WORKPLACE TOXIC GAS DETECTORS – MAJOR REVISION OF STANDARDS

Toxic gas detectors[1] perform a valuable role in the workplace by helping to reduce the risk of ill-health and death which can arise from exposure to toxic gases and vapours. An important consideration in their use is the availability of gas detector standards. These help to reassure and guide the user by setting a minimum standard so that practitioners can choose a suitable and reliable detector that is fit for purpose, and use it effectively throughout its working life. A series of European standards for gas detectors (EN 45544 Parts 1-4) were originally published over 15 years ago to address this need. They have now recently been comprehensively revised:

Confined space work

- EN 45544-1 Workplace atmospheres. Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours.
  - o Part 1: General requirements and test methods. *(to evaluate the performance of personal, portable, transportable and fixed detectors)*

    Part 2: Performance requirements for apparatus used for exposure measurement.

    Part 3: Performance requirements for apparatus used for general gas detection

    Part 4: Guide for selection, installation, use and maintenance

This article describes particularly how these updated standards clarify and revise the relation between the measurement tasks and their associated performance requirements (Parts 1-3), and how the "user guide" (Part 4) has been updated in the light of new knowledge.

Toxic gas detectors can reduce risk in various ways depending on the type of detector and how it is used. However, two basic measurement tasks can be identified and they form the framework of the new standards:

- *general gas detection,* e.g. safety warning, leak detection, which is the most prevalent use of toxic gas detectors; and
- *exposure measurement,* as part of a workplace exposure assessment, for example, according to EN 482 - 'Workplace exposure. General requirements for the performance of procedures for the measurement of chemical agents'.

General gas detection includes the following measurement tasks:

- providing visual and audible alarms to warn workers of potentially harmful toxic gas concentrations;
- providing alarm output signals to initiate operation of ventilation, shutdown of processes, safe evacuation, etc;
- area monitoring to provide continuous information on the concentration of toxic gas over a site;
- measurements to monitor the effectiveness of protection systems, e.g. extraction;
- spot-reading measurements, e.g. to obtain a gas-free work permit;
- leak detection in industrial and commercial environments.

A particular environment where toxic gas detectors (together with oxygen deficiency and flammable gas detectors) play a vital role is in confined spaces[2]. Testing and monitoring the atmosphere should be considered when designing a safe system of work for a confined space, which may form the basis of a permit to work; the atmosphere may need to be tested for the presence of hazardous gas or deficiency of oxygen; and regular monitoring may be necessary, typically using portable (including personal) gas detectors which provide alarms.

Procedures for workplace exposure measurements, are an important part of the process of exposure assessment, which itself is required to be carried out under national laws and regulations[3]. General requirements for such procedures are specified in European standard EN 482. These include unambiguity, selectivity, averaging time and expanded uncertainty[4] for minimum specified measuring ranges. The procedures used for such measurements should give reliable and valid results, so that when compared with occupational exposure limits[5], a correct decision can be made, for instance, as to whether the exposure level is acceptable or control measures (e.g. containment, ventilation, respiratory protection) need to be applied. Specific requirements relating to the use of various types of measuring procedures and measuring devices for all types of chemical agent including direct-reading instruments for gases (EN 45544), the subject of this article, are referenced in EN 482.

EN 482 identifies three types of exposure measurement:

- Screening measurements of time-weighted average concentration *performed to obtain semi-quantitative information on exposure levels to identify potential health hazards, estimate the health risk and determine if the exposure is significantly below or above the occupational exposure limit.*
- Screening measurements of variation of concentration in time and/or space - *performed to provide information on the likely pattern of the concentration of chemical agents in the air; identify locations and periods of elevated exposure; provide information on the location and intensity of emission sources; and estimate the effectiveness of control measures, e.g. ventilation.*
- Measurements for comparison with occupational exposure limits and periodic measurements - *comparison measurements are performed to obtain results of known uncertainty for the average concentration of a chemical agent in the air in a worker's breathing zone. Periodic measurements are performed to determine whether exposure conditions have changed or whether control measures remain effective.*

The requirements for exposure screening measurements are usually less stringent than those for exposure measurements used for comparison with limit values and periodic measurements because the latter two types have regulatory implications.

Performance requirements (Parts 1-3)

The performance requirements for gas detectors depend on the purpose for which they are used. This is reflected in the latest versions of the toxic gas detector standards which have revised and clarified the distinction between the requirements for general gas detection (by far the most common use of gas detectors) and exposure measurement (a more specialised and demanding use, requiring calculation of uncertainty budgets).

It should be noted that the same detector may be used for general gas detection applications (EN 45544-3) and exposure measurements (EN 45544-2). Moreover, a detector used for general gas detection could be certified under the tougher requirements of EN 45544-2, for example, to possibly confer on the manufacturer a market advantage for accuracy.

Detectors for general gas detection are subject to performance requirements for the various tests comparable with those for flammable gas detectors (c.f. EN 60779-29-1), i.e. the deviation from the reference value must be less than a certain value for

Table 1 Examples of standard test gas concentrations and minimum requirements for the lower limit of measurement for detectors tested to EN 45544–2 (2015)

Gas	Volume fraction of standard test gas (ppm V/V)	Lower limit of measurement (ppm V/V)
Ammonia (NH_3)	20	2
Carbon dioxide (CO_2)	5000	500
Carbon monoxide (CO)	30	3
Chlorine (Cl_2)	0.5	0.1
Hydrogen sulphide (H_2S)	5	0.5
Nitric oxide (NO)	25	2.5
Nitrogen dioxide (NO_2)	3	0.3
Ozone (O_3)	0.1	0.01
Sulfur dioxide (SO_2)	2	0.2

Table 2 Commonly used gas detectors for workplace measurements

Operating principle	Typical gases detected*	Measurement tasks** and portability
Chemiluminescence	NO, NO_2, O_3	Mainly Exp; transportable
Colorimetry	Isocyanates, inorganic hydrides	Gen; portable, transportable
Electrochemical (EC)	CO, H_2S, NO, NO_2, Cl_2, NH3, inorganic hydrides	Mainly Gen but also Exp if no interferents; personal, portable, fixed
Flame-ionization (FID)	VOCs***	Mainly Exp with GC; portable, transportable
Gas chromatography (GC)	VOCs	Mainly Exp, used as speciation technique with FID, PID, MS; portable, transportable
Infrared photometry (IR)	CO_2, NH_3	Mainly Gen but also Exp if no interferents; personal, portable, transportable, fixed
Ion mobility spectrometry (IMS)	VOCs	Mainly Gen; portable, transportable, fixed
Mass spectrometry (MS)	VOCs	Exp and Gen; portable, transportable
Photo-ionization (PID)	VOCs	Gen; personal, portable, fixed
Semiconductor (SC)	CO, VOCs, H_2S	Gen; portable, fixed; alarm only
Ultra-violet visible photometry (UV)	VOCs, O_3, NO_2, SO_2, Cl_2	Mainly Gen; transportable

** Other gases can be detected*
*** Gen – general gas detection; Exp – exposure measurement*
**** VOCs - Volatile organic compounds*

Coupling connections

each test. Moreover, their measuring range is defined by the manufacturer. Toxic gas detectors for exposure measurements have more stringent requirements: not only must they be subjected to tests and requirements comparable with those for general gas detectors but their relative expanded uncertainty, i.e. the sum of uncertainties (deviations) from the tests, expressed as a percentage, must be within limits prescribed by EN 482. For measurements for comparison with limit values and periodic measurements, the relative expanded uncertainty must be ≤ 50 % or ≤ 30 % depending on the measuring range and reference period (short term, e.g. 15 min, or long term). While these tolerances may initially seem generous, it should be borne in mind that (a) they are the sum of uncertainties derived from 13 tests; and (b) variation of exposure to chemical agents in the workplace can be significantly greater than indicated by the uncertainty of a single measurement calculated according to EN 482, due to the temporal and spatial variability of workplace exposure.

Additionally, Part 2 of the standard specifies the measuring of the detector, with both the lower and upper limits of measurement being constrained; and the uncertainty of the zero measurement (i.e. that in clean air) must be within a specified limit. Some examples of the lower limit of measurement with associated values of the standard test gas concentration, extracted from the table in EN 45544-1, are shown in Table 1 (above).

If detectors for gases other than those listed in the table in EN 45544-1 are required to be tested, then values for the standard test gas concentration and lower limit of measurement, can be agreed between the manufacturer and the test laboratory, bearing in mind any limit values, should they exist.

Guide for use (Part 4)

The discussion above has been concerned essentially with performance requirements (Parts 1-3 of EN 45544) and therefore more relevant to the manufacturer (and test laboratory). EN 45544-4 (2016) is the guide for use and therefore contains information of value to users directly, if they read the standard themselves, although they are more likely to consult the manufacturer's guidance where the manufacturer can draw on and incorporate information from the standard.

The number of toxic gases occurring in the workplace is very large, and this is matched by toxic gas detectors employing a variety of sensor operating principles. In practice, however, the majority of measurements are conducted using only a few such types of detector. Eleven types of gas detector which could be used for general gas detection and exposure measurement are listed in Annex A of the revised EN 45544-4. This is a reduction from 16 in the previous version to reflect current practice. I have annotated in Table 2 below some brief information regarding the detectable gases and usage of the 11 detector types.

Examples of commercial detectors certified to EN 45544 include those incorporating electrochemical sensors for carbon monoxide and hydrogen sulfide, and infrared sensors for carbon dioxide. These are currently the main workhorses for general gas detection in the workplace, especially for use in confined spaces (together with flammable gas and oxygen sensors in multigas instruments).

A key part of ensuring adequate performance is maintained during the working life of the detector is for the user to regularly test and maintain it. EN 45544-4 provides guidance on inspection and functional checks: "It is strongly recommended that these checks are performed before each day of use". However, there is recognition that this may not be feasible for certain applications, e.g. emergency response, where there may not be sufficient time to conduct inspection and functional checks before use. In these cases, alternative plans for inspection and functional checks should be implemented which provide an equivalent level of safety. The routine inspection and functional checks should include checks that ensure:

- the detector is within its calibration period;
- the detector and associated equipment appear to be satisfactory from a visual inspection;
- there are no leaks in the sampling system for aspirated (e.g. pumped) detectors;
- the batteries have sufficient charge;
- the zero reading in clean air is accurate;
- the apparatus responds correctly to gas, which can be undertaken by using a field calibration kit with the target gas or a surrogate gas (subject to the manufacturer's recommendation);
- the display and audible and/or visual alarms are working, if fitted.

The results of these checks should be recorded and any remedial action should be completed and verified prior to use.

The provision of an alarm is probably the most important safety function of a general gas detector whether it is a personal, portable, transportable or fixed monitor. Updated guidance on alarm setting is provided in EN 45544-4 to reflect this. Alarm set points and the actions to be taken when an alarm is activated should be specifically defined by the employer for each hazard scenario arising from a risk assessment. Gas detectors typically have at least two independent, instantaneous alarms that are usually operated as a pre-alarm and a main alarm. The pre-alarm allows for taking early intervention options before the gas concentration reaches the main alarm set point, e.g. inspection of the area, activation of a ventilation system. Activation of the main alarm may initiate further, drastic action, e.g. evacuation.

Personal and portable detectors usually have, in addition to instantaneous alarms, time weighted average (STEL and TWA[7]) alarms. Typically, instantaneous alarms are used to warn against short term (acute) exposure to a dangerous concentration of toxic gas (i.e. safety related), whereas STEL and TWA alarms may be used to warn against longer term (chronic) effects (i.e. health related).

The alarm set points of the detector should be set specifically for its application. The set point should be low enough so that associated protective measures can be effective, while high enough to avoid false alarms, as far as possible. Frequent false alarms can lead to alarms being ignored, leading to complacency and possibly a potentially dangerous escalation of a toxic gas release. It is therefore recommended in the revised standard that the lowest alarm set point should not be set below twice the lower limit of measurement for detectors conforming to EN 45544-2 or below 10 % of the measuring range for detectors conforming to EN 45544-3. When determining the alarm set points, all delays (e.g. due to gas dispersion, time of response of the detector, the protective measures adopted) should be taken into account. Earlier alarm activation can be achieved through the use of lower alarm set points.

The revised standard also illustrates through diagrams the effect of gas concentration on the time of response and time

Gas testing a fixed detector

to alarm: generally, the time of response is independent of gas concentration, whereas the time to alarm decreases with increasing gas concentration for a given alarm set point. It should be noted, however, that for gases that sorb strongly on the sensor and sampling lines (e.g. hydrogen sulphide, nitrogen dioxide, VOCs) the time of response can increase significantly at low concentrations. Thin films of water or contamination on surfaces can also greatly increase the time of response, especially for water soluble gases (e.g. ammonia, chlorine).

EN 45544-2 and EN 45544-3 specify that the times of response t_{50} and t_{90} [8] do not exceed 60 s and 150 s. These are general purpose, minimum requirements covering all gases and reflect current gas sensor technology. However, for some critical applications e.g. warning of short term health effects, the response time should be as short as possible.

Following the development of this revised European standard, IEC and ISO, collaborating in similar fashion to CENELEC and CEN, initiated in 2014 a Joint Working Group (JWG) for the development of an international standard for workplace toxic gas detectors:

- IEC 62990-1 Workplace atmospheres Part 1: Gas detectors. Performance requirements of detectors for toxic gases. Also numbered as ISO IEC 20435-1.

Again, two types of detector are classified, reflecting the analogous roles of IEC and ISO to those of CENELEC and CEN respectively, but using slightly different terminology:

- Type SM (Safety Monitoring) 'general gas detection' equipment: For general gas detection applications (e.g. safety warning, leak detection), the performance requirements are focused on alarm signalling. The measuring range is defined by the manufacturer.
- Type HM (Health Monitoring) 'occupational exposure' equipment: For occupational exposure measurement, the performance requirements are focused on uncertainty of measurement of gas concentrations in the region of Occupational Exposure Limit Values (OELV).

The development of this international standard is ongoing.

In conclusion, it is anticipated that the publication of these standards at an international level will help to further improve the reliability and effectiveness of toxic gas detectors and in doing so reduce the risk of fatalities and ill-health from exposure to toxic gases in the workplace.

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BS EN 45544-3 (2015) Workplace atmospheres. Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours. Part 3: Performance requirements for apparatus used for general gas detection (BSI)

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Notes

[1] Also known as direct-reading instruments/apparatus/monitors/equipment and continuous measuring instruments in common parlance and standards' terminology.

[2]In Great Britain, the Confined Spaces Regulations, with its associated Code of Practice, apply. Over the last 4 years in GB, there were between 1-5 deaths p.a. and 7-15 incidents in confined spaces of which 13% were due to asphyxiation and poisoning.

[3]For example, European Council Directive 98/24/EC, the Chemical Agents Directive, is enacted in the UK as the Control of Substances Hazardous to Health Regulations - COSHH.

[4] For definitions see BS EN 1540 'Workplace exposure Terminology' which specifies terms and definitions related to the assessment of workplace exposure to chemical and biological agents.

[5] The occupational exposure limit value is the limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period. Different countries may use different values for describing safe levels of potentially toxic substances, see for example, GESTIS (see Bibliography) which is a collection of publicly available databases on hazardous substances.

[6]For a given measurement task, the measurement range over which the requirements for the relative expanded uncertainty have to be met depends on the limit value. However, for most chemical agents the limit values have not been harmonized, therefore a reference value (standard test gas concentration) is used instead of the limit value for the performance tests in EN 45544-1. The values chosen are equal to or close to the limit values used in European countries.

[7]STEL – short term exposure limit, the averaging period typically specified as 15 min in regulations (e.g. COSHH in GB; TWA – time weighted average, the averaging period typically specified as 8 hr for long term exposure in regulations.

[8] t_{50} and t_{90} are the times to reach 50% and 90% of the final indication for an increase in toxic gas concentration.

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