



**MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES**



**DUST EXPLOSIONS AND FACTORS
AFFECTING EXPLOSIBILITY PROPERTIES
OF DUSTS**

UFUK MEVLEVIOĞLU

MASTER THESIS

Department of Chemical Engineering

Thesis Supervisor

Prof. Dr. M.A. Neşet KADIRGAN

Thesis CO- Supervisor

Doç. Dr. Gökçen Alev ÇİFTÇİOĞLU

ISTANBUL, 2019



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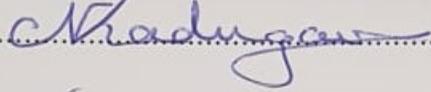
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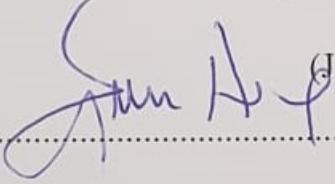
Ufuk MEVLEVİOĞLU, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended his thesis entitled “**Dust Explosions and Factors Affecting Explosibility Properties of Dusts**”, on 25/06/2019..... and has been found to be satisfactory by the jury members.

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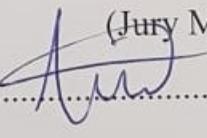
Prof.Dr. M. A. Neşet KADIRGAN (Advisor)

Marmara University 

Prof.Dr. Emin ARCA (Jury Member)

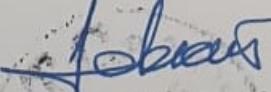
Marmara University 

Assoc. Prof. Dilek DURANOĞLU (Jury Member)

Yıldız Technical University 

APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Ufuk MEVLEVİOĞLU be granted the degree of Master of Science in Department of Chemical Engineering on 26.06.2019..... (Resolution no: 2019/13-22.....).


Director of the Institute
Prof. Dr. Bülent EKİCİ

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I hope this study contributes to protect people from explosion and fire hazards in workplaces and provide a reference for the chemical industry to work according to Turkish and European legislation and standards on protection against explosion and fire.

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Ufuk MEVLEVİOĞLU

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ÖZET

TOZ PATLAMALARI VE TOZLARIN PATLAYICILIK ÖZELLİKLERİNİ ETKİLEYEN FAKTÖRLER

Bu çalışmada, iş yerlerinde karşılaşılabilen patlama ve yangın risklerini değerlendirmek ve bu risklere karşı alınabilecek önlemleri belirlemek için Türkiye'nin ulusal mevzuatı ve TSE standartlarında belirtilen yöntemler incelenmekte ve hayali bir kimya tesisine uygulanmaktadır. Tanklar, silolar veya diğer iş ekipmanlarından ortama yanıcı gaz, sıvı veya tozların boşalabileceği tüm olası salım kaynakları incelenerek farklı yöntemlerle değerlendirilmeli ve sınıflandırılarak gerekli önlemler alınmalıdır. Hayali tesisimizdeki solvent tankı ve pompası için yaptığımız değerlendirmelerde, tank içerisinde Bölge 0 olarak sınıflandırılabilmesi, pompa etrafında ise çeşitli mühendislik yaklaşımlarıyla farklı patlayıcı ortam değerlendirmeleri yapılabileceği sonuçlarına varılmıştır. Polimer toz besleme hunisi için yapılan değerlendirmede, huni içerisinde Bölge 20 olarak sınıflandırılabilmesi, huni etrafında oluşabilecek patlayıcı ortamın tehlike mesafesinin ise, ilgili standartta verilen nitel yöntemlere dayanarak tahmini olarak nasıl yapılabileceği gösterilmiştir. Hidrojen tüpü için yapılan değerlendirmede, kaçak kesit alanının, tehlikeli bölge sınıflandırmasına etkisi incelenmiş, hem bölge sınıfına hem de mesafesine önemli etkileri olduğu gösterilmiştir. Bir doğalgaz vanası için yapılan değerlendirmede ise, 400 mbar ve daha düşük basınçlı doğalgaz hatlarının etrafındaki olası tehlikeli bölgelerin mesafelerinin genellikle ihmal edilebilir olacağı tespit edilmiştir. Sınıflandırılmış olan tüm tehlikeli bölgelerin dahilinde kullanılacak cihazların kategorileri ve diğer özellikleri belirlenmiş, bu bölgelerde patlama ve yangınlara karşı alınabilecek temel önlemler örneklenmiştir. Sonuç olarak kimya endüstrisinde sıkça rastlanabilecek tanklar, pompalar, vb. ekipmanlarla ilgili deneysel veriler üretilmesine ve Türkiye'de, yanıcı tozlarla ilgili standart testleri yapabilecek akredite laboratuvarlara ihtiyaç duyulduğu vurgulanmıştır.

Anahtar Kelimeler: tehlikeli bölge sınıflandırma, yangın ve patlamadan korunma, patlayıcı ortam hesaplamaları

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ABSTRACT

DUST EXPLOSIONS AND FACTORS AFFECTING EXPLOSIBILITY PROPERTIES OF DUSTS

This study introduces the assessment and prevention methods of explosion and fire risks in workplaces stated in Turkey's national legislation and TSE standards, then applies these methods into fictive chemical facilities. All possible emission points on the tanks, silos or other work equipment that a flammable substance might be released from, should be examined and classified by specific methods and necessary precautions should be taken. As a result of the assessments of the solvent tank and solvent pump in our fictive facility, it has been concluded that tank interior can be classified as Zone 0 explosive atmosphere and various explosive atmosphere assessments can be made for the pump by various engineering approaches. It has also been shown that as a result of the assessment of polymer dust feed hopper, hopper interior can be classified as Zone 20 explosive atmosphere and the distance of the explosive atmosphere that can occur around the hopper can be predicted based on qualitative methods given in the relevant standard. Influence of different cross-sectional area assumptions for a leakage have been assessed on a fictive hydrogen cylinder and as a result it has been shown that assumption have a great impact on both the class and extent of the hazardous area classification. As a result of the assessment of a natural gas valve, hazardous areas around natural gas pipelines with 400 mbar or lower pressure will generally have a negligible extent. The categories and other characteristics of the equipment that can be used within these classified hazardous areas have been identified, and precautions that can be taken against explosion and fire risks in these areas have been summarized. As a result, it was emphasized that accredited laboratories for carrying out standard tests on combustible powders and experimental data for tanks, pumps, solvents etc. which are frequently encountered in the chemical industry are needed in Turkey.

Keywords: zone classification, fire and explosion protection, explosive atmosphere calculations

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SYMBOLS

- A_p** : Surface area of pool (m²)
- C_d** : Release factor relating to the openings which includes the effects of turbulence and viscosity
- c_p** : Specific heat at constant pressure (J/kg K)
- f** : A measure of the degree to which the air in the enclosure outside of the release zone is well mixed. (Between 1 and 5)
- k** : Coefficient which is a characteristic of the reliability of LFL value
- LFL** : Lower Flammability Limit (vol/vol)
- M** : Gas or vapour's molar mass (kg/kmol)
- p** : Internal pressure of container (Pa)
- p_a** : Atmospheric pressure (101,325 Pa)
- p_c** : Critical pressure (Pa)
- p_v** : Liquid's vapour pressure at T°C (kPa)
- Δp** : Difference between internal and external pressures of container (Pa)
- Q_g** : Volumetric flow rate of flammable gas from the source (m³/s)
- Q₁** : Volumetric flow rate of air entering the room through apertures (m³/s)
- Q₂** : Volumetric flow rate of air/gas mixture leaving the room (m³/s) = Q₁ + Q_g
- R** : Universal gas constant (8,314 J/kmol K)
- RC** : Release characteristic
- ρ** : Density of the liquid (kg/m³)
- ρ_g** : Density of the vapour or gas (kg/m³)
- S** : Surface area of the liquid release hole (m²)
- T** : Substance's temperature - absolute (K)
- T_a** : Ambient temperature - absolute (K)

- u_w** : Wind speed near the source of release (m/s)
- W** : Liquid release rate (kg/s)
- W_e** : Spilled liquid's evaporation rate - pool of 1 cm deep is assumed (kg/s)
- W_g** : Release rate of gas (kg/s)
- X_b** : Background concentration (vol/vol)
- X_{crit}** : Critical concentration (vol/vol) = 0.25 x LFL
- Z** : Compressibility factor
- γ** : Polytropic index of adiabatic expansion



ABBREVIATIONS

ATEX : Atmosphere Explosive

CCTV : Closed Circuit Tele Vision

EN : European Standards (or European Norms)

IEC : The International Electrotechnical Commission

LEV : Local Exhaust Ventilation

LFL : Lower Flammability Limit

MEC : Minimum Explosive Concentration

MIC : Minimum Ignition Current

MIE : Minimum Ignition Energy

NFPA : National Fire Protection Association (USA)

PPE : Personal Protective Equipment

PVC : Polyvinyl Chloride

SR : Source of Release

TSE : Turkish Standards Institute

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1. INTRODUCTION

The mixture of flammable substances in the form of gas, vapour, dust, fibres, or flyings with air under atmospheric conditions, which, after ignition, permits self-sustaining flame propagation is defined as "explosive atmosphere" [1]. Explosive atmospheres are an important source of danger for employees working in paint/printing, petrochemical, leather, textiles, pharmaceuticals, other chemical industries in terms of workplace safety. Considerable amount of loss of lives, property and equipment damage occur as a result of chemical gas and dust explosions. In all areas where explosive atmospheres might occur, risk assessments should be conducted and then according to the results all necessary technical and organisational measures should be determined, and appropriate equipment and protective systems should be selected [1].

In Turkey, national legislation and standards are established in compliance with European legislation and standards. In accordance with these legislation and standards, all departments, machines, processes, activities and substances in the facilities and their mutual interactions are examined in order to evaluate the formation of explosive atmospheres, the possibility of ignition of these atmospheres, and the severity of the possible explosion [2]. In the course of the evaluation, reasonably foreseeable flammable substance releases that might take place in cases of possible faults and accidents should also be taken into consideration, along with the releases that take place during normal operations. Frequency, duration and rate of release, ventilation, physical and chemical properties of the released flammable substance, temperature, pressure and many other conditions are taken into consideration in order to classify the explosive atmosphere, and accordingly, possible ignition sources are controlled by evaluating the suitability of electrical or driven devices with the class of the hazardous area. As a result of this assessment, all explosive atmospheres in the plants and the risks of ignition are aimed to be taken under control. If the probability of an explosion to take place is not sufficiently reduced, the size of the potential damage should also be examined, and all technical and organisational precautions must be determined and implemented in order to mitigate or eliminate the possible detrimental effects of it.

These procedures play a crucial role in lowering the number of fires and explosions that take place. According to the 2018 Industrial Fire and Explosions Report of UCTEA

Chamber of Chemical Engineers, at least 385 fire and 51 explosions took place in 2018 in Turkey, resulting in at least 25 loss of life and 72 injured workers. Most of these fire and explosions could be prevented by implementing good risk managements systems, conducting accurate risk assessments and taking the necessary precautions. In this manner, comprehensive information sources are crucial for the employers to take reference while considering all these safety issues.

1.1 Scope and Objective

Within the scope of this study; explosive atmospheres that occur when flammable substances in the form of gas, vapour or dust are mixed with oxygen in the air, will be examined in detail. Substances that can be self-oxidizing without the need for atmospheric oxygen, and physical explosions caused by only pressure will be excluded from the scope of the study. Due to the fact that the scope of the study may become too wide to cover otherwise, scope of the study has been limited in this way.

Main purpose of this study is to assist the chemical industry about protecting the workers from explosion hazards and provide solution strategies and recommendations for the industry on protection against explosion and fire, operate in accordance with Turkish and European legislation and standards. This thesis can be used as a further guidance material but even further references may need to be used for protecting an industrial facility against fire and explosions.

1.2 Theoretical Background Information

All legislation and standards about fire and explosion protection have been based on preventing the detrimental accidents from happening again, in Turkey and all around the world. Additionally, these legislation and standards have been and are being amended/updated in order to address problems which are newly discovered as a result of new accidents or new problems arising as the technology advances.

1.2.1 Fire and Explosion

Fire is an exothermic and rapid oxidation reaction in which heat, light and various combustion products are generated. General equation for the oxidation of a hydrocarbon is as follows:



The three main elements that are required for a fire to start are known as fuel, oxidant and ignition. Fuel and oxidant need to be present at a certain ratio range and ignition source (or heat) has to provide sufficient energy in order to start (or sustain) the fire. If one of the 3 main elements are removed or sufficiently reduced, the fire hazard is eliminated.

Explosion is defined as abrupt oxidation or decomposition reaction producing an increase in temperature, pressure, or in both simultaneously [3]. Most explosions generate a shock wave when the very rapid combustion of all or most of the fuel occurs instantly as a result of the oxygen and fuel being dispersed within one another. The chemical reaction of fire and explosion is the same, however, in the event of an explosion, the speed of the reaction is very high, and therefore a shock wave is formed. This high propagation speed requires that fuel and oxygen are dispersed within one another and that the concentration of fuel is between a certain range, in addition to three main elements of fire.

Lowest concentration of the explosion range at which an explosion can occur is called "lower explosion (or flammability) limit" and the highest concentration of the explosion range is "upper explosion (or flammability) limit" and these values are characteristic for each substance [3]. For example, the lower and upper explosion limits are; 1.2%-8.6% for benzene, 4.4%-17% for methane; 2.3%-100% for acetylene [4]. If one of the 5 elements can be removed or reduced adequately, the explosion hazard is eliminated. Although a cloud of combustible substance with a concentration higher than its upper flammability limit is not explosive, there is still a high risk of explosion, because the concentration may enter the explosive range by falling down [5].

All combustible gases present an explosion hazard if there is a potential of their concentration to be between their explosion limits. Liquids that have a considerably higher flash point than the process/ambient temperature do not convey a risk of explosion because they do not release enough vapour to be ignited. However, liquids that have a lower flash point than the process/ambient temperature carry a very serious fire risk because it will release a flammable amount of vapour, together with the risk of explosion if the resulting vapour accumulates in the environment. Naturally, this process is strongly influenced by the temperature of the liquid.

Combustible solids in the form of dust or fibre, can react with atmospheric oxygen and explode if they have a structure that can be scattered in the air like a cloud. Solids in these forms are also capable of sustaining a combustion and burn when they accumulate on surfaces as a layer. If the particle diameter of combustible dust is less than approximately 0.5 mm, there may be a risk of explosion, if it is larger, the explosion is not expected but some fibre-shaped solid particles might form an explosive atmosphere even with a particle diameter larger than 0.5 mm [5]. Smaller particle diameter means longer suspension time of dust in the air, and hence higher explosion likelihood and risk. In general, the minimum concentration of dust that could cause a dust explosion (MEC) is 30-60 g/m³ and the maximum explosion concentration of dusts is 2-4 kg/m³. These limits may vary depending on the various factors like the type, moisture content or average particle size of combustible dust. Therefore, even dusts with exactly the same chemical structure may have very different explosion limits. For example, MEC of aluminium dust were about 5 g/m³ for dust sample with 35 nm average diameter, 8 g/m³ for dust sample with 75 nm average diameter, 8 g/m³ for dust sample with 100 nm average diameter and 50 g/m³ for dust sample with 40 µm average diameter [6]. The dust layers are susceptible to sustained combustion, while dust clouds that suspended in the air might explode if ignited. Accumulated dust layers can be ignited and may cause larger explosions by igniting any explosive atmosphere close to them. In addition to that, accumulated dust layers in a building may be raised into dust clouds by any explosion. If the raised dust clouds are ignited by the first explosion, there will be secondary explosions which may have devastating effects. Adequate measures should always be taken in order to control the dust layers [5].

There are a wide range of ignition sources that can initiate the combustion reaction of flammable substances or explosive atmospheres. Open flames, sparks caused by mechanical friction or impact, electrical apparatus, lightning, static electricity and exothermic reactions are some of the common ignition sources in the chemical industry. All possible ignition sources should be taken into consideration while conducting the risk assessment and determining the necessary precautions, and then they should be removed from the hazardous areas [1].

Electrical equipment might cause hot surfaces or electrical sparks that have sufficient energy for igniting explosive atmospheres, even at low voltages. Even non-electrical

equipment (pneumatic or other type of powered equipment) are capable of creating mechanical sparks or high temperatures as a result of various failures and furthermore, hammers or other hand tools which are made of steel or iron, may produce sparks or heat sufficient to cause ignition due to strike or friction [2,7]. Static electricity can be generated when the films made of electrically non-conductive materials (e.g. polymer) are rotated on reels; when liquids having low electrical conductivity are transmitted through the pipes or mixed in tanks; when solids in dust or granule form are poured into hoppers or transmitted through the pipes; when people doing their daily-routine work or in various other ways.

1.2.2 Explosion and Fire protection

While determining and implementing technical and organisational measures for explosion protection, some basic principles should be considered in a hierarchical order. These principles are discussed below:

a) Preventing the formation of explosive atmosphere.

Generation of an explosive atmosphere can be prevented by avoiding or reducing the use of flammable substances [2]. It is sometimes possible to increase the particle size of dust being used, in order for solid particles to settle onto the floor/surfaces instead of suspending in the air, thereby an explosive atmosphere hazard is mitigated or even eliminated. It may be possible to hold the concentration of flammable substance below the lower explosion limit by limiting the flammable substances release or by increasing the effectiveness of ventilation [2]. In general, concentrations less than 20% of the lower explosion limit are considered safe for industrial applications. Where dust accumulation can occur, strong flows of natural ventilation might give rise to explosive atmospheres by blowing dust accumulated on surfaces. However, it is possible to limit/eliminate the hazardous area by local exhaust ventilation which withdraws gas, vapor or dust directly from the source of release. The addition of inert gases (nitrogen, carbon dioxide, noble gases, etc.), water vapour or inert dusts (calcium carbonate, etc.) which are not reactive with the flammable substances, may prevent the formation of explosive atmospheres [2]. This method is called “inerting”.

b) Preventing the ignition of explosive environment, if it is not possible to prevent the formation of explosive environment due to the nature of the process.

Welding, grinding or other type of hot works, smoking, electrical devices should be kept out of the hazardous areas by organizational measures. For this purpose, "work permit systems" are widely used in the chemical industries. In work permit systems, hot works and all other high-risk activities can only be started with a signed form and special permission to be taken from department managers and occupational safety responsables. Thus, it is aimed to ensure that all necessary precautions are taken such as gas measurements, removal of flammable substances and ignition sources from the hazardous area; checking out the suitability of the equipment to be used and the suitability of the training of the staff to do the work, as well as the emergency action plan etc., in order to safely carry out the high-risk activity.

In hazardous areas, all conductive equipment should be grounded and suitable design and materials should be selected in order to minimize the generation of static electricity and provide electrical conductivity so as to discharge static electricity before accumulating up to a dangerous level [2]. Conductive or anti-static floor coverings, anti-static footwear and work clothes can also be provided as precautions for static electricity. Also, keeping the relative humidity of the air above 65% ensures that the surface of the majority of the non-conductive materials' surfaces absorb enough moisture and become conductive enough to discharge the static electricity through the air. If the humidity falls below about 30%, these same materials could become good insulators, in which case accumulation of charge occurs [8].

Even hand tools like hammer or wrench should not be used in hazardous areas without additional precautions. But in emergency situations, heat treated non-sparking hand tools made of copper-beryllium, aluminium-bronze and similar special alloys may be used if required.

Electrical equipment or power-driven devices in hazardous areas should be explosion proof (ex-proof) and must conform to the features required by the hazardous zone class and flammable material's explosive properties. Equipment categories corresponding to the hazardous zone class are listed in Table 1.1. Manufacturers must demonstrate the category and other features of the equipment they produce, by obtaining "EU-Type Examination

Certificate" (known as "ATEX certificate" in the industry) through accredited organizations [7, 9].

Table 1.1. ATEX equipment categories of the equipment for use in hazardous areas [9, 10]

Zone class	Equipment categories	If designed for ...
0	II 1 G	explosive gas, vapour or fog atmosphere
1	II 1 G or 2 G	
2	II 1 G or 2 G or 3 G	
20	II 1 D	explosive dust atmosphere
21	II 1 D or 2 D	
22	II 1 D or 2 D or 3 D	

The highest possible surface temperature of electrical or power-driven equipment should be lower than the ignition temperature of flammable material which is present in hazardous area [10, 11]. Temperature classes are shown in Table 1.2, corresponding to the highest surface temperature required. Temperature class at row right above the ignition temperature of the flammable material should be selected as the temperature class of the ex-proof equipment to be used in hazardous area. For instance, temperature class of the ex-proof equipment should be selected as "T4" if ignition temperature of the flammable material is 155°C. This selection specifies the minimum required temperature class, thereby equipment with T5 or T6 temperature class can also be used within this hazardous area, but equipment with T1, T2 or T3 temperature class should be prohibited.

Furthermore, gases and vapours, are divided into 3 groups (IIA, IIB, IIC), depending on their ignition sensitivities. The minimum ignition current (MIC) or minimum ignition energy (MIE) of these groups gets lower from group IIA to IIC respectively. The minimum ignition current is defined as the smallest current value in the resistive or inductive circuits that cause ignition of the explosive test mixture in spark test equipment in compliance with the standard IEC 60079-11 [4].

Table 1.2. Temperature classes of equipment to be used in hazardous areas [10]

Temperature class	Highest surface temperature (°C)
T1	450
T2	300
T3	200
T4	135
T5	100
T6	85

c) Ensuring safety of the employees by taking measures that reduce the harmful effects of explosions.

Explosion laboratory tests have shown that the highest explosion pressure for most gas/air and dust/air mixtures is 8-10 bar, but it may be even higher for powders of light metals such as aluminium or magnesium [12]. Plant elements such as tanks, pipes and containers should be designed strong enough to withstand the highest expected internal pressure generated by an explosion inside the equipment. Where it is not possible to design tanks strong enough to withstand the highest possible explosion pressure, the explosion can be redirected towards the safest zone (away from the people and critical equipment control areas) [13]. For this purpose, one side of the tank is designed weaker than other sides deliberately by installing explosion relief vents, in order for the tank to tear from this weak side and explosion pressure to release from this relatively safe side of the tank, thereby protecting the people and equipment at other sides of the tank.

The explosion can be detected by sensors and the explosion flame can be suppressed by injecting fire extinguishing agent into the equipment within a very short reaction time. In the design of these systems, the rate of increase in explosion pressure (dP/dt) is very important. For all flammable substances, this value is characteristic and can be determined by standardized tests [13, 14].

An explosion that travels along a pipe can be detected by sensors and blocked by closing a valve or lid in milliseconds [13].

A flame absorber with a mesh filter can be integrated into the pipeline in which the flammable substance is transferred. This equipment helps to reduce the speed of the flame, let it smother in its own combustion products and extinguish. This equipment can be integrated into the explosion venting systems and a flame-free pressure discharge can be ensured. Thus, explosion venting systems can be established without causing a fire inside the buildings [13].



2. MATERIALS AND METHODS

In this section, at first, methods which is used for the classification of hazardous gas/vapor and dust atmospheres in this study will be explained. Subsequently, a fictive plant will be introduced, which is going to be used for practicing those methods explained.

"Regulation on protecting employees from hazards of explosive atmospheres" and "Regulation on the equipment and protective systems used in a possible explosive environment" are the basic legislation in force, regulating the workplace in Turkey for hazardous area classification and the selection of equipment to be used in these particular zones. In addition to the legislations, TS EN 60079 standard series are widely accepted and used for the same purposes as more detailed resources. Therefore, this study is based on mainly these legislations and standards.

There are also many other legislations and TS EN standards which include important and valuable regulations and information. Although all of these resources cannot be explained here, some of them are referenced in this study, and they should be referenced for related explosion protection designations. These legislation and standards include, but not limited to:

- Regulation On Protecting Buildings From Fire
- TS EN 1127-1 Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology
- TS 12820 : 2006 Petrol Filling Stations - Safety Requirements
- TS EN 16985 Spray booths for organic coating material - Safety requirements
- TS EN IEC 62485-2 Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries
- TS EN 62485-3 Safety requirements for secondary batteries and battery installations - Part 3: Traction batteries
- TS EN 13463-1 Non-electrical equipment for use in potentially explosive atmospheres - Part 1: Basic method and requirements

2.1 Classification of Hazardous Areas

Based upon the frequency of the occurrence and duration of an explosive atmosphere, hazardous areas are classified as shown on Table 2.1, in accordance with these laws and standards.

Table 2.1. Hazardous area (Zone) classes [1]

Zone Class	Description
Zone 0	An area in which an explosive gas atmosphere is present continuously or for long periods or frequently.
Zone 1	An area in which an explosive gas atmosphere is likely to occur periodically or occasionally in normal operation.
Zone 2	An area in which an explosive gas atmosphere is not likely to occur in normal operation but, if it does occur, it will exist for a short period only.
Zone 20	A place in which an explosive dust atmosphere, in the form of a cloud of dust in air, is present continuously, or for long periods or frequently.
Zone 21	A place in which an explosive dust atmosphere, in the form of a cloud of dust in air, is likely to occur in normal operation occasionally.
Zone 22	Area in which an explosive dust atmosphere, in the form of a cloud of combustible dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

"Source of release" is defined as a point or location from which a flammable substance may be released into the atmosphere . There are 3 grades identified of releases [5, 15]:

Continuous release: Continuous, sustained or frequently occurring releases.

Primary release: Periodically or occasionally occurring releases which are expected during normal operation.

Secondary release: Predictable release which is not expected during normal operation, or releases which are expected during normal operation but only rarely and for short periods [5, 15].

In determining the class and extent of a hazardous zone around a source of release, there are various methods and standards that may be used. There are different standards that apply for different states of substances released or for different sources of releases from different equipment and processes. Due to the scope of this study, we are going to study the methods in the standard TS EN 60079-10-1 which includes formulas for flammable liquid, gas or vapour releases and methods in the standard TS EN 60079-10-2 which includes qualitative evaluation methods for combustible dust releases.

2.2 Hazardous area classification methods and formulas for flammable liquid, gas or vapour releases

In this section, methods and formulas for hazardous area classification in standard TS EN 60079-10-1 will be explained. The formulas we are going to use in our case study are shown in Table 2.2. These formulas are established to find and evaluate the release rate of flammable substances and effectiveness of ventilation.

Table 2.2. Formulas to be used in calculations [15]

No	Description	Formula
1	Release rate of gas with non-choked gas velocity (subsonic releases)	$W_g = C_d S p \sqrt{\frac{M}{ZRT} \frac{2\gamma}{\gamma-1} \left[1 - \left(\frac{p_a}{p}\right)^{\frac{\gamma-1}{\gamma}} \right]} \left(\frac{p_a}{p}\right)^{\frac{1}{\gamma}}$
2	Rate of sonic gas releases (choked gas velocity)	$W_g = C_d S p \sqrt{\gamma \frac{M}{ZRT} \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}}$
3	Release rate of liquid leakage	$W = C_d S \sqrt{2\rho\Delta p}$

No	Description	Formula
4	Evaporation rate of spilled liquid (assumed to create a pool of 1 cm deep)	$W_e = \frac{6,55u_w^{0,78}A_p p_v M^{0,667}}{R T}$
5	Volumetric rate of gas release	$Q_g = \frac{W_g}{\rho_g}$
6	Gas or vapour density	$\rho_g = \frac{p_a M}{R T_a}$
7	Polytropic index of adiabatic expansion	$\gamma = \frac{M c_p}{M c_p - R}$
8	Background concentration	$X_b = \frac{f Q_g}{Q_g + Q_1} = \frac{f Q_g}{Q_2}$
9	Release characteristic	$\frac{W_g}{\rho_g k L F L}$
10	Critical pressure	$p_c = p_a \left(\frac{\gamma + 1}{2} \right)^{\frac{\gamma}{\gamma - 1}}$

The velocity of released gas is choked (sonic) if the pressure inside the gas container is higher than the critical pressure p_c . If the internal pressure is lower than the critical pressure p_c , the gas release is sub-sonic (non-choked velocity).

As for the hole surface areas (S) of leakages, standard suggests certain values for different equipment, different sealing elements and different gaskets. These suggestions are shown in Table 2.3.

Table 2.3. Suggested surface areas for secondary grade fluid release openings [15]

Item Type	Item	Expanding of Leakage Hole		
		Opening will not Expand S (mm ²)	Opening may expand S (mm ²)	Opening may blow out S (mm ²)
Sealing elements on fixed parts	Compressed fibre gasket	≥ 0.025 up to 0.25	> 0.25 up to 2.5	(length between two bolts) × (gasket thickness) usually ≥ 1 mm
	Spiral wound gasket	0.025	0.25	(length between two bolts) × (gasket thickness) usually ≥ 0.5 mm
	Ring type joint connections	0.1	0.25	0.5
	Small bore connections up to 50 mm	≥ 0.025 up to 0.1	≥ 0.1 up to 0.25	1.0
Sealing elements on moving parts at low speed	Valve stem packings	0.25	2.5	Define according to Manufacturer's Data but not less than 2.5
	Pressure relief valves	0.1 × (orifice section)	NA	NA
Sealing elements on moving parts at high speed	Pumps and compressors	NA	≥ 1 up to 5	Define according to Manufacturer's Data but not less than 5.0

As for the outdoor ventilation velocities (u_w), standard suggests certain indicative values for different elevations from ground level, different types of release and obstruction of area. These suggestions are shown in Table 2.4.

Table 2.4. Indicative outdoor ventilation velocities [15]

Location Type	Clear Areas			Areas with Obstructions		
	≤ 2 m	> 2 m up to 5 m	> 5 m	≤ 2 m	> 2 m up to 5 m	> 5 m
Height from ground level	≤ 2 m	> 2 m up to 5 m	> 5 m	≤ 2 m	> 2 m up to 5 m	> 5 m
Air flow for lighter than air gas/vapour releases	0.5 m/s	1 m/s	2 m/s	0.5 m/s	0.5 m/s	1 m/s
Air flow for heavier than air gas/vapour releases	0.3 m/s	0.6 m/s	1 m/s	0.15 m/s	0.3 m/s	1 m/s
Air flow for liquid pool evaporation rate at any elevation	0.25 m/s			0.1 m/s		
For indoors, assessments can be based on an assumption of 0.05 m/s air speed, which is normally expected to be present almost everywhere.						

By using the Release Characteristic and u_w values calculated by the formulas above, "degree of dilution" is determined by using the chart in Figure 2.1.

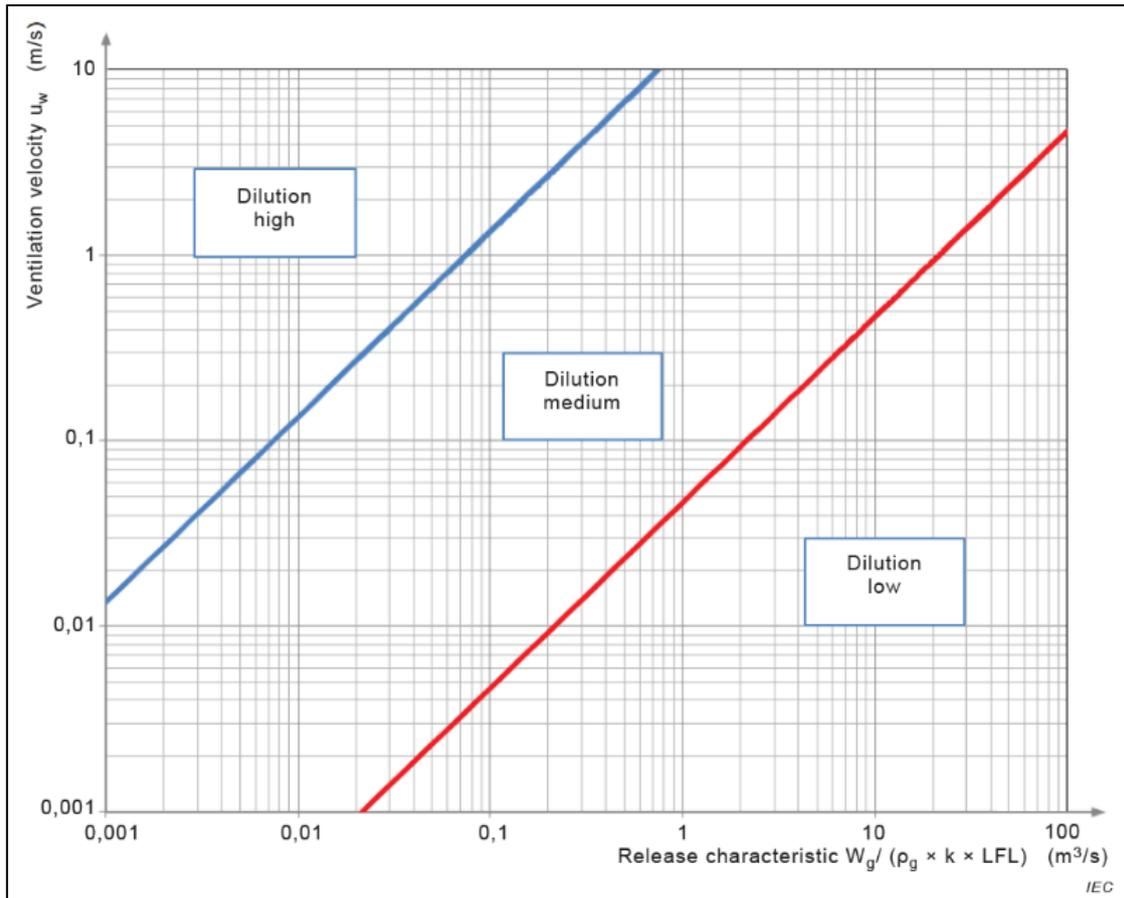


Figure 2.1. Chart for assessing the degree of dilution (This figure is taken as it is directly from the reference) [15]

The degree of dilution indicates the effectiveness of ventilation to dilute a flammable gas release to a safe level. There are 3 degrees of dilution defined [15].

High dilution: The concentration of the flammable gas reduces quickly near the release source and, when the release stops, flammable gas atmosphere does not persist.

Medium dilution: The concentration is controlled resulting in a stable zone boundary, whilst the release is in progress and the explosive gas atmosphere does not persist unduly after the release has stopped.

Low dilution: There is significant concentration whilst release is in progress and/or significant persistence of a flammable atmosphere after the release has stopped.

After this step, the class of the hazardous zone is determined by using “grade of release”, “degree of dilution” and “availability of ventilation” data on Table 2.5. Three levels of availability of the ventilation should be considered [15]:

Good: ventilation is present virtually continuously.

Fair: ventilation is expected to be present during normal operation. Discontinuities are permitted provided they occur infrequently and for short periods.

Poor: ventilation which does not meet the standard of fair or good, but discontinuities are not expected to occur for long periods.

For example, a local exhaust ventilation (LEV) of a chemical reactor can be considered as “Good” in terms of ventilation availability, if it automatically turns on when hatch of the reactor is opened. Same LEV could be considered as “Fair” in terms of ventilation availability, if it can be turned on manually by only supervisors or it could be considered as “Poor”, if it can be turned on and off manually by any operator or worker at production site.

Table 2.5. Table for specifying the class of a hazardous area [15]

Grade of release	Effectiveness of Ventilation						
	High Dilution			Medium Dilution			Low Dilution
	Availability of ventilation						
	Good	Fair	Poor	Good	Fair	Poor	Good, fair or poor
Continuous	Non-hazardous	Zone 2	Zone 1	Zone 0	Zone 0 + Zone 2	Zone 0 + Zone 1	Zone 0
Primary	Non-hazardous	Zone 2	Zone 2	Zone 1	Zone 1 + Zone 2	Zone 1 + Zone 2	Zone 1 or Zone 0
Secondary	Non-hazardous	Non-hazardous	Zone 2	Zone 2	Zone 2	Zone 2	Zone 1 or Zone 0
<p>‘+’ signifies ‘surrounded by’.</p> <p>Availability of ventilation in naturally ventilated enclosed spaces shall never be considered as good.</p>							

For estimating the extent of the classified hazardous area, the "hazardous distance" is determined from the chart in Figure 2.2 by using the Release Characteristic value and the type of release lines. There are 3 types of release are defined [15]:

Jet type release: When internal pressure is high enough, a leak on a pipe fitting will be at a high velocity, creating a jet release. Even though there are not much other air movement in the building, the jet release can disperse by diluting itself.

Diffusion type release: A release which is diffusive with low speed, or a jet release which loses its momentum because of the impingement on nearby surfaces or geometry of release.

Heavy gas type release: Gases or vapours with a higher density than air, spreading horizontally over the surfaces (e.g. platforms or ground).

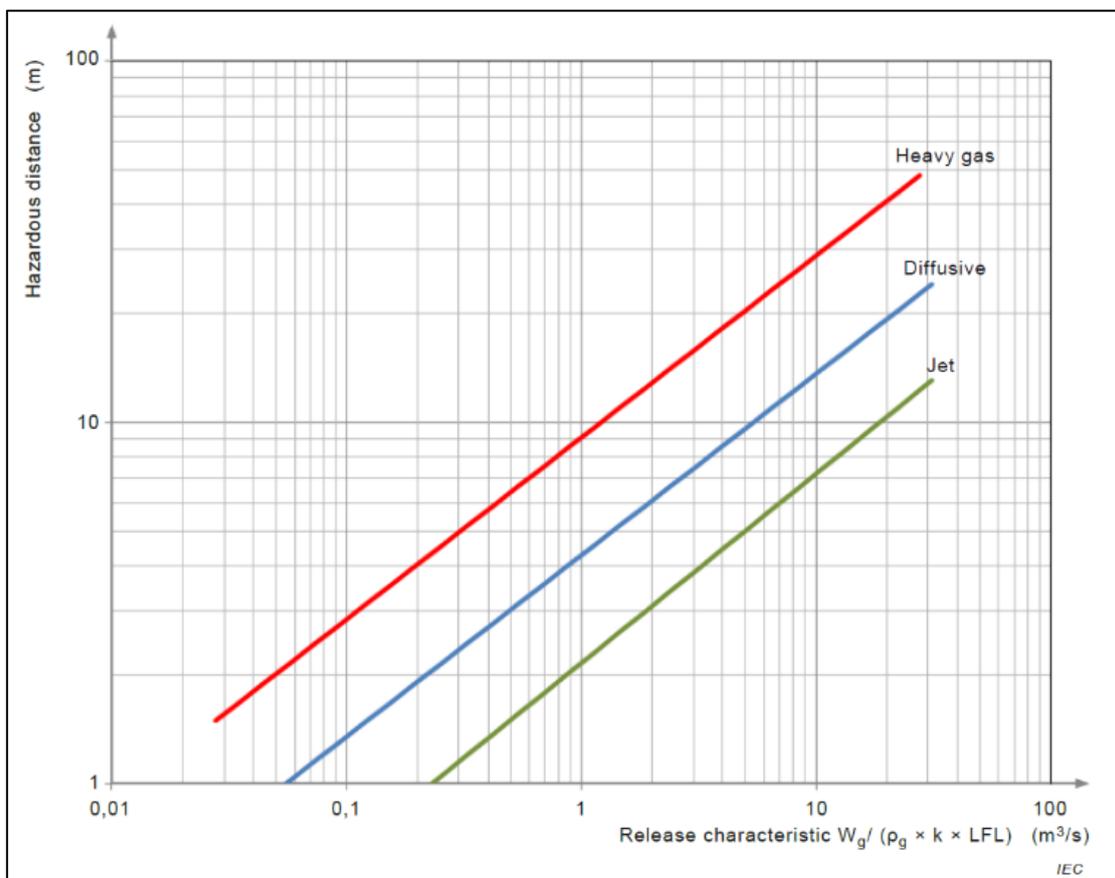


Figure 2.2. Chart for finding the approximate distance of a hazardous area (This figure is taken as it is directly from the reference) [15]

On this chart; extent of a hazardous area can be approximated by reading the distance of the hazardous zone at the point where the value of the release characteristic intersects with the release-type curve.

Hazardous distance may vary depending on the shape of the hazardous zone being

cylindrical, conical or spherical etc. determined by the specifications of the source of release and the conditions of the environment. These modifications or adjustments should only be made by expert(s) who make the hazardous atmosphere assessment. An example of shape of a hazardous area is shown in Figure 2.3.

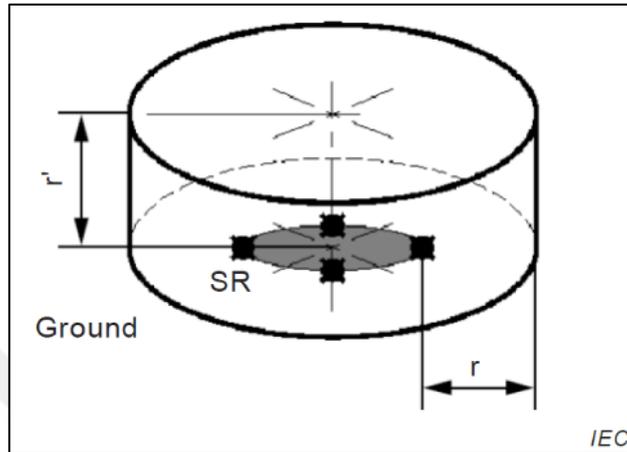


Figure 2.3. Hazardous area of a spilled flammable liquid (non-boiling evaporative pool)

[15]

2.3 Hazardous area classification methods for combustible dust releases

In this section, hazardous area classification of combustible dusts in the standard TS EN 60079-10-2, will be explained. The classes of hazardous areas generated by combustible dusts and the hazardous distances around the source of release can be evaluated based on the frequency and period of releases, observations of worst-case scenarios and by taking into account parameters such as the amount, explosive properties, release rate, particle size and moisture content of dust. Hence, there are no formulas or calculations in the standard.

A previous study has indicated the influence rules of the particle size and moisture content on the explosion characteristics of combustible dusts [16]. Several characteristic parameters including minimum ignition temperature, minimum ignition energy, lower explosive limit, maximum explosion pressure of sulphur dust were determined and investigated by the experimental device such as hot plate, Godbert-Greenwald furnace, Hartmann tube, 20L spherical container of explosive testing. Experimental samples were standard sulphur dust with particle size of $< 75\mu\text{m}$, sulphur dust with particle size of 1.4 – 1.7 mm, and original sulphur dust with particle size of 2–6 mm. Sample with the particle size of 2-6 mm was found to be combustible as a layer but not explosive, thereby poses

only a risk of fire. Maximum explosion pressures were found to be 0.68 MPa and 0.56 MPa for samples with the particle size of $<75\mu\text{m}$ and 1.4–1.7 mm respectively. Lower explosive limits were found to be 20-30 g/m^3 and 100-150 g/m^3 for samples with the particle size of $<75\mu\text{m}$ and 1.4–1.7 mm respectively. Minimum ignition energies were found to be 0.38 mJ and >13 J for samples with the particle size of $<75\mu\text{m}$ and 1.4–1.7 mm respectively. Minimum ignition temperatures were found to be 210°C and 480°C for samples with the particle size of $<75\mu\text{m}$ and 1.4–1.7 mm respectively. These results show that the explosion risk and strength of combustible dust decreases with the increase of particle size. Additionally, the amount of dust required to reach the same distance for the atmosphere to become explosive is much more for dusts with bigger particles than for dusts with smaller particles, thereby, maximum distance of any possible hazardous area can be expected to be shorter for bigger particle size when compared with same amount of dust release with smaller particles. Ignition energies were found to be 4.8 mJ, 8.2 mJ, 25 mJ, 61 mJ, and 68 mJ for samples with water content of 0.7%, 3.2%, 5.4%, 8.5%, and 14.6%, respectively. Minimum ignition temperatures were found to be 210°C , 220°C , 230°C , 250°C , and 265°C for samples with water content of 0.7%, 3.2%, 5.4%, 8.5%, and 14.6%, respectively. These results show that the minimum ignition energy and the minimum ignition temperature increased as the water content increased.

At first, combustibility of the material should be identified and material characteristics such as particle size, moisture content and minimum ignition temperature should be determined. The appropriate dust group shall also be identified; Group IIIA for combustible flyings, IIIB for non-conductive dust, or IIIC for conductive dust. The second step is to identify equipment in which combustible dust is or may be contained and items where sources of dust release can be present, including the formation of dust layers. And lastly, the likelihood of dust release from the identified sources shall be determined.

As part of a process, dust clouds may form continuously, for long durations of time or for short durations of time inside an equipment such as ventilation ducts, silos or cyclones. The process cycle determines the frequency and period of dust clouds. All interior volumes of ducts, production equipment and handling equipment in which a combustible dust is present frequently, for long periods or continuously, should be classified as Zone 20 [5].

The hazardous area classification can be influenced by many factors for the exteriors of a dust containment. The dust may be released out of a leaking equipment, if the internal pressure of the equipment is higher than atmospheric pressures, as in pneumatic transfer with positive pressure. If there is negative pressure within the dust containment, the possibility of a dust release outside of the equipment is very low. Several parameters such as release rate, average particle size, dust amounts and moisture content of dust influences the distances of Zone 21 and Zone 22 formed outside of dust containment. During the assessment for determining the distances, the source of release should be considered, taking into account the conditions causing the release [5].

In the chemical industries, bag emptying stations are commonly in use, at which combustible dusts such as polymers are emptied manually by an operator into a hopper for production purposes. Hazardous area classification of such a bag emptying station with a LEV system is given in Figure 2.4 as an example. Left side of the figure shows the horizontal view and the right side shows vertical view of a bag emptying station.

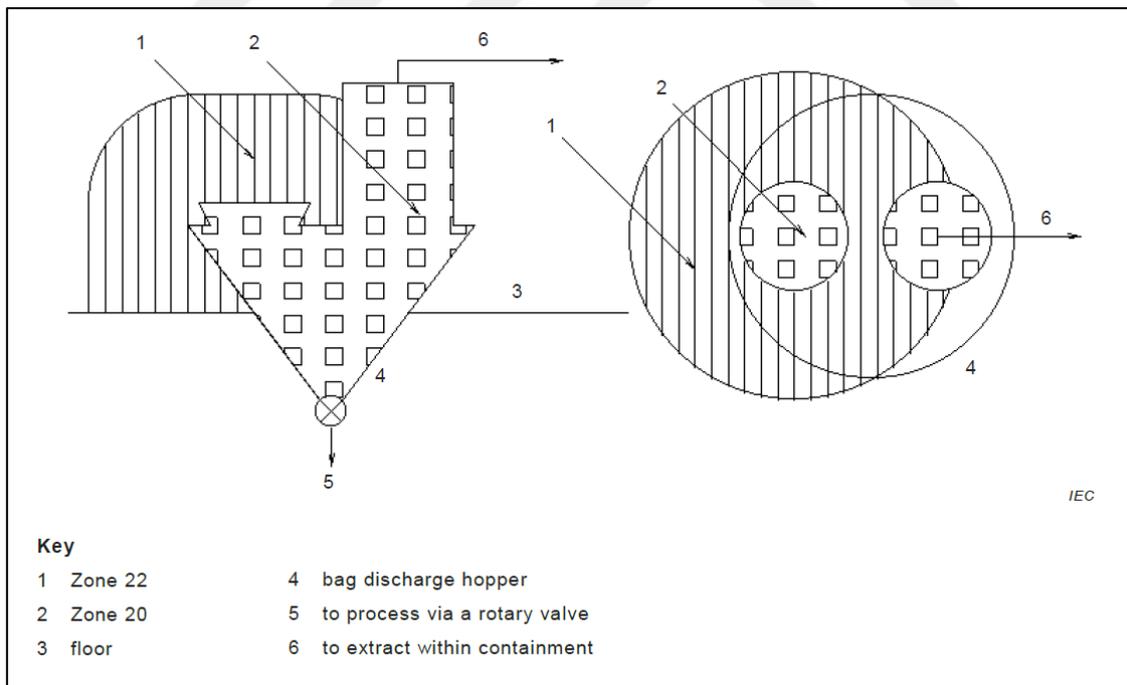


Figure 2.4. Bag emptying station with exhaust ventilation (This figure is taken as it is directly from the reference) [5]

Circumstances or occurrences that may blow the dust layers to form a dust cloud such as ventilation and wind, should also be considered during the area classification. The existence and persistence of a dust layer depends on the grade of release, the rate of dust accumulation, and the efficiency of cleaning system (housekeeping). Three levels of housekeeping can be identified [5]:

Good: Regardless of the grade of release, dust layers are either non-existent or kept to insignificant thickness. The risk of explosion and fire arising from the dust layers is eliminated by this way.

Fair: Dust layers are not insignificant but are expected to be cleaned in a short period (e.g. less than a shift). Normally, before an explosive atmosphere can form or a fire can start, the dust is cleaned.

Poor: Dust layers are significant and remain for a long duration (e.g. more than a shift). A secondary explosion or a fire risk is explicit.

The dust layer accumulations should be taken under control by effective cleaning programmes (housekeeping) and the level of housekeeping must be assessed for hazardous area classification. There is no thickness limit or method suggested in TS EN 60079-10-2 for determining the flammability or explosibility of the accumulated dust layer, but any layer of dust under 0.8 mm thickness is considered as not hazardous in NFPA 654 [17].

2.4 Details of the Fictive Plant

As an application example, some equipment and operations of a fictive package printing plant established at a location where the weather conditions are similar with Marmara Region of Turkey, will be examined. In this kind of plant, there are many sources of release but examining a solvent storage tank, a solvent pump, package film production process, a hydrogen cylinder and a natural gas line will be appropriate for the purpose of this study.

In this fictive plant, ethyl acetate which is used as the ink solvent is stored in steel above ground storage tanks installed outside the building, because of its frequent and abundant use, and it is pumped into the production area with a mechanical seal pump. Especially with high-speed equipment such as pumps or compressors, leakage can be expected while transferring flammable substances. Tanks are not under pressure, but at top of the tanks, there are pressure relief valves for regulating the pressure inside the tank by releasing

solvent vapour outside while filling the tank and letting air inside the tank while pumping solvent to production facilities.

Powdered polyvinyl chloride (PVC) is also used in the plant as main raw material for the packaging film production. At least 90% of the PVC particles are between 0.063 mm and 0.25 mm in diameter. The powder raw material is transferred to the mixers via feed hoppers with integrated local exhaust ventilation (LEV) system. LEV system is interconnected with the hopper lid, activated automatically if lid is opened and stays that way as long as the lid is kept open. According to our design in consideration, the ventilation system is always active during the transfer and the suction performance is efficient. Raw material bags are cut by knife and emptied into the hopper manually. After loading of the raw materials, production begins by transferring the mixture into the extruder and raw materials are melted and transferred along the screw of the extruder by heat and pressure. A strict housekeeping programme is applied throughout production line, which ensures cleaning of the area in consideration for at least twice a day. In this study, hazardous area classification of bag emptying operation and dust accumulation on surfaces around the operation area will be demonstrated, while insides of the ventilation system will not be examined.

Hydrogen is widely used for analysis purposes in chemical industry. Therefore, we will assume there is a hydrogen cylinder which is fixed outside, near the laboratory. Cylinder is connected to an analysis equipment with a pipeline, which has a regulator, valves and joints on it. Cylinder has a capacity to contain 8.8 m³ hydrogen at 300 bar pressure (absolute pressure).

There are many equipment using natural gas as fuel. Most of this equipment such as burners, furnaces or forges, require the gas to be at low pressure such as between 30 – 400 mbar (gauge pressure) and the gas is transferred between main pressure regulation stations and equipment with pipelines. Possible sources of release on gas pipelines include valves, flanges, safety valves and by-pass lines. There is an exhaust fan on the wall of the boiler room, which has a flow rate of 2,500 m³/h.

Significant explosion properties of the hazardous substances we mentioned above are listed in Table 2.6 and Table 2.7.

Table 2.6. Explosion properties of flammable liquids and gases, which are used in fictive plant [4]

Flammable Liquid/Gas	Ignition Temperature (°C)	Flash Point (°C)	LFL (%)	Gas Group	Temperature Class
Ethyl acetate	470	- 4	2.0	IIA	T1
Hydrogen	560	Irrelevant (Gas)	4.0	IIC	T1
Natural Gas (Methane)	600	Irrelevant (Gas)	4.4	IIA	T1

Table 2.7. Explosion properties of combustible dust, which is used in fictive plant [18]

Combustible Dust	MIT (°C)	MIE (mJ)	MEC (g/m³)	Dust Group	Temperature Class
PVC	500-600	300-10000	100-750	IIIB	T 330°C

3. RESULTS AND DISCUSSION

Explosive atmospheres that may be generated during normal operation activities and worst-case scenarios in the fictive facility will be examined in this section. Possible explosive atmospheres will be classified and the extent of these areas will be determined based on the properties of the substances, equipment and processes. Calculation and assessment methods for different types of releases are going to be practiced in order to demonstrate and evaluate their effectiveness and limits. After the classification, necessary precautions will be determined for each hazardous area classified, taking into consideration the zone classes, properties of the substance, equipment and process conditions. Classifications demonstrated and precautions mentioned here may not be sufficient to apply for a real facility, but they can provide basic information to the specialists or researchers in order to assist them with their work and studies.

3.1 Hazardous Area Classifications

The sources of release which are introduced in Section 2.4 will be classified in this section. This classification includes determining the class and extent of a possible explosive atmosphere. In accordance with the relevant TSE standards, only qualitative assessments will be carried out for combustible dusts, while calculation methods will also be used in addition to the qualitative assessments for flammable gases and vapours. Where there are uncertainties about which formula or value to use, different approaches will be practiced and discussed. Additional assessment methods might need to be used in order to specify all fire and explosion risks properly for a similar, real industrial facility.

3.1.1 Calculations and evaluations for ethyl acetate tanks and pumps

The internal volume of the ethyl acetate tanks will continuously contain a high amount of solvent vapour. Although vapour concentration may be expected to exceed the upper explosion limit, an entry of air into the tank which is enough to create an explosive environment is also possible during operations such as filling, discharging, etc. that may also generate static electric. Therefore, all internal volumes of the solvent tanks are classified as **Zone 0**.

Explosive atmospheres that might be generated by leakages from seal of the pumps which are used for transmission of ethyl acetate from and to the storage tanks, will be calculated

and evaluated. The data and assumptions to be used for the calculations are as follows:

- Highest ambient temperature for the worst-case scenario at the plant is:

$$T_a = 40^\circ\text{C} = 312 \text{ K}$$

- Ambient pressure $p_a = 101,325 \text{ Pa}$

- The cross-sectional area of the leakage hole is assumed using Table 2.3; $S = 5\text{mm}^2$

- Max pressure of pumps is approximately 10 bar = $\Delta p = 1.000.000 \text{ Pa}$.

- Lower flammability limit of ethyl acetate is 2% = LFL = 0.02 [4]

- Because the shape of the potential leakage opening will be uncertain, according to the standard examples $C_d = 0.75$

- Molecular weight of ethyl acetate is $M = 88.11 \text{ kg/kmol}$, and liquid density is $\rho = 900 \text{ kg/m}^3$

- Wind speed is assumed using Table 2.4; $u_w = 0.3 \text{ m/s}$

- The LFL value of ethyl acetate is certain. But since possible purity fluctuations might have a slight effect on the LFL value, $k = 0.9$

All necessary calculation results for the assessment is given below, which have been calculated using formulation given in Table 2.2 and values listed above.

Result of the calculation by using Formula No:6 of Table 2.2 for vapour density is:

$$\rho_g = 3.43 \text{ kg/m}^3$$

Result of the calculation by using Formula No:3 of Table 2.2 for the mass flow rate of released liquid is: $W = 0.16 \text{ kg/s}$

Since an explosive atmosphere will be generated by vaporisation of the released liquid, vaporisation rate should be estimated. There is no certain method for this purpose in the standard TS EN 60079-10-1, therefore, 4 different vapour-formation scenarios will be studied and the release will be classified after evaluating these 4 scenarios.

Scenario 1- If 100% of the released solvent is assumed to evaporate as flammable component at the same speed as the liquid release rate, the flammable vapour release rate of this leakage is: $W_g = 0.16 \text{ kg/s}$

Result of the calculation by using Formula No:9 of Table 2.2 for release characteristic is:
 $RC = 2.6 \text{ m}^3/\text{s}$

The data obtained from the calculations above is placed on the chart shown in Figure 2.1. This step is illustrated in Figure 3.1. As seen in this figure, the degree of dilution is identified as “Medium”.

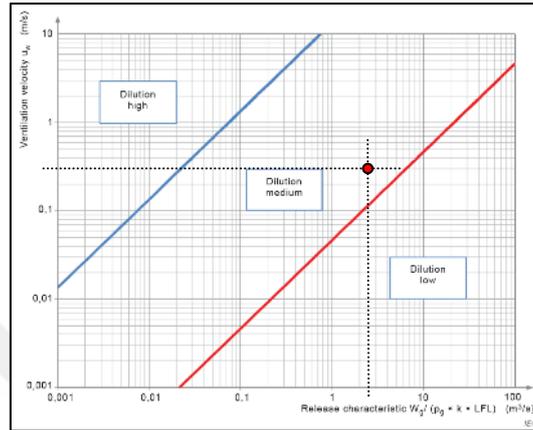


Figure 3.1. Finding the degree of dilution for ethyl acetate pumps

Because the source of release is a possibility of leakage, grade of release is “secondary” and availability of ventilation can be assumed as “Fair”. By using the data above on Table 2.5, the hazardous area class is found to be “Zone 2”. This step is illustrated with arrows on Table 3.1.

Table 3.1. Finding the class of hazardous zone for ethyl acetate pumps

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

Ethyl acetate’s vapour density is greater than that of air, but as evaporation percentage of the leaking liquid is assumed % 100 in our scenario which points at a high-pressure release, determining the type of release as “diffusive” will be more realistic and accurate rather than “heavy gas”. Where the release characteristic value intersects with diffusive release curve on Figure 2.2, the distance of the hazardous area classified as Zone 2 is read as 7

meters. This step is illustrated in Figure 3.2. The relative density of ethyl acetate vapour is approximately 3, but because a much faster release than heavy gas release is expected, hazardous area around the pumps can be determined as a 7-metre radius Zone 2, in a hemispherical form.

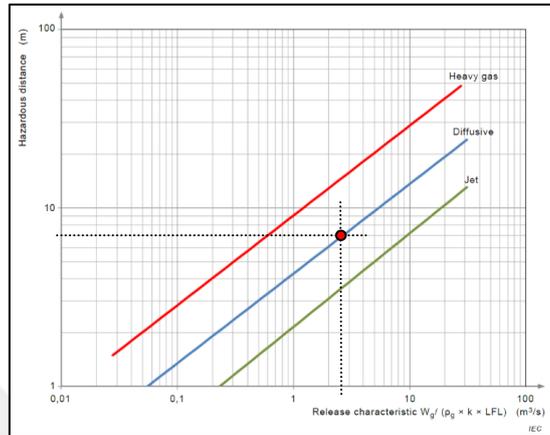


Figure 3.2. Finding the distance of the hazardous area for ethyl acetate pumps

Scenario 2- If evaporation rate of the released liquid is assumed to be 20% of the liquid release rate, the flammable vapour release rate is: $W_g = 3.2 \times 10^{-2} \text{ kg/s}$

Result of the calculation by using Formula No: 9 of Table 2.2 for release characteristic is: $RC = 0.5 \text{ m}^3/\text{s}$

The degree of dilution is identified as “Medium” by placing the data obtained from the calculations above, on the chart shown in Figure 2.1. Because the source of release is a possibility of leakage, grade of release is “secondary” and availability of ventilation can be assumed as “Fair”. By using the data above on Table 2.5, the hazardous area class is found to be “Zone 2”.

Vapour density of ethyl acetate is greater than that of air and because the evaporation of 20% of the fluid in our scenario points at a low-moderate pressure release, the release type should be determined as “heavy gas” release. Where the release characteristic value intersects with heavy gas release curve on Figure 2.2, the distance of the hazardous area classified as Zone 2 is read as 6.5 meters. The relative density of ethyl acetate vapour is approximately 3 and the release is not expected to be of high pressure according to this scenario, indicating that the flammable substance will spread along ground surface, causing the extension to be lesser at vertical plane. Therefore, hazardous area can be

specified as extending horizontally up to 6.5 meters from the source of release, and reach up to 2.5 meters vertically from the source of release, forming a cylindrical shape.

Scenario 3- If there is drainage under the pumps, most of the leakage will be pulled away from the area and collected in a drainage tank. If evaporation rate of the released liquid is assumed to be 2% of the liquid release rate for this reason, the flammable vapour release rate is: $W_g = 3.2 \times 10^{-3} \text{ kg/s}$

Result of the calculation by using Formula No: 9 of Table 2.2 for release characteristic is: $RC = 0.05 \text{ m}^3/\text{s}$

The degree of dilution is identified as “Medium” by placing the data obtained from the calculations above, on the chart shown in Figure 2.1. Because the source of release is a possibility of leakage, grade of release is “secondary” and availability of ventilation can be assumed as “Fair”. By using the data above on Table 2.5, the hazardous area class is found to be “Zone 2”.

Vapour density of ethyl acetate is greater than that of air and because the evaporation of 2% of the fluid in our scenario points at a low-moderate pressure release, the release type should be determined as “heavy gas” release. Where the release characteristic value intersects with heavy gas release curve on Figure 2.2, the distance of the hazardous area classified as Zone 2 is read as 2 meters. The relative density of ethyl acetate vapour is approximately 3 and the release is not expected to be of high pressure according to this scenario, indicating that the flammable substance will spread along ground surface, causing the extension to be lesser at vertical plane. Therefore, hazardous area can be determined to extend up to 2 meters horizontally from the source of release, and reach up to 1 meter vertically from the source of release, forming a cylindrical shape.

Scenario 4- If it is assumed that the leakage creates a pool by dripping and the leakage is not to be noticed for 15 minutes, we can calculate evaporation rate of spilled liquid. Noticing time may be decided according to the operational factors like location of the leakage point, personnel traffic or gas detector existence. The total amount and evaporation rate of leakage can be calculated as follows:

$$\text{Total leakage volume} = W \times t / \rho = 0.16 \text{ m}^3$$

If it is assumed for the leakage to form a 1 cm deep pool, the Surface area of pool is $A_p = 16 \text{ m}^2$

In Marmara region of Turkey where the facility is located, highest possible temperatures in the hottest days of the summer is approximately 40°C . Vapour pressure of ethyl acetate is $P_v = 25.1 \text{ kPa}$ at these temperatures.

Result of the calculation by using Formula No: 4 of Table 2.2 for evaporation rate of liquid is: $W_e = W_g = 7.8 \times 10^{-3} \text{ kg/s}$

Result of the calculation by using Formula No: 9 of Table 2.2 for release characteristic is: $RC = 0.13 \text{ m}^3/\text{s}$

The degree of dilution is identified as “Medium” by placing the data obtained from the calculations above, on the chart shown in Figure 2.1. Because the source of release is a possibility of leakage, grade of release is “secondary” and availability of ventilation can be assumed as “Fair”. By using the data above on Table 2.5, the hazardous area class is found to be “Zone 2”.

Vapour density of ethyl acetate is greater than that of air and vapour is being evaporated from the pool by itself without any forced pressure. Therefore, the release type should be determined as “heavy gas” release. Where the release characteristic value intersects with heavy gas release curve on Figure 2.2, the distance of the hazardous area classified as Zone 2 is read as 3.5 meters. This 3.5 meters of distance starts from the edges of the 16 m^2 liquid pool and naturally, hazardous area will be present above the pool too. Thus, horizontal extension builds up to 6 meters in sum with approximately 2.5 meters of liquid pool radius. The relative density of ethyl acetate vapour is approximately 3 and the release is not expected to be of high pressure according to this scenario, indicating that the flammable substance will spread along ground surface, causing the extension to be lesser at vertical plane. Therefore, hazardous area can be determined to extend up to 6 meters horizontally from the source of release, and reach up to 2.5 meter vertically from the source of release, forming a cylindrical shape.

In all of the scenarios, the possible explosive atmosphere is classified as Zone 2 and in the majority of the scenarios, hazardous area extends up to 6.5 meters horizontally and 2.5 meters vertically in average from the source of release.

3.1.2 Evaluations for PVC dust bag emptying station

Since PVC dust is known to create an explosive environment, explosive dust atmosphere that may occur during the bag emptying through the feed hopper will be evaluated.

According to the technical and safety data sheets of PVC powder manufacturers, diameter of at least 90% of the PVC powder particles that can be used at the plant are between 0.063 mm and 0.25 mm. According to the database values of similar particle size distribution, MEC of the dust can be between 100 - 750 g/m³, MIE can be between 300 – 10,000 mJ and K_{st} value can be as low as 19 bar m/s. Correspondingly, the explosibility of PVC dust can be considered as poor [18].

Since interiors of the feeding hopper and the LEV system are volumes where the dust is emptied directly and transmitted, high concentrations of dust is expected to be present. Therefore, these volumes should be classified as “Zone 20”.

Due to the presence of an effective LEV system, dangerous concentrations of dust are not expected to be present around the feeding hopper in normal operating conditions. However, a particular area around the hopper should be classified as “Zone 22”, taking into consideration that, dust bags might be emptied outside the ventilations influence field due to operator fault or there might be problems with the efficiency of the ventilation system as a result of electrical system faults.

Based on the assessment made about the explosive properties of the PVC powder being poor, it can be considered that it is not necessary to extend the distance of the hazardous area even further in addition to the observed extension of dense dust cloud of the worst case for providing a safety margin. For this fictive scenario, it was assumed that a dense cloud of PVC dust has been observed up to a 1 meter distance from the hopper, during the worst operating conditions. Therefore, a spherical volume with 1 metre in radius around the hopper mouth is classified as “Zone 22”. A typical illustration of this classification was shown in Figure 2.4.

Dusts that are not extracted away by ventilation, accumulate as layers at a rate depending on properties, such as humidity and particle size. The fugitive dust poses an additional risk if it settles on the ground or surfaces and not cleaned effectively. Also, there might be other sources of dust release such as joints between hopper and mixer or other units, if they are damaged, corroded or loosened. As a result, another fire and explosion hazard arise,

because accumulated PVC dust layer might catch fire or form an explosive dust cloud by being blown by a strong air flow.

For the purposes of this study, it was assumed that small dust runaway sources are observed on dust line joints and some dust accumulation under and near the feed hopper have been located during visual inspections. Accumulated dust layers were assumed to have a total surface area of approximately 4 m^2 and an average thickness of approximately 1 mm in worst conditions. In these conditions, surface area of the hazardous dust layer and average thickness should be assumed 5 m^2 and 1.5 mm respectively, in order to provide a safety margin. Taking the housekeeping programme in consideration, housekeeping level can be considered as “fair” because dust layers are cleaned completely at least twice a day, but safe limit of 0.8 mm is exceeded occasionally. Besides, strong air currents might be generated because there are doors between forced ventilated volumes which are opened or closed occasionally. Therefore, accumulated dust might be blown to air and form an explosive dust cloud. Dangerous dust accumulation and strong air currents are expected to occur at the same time very infrequently, therefore the explosive atmosphere is classified as “Zone 22”. Taking into consideration the poor explosive properties and amount of the dust, it can be predicted that blown dust clouds can reach at most 1.5 meters away from the surface and edges of the accumulated layer.

The surface temperature of the outer shell of extruders is between $50 - 170^\circ\text{C}$ which is well below the ignition temperature of PVC dust. Therefore, this equipment will not be considered as a possible ignition source.

3.1.3 Calculations and evaluations for hydrogen cylinder

A fictive hydrogen cylinder is going to be examined which is located at a designed storage area outside. Classification of the cylinder-regulator joint will be sufficient for our study, even though there might be various sources of release along the transfer pipelines of hydrogen. Normally, a leakage is not predicted from a cylinder-regulator joint, but since the cylinder pressure might be very high, even a very low probability of release should be considered.

The data and assumptions to be used for the calculation are as follows:

- Molecular weight of hydrogen is $M = 2 \text{ kg/kmol}$

- Specific heat at constant pressure of hydrogen is $C_p = 14,318 \text{ J/kg K}$
- Max pressure of cylinder and leakage is approximately $300 \text{ bar} = p = 30\,000\,000 \text{ Pa}$.
- Using Table 2.3, 3 cross-sectional area size assumptions will be made for the leakage hole to assess the impact of the hole size assumption on the hazardous area classification; $S_1 = 0.025 \text{ mm}^2$, $S_2 = 0.1 \text{ mm}^2$, $S_3 = 0.25 \text{ mm}^2$
- Because the shape of the potential leakage opening will be uncertain, according to the standard examples $C_d = 0.75$
- Ambient pressure of the area in consideration $p_a = 101\,325 \text{ Pa}$,
- Ambient temperature of the area in consideration $T_a = 293 \text{ K}$
- Compressibility factor of hydrogen at specified gas temperature and pressure (inside the cylinder) is $Z = 1.188$ [19]
- Lower flammability limit of hydrogen is $4\% = \text{LFL} = 0.04$ [4]
- Wind speed is assumed using Table 2.4; $u_w = 0.5 \text{ m/s}$
- Since the LFL value of hydrogen is certain, $k = 1$

All necessary calculation results for the assessment is given below, which have been calculated using formulation given in Table 2.2 and values listed above.

Result of the calculation by using Formula No:7 of Table 2.2 for polytropic index of adiabatic expansion is: $\gamma = 1.41$

Result of the calculation by using Formula No:10 of Table 2.2 for critical pressure is: $p_c = 192\,358 \text{ Pa}$

Since the internal pressure of the gas container is higher than critical pressure, we will use Formula No:2 of Table 2.2 for flammable gas release rate of the leakage. Using 3 different hole size assumptions S_1 , S_2 and S_3 , the calculations resulted as follows: $W_{g1} = 3.21 \times 10^{-4} \text{ kg/s}$, $W_{g2} = 1.28 \times 10^{-3} \text{ kg/s}$, $W_{g3} = 3.21 \times 10^{-3} \text{ kg/s}$

Result of the calculation by using Formula No:6 of Table 2.2 for gas density is $\rho_g = 8.32 \times 10^{-2} \text{ kg/m}^3$

Results of the calculations by using Formula No:9 of Table 2.2 with 3 different hole size assumptions of release characteristic is: $RC_1 = 9.65 \times 10^{-2} \text{ m}^3/\text{s}$, $RC_2 = 3.86 \times 10^{-1} \text{ m}^3/\text{s}$,

$$RC_3 = 9.65 \times 10^{-1} \text{ m}^3/\text{s}$$

The data obtained from the calculations above is placed on the chart shown in Figure 2.1. This step is illustrated in Figure 3.3. As seen in this figure, the degree of dilution is identified as “Medium” for all 3 assumptions.

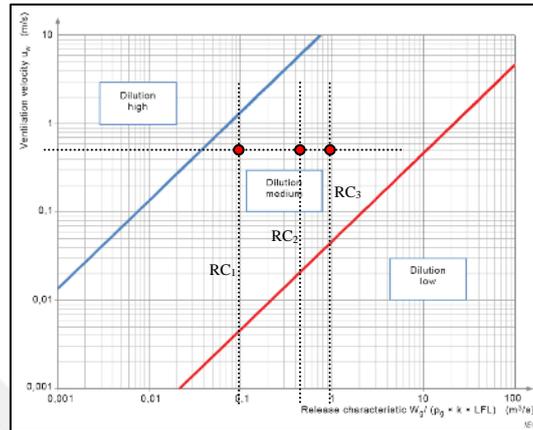


Figure 3.3. Finding the degree of dilution for hydrogen cylinder

Because the source of release is a possibility of leakage, grade of release is “secondary” and availability of ventilation can be assumed as “Fair”. By using the data above on Table 2.5, the hazardous area class is found to be “Zone 2” for all 3 assumptions. This step is illustrated with arrows on Table 3.2.

Table 3.2. Finding the class of the hazardous zone for hydrogen cylinder

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

Hydrogen’s vapour density is much lower than that of air and pressure of the gas releases is very high. Therefore, the release type should be determined as “jet” release. As we can see on Figure 3.4, RC₁ does not intersect with the jet curve which may be interpreted as the extent of the hazardous zone can be neglected or specialist may choose to stay on the safe side and specify a 0.5 m or 1 m distance for the Zone 2. RC₂ intersects with jet curve

at 1.4 m distance and RC₃ intersects with jet curve at 2.2 m distance. These results show that hole size assumption have a heavy impact on the hazardous zone's class and distance.

As the release can be at any direction around the joint with a high pressure and relative density of hydrogen vapour is approximately 0.08, hazardous area should be in the form of a sphere.

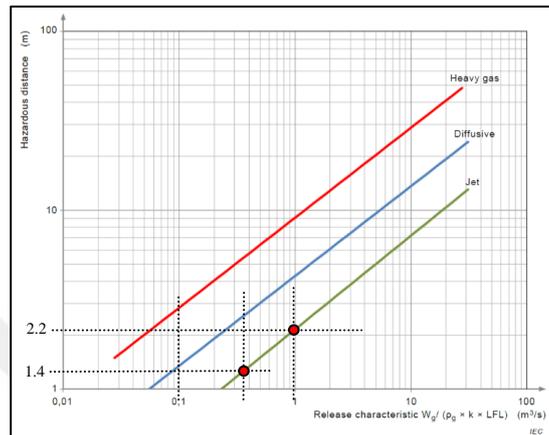


Figure 3.4. Finding the distance of the hazardous area for hydrogen cylinder

3.1.4 Calculations and evaluations for natural gas valve

A fictive ball valve on a natural gas pipeline is going to be examined which is located in a boiler room. In order to classify the hazardous area around a ball valve, we need to build a secondary release scenario.

The data and assumptions to be used for the calculation are as follows:

- Average molecular weight of natural gas depends on the ratios of its contents, but we can assume it; $M = 19 \text{ kg/kmol}$
- Specific heat of natural gas at constant pressure is; $C_p = 2.340 \text{ J/kg K}$
- Max pressure of the gas inside the valve is read as 400 mbar on the gauge.
 $\Delta p = 140\,000 \text{ Pa}$.
- Using Table 2.3, cross-sectional area of the leakage hole will be assumed;
 $S = 0.25 \text{ mm}^2$
- Because the shape of the potential leakage opening will be uncertain, according to the standard examples $C_d = 0.75$

- Ambient pressure of the area in consideration $p_a = 101\ 325\ \text{Pa}$,
- Ambient temperature of the area in consideration $T_a = 303\ \text{K}$
- Compressibility factor of natural gas can be assumed $Z = 1$ at specified gas temperature and pressure.
- Lower flammability limit of natural gas is $4.4\% = \text{LFL} = 0.044$ [4]
- $X_{\text{crit}} = 0.25 \times \text{LFL} = 0.011\ \text{vol/vol}$
- Since the ball valve is in the boiler room, air flow speed is assumed using Table 2.4;
 $u_w = 0.05\ \text{m/s}$
- Exhaust fan provides an air flow of $2,500\ \text{m}^3/\text{h}$ for the boiler room; $Q_2 = 0.7\ \text{m}^3/\text{s}$
- Assuming the ventilation provided by the fan is well mixed through the boiler room;
 $f = 2$
- Since LFL value of natural gas can slightly vary depending on its composition; $k = 0.9$

All necessary calculation results for the assessment is given below, which have been calculated using formulation given in Table 2.2 and values listed above.

Result of the calculation by using Formula No:7 of Table 2.2 for polytropic index of adiabatic expansion is: $\gamma = 1.23$

Result of the calculation by using Formula No:10 of Table 2.2 for critical pressure is:
 $p_c = 181\ 358\ \text{Pa}$

Since the internal pressure of the gas container is lower than the critical pressure, we will use Formula No:1 of Table 2.2 for flammable gas release rate of the leakage. The calculation resulted as follows: $W_g = 4.39 \times 10^{-5}\ \text{kg/s}$

Result of the calculation by using Formula No:6 of Table 2.2 for gas density is
 $\rho_g = 0.76\ \text{kg/m}^3$

Result of the calculation by using Formula No:5 of Table 2.2 for volumetric rate of gas release is; $Q_g = 5.75 \times 10^{-5}\ \text{m}^3/\text{s}$

Result of the calculation by using Formula No:8 of Table 2.2 for background concentration is; $X_b = 1.64 \times 10^{-4}\ \text{vol/vol}$

Thereby, $X_b / X_{\text{crit}} = 1.49 \times 10^{-2}$

Since the background concentration is much lower than the critical concentration, a “High Dilution” is expected.

Results of the calculations by using Formula No:9 of Table 2.2 for release characteristic is: $RC = 1.45 \times 10^{-3} \text{ m}^3/\text{s}$

When the data obtained from the calculations above is placed on the chart shown in Figure 2.1, the degree of dilution is identified as “High”.

Because the source of release is a possibility of leakage, grade of release is “secondary” and availability of ventilation can be assumed as “Fair”. By using the data above on Table 2.5, the area is found to be “Non-Hazardous”. Further study is not required because there will be no distance for a non-hazardous area. In conclusion, the reasonably foreseeable leakage from the ball valve gasket, does not generate a hazardous area in this scenario.

3.2 Necessary Precautions

This section addresses identified explosion and fire risks in order to by eliminating or mitigating them. Effective precautions can be determined using the hierarchical prevention approach, engineering perspective and good industrial application experiences which were also basis of this section. Exclusive precautions for each equipment have been separately identified, as well as mutual precautions which can be implemented to any working unit or equipment with a risk of explosion and fire. There may be other precautions that need to be taken in order to eliminate or mitigate the similar risks to an acceptable level in a real industrial facility. Specialists or researchers should assess the facility or equipment and determine all other measures that are needed for their work or study.

3.2.1 Common precautions for all areas with a risk of explosive atmosphere

In general, we can sort the primary measures that are available or should be taken for places with a risk of explosive atmosphere as follows:

In order to prevent the ignition of explosive atmospheres;

- All equipment like metal tanks, feed hoppers, pipelines, transmission lines, ventilation ducts and machines which are being used within hazardous areas or contain flammable substances, must be properly and adequately grounded. Grounding resistance of all equipment must also be subject to regular inspection individually.

- Easily noticeable and readable safety signs such as "Explosive Atmosphere" and "Keep Fire Away" should be placed in hazardous areas [1].
- Only authorized personnel who have been provided with a special training should be allowed for entry into hazardous areas, and these personnel should be equipped with anti-static work shoes and work clothes made of 100% cotton or anti-static textile materials that minimize the formation and maximize the dissipation of static electricity [1]. Training records should be recorded and trainings should be renewed within suitable periods of time.
- For cutting, welding, grinding or other hot work to be done outside a well-designed workshop, using work permit forms should be obligatory. A work permit system ensures that all necessary actions are taken before, during and after the hot work. A work permit form should contain at least the following information:
 - o Description of the work to be carried out (details of plant and location).
 - o The date and time of issue and the duration over which the permit will remain valid.
 - o Assessment of hazards associated with the job.
 - o Controls required, such as isolations, PPE and emergency procedures.
 - o Signature of the authorised person issuing the permit.
 - o Signature of the competent persons accepting the permit (the workers).

The minimum safety measures required during a hot work are as follows:

- o Suitable type, size and number of fire extinguisher(s) will be available nearby.
- o A firewatcher has to monitor the work during the whole process, whose main duty is to respond to potential fire outbreaks.
- o The floor and the area will be cleaned and kept wet during the process.
- o All combustible materials will be removed at least for 11 meters away or put behind a fire-resistant curtain/sheet.
- o The openings on the wall and on the floor will be sealed.

The minimum safety measures required after the hot work are as follows:

- The hot work area will be monitored for 60 minutes, including hard to spot underground or overhead places when necessary. If the building is fire-resistant and all flammable materials are moved at least 11 meters away, monitoring period can be reduced to 30 minutes.
- When the monitoring time is completed, an additional observation will be made for a time period of up to 3 hours. This observation can be done with one or more of the following; fire detector, CCTV camera, regular safety/maintenance tours, assignment of the factory staff working near the area under consideration

3.2.2 Exclusive precautions for ethyl acetate tanks and pumps

We can sort the primary measures that are available or should be taken for solvent tanks and pumps as follows:

In order to prevent the formation of explosive atmospheres;

- If flammable solvents such as ethyl acetate can be substituted with non-flammable solvents by using water-based non-flammable inks, explosion and fire hazards will be completely eliminated. If this is not possible;
- Using pumps with magnetic drive (without seal), sealed O-ring or other feature which ensure "durable impermeability" for solvent transfer, the possibility of a leakage can be reduced to a negligible level and the pump-induced hazardous area will be eliminated completely. Other sources of release such as flanges, breather vents, relief valves etc. which are connected to the same pipeline with the pumps should also be considered. If this application is not practicable or enough either;
- Installing the pumps at a better ventilated location may reduce the class and extension of hazardous zone or even might ensure a negligible extension, thereby eliminate the risk. For example, in the external environment, the higher a pump is built from the ground, the faster the air flow rate near the pump will be. (This assessment is based on the air flow rate table at standard 60079-10-1:2015.)
- Constructing a secondary containment such as a dike or berm will limit the maximum extent of a hazardous area by containing the spillage within. Secondary containments dimensions should be optimised between minimising the surface area of a possible

leakage and having a capacity enough for containing maximum possible amount of leakage.

- Tanks and safety relief valves should be subject to periodic inspections in order to ensure their safe operation.

In order to prevent the ignition of explosive atmospheres:

- Level control probes and any equipment within the hazardous area classified as Zone 0 (tank interiors), should be ex-proof type with equipment category of at least "Ex II 1G" and with gas group and temperature class of at least "IIA, T1".
- Pump motors and any other equipment within the hazardous area classified as Zone 2, should be ex-proof type with equipment category of at least "Ex II 3G" and with gas group and temperature class of at least "IIA, T1".
- Storage tanks and pumps must be grounded. Grounding resistance should be subject to regular inspection (with 1-year periods at the latest) in order to ensure that the resistance is sufficiently low. Flammable liquids with low conductivity, have a higher potential for generating static electricity, therefore when they are being stored, transferred or handled, the grounding resistance limit may be determined lower, accordingly.
- Near the critical points such as pumps, flanges, etc. where there is a possibility of leakage, placing gas detectors might be considered for emergency alerting purposes and/or automatically securing the system by shutting down valves or de-energising the area etc.

In order to mitigate the destructive effects of an explosion:

- An explosion suppression system can be installed in tanks, taking dP/dt of the flammable substance into consideration.
- Installing explosion relief vents and/or pressure relief valves may be considered in order to divert the pressure of a possible explosion.
- A fire-resistant secondary containment system which usually consists of some combination of dikes, liners, ponds, impoundments, curbs, outer tanks, walls or other equipment capable of containing the stored liquids, should be constructed in order to prevent the associated fire/explosion hazard from spreading to adjacent property.

- Restricting the entrance to the tank area by wire fences and locked doors should be considered in order to prevent the entry of unauthorized people.

3.2.3 Exclusive precautions for PVC dust bag emptying station

We can sort the primary measures that are available or should be taken for bag emptying operations and dust layers around the station, as follows:

In order to prevent the formation of explosive atmospheres;

- Explosive atmosphere hazard can be eliminated by supplying the raw materials in granule or in other forms of massive particles instead of powdered form. This method should be implemented when possible, however, production and quality issues might prevent this precaution from being taken.
- Fugitive dusts may be prevented by a strict maintenance programme. Joints of the dust transferring equipment and ducts and pumps of the ventilation system should be monitored and kept robust and effective.

In order to prevent the ignition of explosive atmospheres;

- The local exhaust ventilation fan and any other equipment within the hazardous area classified as Zone 20, should be ex-proof type with equipment category of at least "Ex II 1D" and with dust group and temperature class of at least " IIIB, T145°C “.
- Any equipment within the hazardous area classified as Zone 22, should be ex-proof type with equipment category of at least "Ex II 3D" and with dust group and temperature class of at least " IIIB, T145°C “.

In order to mitigate the destructive effects of an explosion;

- An explosion suppression system can be installed within the ventilation ducts and dust collector tank, taking dP/dt of the flammable substance into consideration.
- Installing explosion relief vents and/or pressure relief valves at proper locations of ventilation ducts and dust collector tanks may be considered in order to divert the pressure of a possible explosion.

3.2.4 Exclusive precautions for hydrogen cylinder

We can sort the primary measures that are available or should be taken for hydrogen cylinder as follows:

In order to prevent the formation of explosive atmospheres;

- Maximum pressure of the cylinders should be as low as possible in order to reduce the maximum release velocity. This should be taken into consideration while procuring the hydrogen cylinders.
- Cylinders should be stored at a safe location outside the laboratories and buildings. Storage area should be as free as possible from objects or walls that block air flow and have a minimum of 25% of the perimeter open to the atmosphere. This open space can incorporate chain-link fence, lattice construction, open block or similar materials for its full height and width.
- Hydrogen cylinders located outdoors should not be installed within 15 meters of ventilation intakes.
- A regular inspection and maintenance plan should be in place for early detecting the corroded, damaged or loosened regulator, valves, flanges and joints.
- Hydrogen supply lines should have a manual shutoff valve to allow isolation of equipment. A quick connect should never be used in place of a shutoff valve.

In order to prevent the ignition of explosive atmospheres;

- “NO SMOKING WITHIN 10 METERS” signs should be posted around gas cylinder storage areas.
- Any equipment within the hazardous area classified as Zone 2, should be ex-proof type with equipment category of at least “Ex II 3G” and with gas group and temperature class of at least “IIC, T1”.

In order to mitigate the destructive effects of an explosion;

- Hydrogen cylinders located outdoors should not be installed within 3 meters of windows, doors or other building openings. There should be at least 15 meters and concrete walls or other strong structures between the storage areas and rest areas or designated smoking areas.

- Restricting the entrance to the storage area by wire fences and locked doors should be considered in order to prevent the entry of unauthorized people.

3.2.5 Exclusive precautions for natural gas valve

Since natural gas valve was not classified as hazardous area, no precautions are required. However, a gas detector which is interconnected to a solenoid valve is suggested, in order to cut the gas flow should there is a major leakage in the event of a pipeline damage or similar failure.



4. CONCLUSIONS

Due to the fact that the boiling point of ethyl acetate (77°C) is higher than normal ambient conditions (40°C max), likelihood of the evaporation rate of released liquid being same as the rate of release is quite low as it was assumed in first scenario of Section 3.1.1. Furthermore, there is no suggested method for determining the evaporation rate of a spraying release in TS EN 60079-10-1. If the type of release was determined as "heavy gas" instead of "diffusive" in first scenario, then the distance of the hazardous zone would be 15 meters, instead of 7 meters. Difference between these two extension distances is vital and might cause an explosion if underestimated or cause unnecessary expenses if overestimated. Consequently, the evaluations regarding a leakage of a flammable liquid from a positive pressure equipment, is too dependent on engineer's/specialist's approach who carries out the assessment. If experimental data was available for these issues, explosive atmosphere assessments would be more accurate and consistent throughout the sector. Therefore, carrying out and publishing experimental studies especially about liquid leakage scenarios would be beneficial on reducing the evaluation mistakes of specialists.

Since it is very difficult to find information in literature on grounding resistance limits required for different static electrical sources such as flammable liquids having different conductivities, different types of storage tanks or pipelines, academic studies on such issues would be beneficial for the chemical industry.

In Turkey, there is no laboratory that is accredited in accordance with TS EN 14034 series which authorises the laboratory to perform the tests for determining explosibility characteristics of combustible dusts. Therefore, most of the explosive dust atmosphere assessments in Turkey are carried out by the help of information obtained from literature or international sources. In this regard, the establishment of accredited test laboratories in Turkey would help to achieve more reliable results in dust explosion assessments.

Lack of quantitative references or methods may cause a big difference between the extents of the same dust hazardous areas which are classified by different specialists. Therefore, in addition to articles or thesis' such as this one which can be used as a reference, publishing an official guideline or revising the standards by including quantitative references or methods would be beneficial for the specialists and thereby for the chemical industry.

The heavy impact of hole size assumptions on the hazardous zone's class and distance, requires the specialists to be very experienced and/or very inquisitive and careful while carrying out hazardous area classification for secondary release (leak) scenarios. However, explosion protection regulations are issued within the last 7 years in Turkey and specialists are on a developing stage, getting experienced day by day. This stage could be accelerated by providing specific, detailed guidelines and trainings intended for the hazardous area classification specialists.

Risk of explosion and fire in the working places can be reduced by taking measures to prevent the formation or ignition of flammable substances and explosive atmospheres. Where these measures are not sufficient, reducing the destructive effects of the explosion by taking other technical measures can be the last resort in controlling the fire and explosion hazards. Areas where the possibility of an explosive atmosphere cannot be completely eliminated, are classified in accordance with relevant legislation and standards. The explosion protected (Ex-proof) electrical and power-driven equipment must be carefully selected and installed in accordance with the class of the hazardous area and relevant standards. We have practiced some of the hazardous zone classification methods of relevant TSE standards in our fictive case study and have given many examples of measures that may have to be taken.

A great improvement in terms of explosion and fire protection can be achieved if the legislation and standards related to the issue are fully and accurately understood and implemented at workplaces. Likewise, as the number of employees working in accordance with these legislation and standards increases, explosion and fire statistics in Turkey will be expected to improve. It is important for the official institutions to support academic studies and establishment of accredited laboratories that produce experimental data, to publish guidance documents and improve standards. This support can make chemical industry safer and therefore more reliable and efficient.

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CV

Ufuk MEVLEVIOGLU

Health and Safety Specialist

E-mail : umevlevioglu@hotmail.com

Linked-In : <https://www.linkedin.com/in/ufuk-mevlevioglu/>

Educational Background

Master of Science: Occupational Health and Safety, Uskudar University, 2015

Bachelor of Science: Chemical Engineering, Istanbul University, 2005

Certifications

NEBOSH International General Certificate – RRC International, 2019

Safety Data Sheet Author – Chamber of Chemical Engineers, 2016

Advanced Concepts in Chemical Security – USA Chemical Security Program and Istanbul Technical University, 2016

Occupational Safety Specialist – Ministry of Labour and Social Security, 2015

Dangerous Goods Safety Advisor – Directorate General for Dangerous Goods and Combined Transport, 2015

Fire Safety Trainer – Namık Kemal University, 2014

IOSH Managing Safely - Aramis Consultancy, 2013