Safety and Health at Work 12 (2021) 416–420

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Short Communication

Specific Process Conditions for Non-Hazardous Classification of Hydrogen Handling Facilities

Jae-Young Choi, Sang-Hoon Byeon*

Department of Health and Safety Convergence Science, Graduate School, Korea University, Republic of Korea

ARTICLE INFO

Article history:
Received 13 March 2020
Received in revised form
10 May 2021
Accepted 11 May 2021
Available online 18 May 2021

Keywords:
Explosion
Hazardous area
Hydrogen gas leakage
Hydrogen safety
IEC60079-10-1

ABSTRACT

Hazardous area classification design is required to reduce the explosion risk in process plants. Among the international design guidelines, only IEC 60079-10-1 proposes a new type of zone, namely zone 2 NE, to prevent explosion hazards. We studied how to meet the zone 2 NE grade for a facility handling hydrogen gas, which is considered as most dangerous among explosive gases. Zone 2 NE can be achieved considering the grade of release, as well as the availability and effectiveness of ventilation, which are factors indicative of the facility condition and its surroundings. In the present study, we demonstrate that zone 2 NE can be achieved when the degree of ventilation is high by accessing temperature, pressure, and size of leak hole. The release characteristic can be derived by substituting the process condition of the hydrogen gas facility. The equations are summarized considering relation of the operating temperature, operating pressure, and size of leak hole. Through this relationship, the non-hazardous condition can be realized from the perspective of inherent safety by the combination of each parameter before the initial design of the hydrogen gas facility.

1. Introduction

Hazardous area classifications are required to reduce the risk of explosion in process plants. Hazardous area classification selects a zone where a risk of explosion is expected based on the type of flammable material handled by a facility, the process temperature and pressure, and the size of a leak when one occurs while the flammable material is being handled. The zones are generally classified as zones 0, 1, or 2, depending on the duration and probability of the explosion hazard. Each zone is assigned a gas group and a temperature class based on the unique values of flammable materials such as the maximum experimental gap and autoignition temperature. The aim of the hazardous area classification is to reduce the role of the ignition source in accidents by installing the equipment according to the specific grade of the tools present in the zone for a specific gas group and temperature class [1].

The design guidelines for the globally accepted hazardous area classification include API RP 505, EI 15, NFPA 497, and IEC 60079-10-1 [2]. Each code has a different method for calculating the radius of a zone formed by a facility handling flammable materials [3]. Among these, IEC 60079-10-1 introduces the concept of zone 2 NE, which is not mentioned in the other three international codes [4]. Zone 2 NE refers to a class that can be assigned to a non-hazardous location, although there is a risk of explosion. In this case, the location is classified as non-hazardous, because the zone covers a negligible area under normal conditions.

From the perspective of inherent safety, the approach was initiated to determine if zone 2 NE could be selected in advance using the relationship between the operating temperature and pressure of the facility handling the flammable materials and the size of the leak. Research was conducted on the facilities that operate with hydrogen gas, which represents the IIC gas group—which is considered the most severe gas group that can cause explosions with the lowest ignition spark—and to which the highest and most expensive grade of tools are applied [5]. And the similar approach was conducted on the facilities with propane gas [6]. However, this approach just suggested the range of operating pressure under specific process conditions, so a more general approach for applying zone 2 NE is needed.

Previously, computational fluid dynamics modeling was used to study the appropriateness of the virtual volume of IEC 60079-10-1 edition 1.0 [7]. However, after revision IEC 60079-10-1 edition 2.0

---

* Corresponding author. Department of Health and Safety Convergence Science, Graduate School, Korea University, 145 Anam-ro, Seongbuk-gu, Seoul, 02841, Republic of Korea.

E-mail address: shbyeon@korea.ac.kr (S.-H. Byeon).

https://doi.org/10.1016/j.shaw.2021.05.004

Table 1
Indicative outdoor ventilation velocities (u_w)

Type of outdoor location	Unobstructed area			Obstructed area		
Elevation from ground level	≤2 m	>2 m up to 5 m	>5 m	≤2 m	>2 m up to 5 m	>5 m
Indicative ventilation velocities for estimating the dilution of lighter than air gas release	0.5 m/s	1 m/s	2 m/s	0.5 m/s	0.5 m/s	1 m/s

in 2015, the concept of virtual volume is no longer used. Instead, charts for assessing the degree of dilution and estimating hazardous area distance are suggested, and by interpreting these charts, the data of the degree of dilution and hazardous area distance are obtained [8]. However, there are no equations of the charts, so it is not obvious to interpret the data. For supplement of this limitation, there was an approach to interpret the charts to the obvious equations by converting the charts to computer-aided diagnosis (CAD) [9]. However, this approach was just applied to the chart for estimating hazardous area distance, so more study for assessing the degree of dilution is needed.

2. Materials and methods

2.1. Effectiveness of ventilation for hydrogen gas facility to be in zone 2 NE

In IEC 60079-10-1 edition 2.0, the zone type can be calculated through the availability and effectiveness of ventilation and grade of release. This standard is not different from IEC 60079-10-1 edition 1.0. Process plant facilities are generally designed such that no leakage occurs under normal conditions. This criterion corresponds to the secondary grade of release [10]. Moreover, IEC 60079-10-1 edition 2.0 states that the availability of ventilation for the relative density of the handling fluid, if less than 0.8, applies "Good" and 0.5 m/s ventilation is applied. According to the IEC 60079-10-1, a gas with a relative density below 0.8 is considered lighter than air. And the indicative ventilation velocity of lighter than air is defined as shown in Table 1 considering the height of the release source and the type of outdoor location. In case of the indicative ventilation velocity, the lower the value, the less of the degree of dilution, so the lower value could be a conservative approach. Therefore, in this study, the indicative ventilation velocity of lighter than air is applied at 0.5 m/s. This case is applicable in this study as the latter is limited to the hydrogen gas facility. According to Table 2, zone 2 NE can be derived only when a ventilation effectiveness of "High dilution" is applied to the facility.

2.2. Release characteristic for high-dilution scenario in hydrogen gas facility

In IEC 60079-10-1 edition 2.0, a plot is proposed to determine the effectiveness of ventilation through the release characteristic and ventilation velocity. However, when the relative density is less than 0.8, as with hydrogen gas, 0.5 m/s is applied as the ventilation velocity. This case is summarized in Fig. 1.

Hence, when the release characteristic is less than "A," the effectiveness of ventilation is considered as 'high dilution'." However, IEC 60079-10-1 edition 2.0 does not provide a formula for the plot [11]. In this regard, the equation constituting the plot is estimated by converting the X-axis and the Y-axis in the plot into a log scale to form a linear function. A similar approach was applied and proved to the previous study of the hazardous area classification for estimating hazardous area distance [9]. After obtaining the value for "A" through this criterion, we analyze the conditions under which the release characteristic of the hydrogen gas facility can be smaller than "A."

2.3. Derivation of release characteristic of hydrogen gas facility

The release characteristic is a newly introduced parameter in IEC 60079-10-1 edition 2.0. The formula constituting the release characteristic is presented in Eq. (1), and the unit is m^3/s.

$$\frac{W_g}{\rho_g k LFL} \tag{1}$$

LFL is the lower explosive limit for flammable materials covered by the installation and is given in units of vol%. In the case of a facility that handles hydrogen gas, the LFL is substituted with 0.04 as per the hydrogen property of characteristic. k is a parameter that corrects the uncertainty in the LFL of the material. In this study, k is assigned a value of 1, because it is limited to one substance only, namely hydrogen gas. ρ_g refers to the gas density of the material and is introduced in Eq. (2) of IEC 60079-10-1 edition 2.0.

$$\rho_g = \frac{p_a M}{R T_a} \tag{2}$$

p_a represents atmospheric pressure. In this case, as there is hydrogen gas in the air, $p_a = 101{,}325$ Pa. M is the molecular weight of the substance, in this case, $M = 2$ kg/kmol, the molecular weight of hydrogen gas. R is 8,314 J/kmol K, representing the gas constant. T_a is the temperature of the atmosphere. In this case, the ambient temperature is 293.15 K, which is converted from 25°C.

W_g, the last parameter of the release characteristic, refers to the leak rate from a specific facility. It is largely divided into a liquid leak rate and gaseous leak rate formula, and the gaseous leak rate is further divided into sonic and sub-sonic leaks. The critical pressure is compared with the operating pressure inside the facility, and it is thereupon classified as sonic if the operating pressure is higher than critical pressure, and sub-sonic otherwise. In IEC 60079-10-1

Table 2
Zones for grade of release and effectiveness of ventilation

Grade of release	Effectiveness of ventilation						
	High dilution			Medium dilution			Low dilution
	Availability of ventilation						
	Good	Fair	Poor	Good	Fair	Poor	Good, fair, poor
Continuous	Non-hazardous (Zone 0 NE)	Zone 2	Zone 1	Zone 0	Zone 0 + Zone 2	Zone 0 + Zone 1	Zone 0
Primary	Non-hazardous (Zone 1 NE)	Zone 2	Zone 2	Zone 1	Zone 1 + Zone 2	Zone 1 + Zone 2	Zone 1 or Zone 0
Secondary	Non-hazardous (Zone 2 NE)	Non-hazardous	Zone 2	Zone 2	Zone 2	Zone 2	Zone 1 and even Zone 0

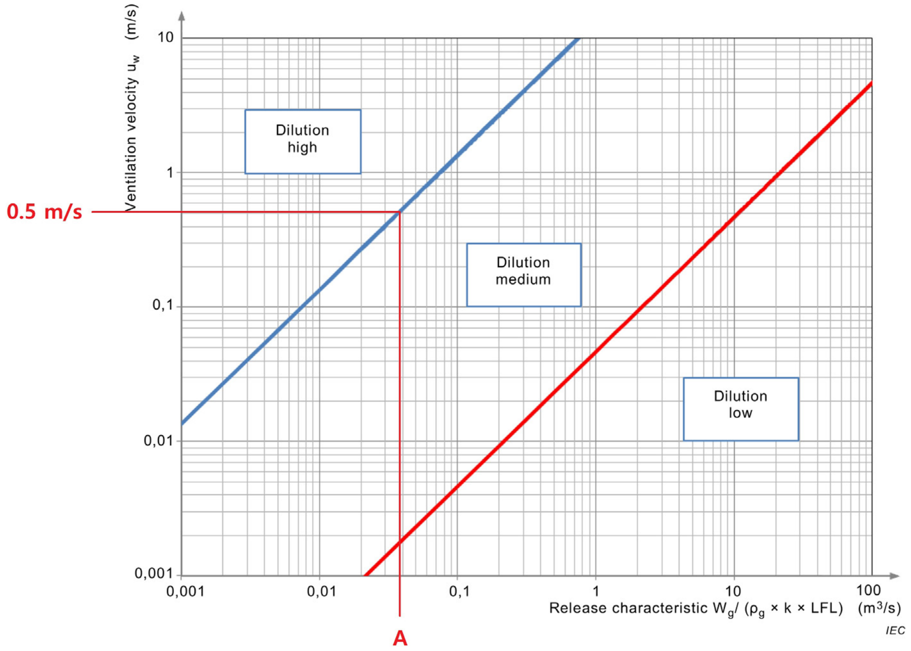

Fig. 1. Chart for assessing the degree of dilution.

edition 2.0, the formula for calculating critical pressure is presented in Eq. (3).

$$P_C \approx 1.89 \times P_a \tag{3}$$

In this study, hydrogen gas handling facilities are investigated. Most installations in process plant often have operating pressures higher than 191,504.25 Pa, and the critical pressure at atmospheric pressure is 101,325 Pa. Therefore, only choked leaks should be considered, and the leak rate formula at that time is the same as in Eq. (4).

$$W_g = C_d S p \sqrt{\gamma \frac{M}{ZRT}} \left(\frac{2}{\gamma + 1} \right)^{(\gamma+1)/2(\gamma-1)} \tag{4}$$

C_d is the discharge coefficient, a dimensionless number without units, representing a correction constant according to the characteristics of the leakage. For sharp orifices, values between 0.5 and 0.75 are applied; for rounded orifices, the values range between 0.95 and 0.99. However, if one cannot limit the case to a specific orifice, a value of 1 is used. S represents the area of the leak, and the unit is m^2. Z depicts the compressibility factor. In the case of an ideal gas, $Z = 1$ may be applied. P is the operating pressure in the installation, in Pa. γ is a polytropic index of adiabatic expansion, which can be obtained from the specific heat capacity, molecular weight, and gas constant, which is the C_p value. The detailed formula is shown in Eq. (5).

$$\gamma = \frac{MC_p}{MC_p - R} \tag{5}$$

This study is limited to the facilities that deal with hydrogen gas, hence the assumptions of each parameter are summarized in Table 3.

3. Results and discussion

3.1. Estimation of release characteristic for hydrogen gas facility under high-dilution condition

After converting the X-axis and Y-axis of Fig. 1 to the log scale, the result of selecting two points that can determine the exact coordinate value is shown in Fig. 2.

The two points were selected as (Log 0.003, Log 0.04) and (Log 0.06, Log 0.8), and the equation of the plot derived from these two points is presented in Eq. (6).

$$\log[\mathit{Ventilation\ Velocity}] = \frac{\log 0.8 - \log 0.04}{\log 0.06 - \log 0.003} (\log[\mathit{Release\ Characteritic}] - \log 0.06) + \log 0.8 \tag{6}$$

The release characteristic obtained by substituting 0.5 m/s as the ventilation velocity in Eq. (6) is 0.0375 m^3/s. Therefore, when the release characteristic of the hydrogen gas facility is lower than 0.0375 m^3/s, it is classified as zone 2 NE or non-hazardous.

3.2. Correlation between operating temperature, pressure, and size of leak hole for non-hazardous application of hydrogen gas facility

If the release characteristic value is 0.0375 m^3/s, and the ρ_g, k, and LFL of Table 3 are applied, the W_g value is obtained as 0.0001245 kg/s. Hence, if W_g is less than 0.0001245 kg/s, the high-dilution condition is obtained. As this study assumes choked leakage, the equation for the leakage hole is summarized in Eq. (7)

Table 3
Assumed parameters of this study

Parameter	Value	Unit
U_w	0.5	m/s
P_a	101,325	Pa
P_c	191,504.25	Pa
M	2	kg/kmol
R	8,314	J/kmol K
T_a	293.15	kg/kmol
ρ_a	0.083	kg/m^3
C_d	1	—
C_p	14,320	J/kg K
γ	1.41	—
Z	1	—
LFL	0.04	vol/vol

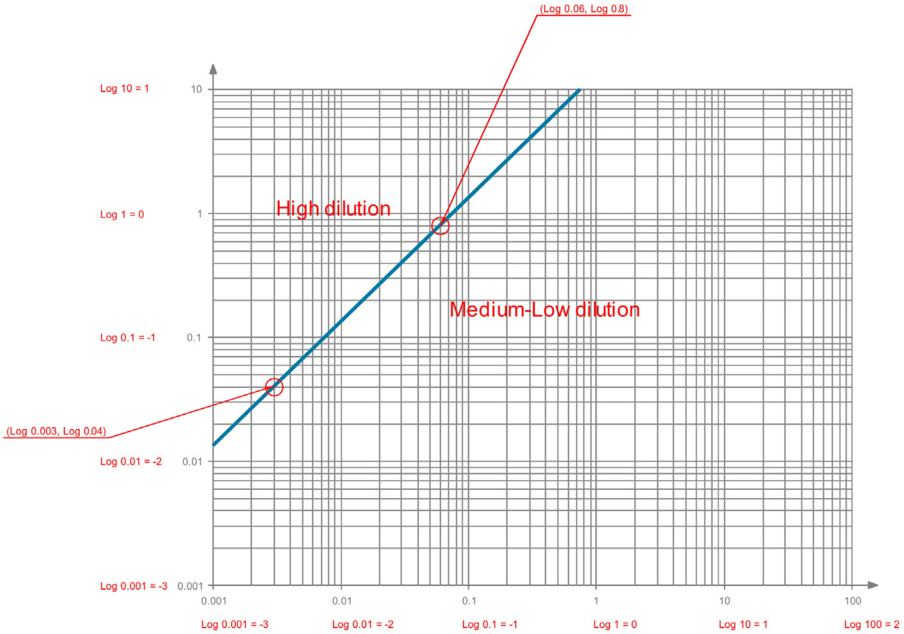

Fig. 2. Derivation of the first-order relation between release characteristic and ventilation velocity.

by substituting parameters except the operating temperature, pressure, and size of the leak hole in Eq. (4).

$$S \leq \frac{\sqrt{T}}{86p} \tag{7}$$

3.3. *Range of leak holes for non-hazardous applications at given operating temperature and pressure in hydrogen gas facility*

In the process plant, hydrogen gas is mainly handled by the continuous catalyst regeneration (CCR) process. The equipment to be selected is shown in Table 4.

For each process facility given in Table 4, Eq. (7) was used to derive the maximum size of the leak hole to create non-hazardous conditions. Hence, it can be deduced that non-hazardous conditions can be applied when the leakage hole size is smaller than 1.3 mm^2 for the reduction gas heater, 0.4 mm^2 for the reduction gas exchanger, and 0.7 mm^2 for the reduction gas filter.

4. Conclusion

IEC 60079-10-1 edition 2.0 is the only widely used hazardous area classification design code in the world with the concept of zone 2 NE. Based on this concept, this study sets the conditions for creating zone 2 NE, that is, non-hazardous conditions, for the hydrogen gas facility. We start with the inductive approach. The degree of ventilation is introduced through analysis of a table chart, which satisfies the zone 2 NE requirement in IEC 60079-10-1 edition 2.0. This code introduces a plot with ventilation velocity as the Y-axis and release characteristic as the X-axis. The degree of ventilation can be derived through the zone where the Y-value is located when the X-value is substituted. However, the plots that make up the X- and Y- values are not introduced separately. The plot was changed to the CAD format, and each axis was transformed to the log-scale to derive the relationship between release characteristic and ventilation velocity as linear equation. Subsequently, the ventilation velocity is set to 0.5 m/s to derive the region where the degree of ventilation is high, which is found to be when the release characteristic is lower than 0.0375 m^3/s. Moreover, the parameters for correlation between operating temperature, pressure, and size of the leak hole were substituted under the hydrogen gas leak condition. Finally, the relationship between the operating temperature, pressure, and leak hole of the facility was derived. The size of the leak hole was proportional to the square root of the operating temperature, and inversely proportional to the operating pressure. Furthermore, a case study was conducted on three facilities of the CCR unit, which is a representative process for handling hydrogen gas in a process plant. In the case study, it was confirmed that the specific size of the leak hole could be derived under given temperature and pressure conditions. Hence, the non-hazardous condition of the hydrogen gas facility should be defined if the leak hole smaller than a certain size could be demonstrated.

Hydrogen is an IIC gas, and it is considered a dangerous gas that can explode at low ignition energy. Therefore, minimizing the explosion risk area formed by IIC in the hazardous area classification design is crucial to reduce the explosion risk in process plants. This study addresses hydrogen gas in a process plant from the viewpoint of inherent safety, by presenting the maximum range that the other one if the two values are known from the operating temperature and pressure, the size of the leak hole of the facility handling hydrogen gas by the correlation. A method to prevent the explosion of IIC gas was presented in the early stage of facility design. By avoiding the construction of unnecessary IIC gas explosion-proof zones and hence the purchase of electric and instrument items that meet the IIC grade rating, it is possible to reduce the cost of

Table 4
Case study: size of leak hole for the non-hazardous condition of CCR process items

Item description	Material handled	Operating condition		Required hole size for non-hazardous
		Temperature	Pressure	
		°C	Pa	mm^2
Reduction gas heater	Hydrogen	572	258,000	1.3
Reduction gas exchanger		300	734,000	0.4
Reduction gas filter		80	300,000	0.7

CCR, continuous catalyst regeneration.

construction by avoiding while minimizing explosion risk in the process plant.

Any disclaimers

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgments

This study did not receive any grants from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Bozek A, Gordon C, Phillips N. Electrical Hazardous Area Classification design as a basis for safer operations. Rec Conf Pap - Annu Pet Chem Ind Conf 2014: 459–64. https://doi.org/10.1109/PCICON.2014.6961911.

[2] Rangel E, Luiz AM, Filho HLDPM. Area classification is not a copy-and-paste process: performing reliable hazardous-area-classification studies. IEEE Ind Appl Mag 2016;22:28–39. https://doi.org/10.1109/MIAS.2015.2458335.

[3] Tommasini R, Pons E, Palamara F. Area classification for explosive atmospheres: comparison between European and North American approaches. IEEE Trans Ind Appl 2014;50:3128–34. https://doi.org/10.1109/TIA.2014.2306980.

[4] Santon R, Ivings M, Webber D, Kelsey A. New methods for hazardous area classification for explosive gas atmospheres. Inst Chem Eng Symp Ser 2012: 339–46.

[5] Hernandez JE, Bradley BA, Crooke RW, Faulkner EB, Lewis WM, Mai VQ, et al. One company's guideline for hazardous area classification. Rec Conf Pap - Annu Pet Chem Ind Conf 1995:243–65. https://doi.org/10.1109/PCICON.1995.523960.

[6] Choi JY, Byeon SH. Operating pressure conditions for non-explosion hazards in plants handling propane gas. Korean Chem Eng Res 2020;58:493–7. https://doi.org/10.9713/kcer.2020.58.3.493.

[7] Webber DM, Ivings MJ, Santon RC. Ventilation theory and dispersion modelling applied to hazardous area classification. J Loss Prev Process Ind 2011;24: 612–21. https://doi.org/10.1016/j.jlp.2011.04.002.

[8] International Electrotechnical Commission. Explosive atmospheres – Part 10-1: classification of areas – explosive gas atmospheres. Geneva: International Electrotechnical Commission; 2015. 2.0 ed.

[9] Choi JY, Byeon SH. A study on complementary method for hazardous area extent by IEC 60079-10-1. Korea Saf Manag Sci 2020;22:73–82. https://doi.org/10.12812/ksms.2020.22.2.073. Edition 2.0.

[10] Zohdirad H, Ebadi T, Givehchi S, Meysami H. Grid-based individual risk calculation in the classification of hazardous area with a risk-based approach. J Loss Prev Process Ind 2016;43:98–105. https://doi.org/10.1016/j.jlp.2016.05.007.

[11] Choi JY. An analysis on the main amendment of hazardous area classification in Korea and a study on its limitation. Korean J Hazard Mater 2018;6:8–17. https://doi.org/10.31333/kihm.2018.6.1.8.