AREA CLASSIFICATION OF NATURAL GAS INSTALLATIONS†

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Whilst area classification has been applied in the past to high pressure natural gas installations, the implementation of the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) has made it necessary to consider area classification for all pressures, including the lower pressures used for distribution and supply. The principal sources of guidance were increasingly regarded as over-conservative and their application at lower pressures, as a means of compliance with DSEAR, was seen as anomalous and problematical for both the industry and the Health and Safety Executive (HSE).

Following earlier work by the Health and Safety Laboratory (HSL) on outdoor installations, a Joint Industry Project was formed to provide data to allow the development of a soundly based approach to area classification for pressures up to 10 barg. The project was completed in 2007, and the results are to be incorporated into revisions of the appropriate guidance.

The project produced new experimental data, predictions from a validated CFD model, and evaluations of area classification and ventilation criteria. The full technical report has been published by HSE. This paper summarises the results with particular reference to their practical application.

INTRODUCTION

Implementation of the ATEX Directives[1,2] has brought about a structured approach to the supply and use of equipment intended for use in hazardous areas. The Equipment Directive[1] deals with the supply of protected equipment whilst, the User Directive[2], implemented in the UK as the Dangerous Substances and Explosive Atmospheres Regulations[3] (DSEAR), deals with the installation and use of protected equipment. DSEAR requires a risk assessment and the installation of appropriate protected equipment in identified hazardous areas.

With the implementation of DSEAR it was necessary to re-consider hazardous area classification for non-domestic gas installations. In the UK, the main relevant sources of guidance are BS EN 60079-10[4], IP 15[5] and IGEM/SR/25[6]. The recommendations provided by these documents were increasingly regarded as excessive for secondary releases from low-pressure gas installations. Earlier theoretical work at HSL[7,8] had demonstrated that the recommendations lead to a very large degree of conservatism when used for area classification of outdoor systems. When applied to low pressure indoor gas systems, the recommendations of these documents generally result in a zone 2 requirement. The gas industry maintained that the incidence of fires or explosions following foreseeable small leaks from flanges, fittings, joints etc. is so low that area classification is inappropriate and that risk assessment based arguments should be applied. However, in many cases area classification was and still is applied by suppliers, required by users, or recommended by enforcing authorities or notified bodies. In the absence of alternative well founded technical data and suitable criteria, recommendations and enforcement were not uniform internationally or nationally. A Joint Industry Project[9] (JIP) was set up by HSE to overcome these difficulties.

VENTILATION

The application of ventilation to area classification was probably first discussed in detail in the seminal publication of Cox, Lees & Ang, 1990[10] and it is now generally accepted by all the relevant standards and codes that ventilation is a critical factor.

Guidance on ventilation assessment is given in IGEM/SR/25[6]. Naturally ventilated indoor spaces are assessed on the basis of ventilator location and relative size, buoyancy effects, and overall location. However, even if 'adequate' ventilation is demonstrated in accordance with this code, it recommends zone 2 within defined distances from secondary sources for all gas pressures, without any lower limit. Similarly adequate ventilation is defined in IP 15 on the basis of air change rates, and the extent of the resulting zone 2 from secondary sources of gas recommended by this code also has no lower pressure limit.

BS EN 60079-10[4] defines the degree of ventilation as high, medium or low on the basis of a calculated hypothetical parameter V_z, which is itself defined as the volume within which the mean concentration of flammable gas arising from a release will be (for secondary releases) 50% of the Lower Explosive Limit (LEL). The standard gives a method for the calculation of V_z, for indoor situations, using the enclosure air change rate and flammable (gas) release rate. It is based on the presumption of instantaneous and homogeneous (perfect) mixing and therefore requires the adoption of an empirical correction factor. Subsequent to the calculation of V_z, area classification can then be associated with ventilation since the standard allows the concept of negligible extent (NE) to be applied if V_z is less than 0.1 m^3, thus defining the ventilation as 'high'. In such an event, unless the ventilation availability is 'poor' as defined by the standard, secondary releases give rise to zone 2 NE in which case no further precautions are required. The concept of V_z is, in effect, a special case of dilution ventilation.

The calculation methods for V_z in the standard had been shown[7,8] to give unrealistically large V_z volumes for outdoor releases. For indoor applications, the methodology is limited in its scope, and had been found to be similarly limited in its application. Few real situations allow the application of zone 2 NE based on the calculation methods in the standard. Relevant and realistic definitions of acceptable natural and mechanical ventilation were clearly required for indoor locations if the zone 2 NE concept were to be applied to low pressure natural gas situations.

JOINT INDUSTRY PROJECT AIMS AND OBJECTIVES

The zone 2 NE approach was recognised as an appropriate method of dealing with foreseeable leaks from low pressure gas systems. It was determined at an early stage that the approach would be limited to gas systems operating at less than 10 barg, on the basis of engineering judgement that zoning, excluding the use of zone 2 NE, was regarded as an appropriate, current and realistic safety measure for higher pressures and there was no intention to encourage the reduction of safety measures. It also ensured that continental distribution systems would be included within the scope. Similarly, since the size of a gas cloud is a function of the hole size, whilst the project examined a range of hole sizes, the minimum recommended size for the application of the V_z concept is 0.25 mm^2. The use of unrealistically small hole sizes can lead to misleadingly small values of leak rate and V_z. The primary aim of the project was to provide an appropriate technical basis for realistic hazardous area classification for foreseeable secondary gas leaks from low pressure natural gas systems. This technical basis would be founded on model predictions of gas cloud volumes, which result from gas releases over a range of hole sizes and pressures in naturally and mechanically ventilated spaces. Cloud volumes would be correlated against enclosure volume and defined ventilation criteria. Model predictions would be validated against experimental data.

The intention was to devise a more soundly based methodology for defining zone 2 NE with the possibility of removing a significant amount of conservatism from the methods given in BS EN 60079-10[4], with the potential for very significant cost savings for industry, enabling any costs to be restricted to areas of genuine risk.

The basic assumption of the standard[4] and its criterion of V_z is that a gas cloud with a V_z smaller than 0.1 m^3 contains so little flammable material that its ignition is an insignificant event and will cause no injury to persons in the vicinity or damage to equipment. It has been indicated informally that the original selection of 0.1 m^3 as the limiting volume for V_z was based on experience and pragmatism and had no experimental or formal theoretical basis. In view of the significance of the criterion in the context of this project and thus in future area classification studies, it was determined that experimental work would be carried out so far as was necessary to confirm its validity.

The following objectives were set to meet the project aims:

- Carry out a review of methods for assessing the effectiveness of ventilation for preventing the build up of gas following a secondary leak. Also review methods for calculating the ventilation rate of naturally ventilated enclosures and make a recommendation on an approach that can be used in an area classification methodology.
- Confirm that the hazard posed by a leak giving a gas cloud with an average concentration of 50% LEL and smaller than 0.1 m^3 is low and therefore its appropriateness as the basis for defining zone 2 NE.
- Carry out a series of experiments to provide data to validate a Computational Fluid Dynamics (CFD) model for predicting gas cloud build up from low pressure, high momentum leaks in enclosures. Simulate these experimental tests using the CFD model and assess its ability to accurately predict the gas concentration field.
- Use the validated CFD model to provide data that can be used to define a methodology for area classification for low pressure secondary gas leaks in enclosures. In particular correlate the gas cloud volume against the mass release rate and ventilation rate.
- Describe how these data can be used for area classification of low pressure gas systems in enclosures and outdoors.

The JIP was carried out between 2006 and 2007 and is reported by Ivings et al., 2008[9]. The full report is available on the HSE website[1]. The support of the following sponsors is gratefully acknowledged.

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Gasunie
Hamworthy Combustion
Knauf Insulation Ltd
National Grid
Northern Gas Networks
SGL Technic Ltd
Slough Heat and Power

[1]www.hse.gov.uk/research/rrhtm/rr630.htm

RESULTS

A review was carried out on the ventilation of enclosures focusing on measures of ventilation effectiveness and how ventilation rates can be measured for input into an area classification methodology. The most accurate approach to calculating air change rates for naturally ventilated enclosures is to make measurements of the decay rate of a tracer gas within the enclosure. However, the time and expense required to do this means that it is not an approach suitable for area classification. BS 5925[11] describes a method for calculating air change rates of naturally ventilated enclosures that is simple to apply and should provide data of sufficient accuracy to be appropriate for area classification. The approach was applied to two enclosures where the air change rate was measured experimentally. In the first of the two cases considered the calculated air change rate was in good agreement with the measurements and in the other case it under-predicted the ventilation rate.

BS EN 60079:10[4] was reviewed in detail. The JIP made a clear distinction between the two definitions given in the standard for the gas cloud volume V_z. They are:

- A hypothetical volume that can be calculated using the formulae in BS EN 60079:10[4] and which is proportional to the mass release rate of a leak divided by the air change rate of the enclosure.
- A gas cloud that has an average gas concentration of 50% LEL.

The two descriptions of V_z above are not equivalent: i.e. the calculation method in BS EN 60079:10[4] for V_z does not provide reasonable estimates of the volume of the gas cloud whose average gas concentration is 50% LEL. Furthermore, the BS EN 60079:10[4] calculated values of V_z were found to be up to three orders of magnitude larger than the gas cloud volumes V_z predicted by using a validated CFD model[9]. The greatest differences are seen in the largest enclosures. This implies that use of BS EN 60079:10[4] for calculating V_z significantly over estimates the hazard and therefore leads to areas requiring a higher area classification than is necessary.

The hazard associated with a leak that leads to a V_z of 0.1 m^3 was assessed through experiments and modelling. It was shown that the hazard is low in terms of the overpressure created on ignition of the cloud and the thermal radiation associated with the explosion and subsequent jet flame. Igniting gas clouds created by a leak leading to a V_z of 0.1 m^3 was found to be difficult and a powerful ignition source was required. However, the overpressure resulting from a fixed volume of gas (e.g. a V_z of 0.1 m^3) increases as the enclosure volume decreases. So whilst it was demonstrated that the V_z criterion is conservative, and can therefore be adopted as a basis for safety for large enclosures, it is not appropriate for small enclosures. An appropriate cut-off would appear to be around 10 m^3, since this implies a theoretical maximum overpressure of 12.5 mbar, established previously as a tolerable limit[12]. Below 10 m^3 the maximum value of V_z should therefore be smaller and an additional criterion has been introduced requiring that V_z should additionally be less than 1% of the enclosure volume to be classified as zone 2 NE. This restriction has been included in the revised version of the standard, IEC 60079-10-1:2008[13].

An approach to zoning outdoors was developed which is based on a conservative estimate of the leak rate required to produce a gas cloud with a V_z of 0.1 m^3. For releases in the open air it has been shown that the largest gas cloud sizes result from conditions where the leak is aligned to the wind direction and the wind speed is low. HSL's integral free jet model, GaJet, was therefore used to calculate the pressure and hole size required to give a gas cloud with a V_z of 0.1 m^3. For choked releases (for methane, where the pressure is above 0.85 barg) the gas cloud volume is dependent only on the mass release rate. It has been shown that the presence of obstructions near to the leak source can act to increase the resulting gas cloud volume compared to the equivalent unobstructed case. It has also been shown that a leak rate of 1 g/s provides a conservative estimate of the leak rate required to give a V_z of 0.1 m^3 in an outdoor environment. However, this criterion may not be appropriate in cases where there is a *high* level of congestion, or an arrangement of obstacles that leads to re-entrainment of gas into the jet or reduces the dilution of the jet greatly. Therefore, for secondary releases in locations that are not heavily congested or confined, leak rates of less than 1 g/s can be appropriately classed as zone 2 NE.

The ventilation in an enclosure is not expected to be any more efficient at diluting a gas leak than if the leak occurred outdoors. By definition, releases within enclosures are likely to experience some form of confinement. Therefore, it is also appropriate to apply the mass release rate criterion for outdoor obstructed releases, 1 g/s, as an upper bound on the release rate for zoning indoors.

An alternative approach to measuring the ventilation effectiveness in enclosures to that in BS EN 60079:10[4] (i.e. V_z) is based on the average gas concentration at the outlet. It has been shown[9] that this is equivalent to an assessment of the ratio of the air entrainment requirement of the leak to the ventilation rate. The current approach differs significantly from BS EN 60079:10[4] in two key ways. Firstly, the average gas concentration at the outlet is dependent on the ventilation rate as opposed to V_z which is dependent on the air change rate of the enclosure. This therefore means that the measure of ventilation effectiveness (i.e. the average gas concentration at the outlet) increases as the enclosure volume increases for a fixed air change rate. Secondly, and most importantly, this new measure of ventilation effectiveness is based on a physical understanding of the behaviour of the dispersion of high momentum jets and has been evaluated against data on gas cloud build up in enclosures.

A validated CFD model has been used to provide data on gas cloud volumes for low pressure gas leaks in enclosures. The data show that there is a strong correlation between the average gas concentration at the outlet, c_{out}, and the gas cloud volume, V_z. For the majority of cases examined, where the average concentration at the outlet was less than 10% LEL the gas cloud volume V_z was found to be less than 0.1 m^3. This suggests that the condition c_{out} less than 10% LEL would provide a more suitable criterion for zone 2 NE rather than using the method of calculating V_z in BS EN 60079:10[4]. The approach described here removes a very large degree of conservatism from the zoning methodology described in BS EN 60079:10[4].

For the above approach to be applicable, the leak source must not be located within a confined space within an enclosure. It has been shown that local confinement of a leak can lead to re-entrainment of gas into the jet resulting in significantly larger gas cloud volumes than would be expected in an unconfined space. Such cases are more likely to occur in large enclosures where the jet length scale is smaller relative to the enclosure and there is more opportunity for short-circuiting of the ventilation to occur leading to stagnant regions.

The CFD model for the above work has been validated against 29 experimental tests carried out in a purpose built enclosure. The experimental tests consisted of releases of simulated methane gas for a range of leak rates and ventilation rates. Three different configurations of the release location and direction were tested and measurements of the point gas concentration measurements were used as the basis for the model validation. The results of the CFD simulations showed good agreement with the experimental data.

The overall results are relatively straightforward to apply and are summarised by the algorithm in Figure 1 below. Their application requires judgements to be made regarding the local ventilation effectiveness and the likely effect of nearby obstructions on the gas dispersion. These results will be used to develop full guidance for area classification in a revised version of IGE/SR/25.

EXAMPLE

The application of the results is illustrated in the example below, drawn from a real installation.

A plant room contains 3 × 1400 kW boilers, each with an unenclosed gas booster, and two separate gas boosters in acoustic enclosures, together with metering and pipework. The room contains a range of other services. It is unzoned. Natural ventilation is provided by 3 louvred 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.

Gas pressures are:

Feed – 20 mbarg
Boiler feed – 54 mbarg from local boosters
LP booster – 23 mbarg
HP booster – 76 mbarg

For nomenclature in the calculations below, see IGEM/SR/25[6] and IEC 60079-10[13] where relevant

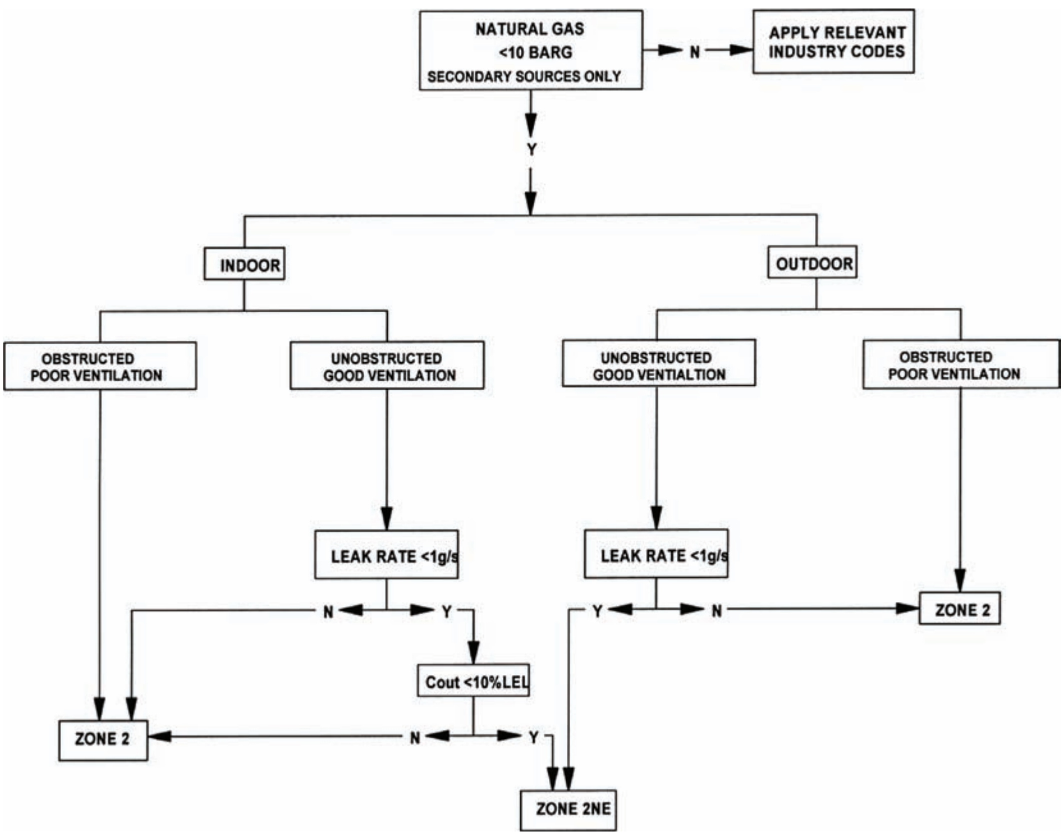

Figure 1. A zoning algorithm for low pressure natural gas systems

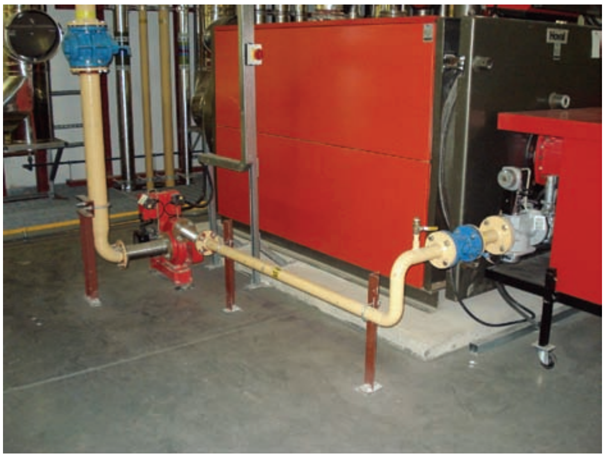

Figure 2. Boiler showing local booster

Figure 3. Gas inlet and ventilation louvre

PLANT ROOM VENTILATION RATE

Applying BS 5925[11]:

Hourly mean wind speed exceeded for 50% of the time, $u_{50} = 4$ m/s for the geographic region of the site (Figure 5 of BS 5925[11]).

Figure 4. Manifolds and booster enclosures

Converting to hourly mean wind speed exceeded for 80% of the time, from Table 9,
$u_{80} = 0.46 \times 4 = 1.84$ m/s
From Table 8, parameters for open flat country, $K = 0.68$, $a = 0.17$
From equation 5,
$u_r = Kz^a u_{80} = 0.68 \times 5.5^{0.17} \times 1.84 = 1.67$ m/s
From Table 12, ventilation rate $Q = 0.025\ Au_r = 0.025 \times 5.83 \times 1.67 = 0.243$ m^3/s, giving an air change rate of $C = 0.243/2660\ s^{-1} = 0.33$ air changes per hour (ach)

The ventilation rate was also measured by direct anemometer readings, and estimated to be 3.32 m^3/s. However the measurements were taken on an exceptionally windy day, when winds in excess of 30 mph (13.4 m/s) were forecast, so that the discrepancy is not surprising and the value estimated from BS 5925[11] can be seen to be compatible.

PLANT ROOM LEAKAGE RATE

The boosters are treated as giving rise to an adverse environment, so that leak sizes of 2.5 mm^2 are used.

Using Cd of 0.8 and standard flow calculation equations[13]:

Leak rate at 76 mbarg = 0.2 g/s
Leak rate at 54 mbarg = 0.17 g/s

Applying IGEM/SR/25[6], A 4.3.4, 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

A4.3.4 of IGEM/SR/25[6], $\sum Tf_i n = 0.0068$, so that the number of simultaneous secondary releases that should be taken into account for the purposes of IGEM/SR/25[6] is two based on Table 13.

For zoning calculations using IGEM/SR/25[6] and the results of the new research, use 2 simultaneous leaks, one at each pressure. Leak rate = 0.2 + 0.17 = 0.37 g/s.

For zoning calculations using IEC 60079-10[13] use the single largest value (Table B.2), leak rate = 0.2 g/s.

PLANT ROOM ZONING CALCULATION USING IEC 60079-10[13]

Calculation of V_z:

From B.5.2.2 Note 1
$LEL_m = 0.416 \times 10^{-3} \times M \times LEL_v$
$M = 16$, $LEL_v = 4.4\%$
$LEL_m = 0.416 \times 10^{-3} \times 16 \times 4.4 = 0.0293\ \mathrm{kg/m^3}$
From equation B1:

$$\left(\frac{dV}{dT}\right)_{\min} = \frac{(dG/dt)_{\max}}{k \times LEL_m} \times \frac{T}{293} = \frac{0.2}{10^3 \times 0.5 \times 0.0293}$$
$$= 0.013\ \mathrm{m^3/s}$$

From equation B.4:

$$V_z = \frac{f \times \left(\frac{dV}{dt}\right)_{\min}}{C}$$
$$= 0.013/9.13 \times 10^{-5} = 142\,\mathrm{m^3} (\text{taking } f = 1)$$

Since $V_z > 0.1\ \mathrm{m^3}$, Zone 2 NE cannot be adopted, irrespective of the value of *f*.

V_z does not exceed V_0, and therefore in accordance with B4.3.3 the ventilation is classed as medium. The area classification for secondary sources is therefore zone 2.

PLANT ROOM ZONING CALCULATION USING IGEM/SR/25[6]

Testing for the availability of good mixing

From A4.5.3, $A_{mix} = VE/178 = 2660/178 = 15\ \mathrm{m^2}$

$A = 5.83\ \mathrm{m^2}$, so that the criterion for the availability of good mixing $A \geq A_{mix}$ is not met, and the ventilation is classed as inadequate. (The ventilation meets the other requirements of A4.5.1, but these are not shown since it fails to meet the IGEM/SR/25[6] criterion for good mixing.)

Testing for poor ventilation

From 5.3.1 (b), $A_A = 21.5 \times 22.5 = 483.75\ \mathrm{m^2}$ (floor area)

Since $A_v = 5.83\ \mathrm{m^2}$, $A_v > 0.01\ A_A$, so that the criterion is met and the ventilation is classed as "inadequate" and not as "poor".

Therefore, in accordance with 5.3.2.2(b) the entire plant room is classified as zone 2.

PLANT ROOM ZONING USING IP 15[5]

The fundamental criterion used to define adequate ventilation in IP 15[5] is the air change rate of 12 ach. In this case the air change rate is 0.33 ach. The ventilation is therefore defined as inadequate, and the area classification of all secondary sources is zone 1 in accordance with Table 6.1.

PLANT ROOM ZONING CALCULATION USING THE RESULTS OF THE CURRENT WORK

The gas pressure is less than 10 barg, satisfying the first criterion.

The degree of obstruction is relatively low. Smoke tests were carried out and showed that there was good air movement in the vicinity of all the secondary sources.

The leakage rate of 0.37 g/s is within the limiting value of 1 g/s. Calculating the value of C_{out}:

Gas density = 0.666 kg/m^3
From Ivings et al., 2008[9]
$C_{out} = 0.37 \times 10^{-3}/(0.243 \times 0.666) = 2.28 \times 10^{-3}$
v/v = 0.228 vol%
LEL = 4.4%, so 10% LEL = 0.44%
$C_{out} < 10\%$ LEL criterion is met. Zone 2 NE applies.

BOOSTER ENCLOSURE ZONING CALCULATION

The LP booster enclosure has a forced ventilation rate (estimated based on measurement) of 0.025 m^3/s.

The leak rate (for one 2.5 mm^2 hole at 23 mbarg[14]) is 0.11 g/s.
$C_{out} = 0.11 \times 10^{-3}/(0.025 \times 0.666) = 6.6 \times 10^{-3}$
v/v = 0.66 vol%
10% LEL = 0.44%
$C_{out} > 10\%$ LEL, so that this criterion is not met, and zone 2 NE cannot be used.

In this case, it was recommended that the acoustic enclosures be removed. There are already three unenclosed boosters in the plant room and these boosters do not produce any significant noise. The enclosures brought about a hazard with no safety gain.

CONCLUSIONS FROM EXAMPLES

The results of this example and others show that area classification using the different methods results in different zoning. In the case of the plant room the use of IEC 60079-10[13] would result in zone 2 at each source, IP 15[5] would result in zone 1 at each source, whilst IGEM/SR/25[6] would require the entire room to be classified as zone 2. Application of the new work shows that all sources may be regarded as zone 2 NE, and that no further protection is required.

OVERALL CONCLUSIONS

The project has produced a set of simple criteria that may be used to allow the classification of Zone 2 NE to be applied to a wide range of natural gas installations operating at pressures below 10 barg. It has been shown that the method is very much less demanding than the previously used methods. Whilst some judgement is required, the use of relatively simple tools, such as a smoke generator, and simple calculations will enable many installations to use a lower classification of zone whilst identifying those that require additional measures, thereby concentrating resources on genuine hazards. It is intended to include the results of this work in an imminent revision of IGEM/SR/25[6].

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