[Proceeding] Hazardous areas extension in explosive atmospheres caused by free gas jets

Original Citation:

Tommasini, R.; Palamara, F.; Pons, E. (2012). *Hazardous areas extension in explosive atmospheres caused by free gas jets.* In: 43rd ESReDA Seminar on Land Use Planning and Risk-Informed Decision Making - Aménagement du Territoire et Prise de Décision en Maitrise de Risques, Rouen, France, October 21-23, 2012. pp. 102-108

Publisher:

Publications Office of the European Union

Published version:

DOI:10.2790/28605

Hazardous areas extension in explosive atmospheres caused by free gas jets

Riccardo Tommasini
Energy Department, Politecnico di Torino,
C.so Duca degli Abruzzi 24, 10129 Torino, Italy

Federica Palamara
Occupational Health and Safety Department, Politecnico di Torino,
C.so Duca degli Abruzzi 24, 10129 Torino, Italy

Enrico Pons
Energy Department, Politecnico di Torino,
C.so Duca degli Abruzzi 24, 10129 Torino, Italy

Abstract

This paper regards the validation procedure of the Italian Guide CEI 31-35 formula, used to calculate the hazardous areas extensions in places where explosive gas atmospheres may be present. In industrial activity, a typical event which cause explosive atmosphere consists of damaging and leakage from unions, gaskets, valves of pipes and vessels. At this purpose, in this work it has been taken into account the accidental discharge of flammable gas into a quiescent atmosphere through an orifice. Validation has been performed by comparing calculated values with experimental data. Two gases have been taken into account: methane and hydrogen. Different scenarios have been analyzed, each one differing from the others in the gas release cross section and in the vessel pressure. Results show that the formula fits well not catastrophic industrial accident situations.

Keywords: Risk Analysis, Explosive gas atmospheres, Hazardous Areas Extension.

1. Introduction

Object of this paper is the risk assessment in industrial activities as regards releases of flammable gases from pressure systems, which can imply the potential for an explosive atmosphere. Such releases into the atmosphere can be expected to occur periodically or occasionally during normal operation from, for example, relief valves (‘Primary releases’). On the other hand, accidental releases, which are not likely to occur during normal operation (‘Secondary releases’) are to be taken into account; this kind of releases regards for example small leaks from pipe-fittings, joints, flanges, valve glands, seals of pumps.

In the work here described particular attention has been paid to gases lighter than the air, such as hydrogen and methane.

In order to guarantee the safety and health protection of workers potentially at risk from explosive atmospheres in industrial activities, hazardous area classification should be carried out as an integral part of the risk assessment to identify areas where controls over ignition sources are needed, as regards construction, installation and use of equipments. Area classification is based on the frequency and persistence of the potentially explosive atmosphere and on the degree of ventilation provided to ensure that any explosive atmosphere does not persist for an extended time.

The work here described particularly regards the determination of the hazardous area extent. The area where the concentration of the considered flammable substance is higher than the LEL ('Lower Explosive Limit') is, by definition, an hazardous zone; the area outside the LEL boundary may be considered a non dangerous zone, if the gas concentration is enough lower than LEL. Authors previously had studied a formula to calculate hazardous area extent whenever dangerous quantities and concentrations of flammable gas may arise; this formula had been analytically found out, based on the diffusion theory of a free turbulent round jet and it had been compared both with calculations performed by the analytical software 'Effects' and with numerical simulations carried out with the Computational Fluid Dynamics code 'Phoenics' [1], [2] [3]. This study had been performed by taking into account: methane, ammonia and hydrogen, but also heavier gases as propane and butane. Furthermore the formula had been introduced in the Italian Guide CEI 31-35 [4],"Guide for classification of hazardous areas", which, in compliance with the European Standard IEC EN 60079-10 [5], regards the classification of hazardous areas, whenever dangerous quantities and concentrations of flammable gas or vapour may arise.

This paper illustrates the validation procedure of the formula, by comparing it with experimental data.

2. Materials and methods

2.1 Method for calculating hazardous area extent

The Italian Guide CEI 31-35 reports eq. (1) able to calculate the extent of hazardous area when a flammable gas is discharged into a quiescent atmosphere through an orifice. Looking at eq. (1), the distance d_z is the distance from the orifice, along the central axis of the jet, at which gas concentration is reduced to the lower explosive limit ('LEL') of the gas.

This equation had been analytically found out by studying the released gas behaviour (subsonic or sonic), which depends on the containment vessel pressure value, P_r respect to the atmospheric one, P_a. Besides, it had taken into account the relationship among the concentration profile of gas, along the axis of the jet, the distance to the orifice and the jet discharge diameter. Finally it had to be considered the strong dependence between the discharged gas concentration and its density (thus its molecular mass) related to the surrounding air [6],[7],[8],[9],[10],[11].

$$d_z = \frac{5{,}2}{k_{dz}\, LEL}\sqrt{P_r}(M)^{-0{,}4}\sqrt{S} \tag{1}$$

where

k_{dz} is a safety coefficient applied to the LEL for the calculation of d_z
P_r is the absolute pressure inside the vessel [Pa]
S is the cross sectional area of the outlet [m^2]
M is the gas molecular mass [kg/kmol]
LEL is the lower explosive limit of the gas [% vol].

Fig. 1 shows an indoor jet flow of methane computed by the Computational Fluid Dynamics software Fluent. Different colours indicate the concentration of methane in air. The parameter d_z represents the distance from the source of release at which the gas concentration (X_m%) along central axis, related to the gas concentration at the outlet, is reduced to the LEL. The area where the concentration of the gas is higher than its LEL is, by definition, an hazardous zone; the external area may be considered a non dangerous zone, if the gas concentration is enough lower than LEL; in fact, actually, the hazardous area is increased by the safety factor k_{dz} (whose typical values range from 0,25 to 0,75 [4]), i.e. the distance d_z is calculated at the k_{dz} ·LEL boundary.

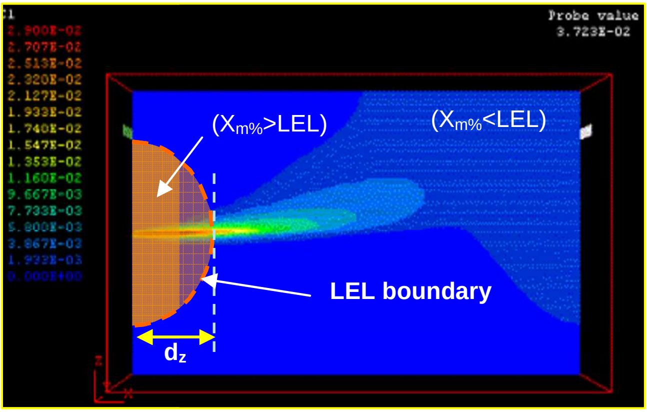

Figure 1. Hazardous zone around a jet flow of methane

Referring to the distance d_z, the hazardous zone can be computed. Fig. 2 shows, as example, a gas release from a damaged flange. The explosive volume can be approximately calculated by considering the volume of a cone having height d_z and depending on the jet direction The hazardous zone around the pipe is a sphere resulting from the envelope of all the possible explosive volumes.

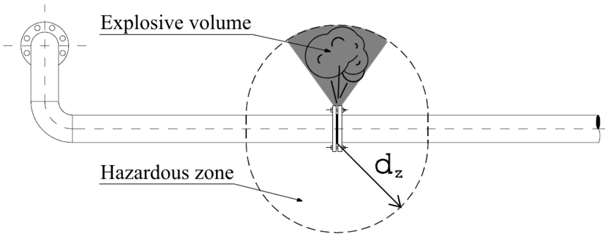

Figure 2. Hazardous zone around a jet flow of gas

2.2 Experimental data

In order to assess the validity of the d_z formula, shown in eq. (1), experimental tests have been considered. The first one consists in natural gas (92% methane) supplied from a vessel via a pressure regulator (ranging from 3.5 to 71 bar) to a nozzle whose internal diameter is equal to 2,7 mm [7].

The second configuration consists of hydrogen leak through a circular orifice whose diameter is 0,5 mm. Hydrogen comes out from a 19 l vessel. By means of a valve connected with a pressurizing system, it is possible to change the storage pressure from 50 to 400 bar [12].

The third configuration consists of hydrogen releasing at 400 bar, through a 0,2 mm nozzle [13].

The fourth configuration consists of hydrogen release, from a tank pressurized to 100 bar, through a 3 mm nozzle [14].

For both methane and hydrogen, gas-air mixture concentrations have been measured along jet axis, at different distances from the release source.

As regards source diameters, they are of the order of magnitude which is typical of small leaks. In fact these experimental data are used to validate eq. (1) which had been studied referring to releases from small orifices.

It can be noticed hydrogen pressures are higher than methane ones; this is due to the fact that normally hydrogen is stored in gas cylinders at higher pressures than the ones at which natural gas is distributed.

3. Results and discussion

Fig.3 shows, for different vessel pressures, both experimental (points) and calculated (continuous lines) d_z values which are function of methane concentration (% in volume) data. Source diameter is equal to 2,7 mm.

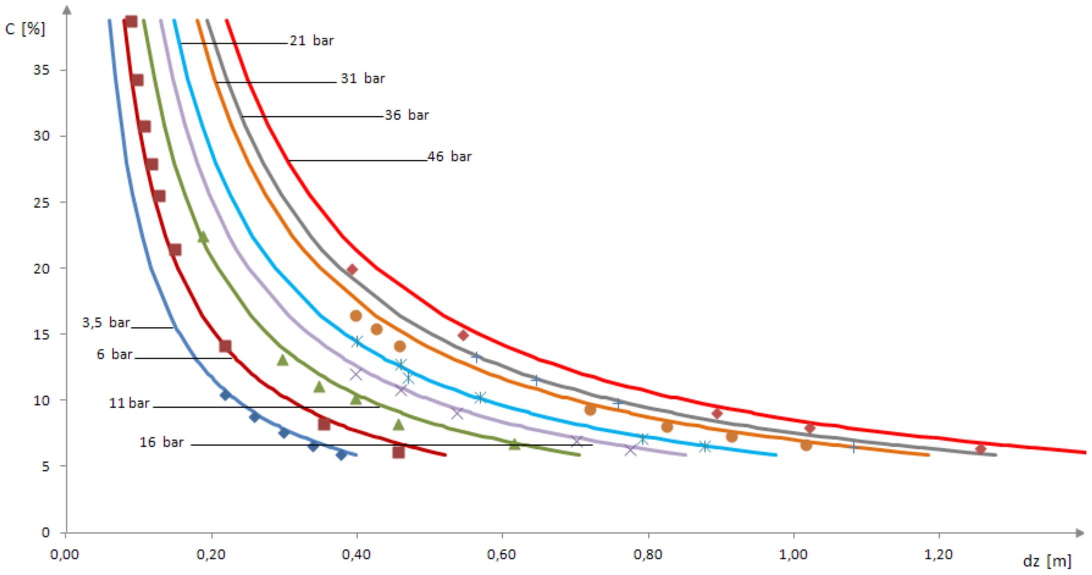

Figure 3. Comparison between experimental and calculated d_z values for methane releases

Figg.4 and 5 show, for different vessel pressures, both experimental (points) and calculated (continuous lines) d_z values which are function of hydrogen concentration (% in volume) data. Source diameters are equal to 0,2 mm, 0,5 mm and 3 mm.

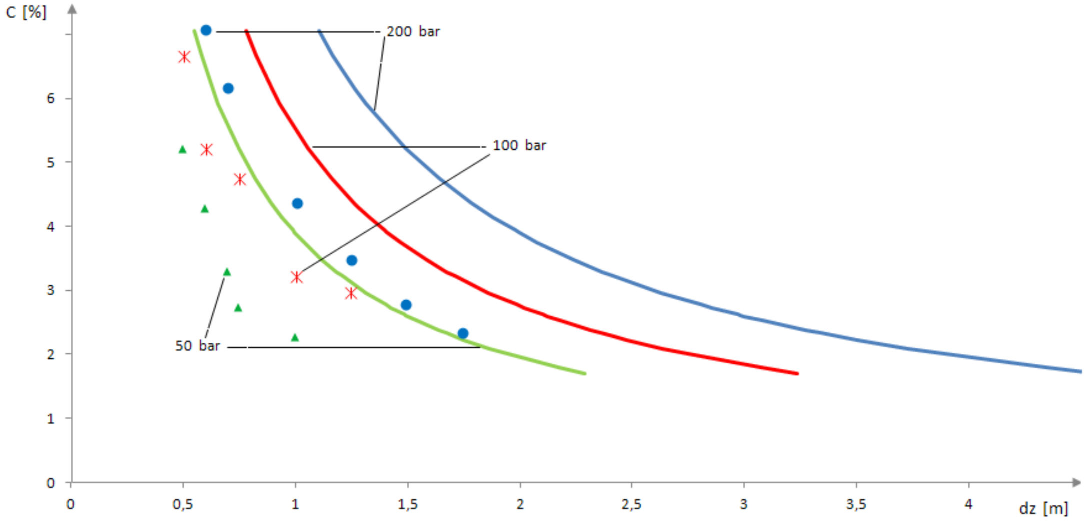

Figure 4. Comparison between experimental and calculated d_z values for hydrogen release (0,5 mm)

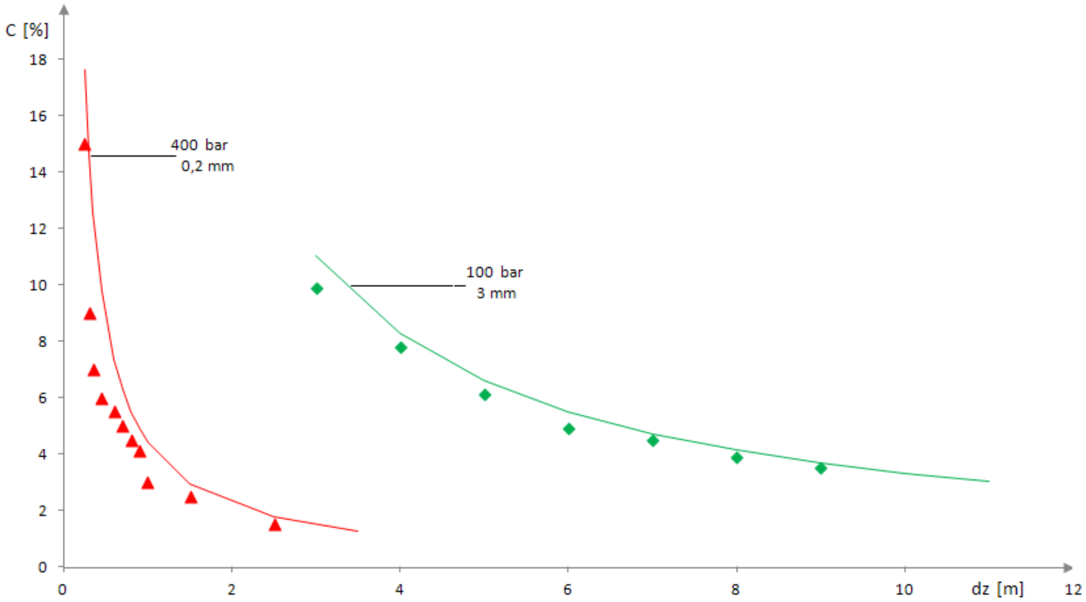

Figure 5. Comparison between experimental and calculated d_z values for hydrogen release (0,2-3 mm)

In order to compare d_z experimental data with the ones calculated by eq. (1), LEL has been substituted with the measured gas concentration values and k_{dz} has been considered equal to 1.

As it regards both methane (releasing from 2,7 mm nozzle) data and the ones regarding hydrogen releasing from 3 mm nozzle, it comes out that the maximum percent deviation between experimental and calculated values is very low (11%). Instead, as it regards hydrogen leak from 0,5 mm nozzle, the calculated d_z values are about 1,7 times the correspondent experimental data and, as it regards hydrogen leak from 0,2 mm, the calculated d_z values are about 1,1 times the correspondent experimental data. It is important to note that all hydrogen experimental d_z data are lower than the ones calculated by eq. (1). Therefore, eq. (1) is precautionary and it turns to safety advantage, thus it can be used in order to assure that, at distances higher than the calculated d_z, gas concentration is lower than LEL.

Besides, it has to be taken into account eq. (1) estimates gas outflows without considering friction and contraction effects during discharging from the holes. This formula had been found out assuming an ideal maximum value of mass flow rate. Actually it has to consider a discharge coefficient. Literature [5] suggests discharge coefficient, C_d, values ranging from about 0,3 to about 0,9; obviously this factor is as higher as discharge section has lower values. Furthermore, the discrepancy between calculated and experimental data could be due to the fact that for small jets, there are more fluctuations in the resulting plume, which implies lower averaged measurements [15].

4. Conclusions

The work here described regards the determination of the hazardous area extent in places where an explosive atmosphere may occur, whenever sonic releases of methane or hydrogen from high pressure sources may arise. At this purpose the formula which had been introduced in the Italian Guide CEI 31-35 has been validated by experimental data on axial decay of gas from under-expanded methane and hydrogen jets. Results confirm the validity of d_z formula as regards not catastrophic events where source diameters are of few millimetres. It is to understand in greater detail the over prediction for leakages from very small nozzles.

Future development regards eq.(1) validation against experimental data regarding heavy flammable gases as propane and butane.

References

[1] Abate A., Pomè R., Tommasini R., (1998) Impianti elettrici nei luoghi con pericolo di esplosione: comportamento dei gas nella formazione di atmosfere esplodibili, *Automazione Energia Informazione (AEI)*, Vol. 85, N. 12.

[2] Tommasini R., (2000) Electrical apparatus for explosive gas atmosphere: a contribution to the evaluation of hazardous areas in indoor places, *Proc. ESREL 2000 SARS and SRA Europe Annual Conference - Foresight and Precaution*, Edinburgh, Scotland, UK.

[3] Tommasini R., Pons E. (2012) Classification of Hazardous Areas Produced by Maintenance Interventions on N.G. Distribution Networks and in Presence of Open Surface of Flammable Liquid. *In: IEEE Transactions on Industry Applications*, vol. 48 n. 2, pp. 593-602.

[4] CEI 31-35 – Electrical apparatus for explosive atmospheres – Guide for classification of hazardous areas (Comitato Elettrotecnico Italiano, Milan, 2007).

[5] CEI EN 60079-10 – Electrical apparatus for explosive gas atmospheres – Part 10: Classification of hazardous areas (Comitato Elettrotecnico Italiano, Milan, 2004).

[6] Committee for the Prevention of Disasters, (1997) Methods for the calculation of physical effects *Yellow Book*, Netherland.

[7] Birch A.D., Brown D.R., Dodson M.G., (1984) The Structure and Concentration Decay of High Pressure Jets of Natural Gas. In: *Combustion Science and Technology*, vol. 36, pp. 249 - 261.

[8] Birch, A.D., Hughes, D.J., and Swaffield, F., (1987) Velocity Decay of High Pressure Jets, *Combustion Science and Technology* vol.52, pp.161-171.

[9] Chen,C.J. and Rodi,W., (1978) A review of experimental data of vertical turbulent buoyant jets, Perga-mon Press.

[10] Ruffin E., Mouilleau Y., Chaineaux J., (1996) Large scale characterization of the concentration field of supercritical jets of hydrogen and methane". In: *Journal of Loss Prevention in the Process Industries* vol. 9.4 pp. 279 –284.

[11] Houf, W., Schefer, R., (2005) Predicting Radiative Heat Fluxes and Flammability Envelopes from Unintended Releases of Hydrogen, Presented at *16th Annual Hydrogen Conference and Hydrogen Expo USA, March 29 – April 1, 2005,* Washington, D.C.

[12] Chaineaux J., (1999) Leak of hydrogen from a pressurized vessel - Measurement of the resulting concentration field. In: *Proceedings of the Workshop on Dissemination of Goals,Preliminary Results and Validation of Methodology, 11 March 1999,* Brussels.

[13] Kouchi, A., Okabayashi, K. Takeno, K. and Chitose, K. (2007) Dispersion Tests on Concentration and its Fluctuations for 40MPa Pressurized Hydrogen *International Conference on Hydrogen Safety, September 11-13, 2007,* San Sebastian, Spain.

[14] Shirvill, L. C., Roberts, P. T., Roberts, T. A., Butler, C. J., & Royle, M. (2006) Dispersion of hydrogen from high-pressure sources. *Proceedings of Hazards XIX conference, March 27–30, 2006*, Manchester, UK.

[15] Middha P., Hansen O. R., Storvik I. E., (2009) Validation of CFD-model for hydrogen dispersion. *Journal of Loss Prevention in the Process Industries* vol. 22 pp.1034–1038.