

*Monitoring VOC emissions:
choosing the best option*





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Envirowise

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Summary

Many companies need to monitor volatile organic compound (VOC) emissions to demonstrate compliance with environmental legislation. However, VOC monitoring can also provide significant benefits to companies, such as **cost savings** from reduced raw material use and **safer working conditions** for operators. VOC monitoring can specifically help your company to:

- take action to reduce solvent use and VOC emissions as part of a structured solvent management programme;
- identify and reduce leaks;
- demonstrate continual improvement in environmental performance;
- fulfil health, safety and environmental requirements;
- optimise process flows.

The Guide is aimed at operators and managers with a technical background. All companies that use solvents should consider implementing a VOC monitoring programme. However, a wide range of VOC monitoring techniques and analytical methods and supplementary equipment to measure temperature, pressure, flow etc are available, making it difficult to choose the most appropriate techniques. This Good Practice Guide is intended to help you choose the most cost-effective VOC monitoring and flow-measurement technique, thereby keeping the expense of monitoring to a minimum.

The Guide describes:

- the reasons for monitoring VOC emissions and measuring flows;
- the role of VOC monitoring in a solvent management plan;
- the advantages and disadvantages of different VOC monitoring and flow-measurement techniques;
- a step-by-step approach to setting up a monitoring programme;
- examples of companies that have benefited from VOC monitoring;
- examples for presenting and standardising results.

Use of the monitoring results should not be limited solely to supplying information to regulators. The data can be extremely valuable in identifying opportunities to reduce solvent consumption and VOC emissions. By helping to reduce overall emissions, monitoring can reduce, or even eliminate, the need for costly abatement equipment.

For further free advice on all aspects of solvent management, contact the Environment and Energy Helpline on 0800 585794 or visit the Envirowise website (www.envirowise.gov.uk).

This Guide was first printed in September 1999 under the Environmental Technology Best Practice Programme which is now known as Envirowise. The publication has been updated and revised.

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Current levels of volatile organic compounds¹ (VOCs) in the atmosphere are a subject of widespread concern and regulation. The large amounts of industrial solvents and solvent-containing materials used by manufacturing companies are a major source of VOC emissions in the UK. For the purpose of this Good Practice Guide, 'solvent' means an organic liquid that evaporates readily at normal temperature and pressure, giving rise to VOC emissions.

This Guide is intended to help your company to monitor and quantify its VOC emissions. As well as monitoring VOC concentrations (eg mg/m³), you should also measure the air-flow velocity in stacks and ducts so that the volumetric flow can be calculated (m³/hr). Together, these data can be used to evaluate mass emission rate (eg kg/hr). This information is particularly useful if you wish to track solvent consumption, or embark on a solvent management programme where a solvent mass balance is often required.

The Guide is relevant to all companies that use solvents, including those that manufacture or use:

- adhesives;
- printing inks;
- paints;
- lacquers and stains.

It is also relevant to companies that use solvent-containing materials such as pre-cleaners and anti-corrosion coatings, or manufacture chemicals or pharmaceuticals.

This Guide was first printed in September 1999 under the Environmental Technology Best Practice Programme which is now known as Envirowise. The publication has been updated and revised in this edition. It is aimed at operators and managers with a technical background.

1.1 The benefits of VOC monitoring

The main reason why many companies monitor their VOC emissions is to provide the information required by a regulator², under an Integrated Pollution Prevention and Control (IPPC) or Local Air Pollution Prevention and Control (LAPPC) process authorisation.

However, as illustrated in the industry examples in section 4, VOC monitoring can also help you to:

- reduce solvent consumption (possibly below the regulatory thresholds);
- identify opportunities to reduce solvent costs and emissions as part of a solvent management programme, possibly avoiding the need to install expensive abatement plant (see section 1.3);
- reduce costs through leak management;

¹ Organic compounds that vaporise readily at room temperature and take part in the formation of low-level ozone.

² Local authority or the Environment Agency (in England and Wales), the Scottish Environment Protection Agency (SEPA) in Scotland or the Environment and Heritage Service in Northern Ireland.

- demonstrate continual improvement in environmental performance, eg as part of an environmental management system (EMS);
- fulfil health and safety requirements and improve working conditions;
- optimise process flows through the plant.

You can obtain **free** advice on the most recent legislation regarding VOC monitoring and industrial use of solvents through the Environment and Energy Helpline on 0800 585794.

1.2 The purpose of this Guide

This Guide is primarily concerned with emissions from stacks and local exhaust ventilation (LEV) systems. Various VOC monitoring and flow-measurement techniques are available, all providing different information. If you decide to monitor your VOC emissions, you should consider a range of issues before deciding on the most appropriate technique. Without careful consideration, the wide choice available can often lead to:

- the wrong technique being chosen, resulting in inaccurate or incomplete data;
- monitoring having to be repeated;
- increased costs and wasted time and effort.

The aim of this Guide is to help you achieve cost savings by choosing the most cost-effective VOC monitoring and flow-measurement technique, ie getting it right first time. The advice given here applies equally, whether you wish to carry out monitoring in-house or decide to contract out the work to a specialist company.

Choosing the most appropriate technique will avoid the cost of repeat monitoring and enable information to be obtained quickly. Data can then be used to highlight areas where emissions are excessive, and action taken to reduce waste.

The measures described in this Guide will help you to:

- reduce the cost of VOC monitoring by selecting the most cost-effective option;
- identify opportunities to reduce emissions, thereby leading to less waste of solvent-containing materials;
- avoid spending money on unnecessary monitoring equipment;
- make a cost-effective evaluation of existing abatement equipment.

Furthermore, the Guide may help you to eliminate, or reduce, the need for end-of-pipe abatement equipment.

1.3 Monitoring and solvent management

Solvent management is a structured approach to reducing solvent consumption and VOC emissions through measurement and analysis. It is based on a mass balance approach, ie what comes in must go out somewhere (the mass of atoms cannot be destroyed, only the state or form altered). You can carry out solvent management either as a stand-alone activity or as part of a broader waste minimisation programme. VOC monitoring helps to gather solvent management data and, consequently, identify where solvent waste can be minimised.

The following Good Practice Guides contain further information on fugitive (uncaptured) emissions and solvent management:

- *Cost-effective reduction of fugitive solvent emissions* (GG71);
- *Cost-effective solvent management* (GG429);
- *Solvent management in practice: industry examples* (GG124).

Free Envirowise publications on reducing solvent use

Envirowise has published a range of free guides and case studies with practical advice on how companies can manage their solvent use and minimise VOC emissions. Both general information and advice specific to different sectors are available. To find out which publications and tools are most applicable to your company, contact the Environment and Energy Helpline free on 0800 585794.

VOC monitoring and flow-measurement techniques

This section describes the techniques available for monitoring VOC emissions and measuring flows in ducts and stacks and the type of information provided by each method. Remember, many of the techniques can also be used for fugitive VOC emission monitoring.

2.1 Taking VOC measurements

VOC emissions can be monitored using:

- **grab sampling**, which involves taking individual, representative samples for subsequent on-site or off-site laboratory analysis (see section 2.2.1 for sampling methods);
- **portable analysers**, where an on-line probe, with or without a data logger, is inserted in the vapour stream;
- **continuous emission monitoring (CEM)**, where an on-line probe is inserted in the vapour stream and connected to automated analysis and recording equipment.

The various techniques available for monitoring VOC emissions are described below. You can use Table 6 (see section 3.4) to compare the relative costs of these monitoring devices.

2.2 Monitoring methods

2.2.1 Sampling collection

Grab samples can be collected in a variety of ways for subsequent analysis. The common methods are detailed below.

Stain or indicator tubes

These tubes (often called Drager tubes after one of the main manufacturers) consist of a glass phial containing a chemical that changes colour when in contact with specific VOCs. A hand-pump is connected to the tube to slowly draw in a sample of the correct volume. You can purchase tubes that are calibrated for any specific VOC, a scale on the side giving an instant indication of VOC concentration.

Sorbent tubes

These tubes (often called NIOSH tubes after the US National Institute for Occupational Safety and Health) contain a sorbent, eg activated carbon or silica gel. A measured volume of sample air is drawn through the tube and some of the VOCs are retained on the sorbent material. The tube is then sent to a laboratory where the VOCs are released, usually by thermal desorption. The sample is then analysed using an appropriate laboratory analysis method, eg gas chromatography (see section 2.3). Sorbent sampling and analytical methods are specified by Health and Safety Executive (HSE) (MDHS series) and NIOSH.

Active sampling filters

These work in a similar way to sorbent tubes, as they are filters impregnated with sorbent. They are designed, however, to capture specific VOCs, eg isocyanates. Like other methods, they are sent to a laboratory for desorption and analysis.

Flexible bags

These are often used for odour sampling and sometimes for VOCs. The bag is made from inert material (usually polytetrafluoroethylene, PTFE) and is purchased already evacuated. The bag is connected to the sampling line and placed in an airtight container. The container is then evacuated using a pump, the bag inflating with the sample (hence it is sometimes called the lung method). The bag is disconnected from the sampling line, sealed and sent for laboratory analysis.

Personal monitors

These are exposure monitors worn by operators, mainly to comply with health and safety requirements. The monitors, which give an indication of ambient conditions, have to be sent away for laboratory analysis.

2.2.2 Monitoring devices

Various hand-held/portable monitoring devices are available. Each device has its own particular strengths and weaknesses, but most have integral data loggers and can be attached to both laptops for data download and portable gas chromatographs (GC) for further sample analysis.

Photoionisation detection (PID)

Photoionisation detectors (PIDs) are a common device for VOC monitoring, as they are compact (hand-held), sensitive and hard-wearing. They give a direct reading of VOC content as total non-methane carbon, ie excluding methane. The solvent is ionised using a high voltage ultraviolet lamp and no fuel is required (unlike FIDs - see below). The electrical current created is proportional to the carbon content of the sample gas. PIDs respond to most organic vapours, but the response varies between compounds. Dust and water vapour can cause problems if not properly dealt with, so devices tend to be fitted with water/dust filters. Most PIDs provide limited information about the identity of the organic compounds present in the sample. However, more advanced PIDs may have built-in gas chromatography (PID(GC)) with a library of specific organic compounds that can be analysed. In either case, you can obtain further details through laboratory analysis of a grab sample.

Flame ionisation detection (FID)

Flame ionisation detectors (FIDs) are very commonly used for VOC monitoring and give a direct reading of total organic carbon (TOC) present, ie including methane. As with PIDs, an instant read-out of carbon content is provided, usually expressed in terms of the equivalent number of methane molecules. The operation of a FID is similar to that of a PID, except that a hydrogen flame is used to ionise the solvent. This means that FIDs cannot be used where there is a potential risk of explosion. To operate a FID, a hydrogen cylinder and a calibration gas cylinder have to be used and maintained. Due to these cylinders, FIDs tend to be slightly larger than PIDs, although still hand-held. Individual compounds can be identified by linking the FID to a portable gas chromatograph (FID(GC)). As with PIDs, dust and water vapour can cause problems if not properly dealt with, so devices tend to be fitted with water/dust filters.

Non-dispersive infrared (NDIR)

Non-dispersive infrared (NDIR) monitors measure the carbon content of the gas and give a direct reading of VOCs. NDIR monitors detect the absorption by, or emission of, infrared radiation from the gas molecules. The amount of absorption or emission depends on the molecular structure of the gas being analysed. NDIR monitors require no fuel, unlike FIDs, but as with both FIDs and PIDs, dust and water vapour can cause problems and, again, most devices are fitted with water/dust filters. NDIRs require regular recalibration and can suffer problems with complex gas mixtures.

Fourier transform infrared (FTIR)

Fourier transform infrared (FTIR) systems can give direct readings of total VOCs and individual compounds, without the need for gas chromatography. Up to thirty gases can be identified and analysed simultaneously by this technique. As it is a relatively new and detailed method of VOC monitoring, the capital cost of the equipment is higher than for other techniques. A number of manufacturers now supply portable versions.

2.3 Laboratory analysis methods

Table 1 shows the techniques widely used by laboratories for VOC analysis. Often, accredited laboratories are able to undertake a wide variety of analyses using a selection of the methods listed below. However, it is always a good idea to check that your analytical requirements are within the scope of the laboratory's accreditation.

Table 1 Laboratory analysis methods used for VOCs

Name	Abbreviation	Compounds analysed
Common analytical methods		
Gas chromatography - flame ionisation detection.	GC-FID	Wide range of VOCs, eg benzene, toluene, butyl acetate and alcohols.
Gas chromatography - photoionisation detection.	GC-PID	Wide range of VOCs, eg benzene, toluene, butyl acetate, alcohols and chlorinated VOCs.
Gas chromatography - mass spectrometry.	GC-MS	Wide range of VOCs; useful when compounds present are not known.
Less common analytical methods		
Gas chromatography - flame photometric detection.	GC-FPD	VOCs such as mercaptans and organosulphides.
Gas chromatography - nitrogen phosphorus detection.	GC-NPD	Used for compounds containing nitrogen and phosphorus only.
Gas chromatography - nitrogen specific detection.	GC-NSD	Used for nitrogen compounds only.
Gas chromatography - electron capture detection.	GC-ECD	Chlorinated VOCs.

2.4 Taking flow velocity measurements

For compliance or mass balance (solvent management plan) purposes, emissions may have to be expressed as a mass emission rate (eg kg/hour) as opposed to a concentration. To do this, you need to determine the volumetric flow rate by measuring the average flow velocity in the stack or duct and multiplying it by the duct cross-sectional area. A number of techniques can be used to measure the flow velocity, three of which are described overleaf.

Pitot-static tube and micro-manometer

This is the most common method, where pitot-static probes are inserted into the flow. They measure its dynamic pressure by calculating the difference between total and static pressure on a manometer. This dynamic pressure value can then be converted to a velocity by using a value for the flow density (see appendix 2). British Standard BS 1042 ellipsoidal pitot tubes are generally used with an electronic micro-manometer and thermometer.

Vane anemometer

This is a simple, mechanical turbine-type unit with a series of vanes, the rate of rotation being measured to indicate the velocity of the flow. This is normally done electronically on a digital display, after appropriate calibration. These devices have to be held in the flow, so they are best suited for duct exhaust measurements.

Hot-wire anemometer

This device works on the principle that electrical resistance is related to the temperature of a wire and heat transfer is related to air-flow velocity. Therefore, these devices can be calibrated to relate electrical current to flow velocity. Physically, these devices involve a probe connected to a digital display. By their nature, hot-wire anemometers are very sensitive to sudden velocity and temperature changes.

A number of different types of such velocity measurement equipment are available, with different performance characteristics and features, eg digital displays, data loggers etc. In each case, you should always check the operating constraints, accuracy and measurement range. Initially, it may be a good idea to use a specialist to obtain samples and advise you on the most suitable technique and equipment to use.

It is important to remember that these devices measure velocity, usually as m/s. To obtain the flow rate (as m³/s), you have to multiply the velocity by the area of the duct (m²). In the case of vents with circular cross-sections, this is:

$$\pi \times (d^2/4)$$

where d = duct internal diameter in metres and $\pi = 3.142$ approximately.

Some flow measuring devices have an integral thermocouple to allow temperature measurement. Temperature is an important parameter where accurate and standardised measurements are required (see section 2.7). In addition, it is important to measure flow in a suitable location within the duct. British Standards BS 3405 and BS 6069 both provide guidance on sampling locations.

2.5 Summary of techniques

Table 2 (overleaf) summarises the range of VOC monitoring and flow-measurement methods available and the information they provide.

Table 2 Summary of VOC and air-flow monitoring techniques

Method	Type of sample	Information provided	How provided	Source of equipment
VOC sampling techniques				
Stain or indicator tubes	Grab	Indicative readings for one specified compound	Direct results	Buy
Sorbent tubes	Grab	Set up for a range of compounds	Laboratory analysis	Buy or contract out
Active sampling filters	Grab	Set up for a particular compound	Laboratory analysis	Buy or contract out
Flexible bags	Grab	Sample of everything in the volume collected	Laboratory analysis	Buy or contract out
Personal monitors	Grab	Set up for a particular compound	Laboratory analysis	Buy or contract out
VOC monitoring devices				
PID	Continuous/portable	Total non-methane carbon	Direct results	Hire, buy or contract out
PID (GC)	Grab	Some speciation*	Laboratory analysis	Buy or contract out
FID	Continuous/portable	Total carbon as methane equivalent	Direct results	Hire, buy or contract out
FID (GC)	Grab	Some speciation*	Laboratory analysis	Buy or contract out
NDIR	Continuous	Some speciation*	Direct results	Buy or contract out
FTIR	Grab	Speciation*	Direct results	Hire, buy or contract out
Flow measurements				
Pitot-static tube with micro-manometer	N/A	Stream velocity	Result calculated from pressure and density	Hire or buy
Vane anemometer	N/A	Stream velocity	Direct results	Hire or buy
Hot-wire anemometer	N/A	Stream velocity	Direct results	Hire or buy

*Individual organic compounds or species present.

2.6 Monitoring standards and guidance

Table 3 lists relevant UK and US standards, and approved VOC and flow monitoring methods. It is important that the monitoring equipment/method complies with the main elements of a recognised standard.

Table 3 Relevant UK and US monitoring standards

Measurement	Technique	Reference method
VOC monitoring		
Total VOCs	Flame ionisation detection (FID); photoionisation detection (PID)	US EPA ³ Method 25A
Total VOCs	Non-dispersive infrared (NDIR)	US EPA ³ Method 25B
Condensable organic compounds ⁴	Condensation FID with gas chromatography	Modified US EPA ³ Method 5
Specific VOC	Adsorption FID	MDHS ⁵ / NIOSH ⁶ / OSHA ⁷
Flow measurements		
Velocity and temperature	Traverse of sampling plane using pitot-static tube and thermocouple	BS 1042 ⁸ /BS 6069 ⁹ /BS 3405 ¹⁰

Obtaining a representative sample of gaseous pollutants is normally straightforward, due to the relatively homogeneous nature of the stream. However, you should make sure that the integrity of the sample is maintained as it is transported from the duct/stack to the monitoring equipment or analyser, and that any elements that will affect the accuracy of the results are removed.

Take care when transferring hot combustion gases via/to relatively cold equipment. Allowing VOCs to condense will, of course, give erroneous results from the gas sample. There are ways in which you can avoid this problem, eg by heating the line from the stack or duct, or, less commonly, by introducing carefully controlled quantities of dry dilution air to stop the dew point being reached, as is often done for odour sampling. For the analysis of combustion gases, it is a good idea to remove water vapour because standard reference conditions for such gases (although not VOCs in general) are normally set for dry air. In-line silica gel traps and water condensate are often used to remove water vapour. As VOCs are volatile, most do not condense at 0°C, so the result is usually unaffected.

Particulates are also a problem because of the way some emission limits are set, and may also need to be removed if significant. You can use particulate filters and traps, but these need to be located within the heated section if condensables are being measured. As mentioned above, some portable devices, eg FIDs and PIDs, will remove water vapour and particulates.

³ US Environmental Protection Agency.

⁴ Using a water/ice condenser.

⁵ Methods for the Determination of Hazardous Substances (UK Health and Safety Executive).

⁶ National Institute for Occupational Safety and Health (USA).

⁷ Occupational Safety and Health Administration (USA).

⁸ British Standard 1042 (various parts): *Measurement of fluid flow in closed conduits. Velocity area methods including using pitot-static tubes* (see www.bsi-global.com).

⁹ British Standard 6069 (various parts): *Characterization of air quality. Stationary source emissions* (see www.bsi-global.com).

¹⁰ British Standard 3405: *Method for measurement of particulate emission including grit and dust (simplified method)* (see www.bsi-global.com).

BS 3405 sets out the requirements for selecting flow-measurement sites on a duct/stack, and flow-measurement and sampling points and traverses across the duct/stack. As a general rule, flow measurements should only be made in linear (non-turbulent) flow areas, five to six diameters downstream and two diameters upstream of any point of turbulence, eg a valve, bend, confluence or outlet.

For more details, see the methods and standards noted above and the following Environment Agency guidance on sampling techniques and requirements:

- Technical Guidance Document (monitoring) M1, *Sampling requirements for monitoring stack emissions to air from industrial installations*, EA, Version 2, July 2002;
- Technical Guidance Document (monitoring) M2, *Monitoring of stack emissions to air*, EA, Version 1, November 2002.

These two documents can be found on the Environment Agency's website (at www.environment-agency.gov.uk).

Environmental legislation may vary between different parts of the UK. For further information on relevant legislation and new legislative developments affecting your company:

- contact the Environment and Energy Helpline on 0800 585794;
- contact the appropriate environmental regulator;
- visit the NetRegs website (www.environment-agency.gov.uk/netregs/) developed by the Environment Agency in collaboration with the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment and Heritage Service (EHSNI).

2.7 Expressing results - standard reference conditions

Emission concentration limits are usually expressed as a mass (eg mg) of substance per Normalised (N) volume (m^3) of gas (ie corrected for standard conditions - see below). Averaging times vary, but often concentration limits have to be expressed as 15-minute or 30-minute means.

Concentration limits can be expressed as mg/Nm^3 of compounds, eg methane, toluene or hexane (which have different numbers of carbon atoms per molecule). Where this is the case, and measurements have been taken as total carbon, a further correction may have to be made (see appendix 1).

Mass emission calculations are normally expressed in kg or tonne units and require a knowledge of the gas flow rate (Nm^3/hr), as discussed in section 2.4.

To allow results from different sites to be compared, taking account of different operating circumstances, you need to set standard reference conditions for reporting. Standard reference conditions specified by current UK legislation are given in Table 4.

Table 4 Standard reference conditions for VOC monitoring

Parameter	Reference conditions
Temperature	273 K (0°C)
Pressure	101.3 kPa (1 atmosphere)
Humidity	Dry (no moisture correction is normally required for non-combustion sources)
Oxygen content	Depends on type of combustion process No oxygen correction is normally necessary for non-combustion processes

Correction for temperature is almost always required, as most measurements will be taken at non-reference temperatures. Corrections for pressure are not normally necessary as any change is usually insignificant.

Correction for oxygen content is necessary when monitoring emissions from combustion processes, eg curing ovens and incineration-based abatement equipment. This is because the amount of oxygen remaining reflects the proportion of excess air used in the combustion process, and allowance is made for this in the legislation. Oxygen content is usually determined via a combustion analyser, using electrochemical or paramagnetic devices.

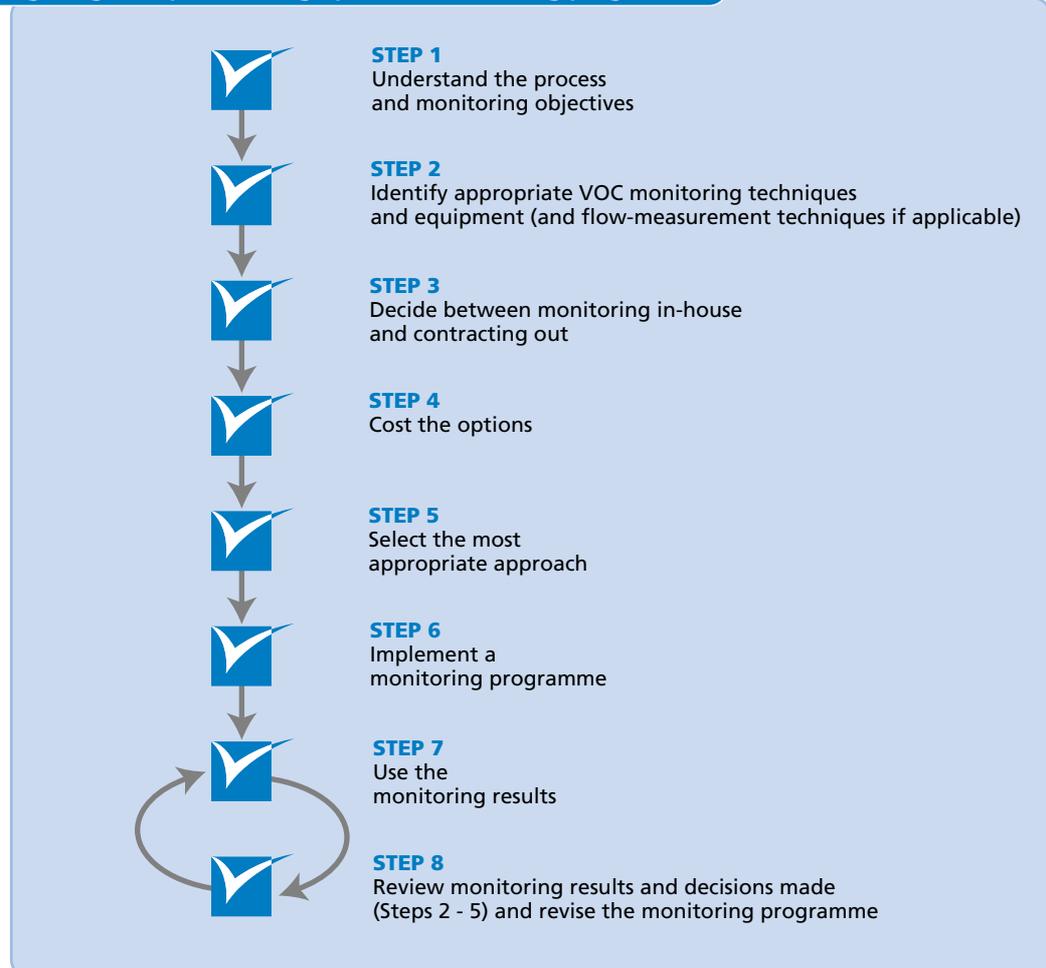
The appendices in this Guide contain the equations that will enable you to:

- convert from parts per million (ppm) of methane to mg/m^3 as carbon;
- convert from mg/m^3 as carbon to mg/m^3 as toluene;
- calculate mass emission rates (kg/hr);
- correct measured emission concentrations to standard reference conditions.

Setting up a monitoring programme

This section describes a step-by-step approach to setting up a VOC monitoring programme (see Fig 1). Each step needs careful consideration.

Fig1 Eight steps to setting up a VOC monitoring programme



3.1 Step 1 - Understand the process and monitoring objectives

Before deciding on a VOC monitoring technique, it is important to think about what actually goes on within your company's processes. Consider the following questions for each process:

- Is the emission a single VOC stream or a complex mixture of VOCs?
- Is the process operating on a batch or continuous basis?
- Is the sampling port in a designated and intrinsically safe area? If not, then equipment that potentially produces sparks or flames (eg FIDs) must not be used.
- Could particulate emissions cause problems?
- Do emissions have a high moisture content? Moisture interferes with most sampling techniques, eg by saturating sorbent tubes and preventing uptake of VOCs, and causing problems with laboratory equipment.

- Are the emissions at a high temperature? High stack temperatures will restrict the use of some VOC concentration and flow-measurement techniques, so it is wise to check the manufacturer's specification before using equipment. In addition, high temperature emissions will affect sampling arrangements, due to the health and safety risks involved.

You also have to think carefully about your monitoring objectives. Most companies introduce monitoring to comply with environmental legislation. In this case, it is important to find out what information the regulator requires to fulfil your company's legal obligations. For example:

- Does the regulator require data obtained once or twice a year from grab samples, or data from continuous emission monitoring?
- Will a value for total VOC or carbon release be sufficient or is information about specific compounds required?
- Do you need to express the monitoring results at reference conditions? For example, do you need to take additional measurements such as pressure, temperature and oxygen content to correct the results (see section 2.7)?
- Do you need to calculate mass emissions? If so, you need to measure the flow rate as well as VOC emission concentrations.
- Are there any other regulatory requirements? For example, many process guidance notes specify concentration limits as 30-minute mean readings.

The monitoring results can prove useful for other purposes, eg cutting costs as part of a systematic solvent management programme designed to reduce solvent consumption. If so, more comprehensive and regular sampling may be necessary for mass balance work to be completed. For more information on conducting solvent mass balances see Good Practice Guide (GG429), *Cost-effective solvent management*, which is available free of charge through the Environment and Energy Helpline on 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

3.2 Step 2 - Identify appropriate techniques and equipment

Your plant may have many different VOC streams, each of which could be monitored using a variety of techniques. When selecting monitoring techniques and equipment it is important to consider a number of factors, including:

- type of data required and monitoring objectives, eg specific compounds or total carbon;
- regularity of monitoring required, for example:
 - continuous, ie monitoring over an extended period to profile the emissions;
 - routine, ie regular monitoring for leaks as part of a maintenance programme;
 - periodic, eg monitoring to comply with legislative requirements, carried out, say, every six months;
- safety considerations;
- particular operating restrictions, eg process temperature, and humidity;
- accuracy and repeatability required;
- reliability and robustness of equipment;
- accreditation/certification of equipment, sampling personnel and laboratory;
- capital and operating costs.

Use section 2 to help you make an initial selection of potential techniques.

When obtaining equipment and/or services, you should discuss the factors above with the contractor/supplier before making a decision. Where possible, use equipment and organisations that are certified to Monitoring Certification Scheme (MCERTS) standards (see section 3.3). If you require objective advice, this is available through the Environment and Energy Helpline on 0800 585794. The Helpline can also provide non-exhaustive lists of monitoring consultants and suppliers of monitoring equipment.

3.3 Step 3 - Decide between monitoring in-house and contracting out

The next step is to decide whether to:

- contract out monitoring to a specialist company;
- hire the equipment and perform the monitoring in-house;
- purchase the equipment and carry out the monitoring in-house.

Table 5 lists the advantages and disadvantages of these three options. You need to think carefully about whether you have the expertise in-house and about the relative capital and on-going costs (see section 3.4).

Table 5 Advantages and disadvantages of different resource methods

Option	Advantages	Disadvantages	Costs
Contract out	<ul style="list-style-type: none"> ■ No need to maintain and calibrate equipment ■ Obtain services of real experts ■ Lower demand on internal staff resources ■ Consultants will identify appropriate methodologies ■ Equipment, sampling team and laboratory analysis can be accredited/certified (eg MCERTS) ■ May provide own access (scaffolding/ cherry picker) and power supply (mobile laboratory) ■ Covered by contractor's insurance 	<ul style="list-style-type: none"> ■ Only get the information requested; if the specification is wrong, costs will increase through re-testing and further analysis ■ Close co-ordination with sampling team may be required to ensure that representative monitoring is carried out (ie at an appropriate time in the production cycle) 	<ul style="list-style-type: none"> ■ Consultant and laboratory fees ■ May involve costs for access to sampling ports (eg scaffolding, fitting of sampling ports)

Table 5 Advantages and disadvantages of different resource methods (continued)

Option	Advantages	Disadvantages	Costs
Hire equipment	<ul style="list-style-type: none"> ■ No on-going maintenance of equipment (minimal maintenance during monitoring) ■ No capital tied up in equipment ■ Accuracy can be ensured (if you know what you are doing!) 	<ul style="list-style-type: none"> ■ May need to supply scaffolding and power supplies ■ Need to ensure equipment is calibrated correctly ■ Only have a small time 'window' to complete monitoring programme ■ Need trained staff to operate the equipment ■ A drain on internal staff resources ■ Have to identify appropriate methodologies 	<ul style="list-style-type: none"> ■ Hiring charges ■ Training ■ Staff time ■ Laboratory analysis (if appropriate) ■ Costs for access to sampling ports (eg scaffolding)
Purchase equipment	<ul style="list-style-type: none"> ■ Flexible - monitoring programme can be carried out when convenient ■ Monitoring can be carried out frequently ■ Accuracy can be ensured (if you know what you are doing!) 	<ul style="list-style-type: none"> ■ Need to calibrate and maintain equipment ■ Capital investment required ■ Need trained staff to operate the equipment ■ Cannot change monitoring technique ■ A drain on internal staff resources ■ Have to identify appropriate methodologies ■ May need to supply scaffolding and power supplies 	<ul style="list-style-type: none"> ■ Purchase ■ Training ■ Maintenance ■ Staff time ■ Laboratory analysis (if appropriate) ■ Costs for access to sampling ports (eg scaffolding)

Using specialist contractors has an added advantage in that competitive tendering can be carried out to select the most suitable contractor, not only in terms of costs but other factors such as certification and accreditation of the methods used.

3.3.1 MCERTS

The Environment Agency has introduced the Monitoring Certification Scheme (MCERTS) to improve the quality of monitoring data. The scheme has been devised to ensure that monitoring equipment and methodologies are standardised and carried out to a high level of competency.

Published performance standards for continuous emissions monitoring (CEM) already exist and other MCERTS standards are being developed to cover areas such as manual stack emissions monitoring and portable emissions monitoring equipment.

Some manufacturers and suppliers of portable monitoring equipment are applying for MCERTS for their VOC monitoring equipment. Under the Pollution Prevention and Control (PPC) guidance, operators are required, as far as possible, to ensure that monitoring complies with the requirements of MCERTS.

For the external analysis of samples, you should choose laboratories with appropriate United Kingdom Accreditation Service (UKAS) accreditation.

3.4 Step 4 - Cost the options

Estimating how much the monitoring programme will cost is an important step. Make sure you include the cost of any in-house resources, such as staff time. Table 6 shows some typical costs associated with different monitoring techniques.

Table 6 Typical costs of different VOC monitoring techniques (2002 prices)

Item	Capital costs	Analysis costs	Hiring costs
VOC monitoring devices			
Photoionisation detection (PID)	From £6 000 to £25 000*	N/A	Up to £650/week
Flame ionisation detection (FID)	From £10 000 to £20 000*	N/A	Up to £600/week
Non-dispersive infrared (NDIR)	From £30 000 to £50 000*	N/A	Up to £300/week
Fourier transform infrared (FTIR)	From £30 000 to £50 000*	N/A	Up to £1 500/week
Indicator tubes (short term)	Up to £200 for the pump and £30 for five tubes	N/A	N/A
Indicator tubes (diffusion tubes)	£40 for ten	N/A	N/A
Sorbent tubes [†]	Up to £500 for the pump; up to £100 for 50 carbon tubes and £100 each for specialist resin tubes	Up to £200/tube	£15/day
Active sampling filters	£100 for 20 filters	Up to £200/filter	N/A

* *Dependent on application.*

[†] *There are a number of sorbent tubes that can be used for monitoring different VOCs, including carbon, Tenax, XAD, silica gel tubes and other resin-coated tubes.*

Table 6 Typical costs of different VOC monitoring techniques (2002 prices) (continued)

Item	Capital costs	Analysis costs	Hiring costs
VOC monitoring devices			
Personal monitors/badges	£50 for five	£30/badge	Up to £100/week
Monitoring contractor (1 stack for total VOCs)	N/A	N/A	Up to £500
Monitoring contractor (10 stacks for specific VOC)	N/A	N/A	Up to £7 500
Flow measurements			
Hot-wire anemometer, pitot-tube pressure manometer and vane anemometer	£250 - £1 400	N/A	£40 - £325

Contact equipment suppliers to obtain quotations for purchasing or hiring monitoring equipment. When obtaining quotations from monitoring contractors, specify:

- what is to be monitored, how regularly and for how long;
- the specific information required and how it is to be reported;
- preferred techniques (if known).

Make sure you understand exactly what the equipment is capable of and its specification. For example, how accurate is it in the expected conditions; does the equipment have a data logger to automatically store information? Remember to ask about issues such as maintenance and calibration costs, and how long it will take to train someone to use the equipment. To ensure that all costs are covered for each technique, use the final column in Table 5 as a checklist.

The Environment and Energy Helpline on 0800 585794 can provide non-exhaustive lists of monitoring consultants and suppliers of monitoring equipment. Alternatively, contact the Source Testing Association (STA) on 01462 457535.

3.5 Step 5 - Select the most appropriate approach

Once you have all the cost information, you will be in a position to choose the most suitable route for your VOC monitoring programme. Use the information obtained from steps 1 - 4 to select the most appropriate and cost-effective approach.

3.6 Step 6 - Implement a monitoring programme

When implementing VOC monitoring (in-house or contracted out) you should:

- assign responsibility for the programme to a member of staff;
- set out what is to be measured, how and when, and draw up a proper monitoring programme including a timetable and key actions/responsibilities;

- conduct appropriate staff training (if necessary);
- establish some means of recording the results (eg on a spreadsheet or database).

When monitoring is contracted out, make sure that your company and the contractor fully agree the programme.

Regardless of the form of measurement used, it is important that all measurements are as accurate and representative as possible. You can achieve this by:

- Studying manufacturer or method notes carefully before making any measurements.
- Choosing duct access and measurement points carefully, bearing in mind that they should be located on the longest and straightest runs of ducting, away from bends and corners, and fans and valves (see section 2.6).
- Conducting monitoring over a period of several days of normal, steady production, and avoiding start-up and shutdown periods.
- Taking sufficient samples to provide statistically meaningful results. For example, a few sets of four or more readings (of adequate length) are usually sufficient to give a sensible overall mean. You should take into account process type and changes as these will influence the concentration of VOCs and how this level changes with time.

3.7 Step 7 - Use the monitoring results

When the monitoring is complete, it is worth sending off the data to the regulator straightaway so that it is not forgotten or becomes outdated. Consider what information is being provided about the process:

- Are the emission levels lower or higher than anticipated?
- Do the emissions suggest problems with housekeeping and process use?
- Is there potential for significant cost savings through improved solvent management?
- Are the most appropriate monitoring techniques and equipment being used?

In fact, monitoring results can be used in a number of useful ways:

- as part of a solvent management programme designed to reduce solvent consumption and VOC emissions;
- to demonstrate continual improvement under an environmental management system (EMS) such as ISO 14001;
- to complement COSHH¹¹ (health and safety) assessments;
- to evaluate the potential benefits of solvent capture and recovery for re-use¹²;
- to determine the optimum size of pollution abatement equipment, thereby avoiding unnecessary expenditure on oversized plant.

It is worth remembering that information on captured mass emissions to air can be used to obtain estimates, through a mass balance, for unknowns such as fugitive (uncaptured) emissions. You can find more on solvent management in Good Practice Guide (GG429) *Cost-effective solvent management*. Detailed advice on monitoring leaks from pipework components is given

¹¹ Control of Substances Hazardous to Health Regulations 1994.

¹² See Good Practice Guide (GG12) *Solvent capture for recovery and re-use from solvent-laden gas streams*, and Good Practice Guide (GG100) *Solvent capture and recovery in practice: industry examples*.

in Good Practice Guide (GG71) *Cost-effective reduction of fugitive solvent emissions*, which also describes techniques to control these emissions. A range of practical measures to reduce solvent use and VOC emissions are described in Good Practice Guide (GG413) *Reducing solvent use by good housekeeping*. All of these publications are available free of charge from the Environment and Energy Helpline on 0800 585794 (or visit www.envirowise.gov.uk).

3.8 Step 8 - Review results and decisions

Once the above steps have been completed, steps 2 - 5 should be reviewed, and if any amendments are necessary, the monitoring programme should be revised.

Remember: If you don't measure it, you can't manage it.

For free advice and publications on solvent management and waste minimisation, contact the Environment and Energy Helpline free on 0800 585794.

Industry examples

These industry examples describe the VOC monitoring strategy adopted by two companies, the techniques chosen and the benefits achieved.

4.1 BIP Ltd

BIP Ltd manufactures a wide range of raw materials for the chemicals and plastics industries, including speciality resins and amino moulding powders. The main production facility at Oldbury in the West Midlands operates continuously and employs 250 people. The Group turnover is approximately £25 million/year and the company is certified to ISO 9000 and ISO 14001. Processes at the Oldbury site, operated under a process authorisation, include:

- the manufacture of:
 - amino moulding powder;
 - amino resin;
 - polyamide intermediate;
 - polyurethane;
- an aqueous distillate incineration unit;
- a solvent distillation unit.

BIP operates a number of complex operations, leading to many small, mixed VOC emissions. The company carries out its own monitoring programme, utilising its staff's extensive in-house technical knowledge and experience of its processes.

For each stream, BIP considered what was to be measured and whether it was a mixed or single stream. A monitoring technique that gave the company the information it required was then devised. BIP is required to monitor some streams for specific compounds. Table 7 (overleaf) lists the monitoring techniques used for the various emission streams. The frequency of monitoring varies between techniques, but all are performed at least once a week and many on a daily basis.

The company's Analytical Environmental, Toxicity and Regulatory Affairs department calculates a solvent mass balance to determine total emissions released from the site. The information generated by the monitoring programme is an important input into this calculation.

BIP is concerned about its environmental performance, and the monitoring data demonstrate the company's major achievement in reducing VOC emissions from the site. Between 1996 and the end of 1997, emissions fell by over 50%, despite an increase in production volume.

Monitoring information is also used to identify areas where further improvements and savings can be made. For example, BIP suspected that its batch mixing and reactor vessels were a major source of emissions to atmosphere. The company carried out additional VOC monitoring of the batch processes and the emissions were identified. The results showed that simple engineering modifications were all that was necessary to reduce VOC emissions, rather than expensive end-of-pipe solutions. These modifications have resulted in quality and yield improvements, lower VOC emissions and reduced raw material waste. The associated annual cost savings are estimated at over £100 000. Implementing the monitoring programme has also brought about

Table 7 VOC monitoring techniques used by BIP Ltd

Technique	Type of sample	Stream monitored	Comments
Stain tubes	Grab	Used to check the calibration of other monitoring equipment	Provides a quick check in harsh environments
Reactive tape	Continuous	Isocyanate	Instantaneous response
Gas chromatography with thermal desorption mass spectroscopy	Grab	Amino resins; amino moulding powder; polyurethane, formaldehyde and polymer intermediates manufacture; effluent treatment; aqueous distillate incinerator	Information about specific compounds required from complex mixture of chemicals
HPLC analysis	Grab	Polyurethane manufacture	Very low detection limits required for isocyanates

further substantial savings, as the need to install expensive abatement equipment has been avoided. Monitoring data were also used to develop alterations to process conditions, leading to an even greater reduction in emissions.

“The monitoring programme at BIP has proved an excellent source of process information. This has allowed us to reduce emissions from the plant substantially and avoid the need for elaborate end-of-pipe solutions, forecast to cost many millions of pounds. Simple modifications have further reduced emissions to the environment, improved quality and reduced raw material losses.”

Jeff Hodgkins

Head of Analytical, Environmental, Toxicity and Regulatory Affairs
BIP Ltd

4.2 EVC Compounds Limited

EVC Compounds Limited is a subsidiary of EVC International SA/NV, Europe’s leading PVC producer. The UK company, based in Helsby, Cheshire, employs 68 people and supplies a wide range of PVC compounds to satisfy diverse market requirements. The site operates a customised version of the International Safety Rating System (ISRS) for loss control, covering all its safety, health and environmental management issues, and is working towards certification to ISO 14001.

Although the site has only a single process authorisation for the release of particulates, it also monitors annually for VOC, lead and antimony emissions from the exit points of several processes. EVC employs an external consultant to carry out this three-day annual exercise at an approximate cost of £4 500.

VOC emissions are generated from the use of plasticisers in some PVC compound formulations that pass through an extrusion process. To minimise VOC and other emissions, conveying and cooling air passes through electrostatic precipitators. VOC monitoring is carried out using a hydrocarbon analyser and detection is by FID with heated lines at 48°C. Once stabilised, readings

are taken over a 15-minute period. The results show that VOC emissions are less than 10 mg/m³ from the exit of the electrostatic precipitators and less than 2 mg/m³ from the exit of the bag filters.

By comparing the monitoring results from year to year, EVC is able to assess the effectiveness of its abatement processes. Regular maintenance is carried out to ensure optimum performance.

“The monitoring and abatement of VOCs are important to EVC Compounds Limited as a control mechanism to ensure compliance with our internal management system standards. These standards, which conform to our IPC authorisation, aim to reduce the environmental impact of our emissions and minimise the formation of photochemical ozone.”

John Lovick

Safety, Health, Environment and Quality Manager
EVC Compounds Limited

This Guide explains how to choose the correct VOC and air-flow monitoring technique to ensure regulatory compliance and allow effective solvent management. The industry examples in section 4 show how companies have been able to use monitoring data to identify opportunities to reduce solvent consumption and, consequently, save considerable sums of money.

If you want to implement a systematic VOC monitoring programme and save money:

- ✔ Decide why you want to monitor your VOC emissions.
- ✔ Identify what information you need from VOC emission monitoring.
- ✔ Decide if you need to monitor other parameters, eg temperature, pressure and velocity.
- ✔ Identify the techniques that will provide the information you require.
- ✔ Cost the options.
- ✔ Choose the most appropriate technique for your circumstances and budget.
- ✔ Use the monitoring data to help you save money by:
 - optimising your process;
 - identifying leaks;
 - identifying excessive solvent use;
 - identifying and implementing opportunities to reduce waste;
 - reducing abatement requirements.
- ✔ Integrate the monitoring programme into a solvent management system. Use Good Practice Guide (GG429), *Cost-effective solvent management*, to help you improve your solvent management.

If necessary, obtain further help by contacting:

- ✔ the Environment and Energy Helpline (free on 0800 585794) for a list of equipment suppliers and monitoring consultants, and free advice on reducing your solvent consumption and VOC emissions;
- ✔ the Source Testing Association (tel: 01462 457535) for a list of monitoring consultants.

The Environment and Energy Helpline can also:

- ✔ Send you free copies of relevant Envirowise publications.
- ✔ Advise you on relevant environmental and other regulations that could affect your operations.
- ✔ Provide *FastTrack* visits, which are available through the Environment and Energy Helpline. *FastTrack* visits are confidential, on-site waste reviews that include up to a day's free advice on resource efficiency from an environmental expert. The aim of the visits is to turn waste into profit by improving resource efficiency and reducing associated costs. This service is available to UK companies with fewer than 250 employees. For information on *FastTrack* visits, contact the Environment and Energy Helpline on 0800 585794 or visit the Envirowise website (www.envirowise.gov.uk).
- ✔ Arrange for a counselling visit to your company, free of charge, if you employ fewer than 250 people (at the discretion of the Helpline Manager). The aim is to help you with a particular environmental issue or problem. This visit could help you to see which monitoring options would best suit your company as part of a systematic approach to environmental best practice.

Converting concentration units

There are two commonly used ways of expressing concentrations of air pollutants:

- as a volume fraction, eg parts per million (ppm);
- as a mass per unit volume, eg milligrams per cubic metre (mg/m^3).

Monitoring equipment frequently gives concentrations in parts per million (ppm) by volume, eg a concentration of 5 ppm means that there are five VOC molecules in one million molecules of air.

If a correction to standard reference conditions is required (see appendix 3), you have to convert the concentration from ppm to mg/m^3 at 0°C , using the following equation:

$$C_m = \frac{M_g}{M_v} \times C_p$$

where:

C_p = Measured concentration of pollutant in parts per million (ppm)

M_v = Molar volume in litres, ie 22.4 litres/mole @ 0°C

M_g = Molar mass of pollutant in grammes, eg 16 for methane and 12 for carbon

C_m = Measured concentration of pollutant (mg/m^3)

If a single pollutant is being monitored, then M_g is the molecular weight of the VOC in question. For example, for a stain tube calibrated for acetone, M_g is the molar mass of acetone, ie 58. If a mixture of pollutants is being monitored and the equipment expresses the reading in terms of methane, M_g should be the molar mass of methane. A further correction to allow for the difference in molar mass between methane and carbon is necessary if a concentration measured in terms of carbon is required (see below).

Example calculation - ppm of methane converted to mg/m^3 as carbon

A flame ionisation detection (FID) device reads 52 ppm of VOCs as methane. The emission limit is $50 \text{ mg}/\text{m}^3$ as carbon. The molar mass of methane (CH_4) is 16.

First, you need to convert the measured concentration from ppm to mg/m^3 in terms of a methane equivalent:

$$C_m = \frac{M_g}{M_v} \times C_p$$

$$C_m \text{ (as methane)} = \frac{16 \times 52}{22.4}$$

= $37.1 \text{ mg}/\text{m}^3$ VOCs as methane.

Second, you have to correct for the difference in molar mass between methane (16) and carbon (12), by multiplying by the ratio of molar masses, ie:

$$C_m \text{ (as carbon)} = 37.1 \times \frac{12}{16}$$

$$= 27.8 \text{ mg/m}^3 \text{ VOCs as carbon}$$

The measured concentration is therefore below the emission limit.

Example calculation - mg/m³ of carbon converted to mg/m³ as toluene

In some cases, a measurement expressed in terms of mg/m³ as carbon may have to be expressed as another VOC, eg hexane or toluene. For example, say a FID reads 21.4 mg/m³ VOCs as carbon but the emission limit is expressed as mg/m³ of toluene. The molar mass of toluene (C₇H₈) is 92 and the molar mass of carbon (C) is 12.

The FID responds to the number of carbon atoms it detects. To convert to 'as substance', in this case toluene, you need to multiply by:

$$\frac{\text{Molecular weight of substance}}{\text{Molecular weight of carbon in substance}}$$

So, for toluene (C₇H₈), this equates to:

$$\frac{(7 \times 12) + 8}{(7 \times 12)} = 1.095$$

Therefore, as the FID reading was 21.4 mg/m³ as carbon:

$$C_m = 21.4 \times 1.095 = 23.433 \text{ mg/m}^3 \text{ VOCs as toluene.}$$

Calculation of mass emission rates

Where it is necessary to measure the mass flow of VOCs, eg in kg/hr, you have to convert from a velocity (m/s), taking into account the dimensions of the duct/stack (in metres) where the velocity was measured.

If you are using a pitot-static tube to measure the dynamic pressure (Pd), the velocity (in m/s) can be calculated from the equation:

$$V = \sqrt{2Pd/\rho}$$

where Pd is the dynamic pressure measured (in kPa) and ρ is the density (kg/m^3) of the sample airstream.

$$V = 1.244 \sqrt{Pd \text{ at } 273 \text{ K (0}^\circ\text{C), } 101.3 \text{ kPa (standard reference conditions)}}$$

$$V = 1.280 \sqrt{Pd \text{ at } 289 \text{ K (16}^\circ\text{C), } 101.3 \text{ kPa (ambient conditions)}}$$

Other values for air density can be found in standard engineering and fluid mechanics tables, if greater accuracy is required.

The mass emission per year can be calculated using the following equation:

$$M_e = V_s \times A_s \times \frac{C_m}{1\,000\,000} \times 3\,600 \times O_h$$

where:

M_e = Mass emission rate (kg/year)

V_s = Velocity in the stack or duct at specified conditions (m/s)

A_s = Cross-sectional area of the stack or duct (m^2)

C_m = Measured concentration of pollutant (mg/m^3) at the same specified conditions

O_h = Hours of plant operation or emission per year

If you are using the above formula, and the concentration of the pollutant is at standard reference conditions, then the velocity in the stack must be at the same reference conditions. Similarly, if the concentration of the pollutant is at stack conditions, then the velocity will also need to be measured at stack conditions. The formulae used to correct concentrations to standard reference conditions are provided in appendix 3.

The cross-sectional area of a circular stack can be calculated using the following equation:

$$A_s = \pi \times \frac{(D_i)^2}{4}$$

where:

D_i = Inside diameter of the stack

$\pi \approx 3.142$

Example calculation - converting to a mass emission rate

The concentration of a pollutant is 50 mg/m³ measured in a stack of circular cross-sectional area with an internal diameter of 0.4 m. The average velocity measured is 15 m/s. The plant operates for 8 000 hrs/year.

First, you have to calculate the area of the stack:

$$A_s = \pi \times \frac{(D_i)^2}{4}$$

$$A_s = \pi \times \frac{(0.4)^2}{4}$$

$$A_s = 0.126 \text{ m}^2$$

Next, you need to calculate the mass emission rate:

$$M_e = V_s \times A_s \times \frac{C_m}{1\,000\,000} \times 3\,600 \times O_h$$

$$M_e = 15 \times 0.126 \times \frac{50}{1\,000\,000} \times 3\,600 \times 8\,000$$

= 2 722 kg/year or 2.722 tonnes/year.

Correcting to standard reference conditions

The following formulae will enable you to convert measured emission concentrations between values at stack conditions and values at reference conditions. Where more than one correction is required, the calculations can be performed in any order.

Oxygen content (combustion processes only)

$$C_r = C_m \times \frac{[20.9 - (O_2)_r]}{[20.9 - (O_2)_m]}$$

where:

C_r = Concentration of pollutant at reference conditions (mg/m³)

C_m = Measured concentration of pollutant (mg/m³)

$(O_2)_r$ = Oxygen content at specified reference conditions (eg 11%)

$(O_2)_m$ = Oxygen content as measured (as a percentage of dry gas)

Temperature

$$C_r = C_m \times \frac{T_r}{T_m}$$

where:

C_r = Concentration of pollutant at reference conditions (mg/m³)

C_m = Measured concentration of pollutant (mg/m³)

T_r = Temperature at reference conditions in kelvin (normally 273 K (0°C))

T_m = Temperature as measured in kelvin, ie 273 K + measured temperature in °C

Pressure

$$C_r = C_m \times \frac{P_r}{P_m}$$

where:

C_r = Concentration of pollutant at reference conditions (mg/m³)

C_m = Measured concentration of pollutant (mg/m³)

P_r = Pressure at reference conditions (normally 101.3 kPa)

P_m = Pressure as measured (kPa)

Water vapour (normally combustion processes only)

$$C_r = C_m \times \frac{(100\% - W_r\%)}{(100\% - W_m\%)}$$

where:

C_r = Concentration of pollutant at reference conditions (mg/m^3)

C_m = Measured concentration of pollutant (mg/m^3)

W_r = Water vapour content (%) at reference conditions (normally 0°C)

W_m = Water vapour content as measured (%)

Envirowise - Practical Environmental Advice for Business - is a Government programme that offers free, independent and practical advice to UK businesses to reduce waste at source and increase profits. It is managed by Momenta, an operating division of AEA Technology plc, and Technology Transfer and Innovation Ltd.

Envirowise offers a range of free services including:

- ✔ Free advice from Envirowise experts through the Environment and Energy Helpline.
- ✔ A variety of publications that provide up-to-date information on waste minimisation issues, methods and successes.
- ✔ Free, on-site waste reviews from Envirowise advisors, called *FastTrack* visits, that help businesses identify and realise savings.
- ✔ Guidance on waste minimisation clubs across the UK that provide a chance for local companies to meet regularly and share best practices in waste minimisation.
- ✔ Best practice seminars and practical workshops that offer an ideal way to examine waste minimisation issues and discuss opportunities and methodologies.



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