargo loading operations and any ballasting into non-gas free cargo tanks.

When gas freeing by fixed mechanical blower, or purging with IG either by displacement or dilution through designated outlets, sufficiently high efflux velocities should be maintained to ensure rapid gas dispersion under any condition.

When gas freeing by portable blowers, it may be necessary to open a tank hatch lid to act as a gas outlet, resulting in a low gas outlet velocity. Vigilance is then required to ensure that gas does not accumulate on deck. If an inerted tank is being gas freed through an open hatch, localised areas may have an atmosphere deficient in oxygen. If practicable, it is preferable to gas free through a small diameter opening, such as a tank cleaning opening, with a temporary standpipe rigged.

In all operations where gas is being vented, exercise great vigilance, especially under bad conditions, e.g. if there is little or no wind. In such cases, it may be prudent to stop operations until conditions improve.

2.2 Loading very high vapour pressure cargoes

2.2.1 Gas evolution

Cargoes yielding deeper layers are sometimes encountered. The main examples are crude oils, which may have their vapour pressures increased by an additional gas, such as butane, and some natural gasolines (by-products of Liquefied Natural Gas (LNG)/LPG production) that are sometimes known as pentanes plus (or C5+).

Examples of the variation of gas layer depth (greater than or equal to 50% by volume concentration level) related to TVP are shown in figure 2.4 for typical natural gasolines and crude oils. Some cargoes have intermediate properties, e.g. flash-stabilised condensates, some distillation overhead products (which may be shipped as clean petroleum products such as naphtha, kerosene or even gas oil) and crude oils with abnormally low methane and ethane content.

The natural gasoline curve in figure 2.4 is for a series of blends with different TVP. The crude oil curve is for a series produced by adding increasing amounts of butane to a crude oil. At lower TVP, the dependence of depth on TVP is not marked for either type of cargo. At greater TVP, the curve becomes progressively steeper, indicating that in this range a small increase in TVP can cause a large increase in gas evolution.

Boiling starts when the TVP exceeds one bar. In the case of the natural gasoline blends, this coincides quite closely with the steep increase in gas layer thickness. However, with the crude oil/butane blends, the steep increase does not occur until a TVP significantly above one bar is reached. Crude oils may be stabilised so that their TVPs are near, or somewhat above, one bar as they enter the tanker. In practice, some boiling may occur even without butanisation, but the gas evolution is not necessarily excessive.

In boiling, gas bubbles form below the surface of the liquid, but only down to a depth at which the total pressure (atmospheric plus hydrostatic) is equal to the TVP. The consequent loss of gas in this region may lead to a local fall in TVP. In addition, the latent heat required to evaporate the gas results in cooling, which also reduces the TVP. The reduction in TVP in the liquid near the surface from both these causes tends to delay boiling, even though the TVP of the bulk of the liquid is above one bar. This is why crude oils can be handled with their TVPs somewhat above one bar. It does not apply to the same extent to the natural gasoline type of product because the gaseous constituents in a crude oil are only a small proportion of the total, whereas a natural gasoline usually consists almost entirely of potentially gaseous compounds. This means that the availability of gas, where boiling, is far greater with the natural gasolines than with crude oils.

Natural gasolines suffer hardly any decrease of TVP due to gas depletion when they begin to boil, and boiling is much more likely to continue than with crude oils.

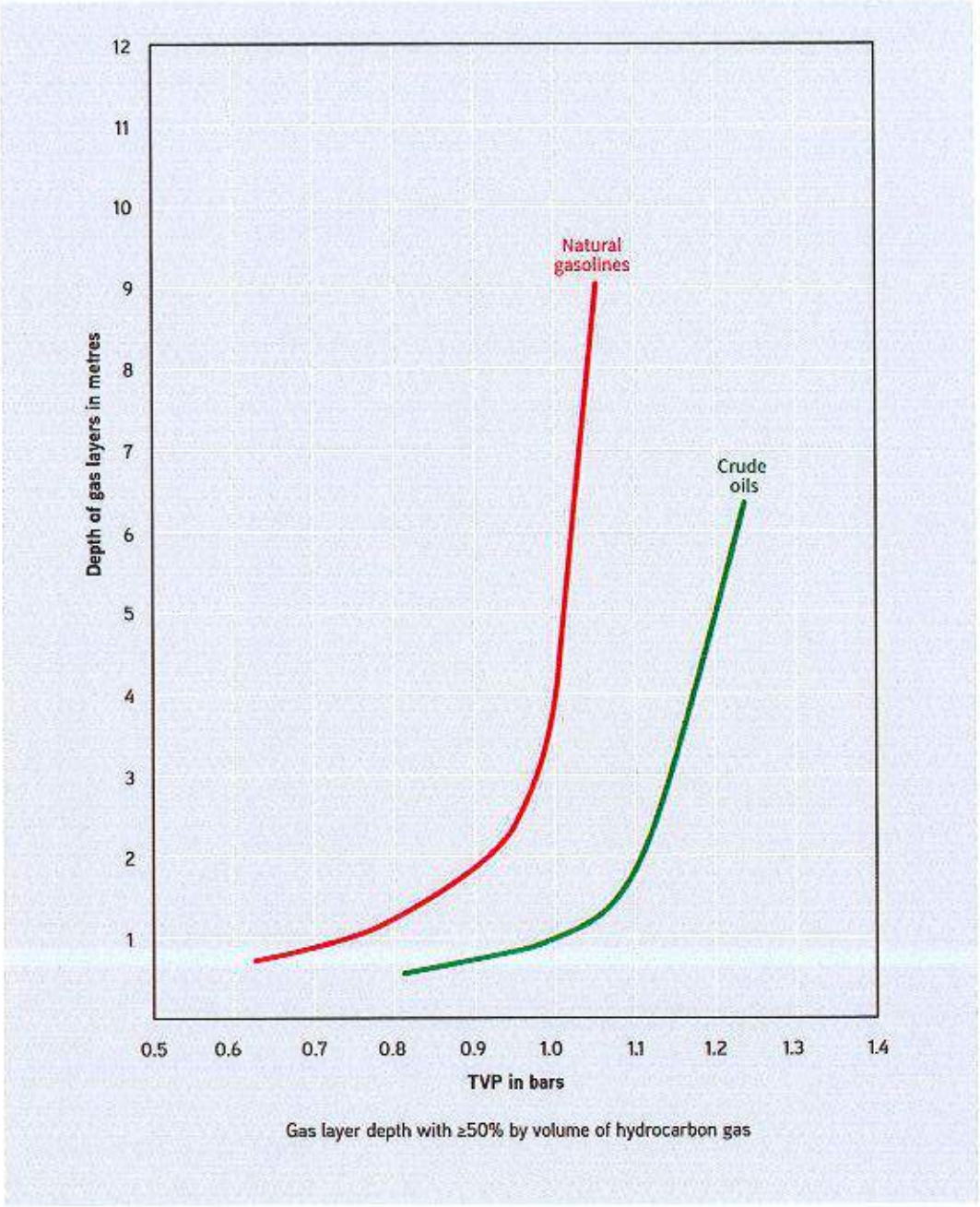


Figure 2.4: Relationship between depth of gas layer and TVP

2.2.2 Special precautions with very high vapour pressure cargoes

When unusually deep gas layers are encountered, very high concentrations of gas, approaching 100% by volume, may be vented for prolonged periods during loading. Excessive amounts of gas may then be present on or around the tanker, which may call for special precautions.

Curves of the kind in figure 2.4 suggest that the TVP at the loading temperature of the cargo should be used as the criterion for determining when special precautions are necessary. The RVP of a cargo gives little guidance unless the temperature of the cargo, when loaded, is also specified. However, it has proved to be difficult to select TVP criteria because they depend, ultimately, on

subjective judgements of acceptable gas conditions on tankers. As a general guide, the available information suggests that special precautions may be needed when the TVP is expected to exceed the following values:

- For natural gasoline type cargoes, e.g. pentanes plus (C5+), 0.75 bar.
- For crude oils, with or without added gas, 1.0 bar.
- For some intermediate cargoes, e.g. flash-stabilised condensates, some distillation overhead products and crude oils with abnormally low methane and ethane contents, TVP limits between the above two values might be appropriate.

When cargo temperature, crude oil stabilisation conditions and RVPs are known, TVPs can be calculated by checking with the above criteria.

Precautions that might be applied are given in section 12.1.8.

2.3 Volatile Organic Compounds

Volatile Organic Compounds (VOCs) are organic compounds that have a high vapour pressure at ambient temperature. These include, but are not limited to, hydrocarbons that are emitted during cargo operations. Some of these compounds are harmful to health and/or the environment, e.g. benzene. For further information on the control of VOC emissions refer to OCIMF's *Volatile Organic Compound Emissions from Cargo Systems on Oil Tankers.*

2.4 Gas measurement

This section describes the operating principles, applications and limitations of equipment and instruments used for measuring concentrations of hydrocarbon gases, other toxic gases and oxygen.

It is essential that any instrument used is:

- Suitable for the gases and atmosphere to be tested.
- Sufficiently accurate for the test required.
- Used within the instrument's design ambient range.
- An approved type.
- Correctly maintained, tested and calibrated.

Manufacturer's instructions or recommendations for any of the instruments mentioned should take precedence over the guidelines in this publication.

2.4.1 Provision of gas measurement instruments

Tankers should be equipped with at least two instruments capable of measuring, as a minimum, concentrations of oxygen, flammable gases or vapours (% LFL), H_2S and CO in order to carry out the tests required for enclosed space entry.

Note that enclosed spaces might have additional atmospheric hazards that may not be detected by these instruments. If this is known to be the case, additional means to measure the toxic gases in the cargoes being carried should be provided. An up-to-date inventory of the instruments should be maintained on board.

Tankers equipped with IG or nitrogen padding should ensure that the instruments are also capable of measuring oxygen and hydrocarbon content (% Vol) in an inert atmosphere.

Gas detection instruments should be capable of remote sampling through the entire height of the compartment for any gas they are designed to detect, unaffected by the atmosphere or any other characteristic of intervening spaces.

Every instrument should have a manual that describes its features, settings and alarms and explains calibration, testing, operation and maintenance. The information in the manuals should be available in the working language of the tanker.

2.4.1.1 Arrangements for gas measurement in double hull spaces and double bottom spaces

Suitable portable instruments for measuring oxygen and flammable vapour concentrations in double hull spaces and double bottom spaces should be provided. In selecting these instruments, pay attention to their use in combination with the fixed gas sampling lines referred to below.

Where the atmosphere in double hull spaces cannot be reliably measured using flexible gas sampling hoses, such spaces should be fitted with permanent gas sampling lines. The configuration of gas sampling lines should be adapted to the design of the spaces.

The construction material and dimensions of gas sampling lines should prevent restriction. Where plastic materials are used, they should be electrically conductive.

2.4.1.2 Protection of cargo pumprooms on tankers

A system for continuous monitoring of the concentration of hydrocarbon gases should be fitted. When this concentration reaches a pre-set level (not be higher than 10% LFL), it should automatically activate a continuous audible and visual alarm in the pumproom, engine control room, cargo control room and navigation bridge to alert personnel to the potential hazard.

2.4.1.3 Arrangements for fixed hydrocarbon gas detection systems in double hull and double bottom spaces of oil tankers

Oil tankers of 20,000 tonnes DWT and above, constructed on or after 1 January 2012, must have a fixed hydrocarbon gas detection system that complies with the fire safety systems code for measuring hydrocarbon gas concentrations in all ballast tanks and void spaces of double hull and double bottom spaces next to the cargo tanks, including the forepeak tank and any other tanks and spaces under the bulkhead deck next to cargo tanks.

Oil tankers with constantly operating inerting systems for such spaces do not need to have fixed hydrocarbon gas detection equipment.

2.4.2 Gas measurement instruments

Some gas measurement instruments can analyse only one type of gas. Others can analyse several pre-set types of gases at the same time (multi-gas detectors) and have a range of capabilities based on different technologies. They can be divided into personal, portable and fixed gas measurement instruments and can be further classified by their function.

Personal gas measurement instruments: these are used to continuously monitor a worker's immediate environment. They should be worn and switched on at all times. They are not to be used in inerted atmospheres or pressures above atmospheric. When a gas measured by the equipment is detected at concentrations above the permissible limit, the instrument will produce an audible and visual alarm and will vibrate to alert the user to an imminent danger.

Portable gas measurement instruments: these measure different atmospheres, usually remotely and using an extension hose, mainly in confined spaces. They are not for personal use but to determine the condition of a particular space, e.g. a cargo tank, ballast tank, cofferdam or drain tank. Many of these instruments can be used in inerted atmospheres at atmospheric pressure and other pressures as defined by the manufacturer.

Fixed gas detection installations: these measure gas concentrations remotely and can be used to measure more than one type of gas at the same time.

2.4.3 Instruments for measuring hydrocarbon concentration

Combustible gas detectors: these measure hydrocarbon gas in air at concentrations below the LFL at atmospheric pressure to detect the presence of potential flammable atmospheres. The readings are usually shown and recorded as % LFL. They are used before entry in spaces such as pumprooms or washed and ventilated cargo tanks.

Hydrocarbon gas meters: these measure hydrocarbon gas as a percentage by volume of the total atmosphere being measured. This is usually done to measure the percentage of hydrocarbon vapour in oxygen deficient atmospheres (inerted cargo tanks). The readings are expressed as the percentage of hydrocarbon vapour by volume and are recorded as % Vol.

2.4.4 Instruments for measuring oxygen concentrations

These instruments measure oxygen concentrations in inerted or non-inerted atmospheres.

Correctly interpreting oxygen concentrations is crucially important. Normal concentration of oxygen in fresh air is 20.9% and modern oxygen analysers are capable of measuring to a high level of accuracy. However, it is always important to check for oxygen, hydrocarbons and other toxic gases before a decision is made to enter an enclosed space.

There could be toxic levels of harmful gases that may not be apparent purely from readings obtained by an oxygen analyser. A small reduction of oxygen concentration, for example, from 20.9% to 20.5% may be due not only to factors such as temperature fluctuations, humidity or equipment accuracy, but also to the presence of toxic gases that should be tested for.

2.4.5 Instruments for measuring toxic gases

Throughout this guide the percentage of oxygen in air is referred to as 21%. However, due to atmosphere characteristics and variation, the percentage of oxygen in air falls several hundredths of a percent below this figure, variously quoted as being between 20.80% and 20.95%.

Modern instrumentation with digital indicators can measure so accurately that the full 21% may be impossible to obtain. If an instrument capable of such accuracy is in use, the manufacturer's instructions should be carefully read and understood so that the readings can be properly interpreted.

Electrochemical sensors: these are suitable for measuring toxic gases down to low ppm levels. However, one should be aware that these sensors are susceptible to cross-sensitivity and, therefore, may measure gases other than the target gas.

Chemical indicator tubes: these can measure a wide range of gases and tubes exist for each specific gas in varying measurement ranges. They can be used to analyse both inerted and non-inerted atmosphere at atmospheric pressure, in accordance with manufacturer's instructions, and are used to find a specific type of gas within enclosed spaces, including hydrocarbon gas, toxic gases and VOCs. For example, there are tubes for H_2S, acetone, ammonia, benzene and ethanol. They are single use only.

Optoelectronic instruments: these combine the chemical indicator tubes with optoelectronic technologies. They can measure a wide range of gases because there is a chip for each specific gas and concentration. They can analyse non-inerted atmospheres and are unaffected by fluctuations in air pressure. They can also measure gases such as methyl tert-butyl ether, acetone, benzene and CO.

Direct-reading Photoionisation Detectors (PIDs): these measure VOCs within enclosed spaces prior to entry, but are not limited to this function. They can also analyse non-inert atmospheres, although samples should be at atmospheric pressure. They provide an accurate, alternative way of

measuring 10% of LFL for enclosed space entry. An exception to this is that there is no response to methane (CH_4), so these instruments should not be used if methane approaching LFL levels may be present.

2.4.6 Technologies used to measure flammable atmospheres, toxic vapours and oxygen

2.4.6.1 Catalytic sensor

Operating principle

This type of sensor consists of two filaments heated to a temperature between 400 and 600°C. When hydrocarbon gas reaches them, oxidation occurs. This chemical reaction causes a variation in the electrical resistance of the filaments. This variation, which is proportional to the gas concentration, is measured by an electronic circuit and projected on an analogue or digital display as % LFL (see figure 2.5).

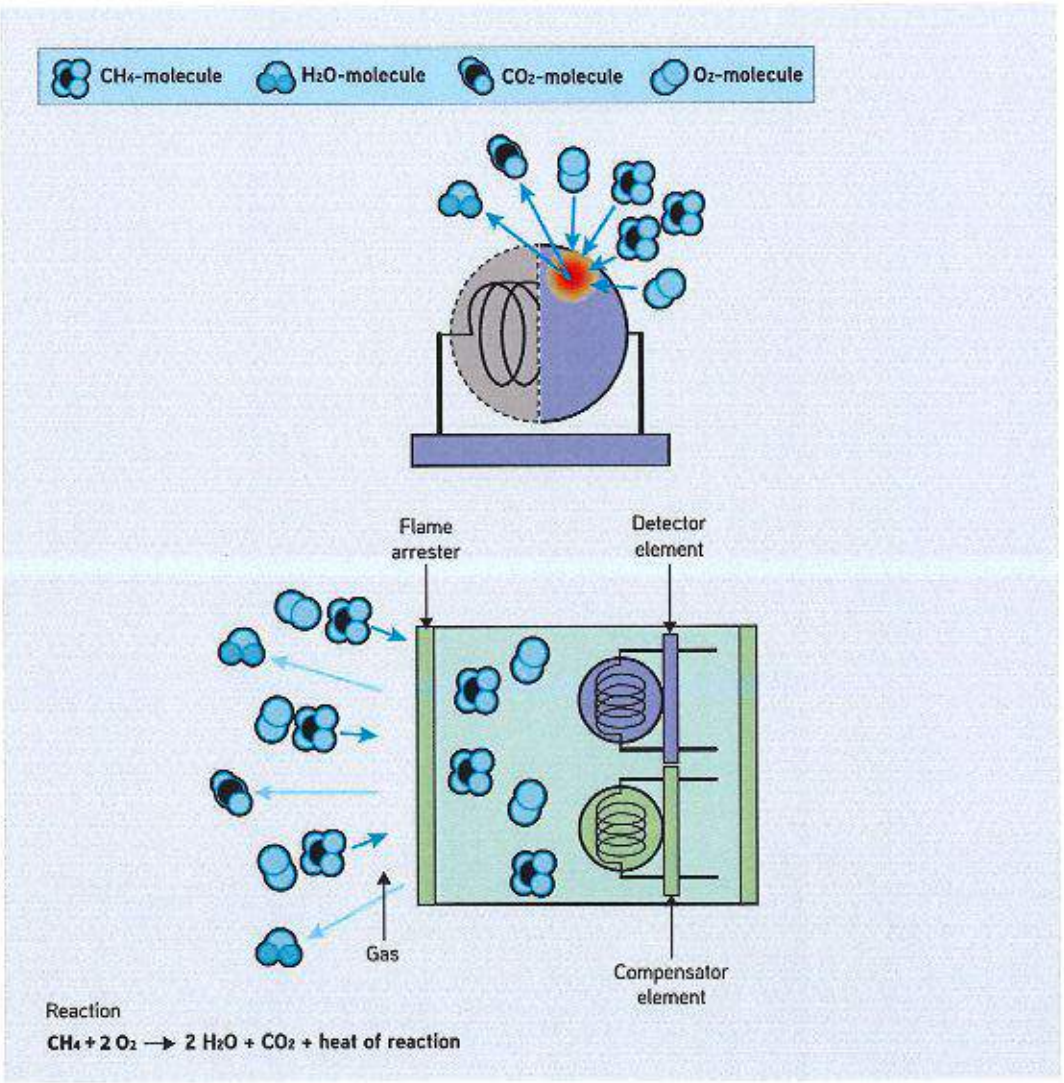


Figure 2.5: Catalytic heated filament sensor

Application

This type of sensor is used to measure the % LFL of flammable gases in air, at atmospheric pressure.

Some examples where these sensors may be used include, but are not limited to:

- Pumprooms.
- Ballast tanks and cofferdams.
- Decks.
- Gas free cargo tanks.
- Near hot work.

Cautions

These sensors should not be used in oxygen depleted atmospheres (less than 11% oxygen by volume).

The samples should always be taken within the manufacturer's design pressure limits, as pressure above these limits could potentially damage the sensor. Liquids, e.g. water, oil, should never enter the sensors. To prevent this, use a water trap and a floating probe. The manufacturer's recommended filters should be used to remove solid particles and humidity from the sample.

Some compounds may reduce the sensitivity of the filaments, either temporarily or permanently, e.g. silicon gases, organic lead compounds, freons, chlorinated hydrocarbons and H_2S. If the presence of H_2S is suspected, this should be tested before any measurements of hydrocarbon concentrations.

The sensors may also be temporarily affected by condensation. This may occur when the instrument is taken from an air-conditioned environment into a humid atmosphere. Allow time for the sensors to acclimatise to the ambient temperature before use.

Gas measurement instruments that use this technology

Combustible gas detector.

2.4.6.2 Thermal conductivity sensor

Operating principle

The sensing element is a non-catalytic heated filament. The composition of the sample gas surrounding the filament determines the rate of heat loss from the filament and, therefore, its electrical resistance.

This variation, which is proportionate to the gas concentration, is measured via an electronic circuit and displayed as % Vol. The heat loss is non-linear but the scale in the instrument reflects this, so a direct reading is given to the user.

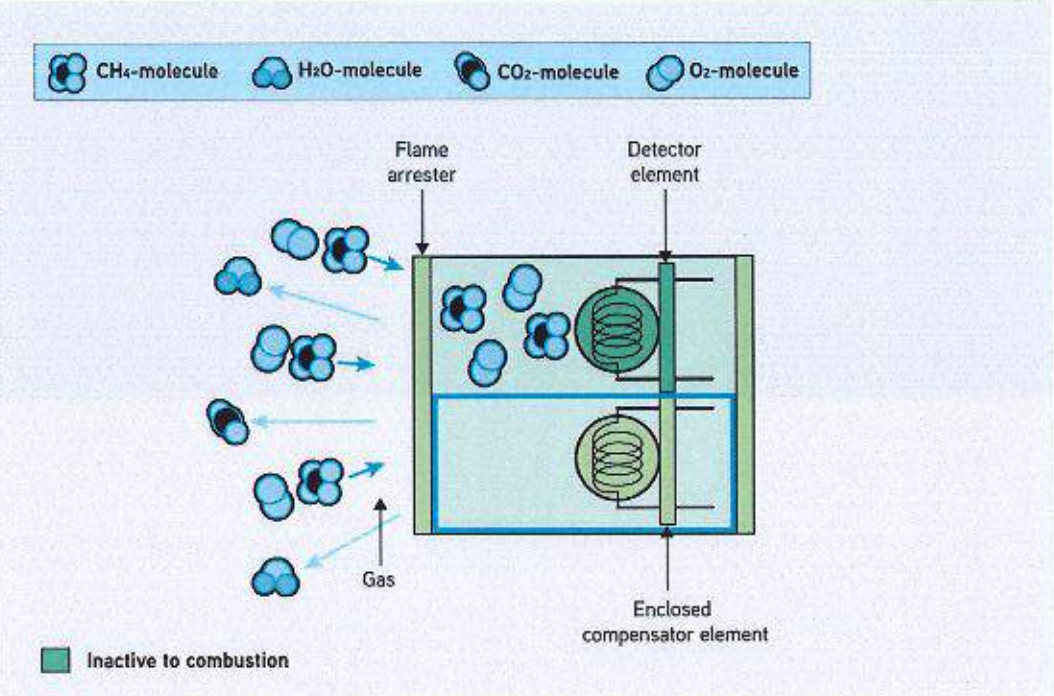


Figure 2.6: Thermal conductivity sensor

Application

This type of sensor does not require oxygen for operation and is capable of measuring concentrations of up to 100% by volume. When used directly on tanks, the pressure should be within the range defined by the manufacturer.

Some examples of areas where it might be used are:

- Inerted cargo tanks.
- Purging of cargo tanks.
- Areas where gas concentrations are expected to exceed the LFL.

Cautions

If a flow sensitive type of thermal conductivity sensor is used, additional care should be given to ensure a stable flow through the instrument, as per maker's recommendations, or it may result in erroneous reading.

Liquids, e.g. water, oil, should never enter this instrument. To prevent this, use a water trap and a floating probe. Only the manufacturer's recommended filters should be used to remove solid particles and humidity from the sample.

Gas measurement instruments that use this technology

Hydrocarbon gas meter.

2.4.6.3 Infrared sensor

Operating principle

This type of sensor is based on the principle that hydrocarbon gases absorb Infrared (IR) light, but air does not.

IR radiation is produced from the transmitter and shines through a window in the measuring chamber. It is focused and reflected by a mirror to a filter to be finally converted into an electric signal.

If the chamber contains a hydrocarbon gas, part of the radiation will be absorbed by the gas. The differences between the radiation from the transmitter and the one received at the filter is proportional to the concentration of the gas analysed (see figure 2.7).

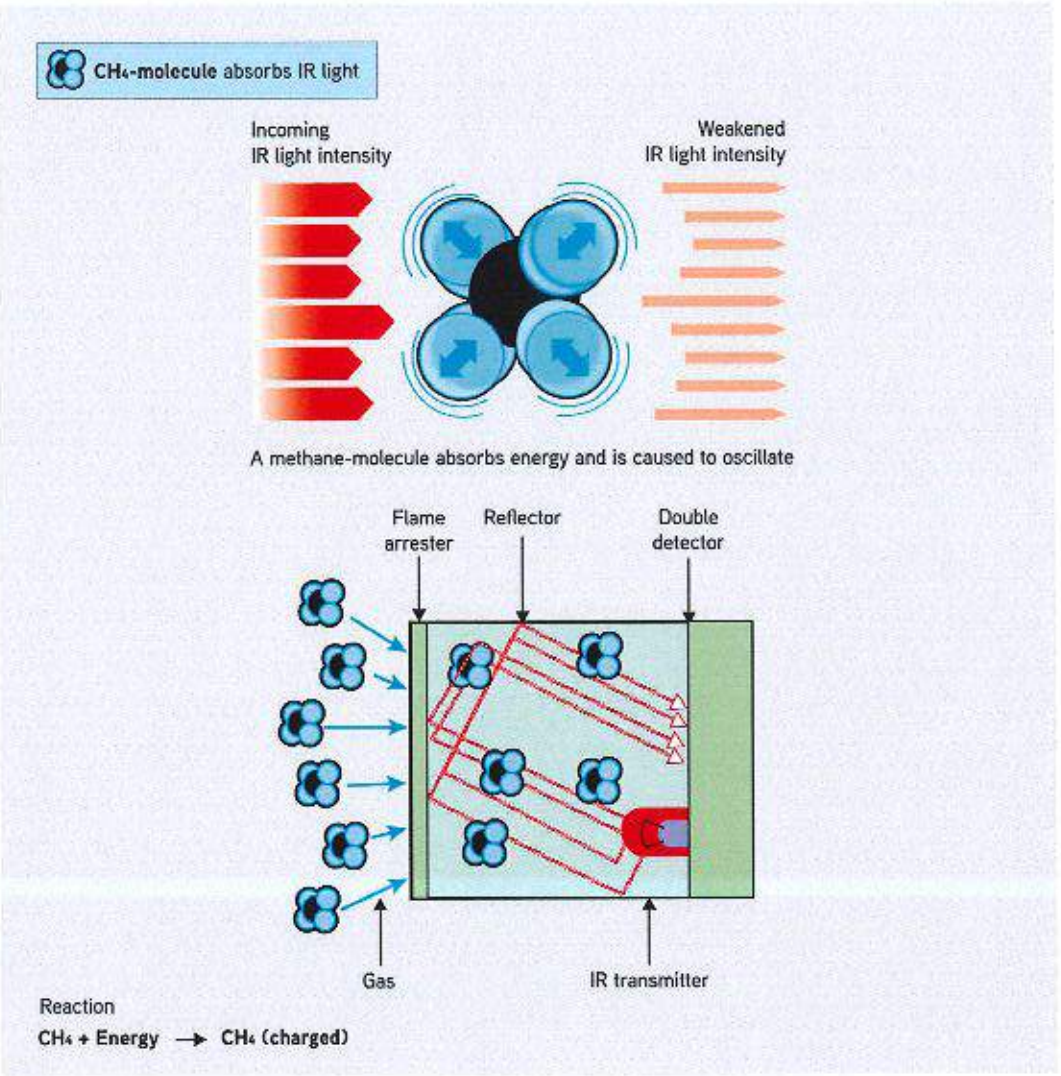


Figure 2.7: IR sensor

Application

Depending on the model, this technology can be used to measure both % LFL and % Vol in inerted and non-inerted atmospheres.

Cautions

Sample pressure limitations depend on the model of the equipment.

Liquids, e.g. water, oil, should never enter this instrument. To prevent this, use a water trap and a floating probe. Only the manufacturer's recommended filters should be used to remove solid particles and humidity from the sample.

This sensor is not affected by concentrations above the scale. The display will go off scale without affecting the instrument. It will read correctly once the concentration reduces sufficiently.

Gas measurement instruments that use this technology

Hydrocarbon gas meter and combustible gas detector.

2.4.6.3.1 Tunable diode laser gas sensor

Operating principle

The gas sample enters the cell of the analyser. A tunable diode laser emits a wavelength of near-IR light, specific to the gas to be measured, into the cell where it passes through the gas and is reflected by a mirror to a detector. Gas molecules in the sample absorb and reduce the intensity of the laser light energy in-direct proportion to their concentration. The detector measures the difference in light intensity and processes this signal to calculate the gas concentration in the sample.

Application

This technology measures a range of gases, including H_2S. This can be point or open-path measurement. Remote sensing is also possible.

Gas measurement instruments that use this technology

Fixed gas detection systems in terminals.

2.4.6.4 Refractive index meter/interferometers

Operating principle

This sensor measures the difference between the refractive indices of the sampled gas and air.

A beam of light is divided into two and then recombined at the eyepiece. One light path is via chambers filled with air, the other path is via chambers where the gas sample is pumped through. The recombined beams show an interference pattern depending on the refractive index of the gas supplied to the measuring chamber.

The interference pattern is interpreted to measure the concentration of gas sampled.

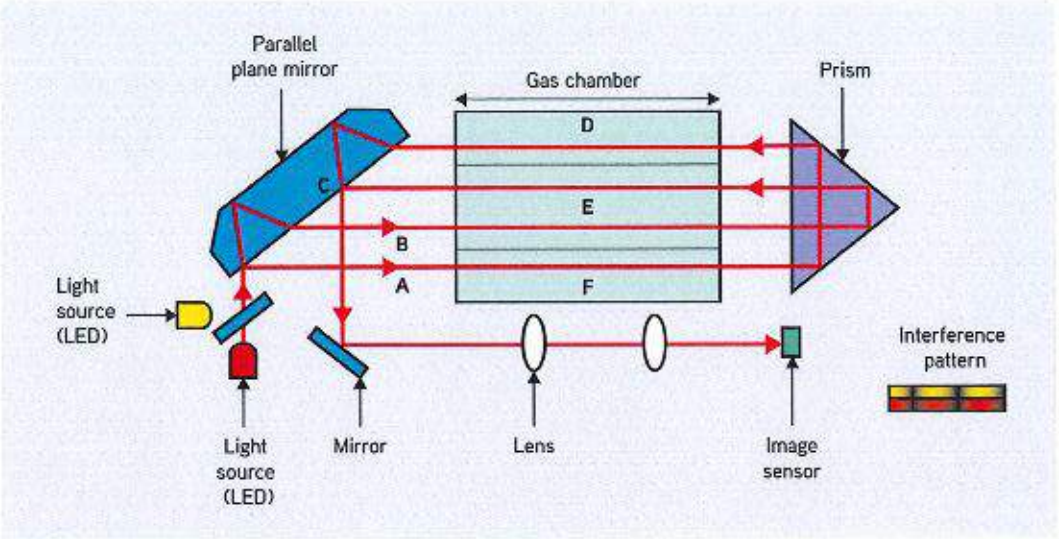


Figure 2.8: Refractive index meter/interferometers

Application

This technology is used to measure not only hydrocarbons, but also other gases such as toxic gases and other compounds.

Cautions

Sample pressure limitations depend on the model of the equipment.

Measuring the concentration of hydrocarbon gas in an inerted atmosphere is affected by the CO_2 present when flue gas is issued for inerting. In this case, soda lime is recommended as an absorbent for CO_2, provided the reading is corrected appropriately.

Liquids (e.g. water, oil) should never enter this instrument. To prevent this, use a water trap and a floating probe. Only the manufacturer's recommended filters should be used to remove solid particles and humidity from the sample.

This sensor is not affected by concentrations above the scale. The display will go off scale without affecting the instrument. It will read correctly once the concentration reduces sufficiently.

Gas measurement instruments that use this technology

Portable refractometer or interferometer.

2.4.6.5 Electrochemical sensor

Operating principle

Measuring cells can be built from compounds, or a mix of them, to react specifically with a gas and so generate an electric current that will be proportional to the concentration of the gas measured. This current is measured via an electronic circuit and visualised in an analogue or digital display (see figure 2.7).

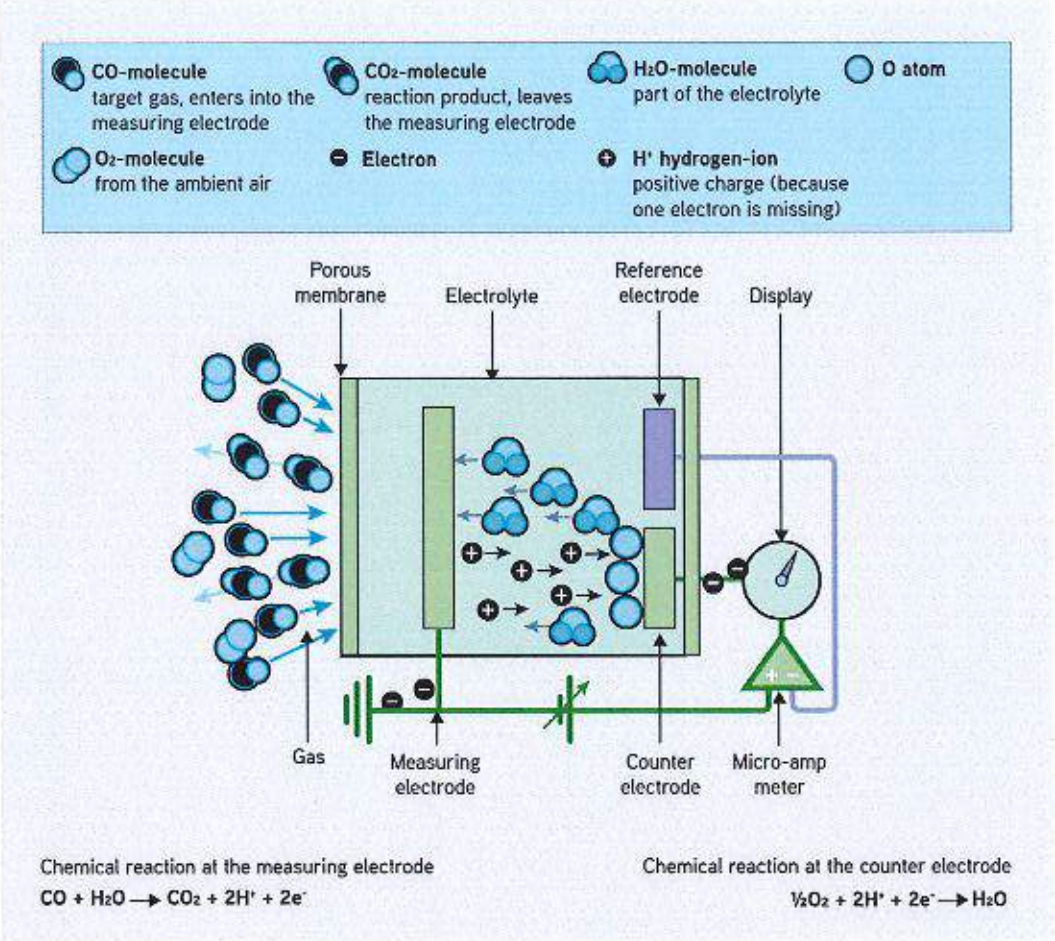


Figure 2.9: Electrochemical sensor

Application

This technology is used to measure not only hydrocarbon gases, but also gases such as ammonia, H_2S, CO, CO_2, SO_2 and oxygen.

Cautions

Sample pressure limitations depend on the model of the equipment.

Liquids (e.g. water, oil) should never enter this instrument. To prevent this, use a water trap and a floating probe. Only the manufacturer's recommended filters should be used to remove solid particles and humidity from the sample.

This sensor can be affected by concentrations over scale. They may cause temporary or permanent loss of sensitivity.

These sensors have an expiry date and should be replaced according to the manufacturer's recommendations.

Gas measurement instruments that use this technology

Hydrocarbon gas meter, oxygen meter and toxic gas measurement in single-gas or multi-gas instruments.

2.4.6.6 Chemical indicator tubes (colorimetric tubes)

Operating principle

Sealed glass tube containing a proprietary filling that reacts with a specific gas to give a visible indication of the concentration of that gas. The colour changes along the tube and the length of discoloration, which is a measure of the gas concentration, is read off an integral scale (see figure 2.10).

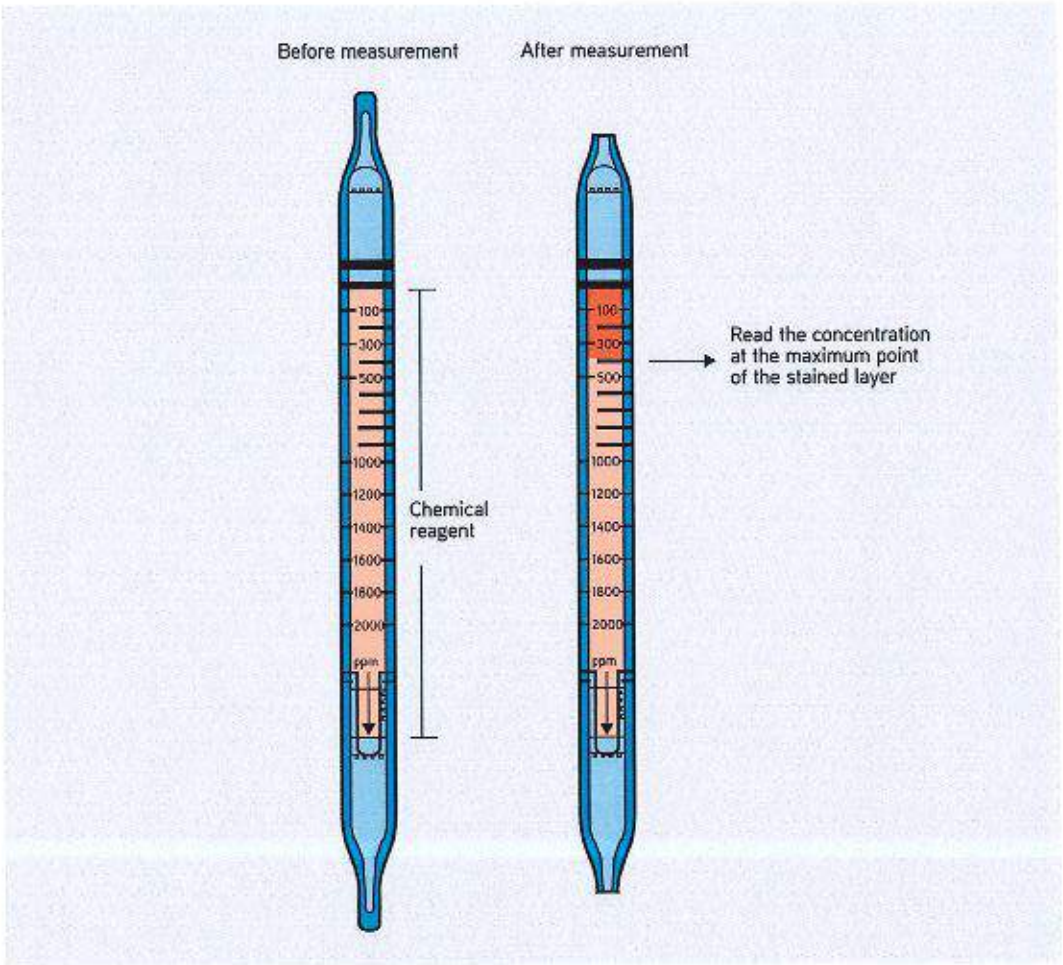


Figure 2.10: Chemical indicator tubes

Application

Chemical indicator tubes are used to measure concentrations of a variety of gases, including H_2S and benzene. An example is measuring benzene in a ventilated cargo tank in preparation for tank entry.

Cautions

Depending on the manufacturer, some tubes are designed to measure gas concentrations in air, while others can be used in inerted atmospheres. Their use is intended to be at atmospheric pressure and in accordance with the manufacturer's instructions.

For accurate results, all the components used should be from the same manufacturer, e.g. tubes, hand pump, hoses, etc. Do not use a tube from one manufacturer with a hand pump from another.

The measurement depends on passing a fixed volume of gas through the glass tube, so any extension hoses should be in strict accordance with the manufacturer's instructions.

All chemical indicator tubes have an expiry date and should be replaced according to the manufacturer's recommendations.

Gas measurement instruments that use this technology

Colorimetric tubes.

2.4.6.7 Chemical reaction via optoelectronic sensor

Operating principle

As with chemical indicator tubes, a given gas reacts with a reagent. In this case the effect is measured by an optoelectronic detector and displayed digitally.

A capillary filled with a specific reagent is inserted into the instrument according to the gas to be measured. The sample is drawn through the capillary and interacts with the reagent. The optoelectronic unit detects the result of this chemical reaction and processes it via electronic circuits to display the concentration of the sample (see figure 2.11).

The time it takes to measure within this technology depends on the concentration of the sample. The higher the concentration, the shorter the analysis. When concentrations are low, the analysis time may be longer.

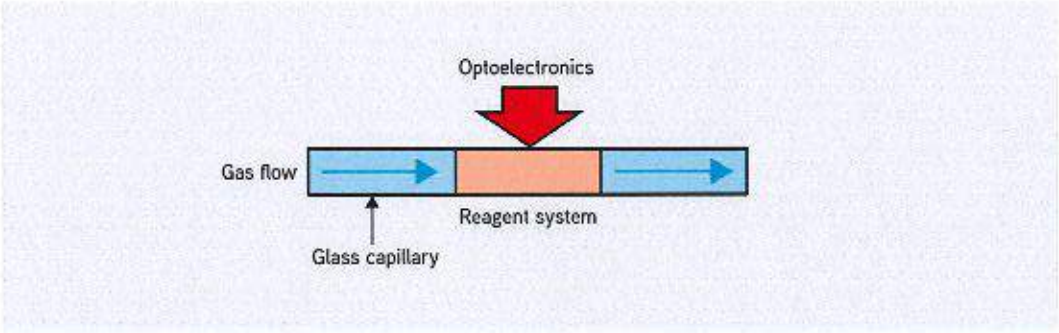


Figure 2.11: Optoelectronic detector sensor

Application

This technology is used for workplace monitoring of a wide variety of gases, including benzene and H_2S at different ranges of concentration.

Cautions

This system is designed to measure gas concentrations in air. Refer to the manufacturer to confirm if it can be used in IG. It should be used at atmospheric pressure.

Liquids, e.g. water, oil, should never enter this instrument. To prevent this, use a water trap.

All the components used should be from the same manufacturer, e.g. chips, measurement instrument, hoses, etc. Do not use a chip from one manufacturer with a measurement instrument from another.

As the measurement depends on a fixed volume of the gas, any extension hoses should be in strict accordance with the manufacturer's instructions.

Gas measurement instruments that use this technology

Proprietary systems.

2.4.6.8 Photoionisation (PID) sensor

Operating principle

A gas sample is introduced to the instrument through the gas inlet and an ultraviolet lamp then ionises hydrocarbon molecules within the sample. The molecules are exposed to an electrical field between electrodes. The magnitude of the resulting current is directly proportional to the concentration of ionised molecules inside the chamber. The current is translated into a direct reading of the gas concentration. This result is produced instantaneously (see figure 2.12).

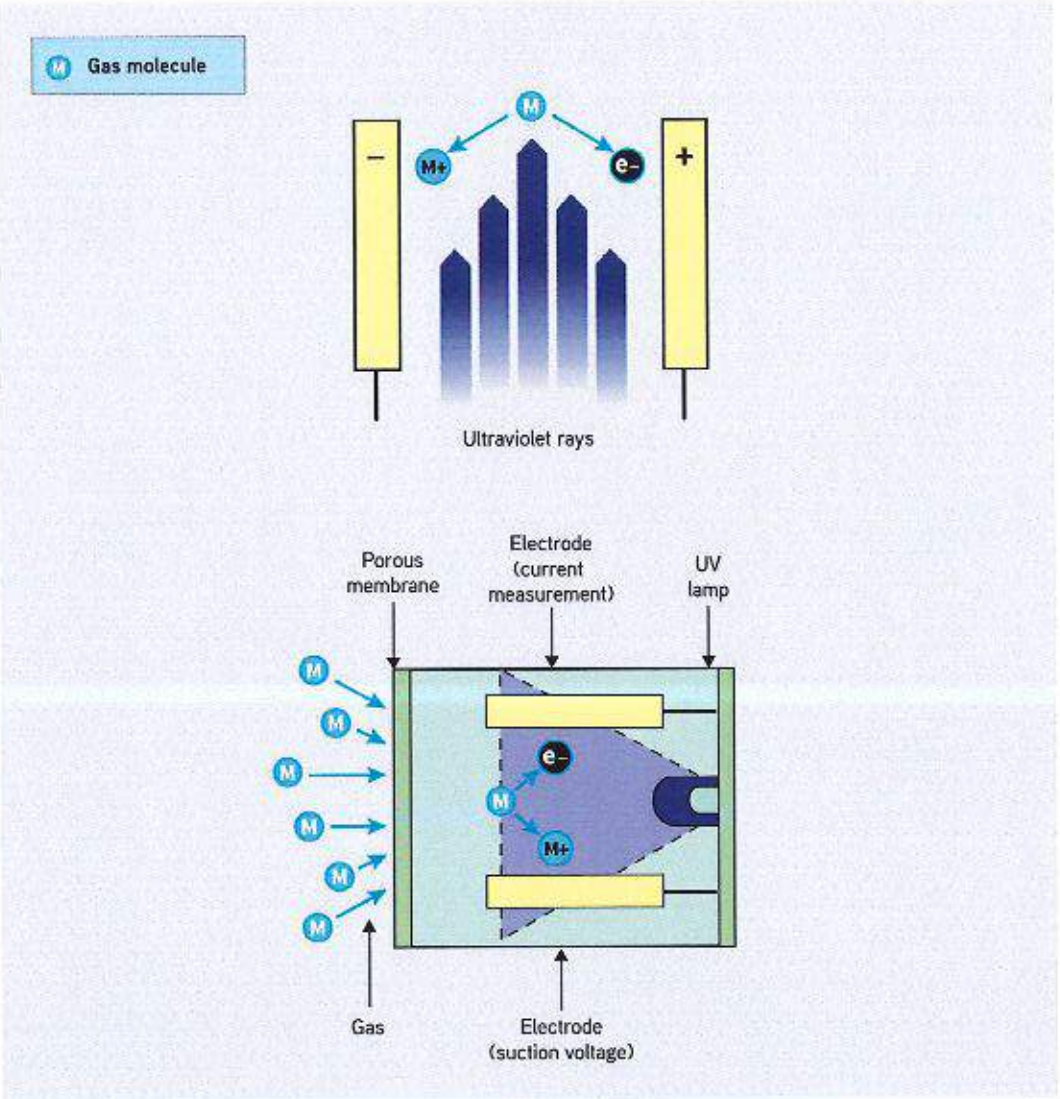


Figure 2.12: PID sensor

Application

This technology is primarily used to measure VOCs such as benzene and other hydrocarbons such as gasoline.

Cautions

Sample pressure limitations depend on the model of the equipment.

These sensors should not be used in an inerted atmosphere.

Liquids, e.g. water, oil, should never enter this instrument. To prevent this, use a water trap and a floating probe. Only the manufacturer's recommended filters should be used to remove solid particles and humidity from the sample.

This sensor is not affected by concentrations that exceed the scale reading and when concentrations reduce the readings will fall back into the range of the scale.

Gas measurement instruments that use this technology

Direct-reading PIDs.

2.4.6.9 Paramagnetic sensors

Operating principle

Unlike most other common gases, oxygen is strongly paramagnetic (i.e. it is attracted by the poles of a magnet but does not retain any permanent magnetism), which means oxygen content can be measured in a wide variety of gas mixtures.

A sample cell has a lightweight body suspended in a magnetic field. When sample gas is drawn through the cell, the torque that the suspended body experiences is proportional to the magnetic susceptibility of the gas. An electric current passing through a coil wound around the suspended body produces an equal and opposing torque. The equalising current is a measure of the magnetic force and so a measure of the magnetic susceptibility of the sample, i.e. related to its oxygen content.

The analyser readings are directly proportional to the pressure in the measuring cell. The unit is calibrated to a specific atmospheric pressure and the small error due to atmospheric pressure variations can be corrected if required. Continuous samples should be supplied to the instrument by positive pressure. They should not be drawn through the analyser by negative pressure as the measuring pressure then becomes uncertain.

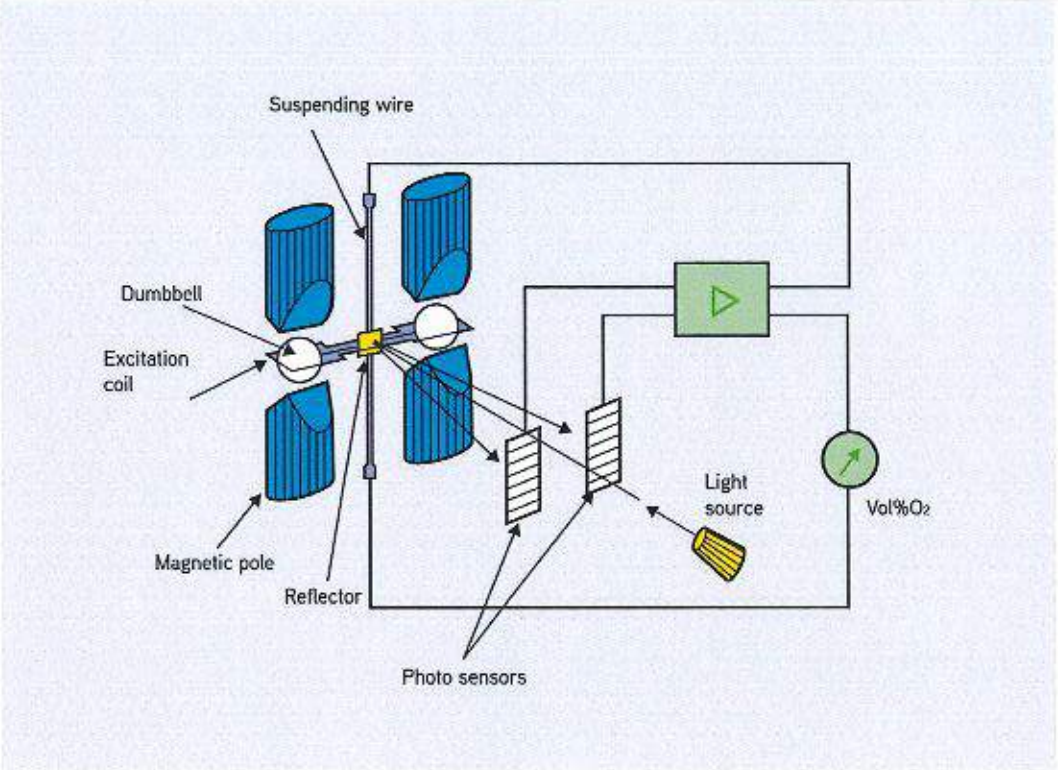


Figure 2.13: Paramagnetic sensor (dumbbell type)

Application

This technology is used to measure oxygen content in both inerted and non-inerted atmospheres.

Cautions

Before use, the analyser should be tested with air for a reference point of 21% oxygen, and with nitrogen or CO_2 for a 0% oxygen reference point.

Releasing nitrogen or CO_2 in a confined or unventilated area can lower the concentration of oxygen to a level that is an immediate danger to life or health. Therefore, calibration should only be carried out in well ventilated areas.

Clear or replace the filter when an increase in sample pressure is needed to maintain a reasonable gas flow through the analyser. The same reduction in flow effect is produced if the filter becomes wet due to insufficient gas drying. Check regularly the need to clean or replace filters.

Gas measurement instruments that use this technology

Fixed oxygen analysers.

2.4.7 Testing and calibrating gas measurement instruments

2.4.7.1 Operational testing (self-testing) gas measurement instruments

Operational testing should not be confused with a span gas check.

Gas measuring instruments should be tested in line with the manufacturer's instructions before daily use. Such tests are meant to ensure the instrument is in good working condition.

Physical checks should include (if applicable):

- Hand pump.
- Extension tubes and houses.
- Tightness of connections.
- Batteries.
- Housing and case.
- Filters and flame arresters.

Instruments not fulfilling the operational and physical tests should be clearly labelled to prevent their use. They should be calibrated and/or repaired before being brought back into use.

During operations it is important to check the instrument and sample lines occasionally. Operators should determine the frequency for these operational checks and record the results.

Operational testing should be included in the tanker and terminal systems for managing safety.

2.4.7.2 Testing gas measurement instruments

Portable and fixed gas measurement instruments should be tested at minimum recommended frequency using test gases as per the manufacturer's instructions and the company's SMS.

In any case, portable and fixed gas measurement instruments should be tested at least every month or after any fault.

When used for enclosed space entry, portable instruments should be tested daily prior to the start of atmosphere checks. This should include a visual inspection and a functional check. The purpose of carrying out a functional check is to verify that the equipment detects gas and gives an audiovisual alarm at required concentrations (International Electrotechnical Commission (IEC) 60079-29-2).

The requirement for pre-use checks should not include fixed equipment as their risk profile is not the same as that of portable instruments.

Testing of gas measurement instruments should only be undertaken by trained personnel, as per the manufacturer's instructions, and the test should be documented appropriately. Testing should not be confused with calibration checks.

2.4.7.3 Calibrating gas measurement instruments

Calibration, adjustment and additional maintenance should be carried out in line with the manufacturer's recommendations.

Calibration should be included in the tanker and terminal systems for managing safety.

2.4.7.4 Disposable personal gas monitors

To confirm they are working properly, disposable personal gas monitors should be tested regularly and in line with the manufacturer's recommendations.

Disposable gas detection monitors cannot be re-calibrated and should be safely discarded when they reach the calibration expiry date. It is important to record the date when disposable instruments are first commissioned in order to establish their expiry date.

2.4.8 Gas measurement instrument alarms

If a gas measurement instrument is fitted with an alarm, it should activate at the appropriate level as determined by the Flag State administration.

If a gas measurement instrument is fitted with an alarm or shutdown function that activates if the manufacturer's calibration interval is exceeded, the alarm should not be bypassed and the instrument should not be used until it is re-calibrated.

2.5 Sampling

2.5.1 Gas sample lines

The material used and the condition of sample lines can affect the accuracy of gas measurements.

Metal tubes are unsuited to most cargo tank gas measurements, so flexible lines should be used.

The gases from crude oils and many petroleum products are composed of paraffinic hydrocarbons and several suitable materials are available for flexible sample tubing. The problem of material selection is more difficult for gases with a high proportion of aromatic hydrocarbons, particularly xylene. In such cases, suppliers of sample tubing should be asked to provide test data showing the suitability of their product for the intended purpose.

Sample tubing should be resistant to hot wash water.

Sample tubing that is cracked, blocked or contaminated with cargo residues greatly affects instrument readings. Check the condition of the tubing regularly and replace any that is found to be defective.

To prevent liquid from being drawn up the gas sampling line and contaminating it, manufacturers provide either a float or probe termination. Operators should consider using these fittings, but be aware of any limitations on their use in order to avoid static hazards.

2.5.2 Filters in sample lines

Filters remove water vapour in some catalytic or non-catalytic filament type hydrocarbon gas meters and extra filters are not normally needed. In wet conditions, such as during tank washing, excessive water can be removed from the gas sample using materials that retain water but do not affect the hydrocarbons. Modern gas measurement instruments often use water traps, consisting of a polytetrafluoroethylene (PTFE) membrane that prevents liquid and moisture passing onto the sensors. Water retaining filters are essential with oxygen meters, particularly the paramagnetic type, because any water vapour in the sample can damage the measuring cell. Only the manufacturer's recommended filters should be used.

2.5.3 Gas sample procedures

Every tank has dead spots where the rate of change of gas concentration during ventilation or purging is less than the average. The location of these dead spots depends on the positions of the inlet and outlet for ventilating air or IG and on the disposition of the structural members in the tank. The dead spots are generally within the tank bottom structure. The sample line should be long enough to allow sampling in the bottom structure.

Differences in gas concentration between the bulk volume of the tank and the dead spots vary depending on the operating procedures. For example, the powerful water jets produced by fixed washing machines are excellent mixing devices and tend to eliminate major differences in gas concentration between one location and another. Similarly, directing powerful jets of ventilating air or IG downwards from the deckhead produces good mixing and minimises variations in concentration.

Because of the hazards associated with these dead spots, refer to chapter 10 before entering any cargo tank or other enclosed space.

2.6 Fixed hydrocarbon gas detection systems

2.6.1 Fixed hydrocarbon gas detection systems on tankers

The system comprises a central unit for gas measuring and gas sampling pipes in all ballast tanks, void spaces next to the cargo tanks, pumprooms and any other tanks and spaces next to cargo tanks.

The system should be able to continuously measure hydrocarbon gas concentrations and may be arranged to operate on a sequential scanning principle, provided that each sampling line of each protected space is analysed at least every 30 minutes.

If the fixed system is not working or being calibrated, make sure it is possible to measure using portable instruments instead.

If the system is out of order, have procedures to continue monitoring the atmosphere with portable instruments and recording the results.

2.6.1.1 Control panels and indicating units

- Control panels should be in the cargo control room, on the navigation bridge or in a gas safe continuously manned central control station.
- Clear information should be displayed on or next to the control panel to allow the crew to readily determine the source of the alarm or fault condition.
- Control panels should have a button or switch to manually reset to normal operating conditions after alarm and fault conditions are cleared.
- Indicating units should be located on the navigation bridge if the control panel is located elsewhere.
- Control panel and indicating unit alarm signals should be distinct from fault condition signals.
- Indicating units may have common alarms servicing multiple sampling points, provided that all sampling points within an alarm group are in the same space.
- Control panels should be able to manually test audible and visual alarms.

2.6.1.2 Alarm conditions

Audible and visual alarms, in accordance with the IMO's *Code on Alerts and Indicators*, should be initiated in the cargo control room, the navigation bridge, at the control panel and at all indicating units under the following conditions:

- On detection of gas concentrations in any monitored space on a pre-set value not higher than the equivalent of 30% of LFL.
- In a fault condition, such as power failure or short circuit.
- Low or no flow in any sampling pipe.
- Tampering with the alarm set point.
- Failure of any self-test functions.

A visual alarm should remain in effect during an alarm condition. The audible alarm may be silenced manually.

If gas concentrations above the alarm set point are detected within the enclosure, the alarm should sound and the analysis unit should be automatically isolated from all sampling pipes and shut down. Take appropriate steps to vent flammable gas inside the enclosure to an open space away from ignition sources.

2.6.1.3 Operation and maintenance

The following onboard maintenance should be carried out monthly and after any fault condition:

- Visual inspection.
- Testing audible and visual alarms.
- Span gas checking.

Additional maintenance should be carried out as specified by the manufacturer's instructions.

The maintenance and testing described above should be included in the tanker's maintenance plan.

Operating and maintenance instructions for the system should be provided on board and include the following information:

- Operating instructions.
- Gases the system is suitable for.
- System diagrams showing sampling points and the relationship of all components.
- Transfer functions relating the output relative to the calibration gas to other gases.
- Calibration, span gas checking and maintenance procedures.
- Troubleshooting procedures.
- Minimum and maximum flow rates.
- The nature and significance of fault signals (MSC.1/Circ.1370 *Guidelines for the Design, Construction and Testing of Fixed Hydrocarbon Gas Detection Systems*).

If the fixed gas detection system should fail, manual checks should be made. Records should be reviewed to ensure that these have been conducted. The manufacturer's instructions for maintaining the system should be followed.

2.6.2 Fixed hydrocarbon gas detection systems in terminals

2.6.2.1 General

Where not already required by local regulations or requirements, terminals that handle crude oil or products containing toxic components should consider installing fixed gas detection and alarm equipment in areas where personnel may be exposed. A risk assessment should be undertaken where this risk to personnel exists and should consider:

- The overall safety and health risk to personnel from hydrocarbon and toxic vapours.
- The appropriate placing of sensors in locations where personnel may work and where leaks or spills could occur, e.g. loading arms, valve manifolds and transfer pumps, to ensure that early and adequate warning of an increased risk of exposure is provided.
- Whether the area is properly ventilated to minimise or eliminate the potential for gas to accumulate.

If, as a result of the risk assessment, there remains doubt that exposure to personnel could occur, the fitting of fixed gas detection is recommended.

Toxic gas detectors may also be installed in the supply air intakes of pressurised control rooms and inside non-pressurised control rooms.

These gas detection systems are, typically, permanent, electrically operated devices that sense the presence of combustible or toxic gases and provide early warning before the gas concentration reaches UFL, acute or chronic toxic levels. They continuously monitor potentially hazardous areas to safeguard against fire or explosion and to protect personnel from toxic gas leaks.

2.6.2.2 Sensors

The systems employ a range of the sensors described above, including catalytic, PID, electrochemical and IR, including tunable diode laser sensors.

Depending on the application, each detector location has its pros and cons. IR detectors are available in open-path and point-types and use the hydrocarbon absorption principle to detect combustible gases. However, they cannot be used on non-hydrocarbon gases, such as hydrogen and CO. IR gas detectors are not susceptible to poisoning since they do not require a reaction to take place. Catalytic sensors may require more maintenance than IR detectors and are susceptible to poisoning.

The analysers may be the remote detection type, where electrical cable connects individual sensors to the analysers. In this case, the central equipment can be installed either in non-hazardous locations, such as pressurised control rooms, or in explosion-proof enclosures in hazardous areas. The remote detection type, which uses remote diffusion detectors, is preferred because it provides rapid response and good reliability.

Alternatively, systems may use a central detection unit that uses a suction pump to draw samples from hazardous areas through tubing to the central location. Central detection units that use sample lines have a relatively slow response time. Where central detection units that use sample lines are installed, users should consider the following:

- Relatively slow response time.
- Particulate contamination in the lines.
- Moisture in the lines that will require them to be heated.

2.6.2.3 Design of system

As well as continuously recording data, gas analysers may have the following functions:

- Individual detection sensors should be connected to an interface so that each sampling circuit can continuously analyse for the presence of gases. When an alarm is triggered the registering sensor will be indicated and the alarm will remain active until manually reset.
- Terminals should be fitted with fixed gas detection of an approved type. The system should measure the range of LFL of hydrocarbons. The system should have two alarm points to alert for high and high-high, based on a risk assessment, international standards and national requirements.
- Alarm levels should be adjustable. Multi-level alarm conditions can be provided with ways to activate ventilation equipment or fire-extinguishing systems, or to shut down the facility.
- An inhibiting or bypass switch (hard wire or soft link) should isolate the detector during routine calibration and maintenance work. This disconnection is necessary for routine calibration and maintenance activities. A key operated switch with supervisory alarm is recommended.
- On complicated or extensive systems, the indication of alarms on a graphic display, such as an outline plan of a facility, is recommended.
- Toxic gas analysers should be set to sound alarms at the monitored location and in the control room when the gas reaches the predetermined level, e.g. when H_2S concentration reaches 5ppm. Alarms should generally be audible and visual.
- The gas detector head assembly should be suitable for the electrical classification of the hazardous area. If installed outdoors it should be weatherproof and corrosion resistant.
- The detecting unit should provide the necessary sensitivity and stability under all conditions to repeat any reading within ± 2% of the full-scale range.

2.6.2.4 Positioning fixed combustible and toxic gas detectors in terminals

Positioning combustible and toxic gas detectors should be based on a risk assessment and consider:

- Elevations, depending on the relative density of air and any potential gas leaks.
- Possible flow direction of leaking gas.
- Proximity to potential hazards.
- Accessibility of detectors for calibration and maintenance.
- Sources of damage, e.g. water and vibration.
- Industry data on the probability of small-bore leaks and frequency of failures.
- Industry data on the probability and frequency of ignitions.
- Computational fluid dynamics modelling.
- 3D gas detection mapping.
- The manufacturer's recommendations for sensors connected to analysers.