# NEW METHODS FOR HAZARDOUS AREA CLASSIFICATION FOR EXPLOSIVE GAS ATMOSPHERES†

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Hazardous Area Classification (HAC) for explosive gas atmospheres is well established, with guidance published in various standards and industry codes of practice. One of these documents, BS EN 60079-10-1:2009 makes use of the concept of a nominal flammable gas cloud volume $V_z$ to determine the level of ventilation and hence the zone. However, the critical formulae given in the standard to estimate $V_z$ have no scientific justification. Previous work reported at Hazards XIX has demonstrated that these formulae over-estimate $V_z$ by several orders of magnitude.

The present paper summarises an alternative methodology for calculating the $V_z$ in both indoor enclosures and outdoor situations. The methodology was developed as part of a Joint Industry Project previously reported at Hazards XXI and as part of more recent work in support of changes to area classification standards. It is based on an integral free-jet model which has been validated by comparing predictions to Computational Fluid Dynamics (CFD) simulations, which were themselves validated against experimental data for gas releases in enclosures. The model formulae are simple to use and easy to apply. For gas leaks within buildings, the ventilation rate is required as an input to the model. Whilst for forced ventilation this is a known parameter, for natural ventilation it is necessary to estimate it. A simple and practical methodology to estimate the natural ventilation rate due to buoyancy and/or the wind is described.

The new methodology is demonstrated using a number of worked examples and compared to the results from the existing BS EN 60079-10-1:2009 standard.

## INTRODUCTION

The control of sources of ignition by the use of specially protected equipment in areas where flammable gases or vapours may arise has been a fundamental safety measure for many years. Thus hazardous areas are classified into zones based on the frequency of the occurrence and the duration of an explosive gas atmosphere. The zones for gases, vapours or mists are currently defined in the relevant standard BS EN 60079-10-1:2009 as:

Zone 0 – a place in which an explosive gas atmosphere is present continuously or for long periods or frequently.

Zone 1 – a place in which an explosive atmosphere is likely to occur in normal operation occasionally.

Zone 2 – a place in which an explosive atmosphere is not likely to occur in normal operation but, if it does occur, will persist for a short time only.

There are three defined grades of release; continuous, primary and secondary. These generally give rise to areas classified as Zones 0, 1, and 2 respectively.

## THE CURRENT STANDARD

The application of ventilation to area classification was first discussed in detail in the seminal publication of Cox, Lees & Ang, 1990 and it is now generally accepted by all the relevant standards and codes that for releases indoors ventilation is a critical factor.

The current relevant standard, BS EN 60079-10-1:2009 defines the degree of ventilation as high, medium or low on the basis of a calculated hypothetical parameter $V_z$. The volume, $V_z$, is defined as the volume within which the mean concentration of flammable gas arising from a release will be 50% (for secondary releases) or 25% (for primary releases) of the Lower Explosive Limit (LEL). In the standard this definition of the 'degree of ventilation' is applied to releases outdoors as well as indoors. Given that the concept of ventilation is meaningless for outdoor releases, the gas cloud volume $V_z$ should be seen as defining the degree of 'dilution' rather than ventilation.

The standard contains a numerical method for estimating $V_z$ for indoor and outdoor situations. It also allows the use of alternative methods such as computational fluid dynamics (CFD).

The value of $V_z$ can then be used to indicate where zoning is not required through the concept of negligible extent (NE). If $V_z$ is less than 0.1 $m^3$ thus defining the ventilation (dilution) as 'high', it is suggested that, if ignited, the cloud would produce such small overpressure and thermal effects that it may be regarded as insignificant. Therefore protected equipment and controls over sources of ignition are not required under such circumstances.

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The numerical method in the standard has no valid scientific basis. It is actually based on the assumption that the ratios between (a) the actual ventilation rate and the ventilation rate required to dilute the release down to a specified level, and (b) the enclosure volume and $V_z$ are equal.

## NATURAL GAS

Area classification studies carried out at a large site in 2005 indicated that the numerical methods in BS EN 60079-10-1 provided grossly conservative values of $V_z$. Subsequent work presented to Hazards XIX (Gant et al., 2006) showed that the values of $V_z$ calculated from the standard were typically between 100 and 3000 times greater than values obtained by using CFD. Table 1 shows the results for methane from a range of hole sizes and pressures. Significantly, all the results from the CFD model for $V_z$ are below the criterion of $0.1\mathrm{m}^3$, whilst all the results calculated from the methodology in the standard are above $0.1\mathrm{m}^3$.

Following this work, and in view of the requirement for valid viable area classification methods for the natural gas industry for the purposes of compliance with the ATEX Directives, a major Joint Industry Project (JIP) was set up, jointly funded by HSE and representatives from the European gas industry and regulatory bodies. The JIP was carried out between 2006 and 2007 and is reported by Ivings et al., 2008. The results were presented to Hazards XXI (Santon and Ivings, 2009).

The work showed, for natural gas releases below 10 barg, that if the average gas concentration at the ventilation outlets is kept below 10% LEL then the gas cloud volume $V_z$ would typically be less than $0.1\ \mathrm{m}^3$. Calculation of the average gas concentration at the outlet is straightforward, based on the volumetric release rate divided by the ventilation rate, and therefore provides a simple means of demonstrating compliance with the Zone 2 NE criterion. This simple approach to area classification can be used as an alternative to CFD to allow a classification of Zone 2 NE for a wide range of natural gas installations operating at pressures below 10 barg. The implications of this work were that many installations will be able to use a lower classification of zone whilst identifying those that require additional measures, thereby concentrating resources on genuine hazards. The work also confirmed the validity of the $0.1\ \mathrm{m}^3$ limit for $V_z$ as the criterion for Zone 2 NE classification through practical experiments. This work was subsequently incorporated into a revision of IGEM/SR/25 (2010), the gas industry's standard for the area classification of natural gas installations. The concept of Zone 2 NE was introduced into this document for the first time.

**Table 1.** Comparison of values of $V_z$ for methane from BS EN 60079-10-1:2009 and CFD (from Gant et al., 2006)

| Case | Leak Conditions | | Gas Cloud Volume, Vz ($\mathrm{m}^3$) | |
|---|---|---|---|---|
| | Pressure (barg) | Area ($\mathrm{mm}^2$) | CFD | BS EN 60079-10-1:2009 |
| 1 | 5.0 | 5.0 | 0.0936 | 12.3 – 61.7 |
| 2 | 5.0 | 2.5 | 0.0326 | 6.17 – 30.8 |
| 3 | 5.0 | 0.25 | 0.0012 | 0.62 – 3.08 |
| 4 | 2.5 | 5.0 | 0.0433 | 7.22 – 36.1 |
| 5 | 2.5 | 2.5 | 0.0148 | 3.60 – 18.0 |
| 6 | 2.5 | 0.25 | 0.0005 | 0.36 – 1.80 |
| 7 | 0.5 | 5.0 | 0.0147 | 2.98 – 14.9 |
| 8 | 0.5 | 2.5 | 0.0054 | 1.50 – 7.48 |
| 9 | 0.5 | 0.25 | 0.0002 | 0.15 – 0.75 |

## OTHER GASES

Having developed a scientifically-based solution for natural gas, it became clear that a generic alternative to the numerical methods in BS EN 60079-10-1:2009 was required for the area classification of other gases including releases both outdoors and indoors.

Integral models of gas jets have been used routinely for the assessment of major hazards for many years. In their simplest form they comprise a few equations describing the axial and radial profiles of concentration and velocity. More sophisticated versions take into account complex source terms, dense and buoyant clouds, rainout etc. Despite their essential simplicity, their scientific credibility is well established and it is therefore appropriate to apply them to the hazardous area classification of pressurised flammable gases.

Here we describe a simple, scientifically-based, integral model for the release of a flammable gas in a ventilated enclosure. The model, called QUADVENT, is described in detail by Webber et al. (2011) including the derivation of the approach. That paper includes solutions for plume releases as well as jet releases.

Firstly it is necessary to distinguish between sonic (choked) and subsonic releases. Unchoked flow will result if:

$$\frac{P}{P_a} \lesssim 1.9 \tag{1}$$

where $P$ is the gas storage pressure and $P_a$ is atmospheric pressure.

It is also necessary to define a pseudo source hole radius when the flow is sonic.

$$r_s = r_0\sqrt{1 + 0.5\left(\frac{P}{P_a} - 1.9\right)} \tag{2}$$

where $r_s$ is the pseudo source radius and $r_o$ is the hole radius, in metres.

The derivation of the following equations is given in Webber et al. (2011).

JET RELEASE IN A VENTILATED ENCLOSURE

The gas cloud volume $V_z$ ($m^3$) can be calculated as

$$V_Z = \min\left\{\frac{9\pi r_s^3}{16\alpha}\left(\frac{\rho_b}{\rho_s}\right)^{3/2}\left(\frac{1-x_b}{x_{crit}-x_b}\right)^3, V_0\right\} \quad ;x_b < x_{crit}$$
$$= V_0 \quad ;x_b \geq x_{crit} \tag{3}$$

where $\rho_b$ ($kg/m^3$) is the density of the background (which normally approximates to that of air), $\rho_s$ ($kg/m^3$) is the density of the source gas, $\alpha$ is the entrainment coefficient (recommended value 0.05), $x_b$ (v/v) is the background concentration, $x_{crit}$ (v/v) is the concentation of interest (50% LEL for secondary releases) and $V_o$ ($m^3$) is the net enclosure volume. The background concentration of flammable gas in the enclosure is

$$x_b = \frac{q_s}{\varepsilon q_1} \tag{4}$$

where $q_1$ ($m^3/s$) is the ventilation rate, $q_s$ ($m^3/s$) is the source gas volume flowrate and $\varepsilon$ is the efficiency of background mixing (see below). The leak rate $q_s$ can be derived from standard methods for the estimation of leak flowrates. Appropriate methods are included in BS EN 60079-10-1:2009, Annex A.

JET RELEASES OUTDOORS

In this case there is zero background concentration, $x_b = 0$, and the background density is that of pure air in which case equation (3) reduces to

$$V_Z = \frac{9\pi r_s^3}{16\alpha}\left(\frac{\rho_a}{\rho_s}\right)^{3/2}\left(\frac{1}{x_{crit}}\right)^3 \tag{5}$$

ZONE EXTENT FROM A JET RELEASE

The axial distance $z$ to a concentration $x_{zone}$ may be derived as an approximation to the zone extent. In this case, an appropriate value of $x_{zone}$ should be chosen. BS EN 60079-10-1 uses 100% LEL for example.

$$z = \frac{r_s}{\mu}\frac{(1 - x_{zone})}{(x_{zone} - x_b)} \tag{6}$$

where

$$\mu \equiv 2\alpha\sqrt{\frac{\rho_s}{\rho_b}} \tag{7}$$

This calculation only makes sense if the background concentration is less than the zone extent concentration, i.e. $x_b < x_{zone}$, otherwise the zone would extend throughout the enclosure.

VALIDATION

Equation (3) above has been validated (Webber et al., 2011) against detailed CFD simulations which themselves have been validated against experimental data (Ivings et al., 2008). The validation data includes simulations of a range of flammable gas release rates in enclosures of various sizes at a range of different ventilation rates. All of the simulations are for unobstructed releases of methane in a ventilation controlled chamber. The agreement between the QUADVENT model and the CFD simulations is surprisingly good considering how simple the QUADVENT calculation is. Figure 1 below shows an example of the model validation data, which in this case was for releases in a 44.7 $m^3$ enclosure. The qualitative behaviour of gas cloud build up in a ventilated enclosure is very clearly captured by the QUADVENT model. Where the average gas concentration at the outlet is low, for example for a small release in a large enclosure, the exact value of the ventilation rate has little effect on the gas cloud volume. In such cases the critical factors are the source of the release (hole size and pressure) and the flow rate of fresh air to the leak location, i.e. the *local* ventilation effectiveness. As the average concentration at the outlet tends towards the concentration defining the gas cloud volume, $x_{crit}$ in this case, the ventilation rate becomes critical to the gas cloud build up and the gas cloud volume rapidly becomes equal to the enclosure volume.

The cases considered in the validation study are all for unobstructed releases, as this is what QUADVENT is essentially modelling. The CFD simulations presented by Ivings et al. (2008) considered a wide range of cases to assess the effects of obstructions near to the leak source on the gas cloud build up. Some of the cases were artificially contrived to try and find the largest reasonable increase in gas cloud volume that could be obtained for a given release rate and ventilation rate.

To apply QUADVENT to an obstructed release the only free parameter is the efficiency of mixing $\varepsilon$. Using a value $\varepsilon = \frac{1}{3}$ is sufficient to account for the effects of the obstructions on the gas cloud build up for all of the considered releases in the 44.7 $m^3$ enclosure. However, a value of $\varepsilon = \frac{1}{10}$ is required for releases in the 400 $m^3$ enclosure. This simply demonstrates that the degree to which the ventilation is well-distributed throughout the enclosure, represented by $\varepsilon$, is just one factor that affects the gas cloud build up. The other key factor, which is particularly important for releases in large enclosures is the effectiveness of the *local* ventilation. An assessment of the local ventilation effectiveness will be needed to confirm that fresh ventilation air is effectively reaching the leak source through visual inspection, smoke tests or other effective means.

## ENCLOSURE AND BUILDING VENTILATION

The ventilation rate of an enclosure is a key input to an area classification assessment. Forced ventilation rates can be established from design or equipment specifications, but in many cases the enclosure will be naturally ventilated and hence the ventilation rate will not be specified but must be

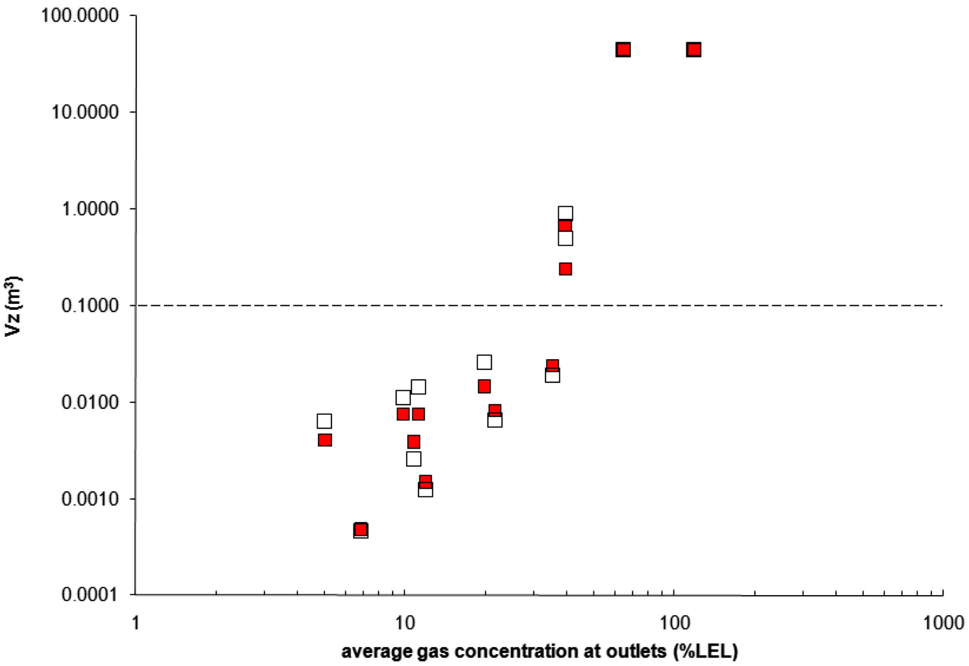


**Figure 1.** Predictions from CFD (filled symbols) and the integral model QUADVENT (hollow symbols) for $V_z$ plotted against the concentration at the ventilation outlet. Points corresponding to different jet release rates and ventilation rates are included in the figure.

measured or calculated. The natural ventilation rate will vary through time as it is strongly influenced by the weather conditions. Simple approaches for the estimation of ventilation rates, suitable for use as part of HAC methodologies, are therefore required.

Natural ventilation consists of two main elements: wind driven and buoyancy driven ventilation. When estimating the ventilation rate as part of a HAC assessment only planned ventilation openings are included. The effect on ventilation rate of adventitious openings, due to cracks and gaps in a structure, are not considered.

The ventilation in an enclosure can be simply described from the flow rates, $q_i$ ($m^3\ s^{-1}$), through each of the $i$ openings. For an enclosure where the interior can be considered to form a single volume, mass continuity tells us that

$$\sum \rho_i\, q_i = 0 \tag{8}$$

where $\rho_i$ ($kg\ m^{-3}$) is the density of the flow through the opening.

There can be multiple planned ventilation openings on any surface of the enclosure. The flow rate through each opening, $i$, can be written as

$$q_i = \mathrm{sgn}(\Delta p_i) C_d A_i \sqrt{\frac{2|\Delta p_i|}{\rho_i}} \tag{9}$$

where $A_i$ ($m^2$) is the area of opening $i$ and $\sqrt{2|\Delta p_i|/\rho_i}$ ($m\ s^{-1}$) is the magnitude of the velocity through the opening, driven by the pressure difference, $\Delta p_i$ (Pa). The sign of the pressure difference across an opening determines the direction of the flow through it. The coefficient of discharge, $C_d$, is the loss coefficient for an opening, accounting for the difference between the ideal and actual flow rates. For a planned ventilation opening a typical value for the coefficient of discharge is 0.6.

The pressure difference at each opening $i$ will be due to a combination of wind and buoyancy forces. The pressure differences can be added to give the pressure difference across an opening. The pressure difference $\Delta p_i$ at each opening $i$ will be due to a combination of wind and buoyancy forces:

$$\Delta p_i = \Delta p_0 - \Delta\rho_0 g z_i + 0.5 C_{p,i} \rho_{out} U^2 \tag{10}$$

where $\Delta p_O$ (Pa) is a reference pressure difference. The second term on the right hand side represents pressure difference due to buoyancy, where $\Delta\rho_O$ ($kg\ m^{-3}$) is the difference between external and internal densities at the reference height, g ($m\ s^{-2}$) is the acceleration due to gravity and $z_i$ (m) is the distance of the mid-height of opening $i$ above the reference height. The third term on the right hand side represents the pressure difference due to wind effects for small openings, where $C_{p,i}$ is the coefficient of pressure for opening $i$, $U$ ($m\ s^{-1}$) is the velocity of undisturbed flow at the reference height used in the measurement of $C_{p,i}$, (typically the roof height of a structure is used as the reference height) and $\rho_{out}$ ($kg\ m^{-3}$) is the density of the external air.

Both the coefficient of pressure, determined by a structure and its surroundings, and the wind speed will affect the estimate of the ventilation rate.

Tables of coefficients of pressure for structures are available in BS5925:1991 and Liddament (1996). For more complicated structures and openings it may be necessary to make experimental measurements or perform CFD simulations.

A realistic worse case condition for the wind speed is the speed exceeded for 80% of the time. For sites in the UK BS5925:1991 provides information on wind speed that can be used to calculate this value. A map of the UK provides the wind speed, measured at a height of 10 m, exceeded for 50% of the time. Information is given to transform this value to the reference wind speed exceeded for 80% of the time. Finally, the wind speed exceeded for 80% of the time at 10 m can be transformed to an effective undisturbed wind speed at the building height, that can be used with the pressure coefficients. The available correlations describing the variation with height account for the effect of terrain, e.g. rural, open or city, and height.

The system of equations, (8)–(10), can be solved by using an iterative approach to find the value of $\Delta p_0$ that enforces mass continuity for the enclosure. A solution can be found with spreadsheets using solvers to find the value obeying the continuity constraint. An example of a spreadsheet containing this simple model of wind and buoyancy driven ventilation, developed for the purpose of ventilation design, is available from the Chartered Institution of Building Services Engineers: www.cibse.org/venttools. This does not use an iterative solution but demonstrates how the model could be described in a spreadsheet.

The calculation of natural ventilation described above is a general solution for a structure that can be represented as a single enclosure. The contribution to the ventilation from multiple openings, on any surface of the enclosure, due to the influences of wind and buoyancy can be considered. Both simpler and more complex cases can also be considered.

In BS5925:1991 simpler examples of natural ventilation, where openings are only on the upwind and downwind surfaces of a single enclosure, are presented. For these examples analytical solutions can be found for either wind driven, or buoyancy driven, ventilation, but not their combined effects. The approach suggested in BS5925:1991 is to calculate the flow rates due to buoyancy and wind separately, then use whichever of these values is larger as the flow rate. The approach suggested here is to calculate the flow due to both buoyancy and wind and treat the larger flow as representing their combined effects. The areas of openings can be combined in the calculations, allowing some flexibility in representation, but not the flexibility available by using an iterative solution.

More complex enclosures, for example, where treating a structure as containing a single volume is inappropriate, due to internal partitioning, can also be examined. In these cases multizone models, such as COMIS (Haas et al., 2002) or CONTAM (Walton and Dols, 2010), can be used to calculate ventilation flows.

For more complex enclosures, where the above approach is unsuitable, experimental measurements, or CFD simulations, may be necessary to determine the ventilation rate, but many factors, including the weather conditions, must be taken into account. Clearly the amount of effort that is put in to determining the ventilation rate should be in proportion to the degree of accuracy required for the ventilation rate estimate.

## LIMITATIONS AND RECOMMENDATIONS

There are certain limitations that should be noted when applying this work.

- The biggest uncertainty lies in estimating the size of the hole. The value of $V_z$ depends on the cube of the radius and is therefore sensitive to it. The size of expected hole must not, therefore, be underestimated. A minimum of $0.25 mm^2$ is recommended unless sensitive leak testing procedures have been applied to test the security of the system at construction and regularly thereafter in which case a minimum value of $0.025 mm^2$ may be used for pressures up to 100 mbarg. Further guidance on hole sizes is given in Cox, Lees, and Ang, 1990.
- The build up of flammable gas following a release from a pressurised system can be strongly affected by local obstructions to the resulting jet and to the ventilation flow. Both have a very significant effect on the dispersion of the flammable gas and the resulting size of gas cloud. It is therefore very important that the effect of this congestion/confinement is accounted for in an area classification methodology. Further guidance is given in IGEM/SR/25, 2010.
- A preliminary assessment of the effects of confinement/congestion on the gas cloud build up can be carried out by assigning an appropriate value to the efficiency of mixing, $\varepsilon$. A value of $\varepsilon = 1$ represents an unobstructed release, $\varepsilon = \frac{1}{2}$ represents a moderate degree of obstruction and $\varepsilon = \frac{1}{3}$ represents a significant obstruction to the ventilation flow. These values are taken from an analysis of the data produced by the JIP (Ivings et al, 2008). For larger enclosures, say over $100 m^3$, this approach is not sufficient on its own and an assessment of local ventilation effectiveness will be needed to confirm that fresh ventilation air is effectively reaching the leak source through visual inspection, smoke tests or other effective means.
- Uncertainty in the model accuracy needs to be accounted for in applying this area classification methodology. This can be done by applying a safety factor of two to the estimated ventilation rate or by ensuring that the hole size is over-estimated.
- The indoor release result assumes that the effects of ventilation permeate the whole room. If the release is likely to be within a sub-chamber which is largely isolated from the effects of ventilation in the main room, then $V_z$ should be computed for the volume of the sub-chamber with a lower ventilation rate, or simply set to be the volume of the sub-chamber, which is likely to be greater than $0.1 m^3$.

- Consideration must also be given to the integrity of the vessel or pipe-work containing the hazardous gas. If the pressure is sufficiently high, any small hole which appears may rapidly enlarge, so that, for example, a pin-prick hole at 100 barg would not be considered credible. For this reason, it is recommended that the classification of NE should be limited to a gas storage pressure of 10 barg. This constraint may be raised to 20 barg based on risk assessment taking the consequences of ignition, i.e. the risk of injury into account. (The methodology for the estimation of exposure and ignition probability in EI15 (2005) Annex C may be used to determine the hole size to be used based on release frequency level.)
- For enclosure volumes of less than 10m$^3$ the criterion of 0.1 m$^3$ for $V_z$ should be reduced to 1% of the enclosure volume. This constraint is taken from BS EN 60079-10-1:2009 and is based on Ivings et al. (2008).
- The guidance in BS EN 60079-10-1:2009 on the availability of ventilation should be observed.
- Whilst this methodology is valid for all gases, it should be noted that the validation of the criterion of 0.1 m$^3$ for the value of $V_z$ leading to an NE classification has only been carried out for natural gas.

## EXAMPLES

For nomenclature and clause references in the calculations below, see IGEM/SR/25 and BS EN 60079-10 where relevant.

### EXAMPLE 1

Outdoor butane gas pipework, secondary releases

LEL = 1.5% v/v

Molecular weight = 58.123 kg/kmol

Pressure P = 4.5 bara (4.5 × 10$^5$ Pa)

Hole size = 0.25 mm$^2$ (Typical value for screwed pipework with small valves)

(A) Applying BS EN 60079-10-1:2009

The release rate calculated from clause A.3.2.1 for choked flow is 0.000344 kg/s.

Calculation of $V_z$:

From B.5.2.2 Note 1, $LEL_m = 0.416 \times 10^{-3} \times M \times LEL_v$

$$LEL_m = 0.416 \times 10^{-3} \times 58.123 \times 1.5 = 0.0363 \text{ kg/m}^3$$

$$\text{From equation B1:} \left(\frac{dV}{dT}\right)_{min} = \frac{(dG/dt)_{max}}{k \times LEL_m} \times \frac{T}{293} = \frac{0.000344}{0.5 \times 0.0363} = 0.019 \text{ m}^3/\text{s}$$

$$\text{From equation B.5:} V_z = \frac{f \times \left(\frac{dV}{dt}\right)_{min}}{0.03} = 0.019/0.03 = 0.63 \text{ m}^3 (\text{taking } f = 1)$$

Since $V_z > 0.1$ m$^3$, Zone 2 NE cannot be adopted, irrespective of the value of $f$, the factor ($\geq 1$) to allow for impeded flow. $V_z$ does not exceed 3400 m$^3$, the value assumed by the standard to represent outdoor circumstances, and therefore in accordance with B.5.3 the ventilation is classed as medium. The availability of outdoor ventilation is classed as good, and therefore according to Table B.1 the area classification for secondary sources is Zone 2.

(B) Applying QUADVENT

Equations (2) and (5) can be applied using

$r_o = 0.28$ mm (for a hole area of 0.25 mm$^2$)

$\rho_s = 2.47$ kg/m$^3$

$\rho_a = 1.204$ kg/m$^3$

$x_{crit} = 50\%$ LEL = 0.0075 v/v

Therefore

$$r_s = 0.28\sqrt{1 + 0.5\left(\frac{4.5}{1} - 1.9\right)} = 0.42 \text{ mm}$$

$$V_Z = \frac{9\pi 0.42^3}{16 \times 0.05 \times 10^9}\left(\frac{1.204}{2.47}\right)^{3/2}\left(\frac{1}{0.0075}\right)^3 = 0.0021 \text{ m}^3$$

$V_z$ is less than 0.1 m$^3$ and the area classification is therefore Zone 2 NE providing other constraints such as freedom from local confinement and congestion are met.

### EXAMPLE 2

A plant room contains 3 × 1400 kW boilers fired by natural gas, together with gas boosters, metering and pipework. Natural ventilation is provided by 3 louvered vents which are all in one wall. The total ventilation area is 5.83 m$^2$. The room net volume is 2660 m$^3$. There are no primary sources of release. Maximum gas pressure is 76 mbarg.

From Santon and Ivings (2009) applying BS 5925:1991 the ventilation rate is 0.243 m$^3$/s, giving an air change rate of $C = 0.243/2660 \text{ s}^{-1} = 0.0000913 \text{ s}^{-1}$. The ventilation was checked using an anemometer and the estimate was confirmed as conservative. It was also confirmed by smoke tests that there were no significant stagnant areas or areas of recirculation.

The boosters are treated as giving rise to an adverse environment, so that leak sizes of 2.5 mm$^2$ are used. Using $C_d$ of 0.8 and standard flow calculation equations from BS EN 60079-10-1:2009, leak rate at 76 mbarg = 0.25 g/s.

Applying IGEM/SR/25 (2010), A7.1.1, the total numbers of gas fittings is approximately 8 regulators, 24 valves, 88 flanges and 22 screwed joints. The room is normally visited daily, but for the purposes of frequency of inspection it is assumed to be visited at worst every 2 weeks. Applying the calculation methodology in section A7.1.2 of IGEM/SR/25 (2010), $\sum Tf_i n = 0.0068$, so that the number of simultaneous secondary releases that should be taken into account for the purposes of IGEM/SR/25 (2010) is two based on Table 7. For comparative zoning calculations the leak rate of 0.5 g/s is therefore used in all examples below.

(A) Applying BS EN 60079-10-1:2009
Calculation of $V_z$:

From B.5.2.2 Note 1, $LEL_m = 0.416 \times 10^{-3} \times M \times LEL_v$

$M = 17$ kg/kmol, $LEL_v = 4.4\%$ v/v

$LEL_m = 0.416 \times 10^{-3} \times 17 \times 4.4 = 0.0311$ kg/m$^3$

From equation B1:

$$\left(\frac{dV}{dT}\right)_{min} = \frac{(dG/dt)_{max}}{k \times LEL_m} \times \frac{T}{293} = \frac{0.5}{10^3 \times 0.5 \times 0.0311}$$

$$= 0.032 \text{ m}^3/\text{s}$$

From equation B.4:

$$V_z = \frac{f \times \left(\frac{dV}{dt}\right)_{min}}{C} = 0.032/0.0000913 = 350 \text{ m}^3 (\text{taking } f = 1)$$

Since $V_z > 0.1$ m$^3$, Zone 2 NE cannot be adopted, irrespective of the value of *f*. $V_z$ does not exceed $V_0$, and therefore in accordance with B4 the ventilation is classed as medium. From table B.2 the area classification for secondary sources is therefore Zone 2.

(B) Applying IGEM/SR/25 (2010)
Applying A7.2.1, to assess the adequacy of the ventilation:

Calculating the value of the bulk gas concentration $C_{out}$

Gas density = 0.666 kg/m$^3$

From Ivings et al. (2008)

$C_{out} = 0.5 \times 10^{-3}/(0.243 \times 0.666) = 2.47 \times 10^{-3}$ v/v = 0.31% v/v

LEL = 4.4 % v/v, so 10 % LEL = 0.44% v/v

$C_{out} < 10$ % LEL criterion is met. The ventilation is "more than adequate". It meets the other criteria in A7.2 so that, in accordance with 5.3.1 (a) the zone distances in Table 1 apply and Zone 2 NE applies.

(C) Applying QUADVENT
Equations (3) and (4) are applicable using

$q_s$ = leak rate = 0.5/698 m$^3$/s = 0.000716 m$^3$/s (equivalent to 0.5g/s)

$\varepsilon$ = efficiency of background mixing = $\frac{1}{2}$ (in this case)

$q_1$ = ventilation rate = 0.243 m$^3$/s

$r_s$ = 0.892 mm (for a hole area of 2.5 mm$^2$)

$\rho_s$ = 0.698 kg/m$^3$

$\rho_b \approx 1.204$ kg/m$^3$ (density of air) (a more accurate value can be calculated if necessary)

$x_{crit}$ = 50% LEL ≡ 0.022 v/v

$x_b = 0.5 \times 2/698 \times 0.243 = 0.0059$ v/v

$$V_z = \frac{9 \times \pi \times 0.892^3}{16 \times 0.05 \times 10^9}\left(\frac{1.204}{0.698}\right)^{1.5}\left(\frac{1-0.0059}{0.022-0.0059}\right)^3$$

$$= 0.013 \text{ m}^3$$

$V_z$ is less than 0.1m$^3$ and the area classification is therefore Zone 2 NE.

SUMMARY FROM EXAMPLES
In both cases the use of BS EN 60079-10-1:2009 results in a classification of Zone 2, whilst QUADVENT results in a classification of Zone 2 NE. In the second example, the use of the industry code IGEM/SR/25 (2010) also results in a classification of Zone 2 NE.

## CONCLUSIONS

We have developed QUADVENT for the purposes of area classification for gases and as an alternative for estimating the parameter $V_z$ as defined in BS EN 60079-10-1:2009. The methodology in the standard has no basis in science and gives arbitrary results. QUADVENT is based on simple well established jet model theory, and has been validated against experimentally validated CFD. It has been shown to provide solutions that are significantly lower than those resulting from the use of the methodology in the standard, and which are compatible with the gas industry standard IGEM/SR/25 (2010). Future work to extend the principles to flashing liquids and other scenarios is planned.

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