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ORIGINAL ARTICLE

Hazardous Area Classification Assessment at a Pharmaceutical Industry in East Jakarta

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ABSTRACT

Introduction: Fire is a common risk in any industrial facility that uses combustible and flammable raw materials, products, or supporting materials. Among others, the pharmaceutical industry is exposed to such risk due to the application of flammable liquids including ethanol as a volatile solvent in production areas, which has the potential to form explosive atmospheres through evaporation from pools created by accidental releases. Therefore, this study aims to analyze the hazardous area classification (HAC) in ethanol storage areas to facilitate the execution of risk mitigation efforts for reducing the role of ignition sources that cause fire and explosion. **Methods:** The HAC assessment was carried out in December 2021 - January 2022 using the quantitative method outlined in the International Electrotechnical Commission (IEC) standard: IEC/EN 60079-10-1 for zone determination. During flash point analysis, the ASTM D-93 method was employed to define the class of ethanol as a flammable liquid. **Results:** The ethanol storage areas fell into the zone 2 category based on the secondary grade of release, as well as the areas' ventilation effectiveness with a medium dilution, and fair ventilation availability. The extent of zone 2 is up to 3 m from the release source. **Conclusion:** Ignition sources capable of leading to fire and explosion incidents in ethanol storage areas should be controlled.

Keywords: ethanol storage, explosive atmosphere, hazardous area classification, IEC/EN 60079-10-1

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INTRODUCTION

Fire is a common risk in any industrial facility that uses combustible and flammable raw materials, products, or supporting materials. In order for a fire to occur, all three required elements, namely oxygen, combustible materials, and ignition sources, must be satisfied. The combustible materials' leakage together with the surrounding air (oxygen) often leads to fire or explosion. Their ignition can cause a fire that will damage the facility with consequences including the threatening of workers' lives, and business loss. Therefore, it is extremely important to ensure taking special precautions to manage the ignition source where such combustible or flammable materials are used. Ignition sources can be classified into mechanical, chemical, and electrical, including friction, heat impact, and heat of reaction. The electrical ignition source is static electricity and electric sparks. Out of the 68 fire and explosion accidents that occurred from 2010 to 2016, static electricity accounted for 26 cases (38%), and 13 cases (19%) were due to electric sparks (Jae, Chang and Lee, 2018). The electricity used in equipment and facilities must be managed properly to minimize the ignition potential. This requires careful equipment selection and installation, as well as maintenance to guarantee their integrity and prevent the tendency of becoming a fire source. One way of reducing an ignition source potential in electrical equipment is to ensure they are designed and installed in accordance with the hazardous area.

A hazardous area is defined as an area with a possibility of fire or explosion due to an available mixture of flammable and non-toxic gases or substances capable of burning (Lestari *et al*., 2021). This requires special equipment and installation to

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protect against potentially flammable and explosive substances (Bahadori, 2014).

The hazardous area classification (HAC) is carried out to provide a fire and explosion risk profile in an area. This cannot predict accurately that an explosion will occur, but only separates a facility area into several levels of fire and explosion possibilities, and it is a risk mitigation (Lestari *et al*., 2021).

The HAC method is applied in classifying areas within an industrial facility that uses combustible or flammable materials. It helps determine the appropriate type of equipment for the areas to minimize potential ignition sources. HAC assessment is the first step taken during the classification to ensure proper equipment selection and installation.

In the assessment process, release sources of hazardous chemicals such as flammable liquids, gases, vapor, and combustible dust are analyzed. This also includes determining the likelihood, quantity, and duration of leakage or release to evaluate ventilation effectiveness. Furthermore, HAC involves evaluating each area within an industry for ventilation effectiveness and possible risk based on the group of gases present and zones that require electrical installations in compliance with IEC/EN 60079-10-1 standards. Hazard zone classification for flammable gas and liquid begins from zones 0, 1, and 2 according to the risk level. Zones 20, 21, and 22 are only intended for areas containing combustible chemicals in the form of dust (combustible dust). The determination of gas or dust groups along with temperature classes is applied to each hazardous zone by considering the characteristics such as auto-ignition temperature and maximum experimental gap (Choi and Byeon, 2021).

The pharmaceutical industry produces drugs or Active Pharmaceutical Ingredients (API) for the market. The products are manufactured through both chemical and physical means from hazardous chemicals used in various operation units, which exist in liquid, solid, and gaseous forms that are flammable, toxic, harmful to the environment, etc. Consequently, the industry faces a high risk of fire and explosion due to the handling of several hazardous chemicals (Pal, 2019).

HAC in the pharmaceutical sector is the evaluation and classification of hazardous locations according to scientific and engineering principles, within facilities where chemicals are manufactured, processed, or utilized. The classification is performed solely to ensure the safe and proper specification and installation of electrical/electronic equipment. Based on this, (Pal, 2019) determined the classification of hazardous areas in acetone storage tanks in a pharmaceutical industry with respect to the source of release and ventilation. The result of HAC recommended that electrical equipment should not be used in zone 0 where the leak/release source is found inside acetone storage tanks. Meanwhile, areas around the storage tanks and their handhole/ventilation port as well as the dyke area are designated as zones 1 and 2 which require using only enclosed flameproof electrical equipment. In this study, the extent of zones was determined, specifically zone 1 reached 1.5 m from the handhole/ventilation area, while zone 2 was 3 m from areas surrounding the storage tanks and dyke (Pal, 2019).

Besides acetone, ethanol is more widely employed in the pharmaceutical industry. Ethyl alcohol, commonly known as ethanol is identical in composition to potable alcohol. Ethanol with the molecular formula C_2H_6O is clear, colorless, volatile liquid with a pleasant smell prepared by sugar fermentation (Onyekwelu, 2019). The vapor is combustible with air in proportions of 3.5-15% (Guillaume *et al*., 2013).

OSHA and National Fire Protection Association (NFPA) classified ethanol as a flammable liquid. According to OSHA, C_2H_6O meets the criteria for category 2 flammable liquid because it ignites at normal room temperatures, and has a flash point of 550 F and 1730 F boiling point (OSHA, 2022).

Ethanol vapor's combination with air in the presence of ignition sources can generate fire and explosion. The compound's lower and upper explosive limits are 3.3 and 19%, respectively, by volume in air. This range includes airborne ethanol concentrations that can ignite and burn when there is an ignition source (OSHA, 2022).

Fire and explosion hazards exist during the initial formation of ethanol as well as all through the product's purification, storage, and transportation phases. Three components must be present for a fire to occur, namely fuel, oxygen (oxidizing agent), and heat. For ethanol fire, its vapor represents "fuel" in the fire triangle, oxygen is the "oxidizing agent", and "heat" comes from ignition sources that cause the vapor to first burn (OSHA, 2022.)

PT. XY as a pharmaceutical industry in Jakarta uses ethanol in the production process of both solid and liquid dosages. A total of 100 kg, 20 kg, and 5 kg ethanol are required in the solid dosage process, both for products and the cleaning process. This scenario has a potential hazard that tends to increase fire and explosion risk, particularly during storage, production, and cleaning activities. Ethanol as a volatile solvent can form explosive atmospheres due to its evaporation from pools created by accidental releases. This phenomenon appears more hazardous in indoor zones once there is a failure of artificial ventilation systems or inadequate air flow (Lauri, 2021).

At PT. XY, only ethanol is kept in the separate indoor flammable storage area inside 20 plastic drums (@ 200 l). The average total stock of C2H6O in this store is 4.000 L. Ethanol is a Class IB flammable liquid, hence, fire and explosion risk must be managed from the storage area, which cannot be isolated from loading and unloading activities. This management is performed to prevent the worst-case scenario of an accidental release. Therefore, HAC is needed to determine area classification and identify potential improvements concerning the prevention of ignition in a hazardous area.

HAC assessment was carried out at PT. XY for approximately 2 months from early December 2021 to late January 2022. This referred to the IEC/EN 60079-10-1 guidelines and involved an external laboratory to test the flash point of ethanol at a 96% concentration stored and used by PT. XY. With this assessment, it is expected that the company can implement corrective actions to prevent the fire and explosion risk according to the established recommendations.

METHODS

This assessment was carried out in December 2021 - January 2022 using the quantitative method outlined in IEC/EN 60079-10-1 for zone classification. This classification depends on the following parameters, namely source release grade, dilution degree, and ventilation availability

The first step in evaluating hazardous areas based on IEC/EN 60079-10-1 guidelines was to determine the combustible gas/vapor release scenarios, i.e., release from piping flanges, seal, venting, etc. Afterward, the type of flammable material (vapor or gas) was confirmed to help ascertain the appropriate calculation for the release rate. At this stage, the physical and chemical data were compiled from flammable materials to calculate the release rate, such as molecular mass, vapor pressure, Low Flammable Limit (LFL), etc. Furthermore, the ventilation velocity was evaluated by direct/real measurements or using IEC/EN 60079-10-1 guidelines. The degree of dilution was estimated by calculating the release characteristics with the following formula (1):

$$\frac{Wg}{Pg\ K\ LFL} \quad (1)$$

Wg= mass release rate of gas (kg/s); Pg= gas or vapor density at the ambient temperature (kg/m^3); K= safety factor; LFL= Lower Flammable Limit (vol/vol).

The background concentration for indoor release was then measured and compared with background criteria which were 25% of the Low Explosive Limit (LEL).

Figure 1 is used to estimate the dilution degree based on ventilation velocity and release characteristics value, while the hazardous zone is determined with Table 1 according to dilution degree and ventilation availability.

The extent of hazardous zones is evaluated from the characteristics and type of release (gas or vapor) using the chart in Figure 2. Besides, the flash point analysis was conducted by an external laboratory using the ASTM D-93 method to define ethanol's category.

RESULT

Ethanol with 96% concentration was stored indoor in plastic drums at a flash point of 160C based on testing. Also, it had a 780C boiling point according to the Safety Data Sheet (SDS) and was categorized as a Class 1B liquid (Marando, 2021). The existing ethanol tanks found were empty and not used anymore. Therefore, the potential risk of flammable vapor release from leaking drums (possibly due to being struck by a forklift) was classified as secondary release grade. Characteristics of release from ethanol are as follows: Flammable substances (Ethanol); Molecular mass (M) (46.07 g/mol); Vapor pressure (Pv) (12.874 Kpa); Storage temperature (Ta) (3060K (Ta)); The temperature of a liquid (T) (2730 K); LFL (3.3% vol.); Auto-ignition temperature (3630 C); Volumetric evaporation rate (229E-03); Pool surface area (Ap) (20 m^2).

The volumetric evaporation rate was calculated based on the following formula (2):

$$Qg = \frac{6{,}5\ uw^{0{,}78}\ Ap\ Pv}{10^5\ M^{0{,}333}}\ \mathrm{X}\ \frac{Ta}{T}\left(\frac{m^3}{s}\right) \quad (2)$$

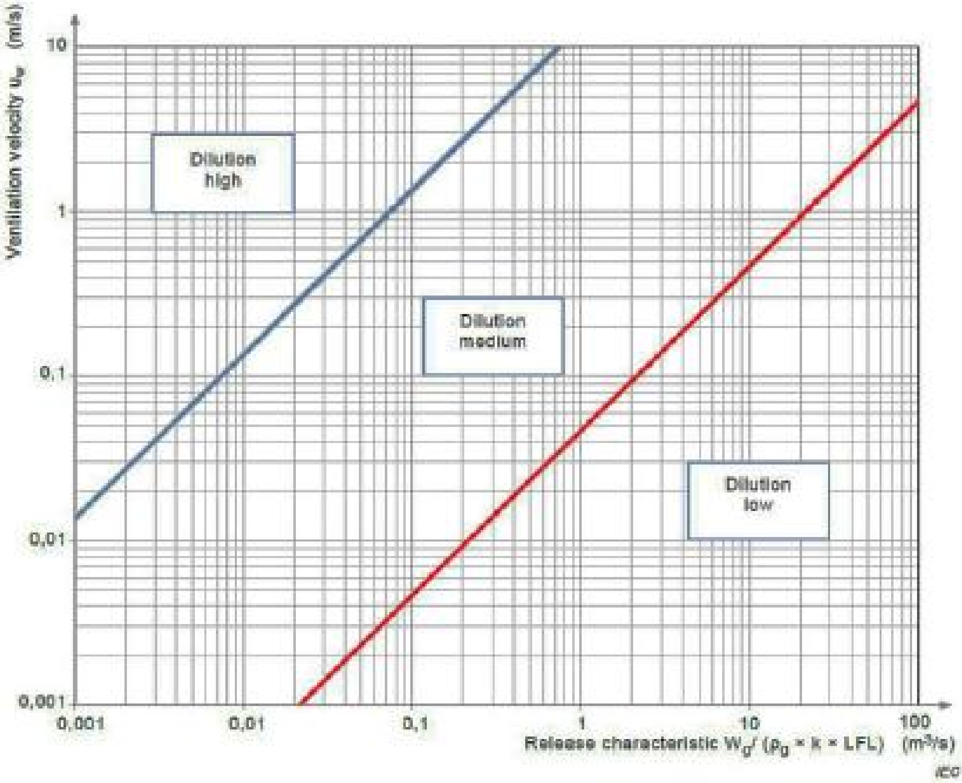

Figure 1. Determination of Dilution Degree Assessment

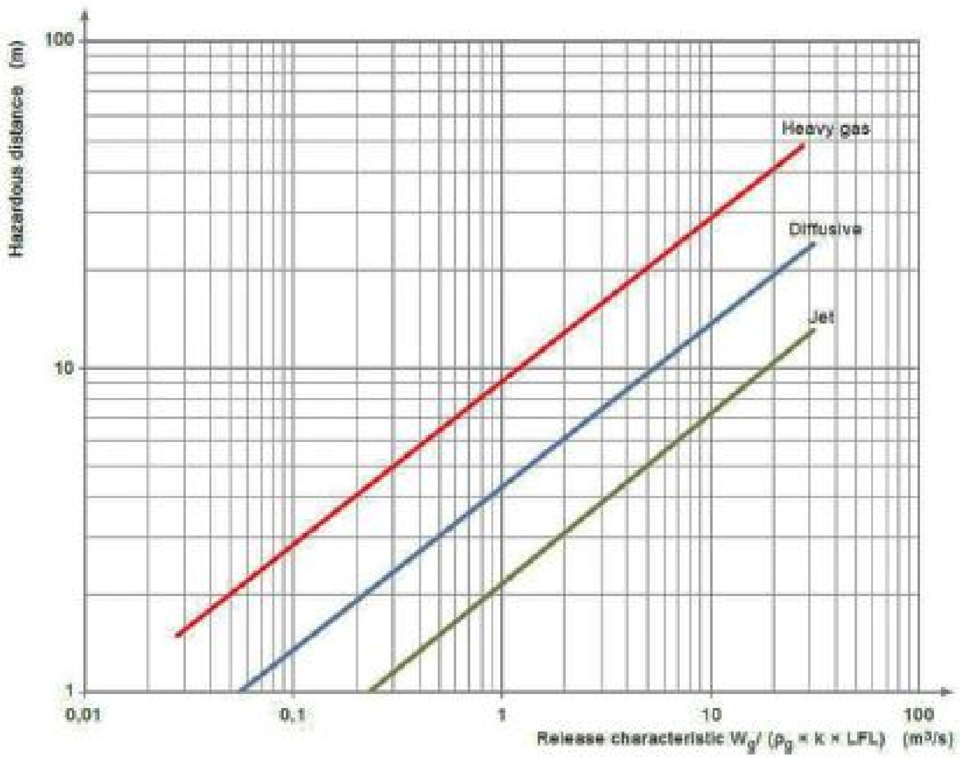

Figure 2. Determination of the Estimated Distance to Hazardous Area (Extent Zone)

Table 1. Hazardous Zone Determination by the Grade of Release and Ventilation Effectiveness

Grade of Release	Ventilation Effectiveness						
	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[c]	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	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[d]

a.Zone 0 NE, 1 NE, or 2 NE indicates a theoretical zone that would be negligible extent under normal conditions.

b.Zone 2 created by a secondary grade of release may exceed the one attributable to a primary or continuous grade of release. In this case, the greater distance should be selected.

c.Zone 1 is not needed here because small zone 0 is found in the area where the release is not controlled by ventilation, and larger zone 2 is for when ventilation fails.

d.Zone 0 contains very weak ventilation and the grade of release is in such a way that in normal operations, an explosive gas atmosphere keeps existing almost continuously (i.e. approaching a 'no ventilation' condition).

'+' signifies 'surrounded by'

The availability of ventilation in a naturally ventilated enclosed space is commonly not

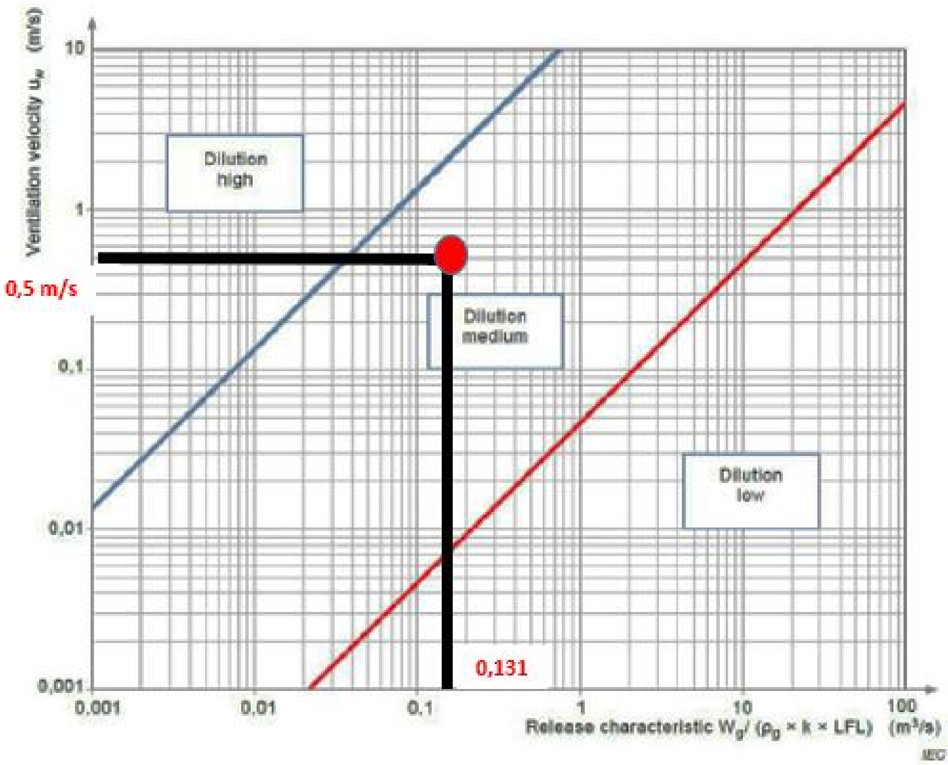

Figure 3. Degree of Dilution in Ethanol Storage Areas

The ventilation velocity in the storage area was 0.5 m/s as recommended in IEC/EN 60079-10-1 for enclosed areas and based on the evaluation of the ambient condition. The release characteristics were determined with formula (1). From formula (2), Qg i.e. volumetric evaporation rate, is equal to Wg/Pg, and it can be simplified to:

$$\frac{Qg}{K\,LFL} \quad (3)$$

Figure 1 shows a release characteristic of 0.131 m^3/s (based on formula (3) calculation), a safety factor of 0.5, and 0.5 m/s ventilation velocity, hence the dilution degree of ethanol storage areas is medium as indicated in Figure 3.

According to Table 1, ventilation availability is assumed as fair, and the grade of release is secondary (the leak does not occur all the time), then the storage zone fell into category 2. Zone mapping in storage is demonstrated in Figure 4.

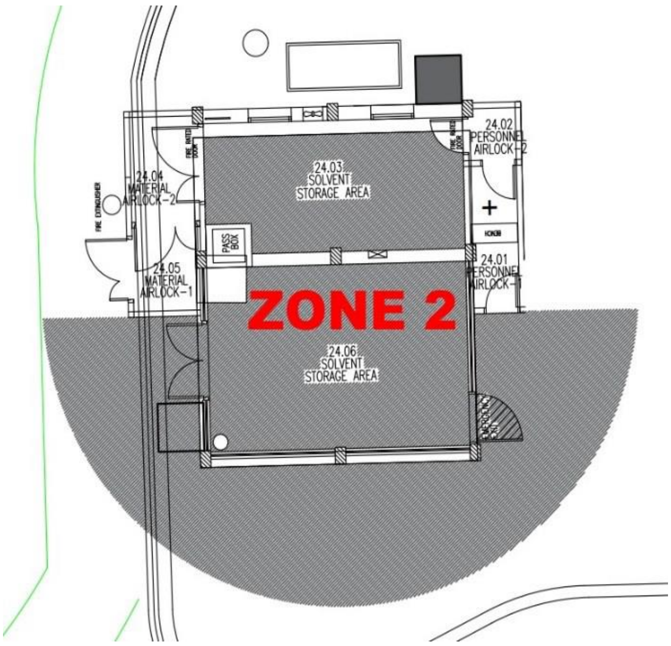

Figure 4. Zone Mapping for Ethanol Storage Areas

Figure 6. Zone for Ethanol Storage with Ventilated Wall

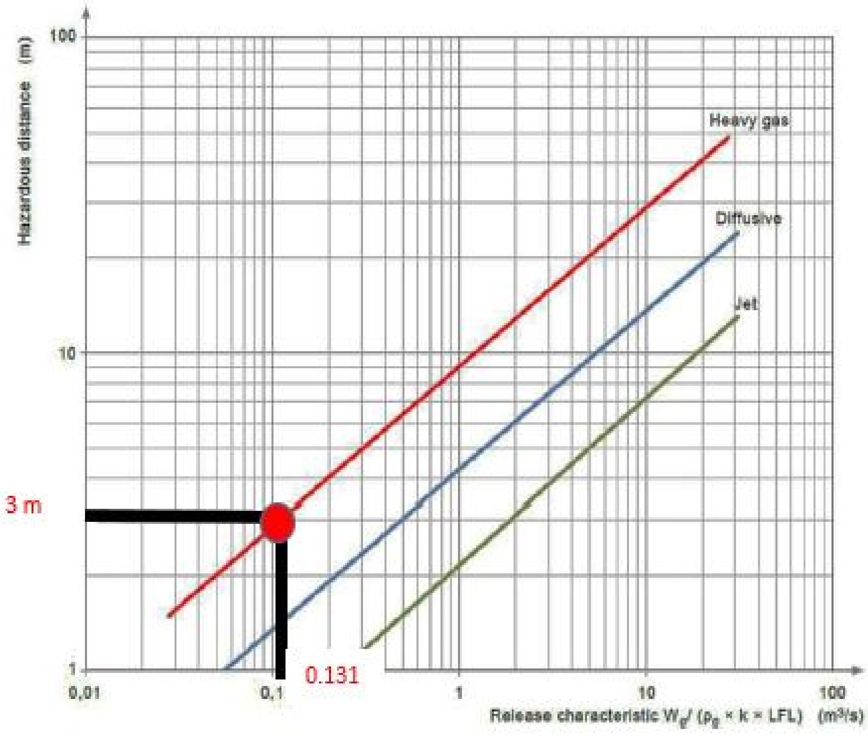

Figure 5. Hazardous Area Distances for Ethanol Storage

Figure 2 shows the extent of zone and heavy gas characteristics where ethanol vapor is heavier than air, and the zone is 3 m from the release source as indicated in Figure 5. Since the drums are stored near the wall and the next room has mechanical ventilation, the extent of zone 2 is up to 3 m wide around the pierced concrete wall as displayed in the real picture presented in Figures 6 & 7. This also applied to outside storage areas indicated in figure 8.

DISCUSSION

The Grade of Release Sources at Ethanol Storage Areas

Before discussing the source of release, it is necessary to know the characteristics of ethanol as a flammable liquid. The NFPA grouped flammable liquids based on flash and boiling points as class I with sub-classifications. As already mentioned in the results, ethanol is a class 1B flammable liquid that has a flash point of 160C (below 22.8^{0}C) and a boiling point of 78^{0}C (above 37.8^{0}C) (Marando, 2021).

The things that are considered in determining the classification of hazardous areas include the grade of release and ventilation effectiveness. The release source refers to the point from which a flammable liquid is leaked into the surrounding environment to form an explosive atmosphere. The grade of release is divided into three classifications, namely continuous, primary, and secondary (Buyukkidan, Gumus and Uslu, 2021). Basically, one of the factors, i.e. grade of release, can define the hazardous zone, where continuous, primary, and secondary release produces zones 0,1, and 2, respectively. This is not appropriate without considering ventilation effectiveness in the process (International Electrotechnical Commission, 2020).

Based on the results, the potential release source comes from drums' leakage specifically while loading and unloading ethanol using a forklift. The leakage scenario is observed from one drum containing 200 L due to the unavailable history of release in large quantities. Furthermore, the operators always physically inspect the ethanol drum twice and drive the forklift carefully based on the provided procedures and license regulations. The leaks at ethanol storage tanks are classified as a secondary grade of release sources because they only occur occasionally. Secondary grade releases do not occur under normal conditions and for more than a few resources at the same time, only the largest value should be considered (International Electrotechnical Commission, 2020).

In a case study on evaporation in a bioethanol storage depot (Lauri, 2020), emission/release sources in case of failure can come from some components such as flanges, valves, and pumps. The potential release source examined is the flange used in connecting the bioethanol transfer pipe to the tanks. Leakages from the flange are usually due to gasket wear. This situation triggers a possible occurrence of an explosive mixture in the depot during normal operations, and the release source is classified under primary grade.

Evaluation of the release source based on its form includes the release rate of hazardous chemicals existing as gases or vapors, liquids, and

Figure 7. Zone for Ethanol Storage with Mechanical Ventilation

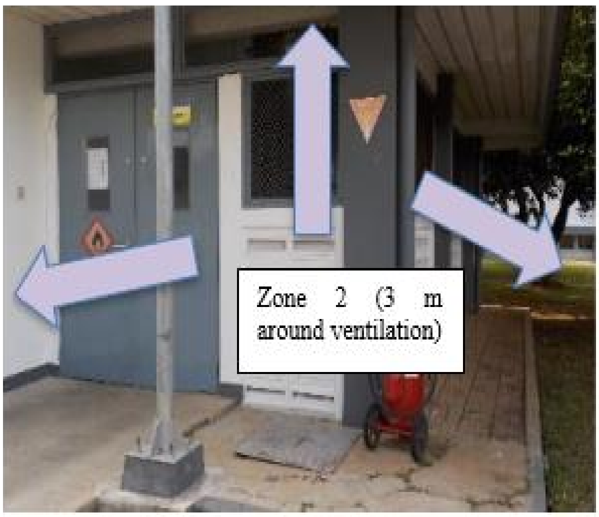

Figure 8. Zone for Outside Ethanol Storage

evaporation pools. This can be calculated based on the guidelines presented in appendix B of IEC/EN 60079-101. During ethanol storage, the release source is evaluated according to the release rates of evaporating pools. This general scenario states that any leakage inevitably leads to the formation of a pool near the source (Bozek, 2018).

The scenario of a possible release source with a total loss of one drum (200 L) had a pool surface area (Ap. in m^2) of 200 L/10 cm which was equal to 20 m^2. This was used due to the unavailable history of catastrophic incidents resulting from container leaks, but some leaks tend to occur from loading and unloading activities performed with a forklift in the storage area.

There is a greater risk of fire due to thermal exposure in large-volume ethanol storage tanks. The results of the case study presented by Sjöström *et al*. (2015) showed that an increase in the ethanol content caused an elevation in the thermal impact such that the entire surface burned in a large-scale fire test with a fuel area of 254 m^2. A small-scale fire test carried out on an area of 2 m^2 conversely indicated that the ethanol content reduced the thermal impact on the surrounding environment. Therefore, the thermal impact of a large pool of fires on the immediate area will pose a risk of damage to facilities, as well as increase fatal injuries and fire spread, making extinguishing efforts more difficult (Sjöström *et al*., 2015).

Dilution Degree in Ethanol Storage Areas

An explosion can occur supposing a flammable substance (its concentration must be included within its flammability limits), oxygen, and the required activation energy which is provided by an ignition source, are simultaneously present. Ethanol mists with an energy of 20 J will be ignited. The flame propagations observed for ethanol as the minimum ignition energy is 0.23 mJ (El-Zahlanieh *et al*., 2020).

The evaporation rate helps in determining the dilution degree, which is a required parameter for identifying areas where an explosive atmosphere may occur (Lauri, 2021). The dilution degrees are divided into three categories, namely high, medium, and low (International Electrotechnical Commission, 2020).

In this study, before estimating the dilution degree in ethanol storage, the pool surface area, and volumetric evaporation rate according to formula 2 were calculated, alongside release characteristics with the results of 0.131 m3/s and ventilation velocity of 0.5 m/s. Ventilation availability is considered fair as there is no backup ventilation fan in case the main one fails to work in the storage area for short periods. The final result showed that the dilution degree was medium as indicated in Figure 3. Medium dilution is a concentration that can be controlled during the release, and in particular, atmospheres containing explosive gases shortly after the release is then stopped to establish a stable zone boundary (International Electrotechnical Commission, 2020).

Increasing the ventilation velocity causes a small decrease in the pool radius (3.6%) since the evaporation rate is much lower than the mass flow released from the control valve. The pool radius trend strongly influences the biofuel evaporation rate. In a case study focused on the formation of an explosive atmosphere during bioethanol storage (Lauri, 2021), elevating the ventilation velocity causes an increase in the evaporation rate, but not high enough to modify the dilution degree (its value is medium).

Hazardous Area Classification in Ethanol Storage

The zones in HAC are determined based on the type of flammable/combustible material, temperature, and heat pressure, as well as the leak size present while handling the material (Choi and Byeon, 2021). In the IEC/EN 600-79-1 standard, the zone type found in a hazardous area based on the grade of release and ventilation effectiveness is specified in Table 1. Furthermore, the zone type determines the selection of proper equipment (electrical and mechanical). This will influence work and emergency procedures where special precautions/restrictions must be taken to reduce the possibility of fire originating from ignition sources in hazardous areas (Nilsen *et al*., 2007).

Standard electrical equipment used in hazardous areas includes explosion-proof containers or enclosures, intrinsically safe equipment types, inter-space protection systems, and non-sparking maintenance tools (Setiawan, Nugroho and Zaman, 2020).

The cover or container of electrical equipment used in hazardous areas has a protective design meant to prevent sparks or explosions from escaping to the exterior because the lid's density is high (Setiawan, Nugroho and Zaman, 2020).

Ventilation effectiveness assessment in an ethanol storage area is based on the degree of dilution and ventilation availability. The dilution degree is pre-defined to be medium, while ventilation availability in the storage tanks is considered fair because the Air Handling Unit (AHU) can be turned off for a short period during repair or preventive maintenance. After determining the grade of release and ventilation effectiveness, the final result showed that the storage area is hazardous with zone 2 and an extent of 3 m from the release source. Zone 2 can be described as an area with an explosive gas atmosphere that occurs for a short time in abnormal operations (International Electrotechnical Commission, 2020). The extent of zone is based on release characteristics and type of release.

Once the NFPA approach is used, the ethanol storage process size, pressure, and flow rate will fall into the small/low category, hence, Figure 5.10.1 (e) of the NFPA 497 standard applies. The zone based on NFPA 497 standard is the same as the Division or zone 2 in the IEC approach but the extent is more than twice, i.e. 7.62 m, of the value obtained with the IEC approach (Goyette, 2011).

The equipment group and temperature class for this zone 2 in the ethanol storage area are called Zone 2 IIA T2. One of the selections of this equipment is based on the temperature class of the flammable liquids regulated by the IEC. When selecting suitable equipment, the temperature class must be lower than the minimum ignition of explosive mixtures in hazardous areas to reduce fire and explosion risk. The temperature classes based on IEC/EN 60079 standards were 6, namely T1 (450^{0}C), T2 (300^{0}C), T3 (200^{0}C), T4 (135^{0}C), T5 (1000^{0}C), and T6 (85^{0}C) (Ahirwal, Singh and Vishwakarma, 2015).

Electrical equipment which are the ignition sources in the ethanol storage area must meet the level of protection (explosion-proof) according to zone 2 standards including lighting, AHU motors, and fire alarm system installation. A certificate of conformity for Atmosphere Explosion (ATEX) from this equipment should be checked. Besides, the ventilation fan has no alarm to indicate failure as well as no backup fan in case the main one stops working. Therefore, the storage area is categorized as zone 2 and the installation of an alarm is recommended. Foam fire extinguishers (Aqueous Film Forming/AFF) weighing 25 kg were placed outside the ethanol storage area and the inside was equipped with heat detectors for detecting a drastic increase in room temperature that has the potential to cause a fire outbreak. Additional engineering controls (early warning systems) are needed for safe use by detecting the presence of ethanol vapor released into the air through the installation of flame/LEL gas detectors in the storage area. This is to confirm whether the LEL level is within the standard acceptable limits.

The same method is also used in zones with scenarios of leakages from pumps handling liquid pentane during the refinery processes under normal operation. This outflow from the pump seal creates a flammable vapor mixture in the atmosphere containing the leaks, which collect to form a pool within the containment dyke. The flammable vapor mixture is determined by the ambient air temperature and vapor pressure of the liquid pentane. Pentane is a flammable liquid with a vapor pressure of 75 kPA at 20^{0}C and a molecular weight of 72 kg/mol. To calculate the release characteristic value of pentane for determining the zone and its extent, the data on ventilation speed, safety factor, and LFL with a final volume of 0.4 m^3/s are needed. This is based on a safety factor value of 0.5, 1.5% LFL, and 0.25 m/s ventilation/wind speed. Therefore, the pentane release area is categorized as zone 2 with medium dilution. Zone 2 has an extent of approximately 6 m for heavy gas release according to the standards (Bozek, 2018).

A case study for an area with tanks containing Liquefied Petroleum Gas (LPG) also used the same method, resulting in the area being categorized as zone 2. This was based on the secondary release of LPG from the tanks' bottom, and the release characteristics were calculated under sonic and subsonic conditions with values of 4.947 and 3.927 m3/s, respectively, at a 1.08 m radius (Buyukkidan, Gumus and Uslu, 2021).

In addition to the method based on IEC/EN 60079-10-1, a risk assessment method involving a matrix is also used to determine the explosive atmosphere severity. A total score of 12 was obtained from this assessment by multiplying the probability of occurrence in a week (3P) and the consequences that could lead to serious injury (4P). Serious threats and devastating effects were clearly fictionalized by explosion scenarios of the LPG tanks with ALOHA software, divided into several modeling scenarios (Buyukkidan, Gumus and Uslu, 2021).

In another case study based on the NFPA 497 standard with a leakage scenario of flammable liquids located indoor at the floor level. This assessment applied divisions corresponding to the zone concept, where adequate ventilation is assumed to be provided. The results categorized this area as divisions or zones 1 and 2. Division 1 is an underground location such as a sump or trench with an extent reaching 7.62 m. Meanwhile, division 2 is a place for handling or storing flammable liquids with an extent of up to 1.52 m from the release source (Tommasini, Pons and Palamara, 2014)

This described approach is very similar to the IEC 6007910-1 concept of ventilation degree where Medium Ventilation (MV) "can control an explosive atmosphere concentration, leading to a stable zone boundary while the release is still in progress". In other words, with MV, the hazardous zone only exists near the release source and the explosive atmosphere concentration outside this boundary is slightly lower than LEL (Tommasini, Pons and Palamara, 2014).

CONCLUSION

The evaluation of HAC was carried out based on the grade of release, as well as ventilation effectiveness and availability. The results showed that the ethanol storage area was classified as zone 2 with an extent of 3 m from the release source. Therefore, risk mitigation measures should be taken to reduce ignition by implementing a risk control hierarchy. Engineering controls can be applied within PT. XY by changing all electrical equipment to those containing flame-proof specifications in compliance with zone 2 (zone 2 IIA T2), which includes lighting equipment, AHU motors, and fire detectors. Additional engineering controls are needed for safe use by detecting the presence of ethanol vapor released into the air through the installation of flame/LEL gas detectors in the storage area. Administrative control must also be implemented by positioning hazardous signs in the ethanol storage area and conducting regular emergency training to ensure that employees can safely handle ethanol and respond to spills from this chemical.

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