# POLITECNICO DI TORINO

COLLEGIO DI INGEGNERIA PER L'AMBIENTE E IL TERRITORIO

**Master of Science Degree**
**Georesource and Geoenergy Engineering**

Master Thesis

# Hazardous Area Classification on Heating Unit of DRI Plant

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# Declaration

I "Farzaneh Shahabi," hereby declare that this thesis represents my work, which has been done after registration for the degree of master of Science at Politecnico di Torino University, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications.

I have read the University's current research ethics guidelines and accept responsibility for conducting the procedures in accordance with the University's Committee. The project is under the title of "Hazardous area classification on heating unit of DRI plant" and under the supervision of Prof. Dr." Danielle Martinelli" and I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

# Acknowledgment

I would like to express my deepest gratitude to my supervisor, Professor **Daniele Martinelli**, for his immense expertise, patience, and insightful critiques throughout my research journey. His deep commitment to academic excellence attention to detail have significantly influenced the development of this dissertation.

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# Abstract

This study's objective is to outline the standards, requirements, and criteria that must be adhered to provide a methodology for classifying explosion-hazardous areas and determining the extension of the hazardous area within the fuel system and burners of the bottom fired process gas heater used in Direct Reduced Iron (DRI) plants. The thesis aims to define and apply the relevant requirements, standards, and criteria necessary for identifying potential ignition sources and evaluating the dispersion of flammable gases. By following recognized industrial guidelines, the study ensures a systematic and safe approach to hazard area classification, supporting safer design, operation, and heating system maintenance.

Classifying hazardous areas has become a basic safety necessity in modern industrial settings, not only for regulatory compliance but also to minimize the risk of fire and explosion, safety of workers, and guarantee operational reliability. It is a crucial part of process safety management since it has a direct impact on maintenance planning, plant layout, and equipment selection when implemented correctly. The main goal of this study is to perform an accurate HAC for the DRI plant's heating unit in compliance with IEC 60079-10-1 and ATEX Directive 2014/34/EU. Identifying possible release sources (such as flanges, valves, and burner connections), determining the kind of flammable substances involved, are all parts of the method.

A Direct Reduced Iron (DRI) plant uses a reducing gas, usually a combination of hydrogen and natural gas, to reduce iron ore in its solid state. The heating unit, which provides the thermal energy needed for reduction by feeding flammable gases to burners, is an essential part of the procedure. Hazardous area classification (HAC) is crucial for safe design and operation because of the possible risk of explosive atmospheres caused by the presence of flammable materials and high operating pressures.

According to the analysis, the hazardous area surrounding the heating unit is classified as Zone 2, which is equivalent to areas where an explosive gas atmosphere is unlikely to occur during normal operation and, if it happens, will only last for a short period of time. A conservative safety approach taking into account and the presence of hydrogen, which is classified as belonging to Gas Group IIC (the most severe group due to its high diffusivity and low ignition

energy), resulted in the selection of Temperature Class T4 (maximum surface temperature 135 °C) to ensure compliance while decreasing ignition risks.

The heating unit's electrical and mechanical equipment that are explosion-protected are chosen using this classification result as: **Zone 2, IIC, T4**, as well as to specify inspection and maintenance procedures. The study lowers the risk of ignition and ensures regulatory compliance by utilizing engineering judgment and international standards to make the DRI plant more reliable and secure.

# Symbols

| | |
|---|---|
| $C_d$ | Discharge coefficient (Dimensionless), relating to the openings, which includes the effects of turbulence and viscosity |
| $C_p$ | Specific heat at constant pressure (J/kg K) |
| $\gamma$ | Polytropic index of adiabatic expansion or ratio of specific heats (dimensionless) |
| **M** | Molar mass of gas or vapour (kg/kmol) |
| $P_a$ | Atmospheric pressure |
| **P** | Internal pressure of container (Pa) |
| **pc** | Critical pressure (Pa) |
| **Qg** | Volumetric flow rate of flammable gas from the source (m3/s) |
| **R** | Universal gas constant (8,314 J/kmol K) |
| $\rho_g$ | Density of the liquid (kg/m$^3$) |
| **S** | Surface area of the liquid release hole (m2) |
| **T** | Substance's temperature - absolute (K) |
| $T_a$ | Ambient temperature - absolute (K) |
| **uw** | Wind speed near the source of release (m/s) |
| **Wg** | Release rate of gas (kg/s) |
| **Z** | Compressibility factor |
| **LFL** | Lower Flammability Limit (vol/vol) |
| **K** | Coefficient which is a characteristic of the reliability of LFL value |

# Abbreviations

| | |
|---|---|
| **IEC** | International Electrotechnical Commission |
| **EN** | European Standards |
| **ATEX** | Atmosphere Explosive |
| **NFPA** | National Fire Protection Association (USA) |
| **LFL** | Lower Flammability Limit |
| **LEV** | Local Exhaust Ventilation |
| **MEC** | Minimum Explosive Concentration |
| **MIC** | Minimum Ignition Current |
| **SR** | Source of Release |
| **PPE** | Personal Protective Equipment |
| **HAC** | Hazardous Area Classification |
| **DRI** | Direct Reduction Iron |
| **PFD** | Process Flow Diagram |
| **PID** | Piping and Instrument Diagram |
| **IEE** | Institute of Electrical and Electronics Engineers |
| **DCS** | Distributed Control System |
| **BMS** | Burner Management System |

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# CHAPTER 1

# INTRODUCTION

# Introduction

An "explosive atmosphere" is a mixture of air and combustible materials in the form of gas, vapor, dust, fibers, or flying particles that, when ignited, allow for the spread of an able to survive flame. In terms of workplace safety, workers in all kinds of industries and more specifically industries in direct relation with chemical substances like the paint and printing, petrochemical, leather, textile, pharmaceutical, and other chemical sectors are particularly vulnerable to explosive atmospheres. Chemical gas and dust explosions cause a significant number of human injuries as well as damage to property and equipment. Hazardous assessments should be carried out in all locations where explosive atmospheres could occur. Based on what is discovered, all organizational and technological measures that are required should be identified, and appropriate protective systems and equipment should be implemented.

Along with emissions that occur during normal operations, the analysis should also account for likely flammable material releases that could occur in the event of potential defects and accidents. In order to categorize the explosive atmosphere, a number of factors are taken into account, including temperature, pressure, ventilation, frequency, duration, and rate of release, as well as the physical and chemical characteristics of the released flammable material. In accordance with these factors, potential sources of ignition are managed by assessing how well electrical or driven devices suitable the hazardous area class therefore safety measures are essential for reducing the frequency of explosions and fires.

Hazardous area classification is vital in DRI plants due to the presence of flammable gases like hydrogen and carbon monoxide. These gases can form explosive atmospheres under certain conditions, posing significant risks to plant safety. Implementing proper classification helps in identifying zones where explosive atmospheres may occur, facilitating the selection of appropriate equipment and preventive measures. The ATEX Directive 2014/34/EU provides a framework for controlling explosive atmospheres and ensuring the safety of workers and equipment in such environments.

## 1.1 Scope and objective

The primary focus of this thesis is to explain the concept and methods of Hazardous Area Classification (HAC), an essential aspect of process safety in industries processing combustible compounds. HAC is the methodical process of identifying possibilities for explosive atmospheres and classifying them into zones according to the frequency and length of time when flammable gases, vapors, or dust are present. In order to prevent ignition, this classification directs the selection of appropriate mechanical and electrical equipment. The study's methodology will be based on standards that are globally accepted, mainly the IEC 60079 series and the ATEX Directives (2014/34/EU and 1999/92/EC), which offer the framework for classifying temperature classes and equipment protection levels, defining zone types (Zone 0, 1, 2), and determining the extent of each zone.

The scope of this work also comprises applying this categorization system to the heating unit of a Direct Reduced Iron (DRI) plant, which has been chosen as a representative and relevant industrial plant as an example. The investigation will involve identifying probable release sources, analyzing gas behavior, and taking ventilation and operational conditions into account to determine the likelihood of explosive atmospheres. The heating unit will be analyzed in detail for each stream, and dangerous zones will be shown on the 2D layout plant drawings. This practical implementation not only demonstrates the methodology but it additionally supports safer design, maintenance, and operational practices by showing a clear, visual representation of risk zones within the unit.

A summary of each chapter is given below:

**Chapter 1** provides a short introduction to describe the research objectives and scope of the study. Also, gives a summary of published studies on this topic

**Chapter 2** Covers the fundamental concepts of Hazardous Area Classification (HAC), including what constitutes an explosive atmosphere and why classification is necessary for safety. It provides important definitions, types of hazardous zones (Zones 0, 1, and 2), and affecting factors, including release sources and ventilation. Relevant international and European standards such as ATEX and IEC 60079 are also discussed.

**Chapter 3** discusses a specific case study: the heating unit of a Direct Reduced Iron (DRI) plant. It outlines the plant layout, process flow, and primary equipment, with a focus on the parts that handle flammable gases such as hydrogen, carbon monoxide, and hydrocarbons. The goal is to offer context for the use of HAC methodology in a practical industrial setting.

**Chapter 4** describes a detailed step-by-step process for doing hazardous area classification. It includes identifying release sources, determining the grade of release, evaluating ventilation conditions, and calculating zone extent. The results are supported by drawings, zone maps, and, when applicable, quantitative estimates.

**Chapter 5** highlights the study's results and evaluates the success of the hazardous area classification approach used to the DRI heating unit. It emphasizes possible recommendations for equipment selection and considerations for future risk assessments.

## 1.2 Literature review

A key contribution to the field of Hazardous Area Classification (HAC) has been made by Ezzat et al. Chem Sci J (2018), titled "Applying a Hazard Area Classification Study on an LPG/SNG System in a Steel Factory to Highlight Major Hazards."

Because the flammable chemicals under this study—Liquefied Petroleum Gas (LPG) and Synthetic Natural Gas (SNG)—contain substantial concentrations of hydrocarbons, such as propane, butane, and methane, this paper has a lot in common with the topic of my thesis. These components react chemically similarly to the hydrogen, carbon monoxide, and hydrocarbon mixes commonly found in Direct Reduced Iron (DRI) plants' heating units, and they also pose a similar risk of explosion. The risk scenarios and zone categorization principles are readily transferable across the two systems since they both use pressurized, flammable gases and have similar equipment, such as compressors, pipelines, safety valves, and flanges.

(Ezzat *et al.*, 2018) According to established standards like IP15 and NFPA 497, which are American standards, but the procedure is pretty much the same with IEC and ATEX, the technique described in the paper involves identifying sources of release, evaluating ventilation conditions, and calculating the size of hazardous zones. Storage tanks, compressors, unloading stations, and flares are all carefully categorized in the case study, which makes it clear how zone designations (Zone 0, 1, 2) vary based on the possibility of gas release and the level of effectiveness of ventilation. Their results provide validity to the claim that appropriate HAC improves worker safety, lowers the possibility of financial damage from accidents, and guarantees regulatory compliance. For corporations that seek to properly handle explosive atmospheres connected to pressurized flammable gases, especially those in the petrochemical sector, a HAC study is a must.(Ezzat *et al.*, 2018)

Hazardous Area Classification (HAC) is essential in plants with flammable gas systems, especially those with pressurized lines, heaters, and burners, as explained in detail in *Bahadori, A. (2013*) Hazardous Area Classification in Petroleum and Chemical Plants. In this book emphasizes how even minor gas line leaks, particularly those that operate at high temperatures and pressures, can quickly create explosive atmospheres if they are not properly contained or ventilated. The book highlights that since burner tips, pilot lines, and main gas pipes are all possible sources of explosive release and ignition, hazardous zones must be established around these components in systems like gas-fired heating units, which are frequently used in DRI plants. In particular, it has been advised that instrumentation taps, valve assemblies, and flange connections along pipes are often disregarded sources of release requiring careful zoning, particularly in enclosed heated regions with restricted ventilation.

Several real-life instances that show zone definitions around gas-handling equipment are included in the book. For example, it states that a pipeline with flanged joints or manual valves may be regarded as a secondary grade release, frequently categorized as Zone 2, depending on the ventilation rate, but a continuous release source, like a burner pilot flame, would normally be classified as Zone 1. Due to possible leak scenarios during maintenance or startup, *Bahadori* provides a scenario of a natural gas pipeline feeding a heater that needed a hazardous zone radius of 5 to 8 meters around valve clusters and burner access points.
Additionally, it has been described how a gas plant's not sufficiently ventilated burner skid expanded its Zone 1 coverage well beyond what was expected, highlighting the necessity of evaluating ventilation and physical barriers during classification. These results provide useful information about the need to assess the explosion risks of common heating equipment and pipeline fittings.

Since the heating unit under study in this thesis uses comparable burner systems, gas pipes, and pressured components, these examples are immediately relevant. This thesis may establish actual hazardous zones surrounding gas-operated equipment by using in these methods, especially the treatment of secondary grade discharges and the consideration of ventilation effectiveness. The construction of 3D zone drawings, which will aid in communicating danger levels and directing the safe selection of equipment in accordance with ATEX and IEC regulations, will also be supported by the recorded zone distances and classification logic from the book. *(Bahadori, 2013)*

A structured and methodical approach to Hazardous Area Classification (HAC) for situations that may contain flammable gases or vapors is provided by the technique outlined by *S.* (Quesnel *et al.*, 2024). Their framework stresses a risk-based approach that begins with identifying all possible sources of gas release and is in line with international standards like IEC 60079-10-1. Depending on how often and for how long a flammable atmosphere is present, these are divided into three grades of release: continuous, primary, and secondary. Because it influences how the gas behaves and disperses in the air, it has been examined how important it is to comprehend the material's qualities (such as its vapor density, flash point, and lower flammable limit).

The definition of zone types and extents using dispersion modeling and/or standard reference tables is an essential part of the methods covered. The allocation of Zones 0, 1, and 2 is described in the study based on the combination of ventilation quality and release frequency. Particularly in more intricate or partially constrained geometries, the extent of each dangerous zone is either modified using dispersion calculations or obtained from standards. The authors also emphasize how mapping hazardous areas using 3D modeling techniques improves risk communication and accuracy in operational and design contexts. In gas-fired systems, such as those found in DRI facilities, where valves, burners, and flanged joints can operate as secondary release sources in locations with different ventilation conditions, this technique is particularly relevant.

The approach offered ensures that the classification of gas-handling equipment around the DRI heating unit complies with international safety best practices and offers a practical and scientific basis for carrying out the hazardous area assessment in this thesis. (Quesnel *et al.*, 2024)

Another study published by the International Journal of Business and Technology Management showed that the significance of methodically classifying hazardous areas by considering fluid characteristics, ventilation conditions, and release sources—principles that are closely aligned with the ATEX-based technique used in this thesis. Both studies focus on areas with flammable gases and emphasize the importance of correctly classifying zones (Zone 0, 1, or 2) to inform the selection of appropriate safe equipment. One important similarity between the heating unit of a DRI plant and the drilling platforms under study is the presence of equipment like burners, pumps, and valves—all of which are typical sources of ignition. The computation of hazard radii to specify the geographical boundaries of risk zones is another common feature. Conservative and efficient risk management is ensured in both situations by the focus on recognizing secondary and primary grade releases. Their strategy supports the thesis's goal of reducing the risk of explosions and improving industrial layout by accurately classifying hazardous areas.*(Nur Liyana Shafie and Roslina Mohammad, 2023)*

Similar to the methodology used in this thesis, the study reported in AREA CLASSIFICATION OF NATURAL GAS INSTALLATIONS focuses on the classification of hazardous areas at an oil and gas production plant using a methodical approach in accordance with ATEX requirements. My thesis and the case study both deal with flammable gasses under pressure, and they also use similar pieces of equipment like compressors, venting systems, flanges, and valves—all of which have the ability to release gas. The hazardous material in the article is classified under Gas Group IIB, but in my thesis, the more stringent Gas Group IIC is taken into consideration, necessitating greater controls, because of the presence of hydrogen and methane. The categorization criteria, which are based on ventilation efficiency, frequency, and release level, are immediately relevant in spite of this discrepancy. *(Santon and Ivings, 2009)*

The study published by IEE explores the classification of hazardous areas near open surfaces of flammable liquids and during maintenance interventions on natural gas networks. My research addresses ongoing operational hazards in the heating unit of a DRI plant, where hydrogen and methane gasses are the primary hazardous substances, whereas their concentration is on temporary and scenario-based gas or liquid releases. Since each type of hazardous substance acts differently in terms of release pattern, dispersion, and fire risk, a significant addition of their work is the focus placed on the necessity of accurately identifying the type of material—gas, liquid, or dust—before completing classification. This realization effectively supports my study's methodology, which holds that precise identification of the gas group (IIC) and material type is necessary for reliable classification. Although their case studies focus on leaks caused by maintenance, they both aim to reduce the risk of explosions by specialized design and controls by defining appropriate zones by comprehending release sources, frequency, and material behavior. *(Riccardo Tommasini and Enrico Pons 2011)*

(Zohdirad *et al.*, 2016) conducted a hazardous area classification study in a natural gas dehydration and dew point control unit, where the analysis was centered around key release sources such as valves, flanges, pump seals, and pressure safety valves. These components were shown to be the main causes of gas leaks during operation, and the size of hazardous zones was directly impacted by their properties. Based on the frequency and duration of discharges, the study mainly identified areas as Zone 1 and Zone 2 using the IEC 60079-10-1 standard. Based on the kind of hydrocarbons involved, the study allocated the compounds to Gas Group IIA and took them into consideration a temperature class of T3 for equipment selection and safety evaluation. By analyzing each source separately and using risk-based distance modeling, tit has been showed that accurate identification and categorization of possible leak locations is essential for avoiding the development of explosive atmospheres, particularly in facilities that deal with flammable gases under pressure.

*(Yim and Chung, 2014)* used lighter-than-air flammable gases like hydrogen, methane (city gas), and ammonia to perform a comprehensive evaluation of explosive hazardous areas (EHAs) in facilities. They measured fictitious volumes for various kinds of leakage scenarios with varying pipe diameters and pressures using the IEC 60079-10-1 standard. They found that even the smallest leak (e.g., 0.01 MPa, 25 mm pipe) produced a volume beyond 0.1 $m^3$, which is equivalent to a Zone 2 classification under medium ventilation conditions. According to their analysis, hazardous zones for methane and hydrogen need to be identified, and Zones 1 and 2 are part of the appropriate classification. For hydrogen, Gas Group IIC is used, and the temperature classes T1–T3 are determined by the substance and the conditions. The study emphasizes how crucial it is to determine which flammable gas is present because gas properties like molecular weight and LEL (Lower Explosion Limit) have significant effects on the extent that the hazardous area is. These findings clearly show the significance of thoroughly assessing the release source in heating units that include combustible gases such as methane and hydrogen.

# CHAPTER 2

# AREA CLASSIFICATION DESCRIPTION

## 2.1. Reference Standards

Since we are studying the heating unit of the DRI plant, which is the unit with the highest hazard potential and the main streams are gases/Vapors, also because the case study under this thesis is located in Europe the hazardous Area classification and extension of hazardous locations for Vapors and gases will operate in compliance with these standards:

- **ATEX 2014/34/CE Atex Directive**

ATEX is an abbreviation for "ATmosphere EXplosible". At the same time, ATEX is the abbreviated name of the European Directive 2014/34/EC concerning the placing on the market of explosion-proof electrical and mechanical equipment, components, and protective systems. Directive 2014/34/EC applies to the manufacture of products that are used in potentially explosive atmospheres. Consequently, the manufacturer has sole responsibility for ensuring that any products falling within this category comply with the Directive. The ATEX Directive applies to all electrical and mechanical equipment and protective systems that are located within potentially explosive environments.

It also covers safety, controlling, and regulating devices intended for use in outside areas, potentially explosive atmospheres, but required for or contributing to the safe functioning of equipment and protective systems concerning the risks of explosion.

Equipment and protective systems that fall under Directive 2014/34/EC may be placed on the market only if they bear a CE mark and are accompanied by an EC attestation of conformity certifying that the basic health and safety requirements have been met and that the applicable conformity assessment procedures have been observed. In addition, they must be accompanied by a set of operating instructions

- **BS EN IEC 60079-10-2021** (Explosive atmospheres- Classification of areas - Explosive gas atmospheres)

BS EN IEC 60079-10-1 is the tenth part of a BS EN IEC 60079 series of documents on the explosive atmosphere. BS EN IEC 60079-10-1 is an international standard that deals with the classification of three-dimensional areas relating to explosive gas atmospheres. In order to enable the appropriate design, building, operation, and maintenance of equipment for use in hazardous environments, this standard considers the classification of locations where flammable gas or vapor hazards may arise. It is also intended to be applied in situations where flammable gas or vapor mixed with air could present an ignite threat. Variations above and below the reference levels of 101.3 kPa (1013 mbar) and 20 °C (293 K) are allowed under BS EN IEC 60079-10-1 conditions, so long as they have negligible impact on the explosion properties of the flammable substances.

## 2.2. Area Classification

Wherever the first two requirements for an explosion area met, hazardous areas may arise in industries and workplaces. Typical examples of hazardous areas include Chemical factories, refineries, enameling plants, paint shops, cleaning supplies, mills and storage for milled products and other flammable dusts, tank farms, and loading locations for flammable gases and this demonstrates how widespread and significant hazardous areas are in various industries.

As a rule, three basic requirements must be met for an explosion to take place in atmospheric air: *(Bahadori, 2013)*

1. A flammable substance needs to be present in sufficient quantity to produce an ignitable or explosive mixture.
2. An oxidizer must be present in sufficient quantity, along with the flammable substance, to produce an explosive mixture. The most common oxidizer is air (O2)
3. A source of ignition—a spark or high heat—must be present.

The fire triangle is shown as Figure 1. It is commonly used as a model to understand how a fire starts and how it can be prevented. The presence of these three elements makes up the sides of the ignition triangle. If any one of the three elements is missing, an explosion will not occur. All three elements must exist simultaneously for an explosion to occur. Scholars have also introduced a fourth element in the equation, known as the uninhibited chain reaction, thereby giving the fire chemical reaction an additional side. This is referred to as the fire tetrahedron.

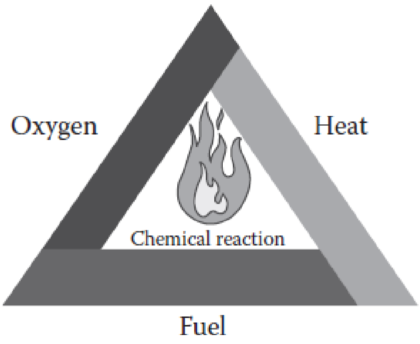


*Figure 1: Fire Triangle( with the courtesy (Bahadori)*

What we mean by "Area Classification" is to analyze the environment that has the potential for an explosion under atmospheric conditions and then to define, select, and install equipment properly and safely, and to make sure that all the facilities are using and operating safely and stay away from the risk as much as possible.

Knowing the classification improves the ability to preparation of safety procedures for plant operation and maintenance.  Also reduces the overall installation risk level.

## 2.3. Definitions

**Area Classification:  Zone 0, Zone 1, Zone 2**

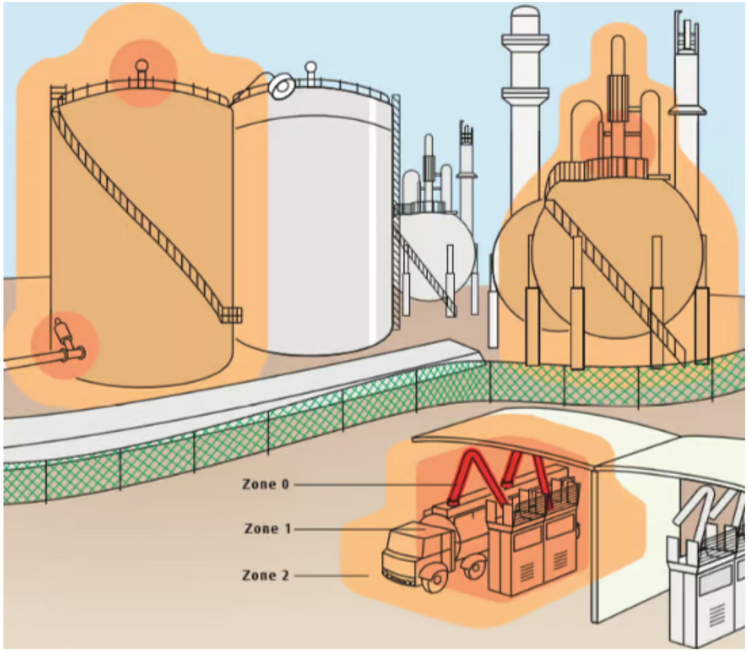


*Figure 2: Schematic classification of Zone 0,1,2*

Therefore, it is genuinely important to consider whether to extend the hazardous zones in areas where dangerous quantities and volumes of flammable gas may occur. For the design, installation, and usage of equipment, these zones are defined as "areas where an explosive gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions." *(Marangon and Carcassi, 2006)*

Based on the frequency and duration of an explosive environment, hazardous places are categorized into zones.*(Directive 1999/92/EC, 2000)*

The extent of the measures to be taken in accordance with DIRECTIVE 1999/92/E, is determined by this classification.

*Table 1: Zone Categories with the courtesy of (Directive 1999/92/EC, 2000)*

| | |
|---|---|
| Zone 0 | A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapor or mist is present continuously or for long periods or frequently. |
| Zone 1 | A place in which an explosive atmosphere consisting of a mixture with air or flammable substances in the form of gas, vapor or mist is likely to occur in normal operation occasionally. |
| Zone 2 | A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapor or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only |

The lack of numbers for the time frame categories—frequently, infrequently, and short duration, for example, makes these concepts less obvious. Some sources provide extra information, such as the German ATEX handbook from VBG of the statutory accident insurance, which provides the following explanations. (Quesnel *et al.*, 2024)

- Zone 0: The term "frequently" is to be used in the sense of "mostly in terms of time", which means that potentially explosive areas are assigned to Zone 0 if an explosive atmosphere prevails for more than 50% of the operating time of a system. (Quesnel *et al.*, 2024)

- Zone 1: If the presence of an explosive atmosphere exceeds a period of around 30 minutes per year or occurs occasionally, for example, daily, but is less than 50% of the operating time of the system, zone 1 is generally considered to be present. (Quesnel *et al.*, 2024)

- Zone 2: The consensus among many experts is that the term “short-term” corresponds to a period of around 30 minutes per year. Furthermore, it is stated that an explosive atmosphere is not normally to be expected in normal operation. If an explosive atmosphere occurs for a short time once a year, the affected area should already be classified in Zone 2. (Quesnel *et al.*, 2024)

The most common values used in industry are: *(COMAH, 2004)*

- Zone 0: Explosive atmosphere for more than 1000 hour/year
- Zone 1: Explosive atmosphere for more than 10, but less than 1000 hour/year
- Zone 2: Explosive atmosphere for less than 10 hour/year, but still sufficiently likely as to require controls over ignition sources.

According to **BS EN IEC 60079-10-1:2021** necessary terms are defined as below:

**Boiling Point**: Liquid boils at this temperature in atmospheric conditions.

**Enclosed Area**: A three-dimensional area that is large enough to let individuals in and surrounded by more than two-thirds of the potential projected plane surface area. This would require the presence of two-thirds of the walls, ceiling, and/or floor in a typical building.

**Flammable**: Able to ignite easily, intensely burning, or rapidly spread flames.

**Source of Release**: A location where a flammable gas, vapor, or liquid could be released into the atmosphere and cause the formation of an ignitable gas atmosphere.

**Release Rate**: The amount of flammable gas or vapor released from the source of release per unit of time.

**Grade of Release**: There are three main grades of release, ranked in order of decreasing likelihood that an explosive gas atmosphere will be present.

1- Continuous
2- Primary
3- Secondary

Grade of release is dependent solely on the frequency and duration of the release. It is independent of the rate and quantity of the release, the degree of ventilation or characteristics of the fluid (although these factors determine the hazardous area dimensions). In "open air" conditions, there is a relationship between the grade of release and the zone to which it gives rise:

Typically

- A constant grade of release results in a Zone 0.
- A primary grade results in a Zone 1
- A secondary grade results in a Zane 2

**Heavier-than-air Gases or Vapors**: Those gases or vapors that have a relative density greater than 1.2 are regarded as Heavier-than-air gases.

**Ignition Temperature (AIT)**: (Auto Ignition Temperature) The lowest temperature at which a heated surface will ignite a combustible substance or mixture in the form of gas or vapor under specific conditions.

**Lighter-than-air Gases or Vapors**: Those gases or vapors that have a relative density lower than 0.8 are regarded as lighter-than-air gases

**Normal Operation(s)**: The situation when the equipment is operating within its design parameters.

**Vapor pressure:** the pressure exerted when a liquid or solid is in equilibrium with its vapor. It is a quality of a substance that is determined by ASTM D 323-82 and related to environmental conditions.

**Ventilation:** Air movement, whether natural or artificial(for example by fan), and to be replaced with the atmospheric air.

**Adequate Ventilation:** Enough ventilation to keep enough amounts of an ignitable mixture from accumulating in one place.

**Dilution:** It describes how well the ventilation can dilute the release. Dilution ventilation shall be sufficient to immediately bring the flammable gas concentration below 25% of the Lower Flammability Limit (LFL) and keep it so all the time.

- **High dilution**: concentration near the source of the release reduces quickly with virtually no persistence after the stop of the release.
- **Medium dilution**: A stable zone boundary is given whilst the release is in progress. The explosive gas atmosphere does not persist unduly after the release is stopped.
- **Low dilution**: There is a significant concentration whilst the release is ongoing, and a significant persistence of an explosive zone once the release has stopped. *(Nala and Co Cork, 2021)*

**Gas Groups and Classes Classification:** For purposes of testing, approval, and area classification, vapors and dusts are subdivided in different categories, named Groups as per Atex Directive

Group I: Underground mining where methane and coal dust are present.

Group II: Gases occurring in surface industries.

**Gas Sub Groups:** For purposes of testing, approval, and area classification, vapors and gases are subdivided into different subgroups.

*Table 2: Gas Groups and Sub Groups*

| Group I | Group II | | | | | |
|---|---|---|---|---|---|---|
| Underground mining where methane and coal dust are present. | Gases occurring in surface industries | | | | | |
| | Group IIA | | Group IIB | | Group IIC | |
| | Atmosphere containing | Acetone | Atmosphere containing | Acetaldehyde | Atmosphere containing | Hydrogen |
| | | Ammonia | | | | |
| | | Ethyl alcohol | | | | |
| | | Gasoline | | Ethylene | | |
| | | Methane | | | | |
| | | Propane | | | | |

In this case study, since the system operates at the surface level and hydrogen, which is added to the feeds to the burners in order to optimize efficiency and address environmental issues, is the most hazardous substance involved, as will be further explained, the gas group is classified as IIC.

### Temperature class of electrical apparatus

The highest temperature that can be reached in service under the most undesirable conditions (but within tolerances) by any component or surface of an electrical apparatus that could cause the surrounding atmosphere to ignite is defined by the temperature class of electrical apparatus for explosive gas atmospheres.

The ignition temperature of the flammable substance that creates the explosive atmosphere has an impact on the choice of temperature class for electrical equipment.

Electrical equipment is categorized by the IEC (International Electrotechnical Commission) requirements temperature classification system according to how well it can tolerate specific operating temperatures. These classifications guarantee that equipment can operate safely in unexpected environmental circumstances.

For both manufacturers and end users, the IEC's temperatures are essential. Manufacturers can make sure that their products are made to endure specific outside circumstances by putting these guidelines into operation. This makes it possible for them to give accurate data regarding the anticipated reliability, lifetime, and performance of their electrical equipment.

According to IEC 60079-0, the typical atmospheric conditions that electrical equipment can be assumed to function in are:

- Temperature –20 °C to +60 °C;
- Pressure 80 kPa (0,8 bar) to 110 kPa (1,1 bar)
- Air with normal oxygen content, typically 21 % (volume percentage)

According to the IEC Standard, the maximum surface temperature of electrical apparatus shall be less than the Ignition temperature of gas or vapor originating the explosive atmosphere.

| **maximum surface temperature of electrical apparatus** | **<** | **Ignition temperature of gas or vapor originating the explosive atmosphere** |
|---|---|---|

*Table 3: Temperature Class (IEC Standard)*

| **Temperature Class** | **Maximum Surface Temperature of electrical apparatus °C (°F)** | **Ignition temperature of gas or vapor originating the explosive atmosphere °C (°F)** |
|---|---|---|
| **T1** | **≤ 450(842)** | **≥ 450(842)** |
| **T2** | **≤ 300(572)** | **≥ 300(572)** |
| **T3** | **≤ 200(392)** | **≥ 200(392)** |
| **T4** | **≤ 135(275)** | **≥ 135(275)** |
| **T5** | **≤ 100(212)** | **≥ 100(212)** |
| **T6** | **≤ 85(185)** | **≥ 85(185)** |

Electrical and non-electrical equipment installed within a hazardous area shall guarantee that maximum surface temperature is lower than ignition temperature of the gas and/or dust generating the hazardous area.

A more cautious approach was deliberately taken in this study by choosing Temperature Class T4 (maximum surface temperature 135 °C), even though the ignition temperatures of the flammable substances involved—primarily hydrogen, natural gas, and other light hydrocarbons—are relatively high (typically above 500 °C) and would theoretically permit the adoption of Temperature Class T5 or T6. In the application of ATEX (Directive 2014/34/EU) and IEC 60079-10-1, where choosing a lower temperature class is advised when dealing with high-diffusivity gases like hydrogen (Gas Group IIC), particularly under high-pressure conditions (up to 15 bars in this case), industry best practices and standard safety margins support this decision.

The risk of ignition is greatly increased by hydrogen's high flame speed, low minimum ignition energy, and tendency to leak through small openings, significantly in the case of equipment failure or hot surface formation. By taking into consideration potential equipment degradation, abnormal operating conditions, or uncertainty in the actual surface temperatures of components over time, T4 implementation thus adds an extra degree of safety.

# CHAPTER 3

# CASE STUDY DESCRIPTION

## 3.1. Plant Process Description

Direct reduced iron (DRI), also known as sponge iron, is made when iron ore (in lumps, pellets, or fines) is directly reduced into iron using a reducing gas that contains hydrogen and/or elemental carbon (from coal or natural gas). A lot of ores can be reduced directly. The term "direct reduction" describes solid-state procedures that, at temperatures lower than iron's melting point, convert iron oxides to metallic iron. The term "reduced iron" comes from these procedures, such as heating the iron ore in a furnace at a high temperature, about 800°C to 1200°C, when syngas, a combination of carbon and hydrogen, is present.

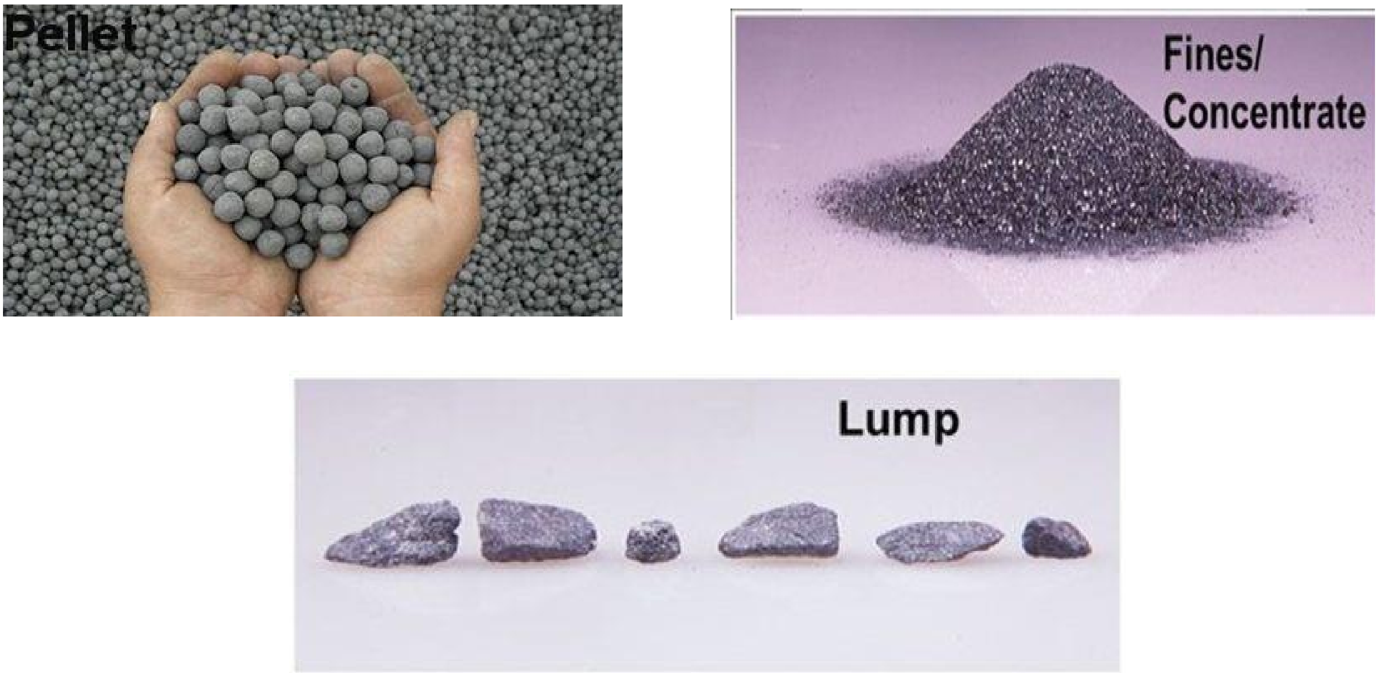


*Figure 3: Different Types of Iron Ore*

For almost 50 years, HYL (now Tenova HYL) has created technology to increase steel plants' efficiency and competitiveness in the steelmaking industry. Although HYL direct reduction (DR) is certainly the most well-known, there are other technologies that are intended to produce steel in more economical and efficient methods. Over the years, the HYL Process has been refined, and the most recent version of the technology, known as the HYL ZR (selfreforming) Process, was created to enable the reduction of iron ores in a shaft furnace without the need for external gas reforming apparatus. *(Duarte and Becerra, 2007)*

Due to its increased stability, this process scheme can produce High Carbon DRI, enabling producers to maximize the use of carbon in the steel-making process while also eliminating the need for expensive briquetting equipment for product sales to merchants. The new brand ENERGIRON is at the forefront of the direct reduction market thanks to the recent partnership with Tenova HYL, Techint, and Danieli. *(Maggiolino, 2018)*

(Pauluzzi *et al.*, 2021) Global environmental regulations place strict requirements on the design of all kinds of industrial plant operations. The flexible process configuration of ENERGIRON technology allows it to meet and surpass these specifications. The process can be easily established to run using coke oven gas, syngas from coal gasifiers, and other hydrocarbon sources in locales where natural gas is either too expensive or not easily accessible. More significantly, the process's water and air effluents are easily controlled and have minimal levels. Over the past ten years, the use of selective carbon dioxide removal technologies has been crucial in significantly reducing emissions levels and giving the plant operator access to more sources of income from the CO2 that is captured.(Pauluzzi *et al.*, 2021)

When paired with the high temperature Pneumatic Transport System, an ENERGIRON plant's closed system and high pressure operation minimize dust emissions to settling tanks and the air, making the process more cost-effective and environmentally friendly.

One important step in lowering the size and increasing the effectiveness of direct reduction plants is the ENERGIRON Process, which is shown in Figure 4 and is based on the ZR scheme. Oxygen is injected at the reactor's input, natural gas is fed as make-up to the reducing gas circuit, and reducing gases are produced in situ in the reduction reactor.

An external reducing gas reformer is not necessary because all reducing gases are produced in the reduction section, utilizing the metallic iron's catalytic effect inside the shaft furnace to achieve maximum reduction efficiency. A ZR plant has a lower total investment than a traditional DR plant with a reformer, in addition to having reduced operating and maintenance costs and better DRI quality.

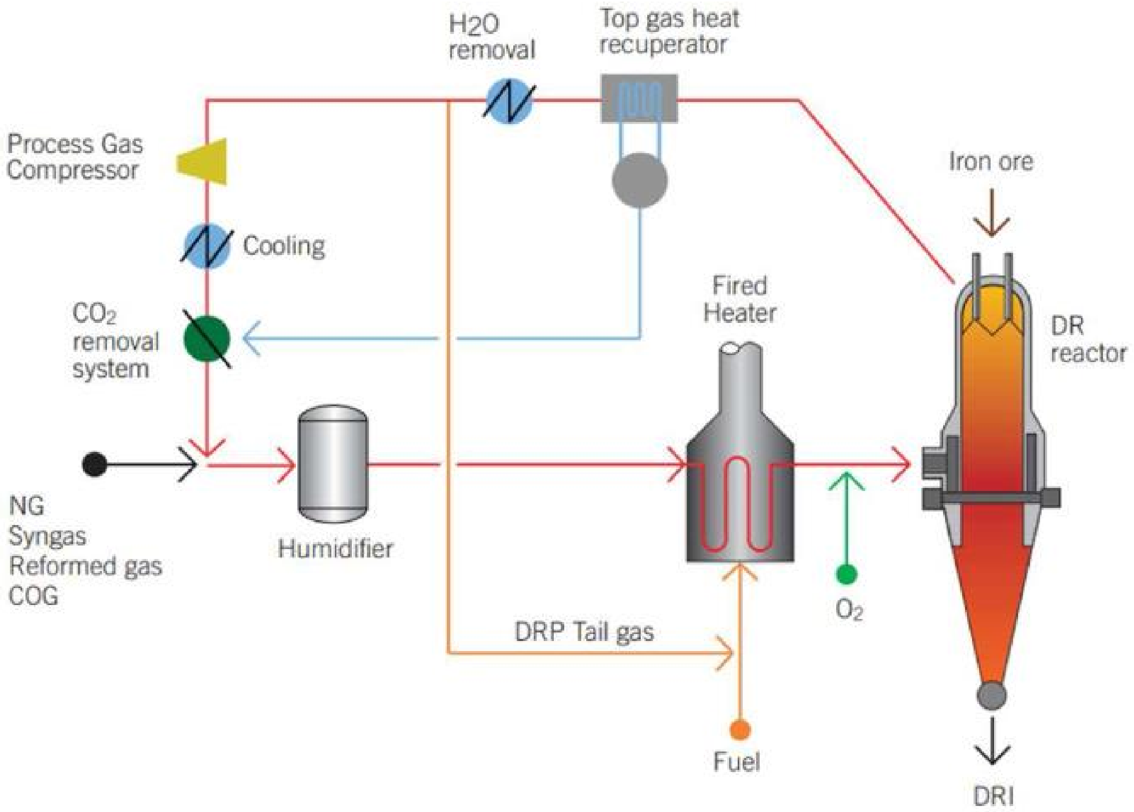


*Figure 4: Flowsheet of DRI Plant(with the courtesy of ENERGIRON)*

Direct utilization of natural gas is allowable under the basic ENERGIRON plan. Obviously, the conventional steam-natural gas reforming equipment that has formally defined the process can also be used in ENERGIRON plants. Depending on the particular situation and availability, additional reducing agents, including hydrogen, gases from the gasification of coal, petcoke, and related fossil fuels, and coke-oven gas, are also possible sources of reducing gas.

Furthermore, the DR plant can be built to produce hot DRI, high-carbon DRI, or any mix of these products that can be fed straight to adjacent EAF through the HYTEMP System or to briquetting equipment that produces HBI.

Reforming reactions:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$
$$CH_4 + CO_2 \rightarrow 2CO + 2H_2$$

Reducing reactions:

$Fe_2O_3 + 3CO \rightarrow 2Fe^0 + 3CO_2$

$Fe_2O_3 + 3H_2 \rightarrow 2Fe^0 + 3H_2O$

High reduction temperature (over 1050°C), "in-situ" reforming within the shaft furnace, and lowered utilization of thermal equipment in the plant all contribute to the ZR process's overall energy efficiency. As a result, the product uses the majority of the energy used in the process, with the minimum energy losses to the environment. The selective removal of both by-products generated by the reduction process, specifically carbon dioxide (CO2) and water (H2O), is one of the intrinsic features of the process scheme and is essential for this purpose. These are eliminated using CO2 removal systems and top gas scrubbing, respectively.

A high productivity of about 10 tonne/hour × $m^2$ is made possible by the shaft furnace's operation at elevated pressure (6 bars, absolute), which also reduces dust losses due to top gas carryover. consumption of iron ore will be decreased as well as the operational costs.*(Duarte and Becerra, 2007)*

## 3.2. Heating Unit Description

The steel industry is under unprecedented pressure to lower $CO_2$ emissions and achieve sustainable energy development as a result of the growing environmental problems and ongoing depletion of fossil fuels. considering its variety of sources, high calorific value, good thermal conductivity, and high reaction rate, hydrogen is regarded as the most promising clean energy of the twenty-first century. Therefore, it has a lot of promise for use in the steel industry.

To clean, heat, and modify the gas composition to the required characteristics suitable for iron ore reduction, the main process gas loop consists of multiple unit operations.

The most efficient gas reformer in the world has been modified by the latest technology to create a Process Gas Heater (PGH) that can be used with a variety of alternative fuels, including hydrogen, in the DRI Process.

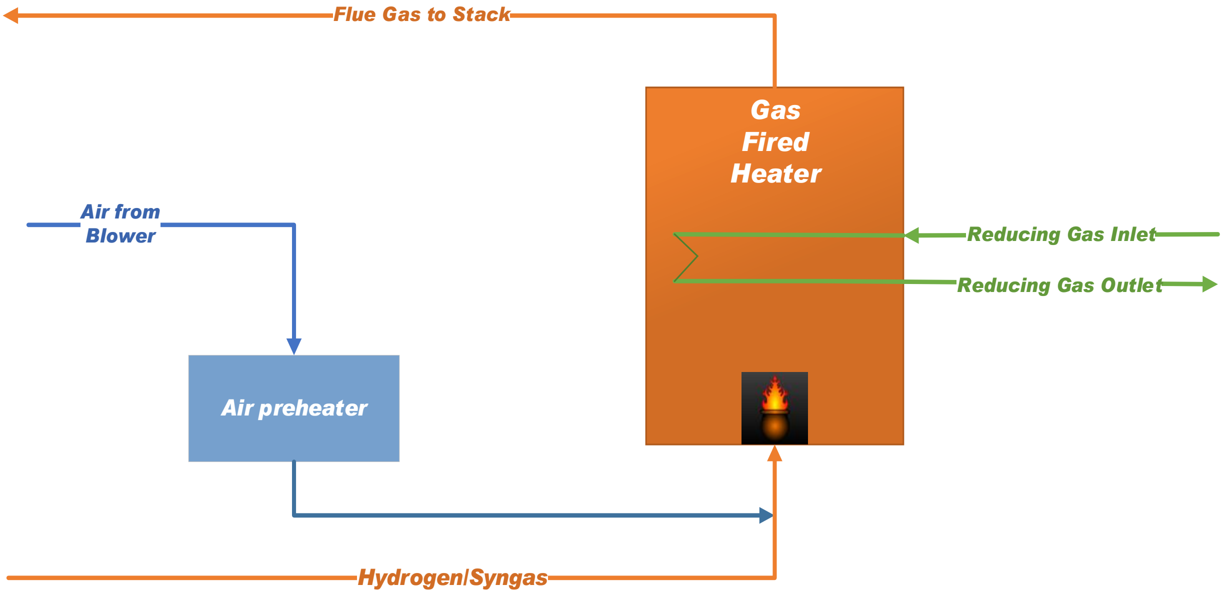


*Figure 5: DRI Heating unit Block Diagram*

The needed heat duty is not significantly affected by the entrance gas temperature range of 35°C to 55°C, since the exit gas stream must be heated to a considerably higher temperature. The lowest temperature needed for direct reduction is 760°C, although the state-of-the-art requires substantially higher temperatures. In most factories, it is preferable to heat the gas to the highest temperature feasible, which is mostly constrained by the DRI's softening temperature. It is reasonable to assume that the heater's output gas will be around 950°C in current plants.

In this regard, in new plants or to modify the process of previous DRI plants, Hydrogen is being added to the burner's fuel.

## 3.3. Process Gas Fired Heater

According to the detailed PFD of the heating unit of the DRI plant shown in Figure 5, this unit includes a gas-fired process heater responsible for increasing the temperature of process gases used in the blast furnace in the reduction unit of iron ore, which will rise from the range of atmospheric to almost the iron melting point.

The fuel of the fired heater is a combination of Natural gas, Tail gas, including Hydrogen, and cooling tail gas, which is a recycled stream from the cooling section of the blast furnace, which still contains some combustible components (e.g CO & H2& CH4) and using as a fuel helps the efficiency of the system.

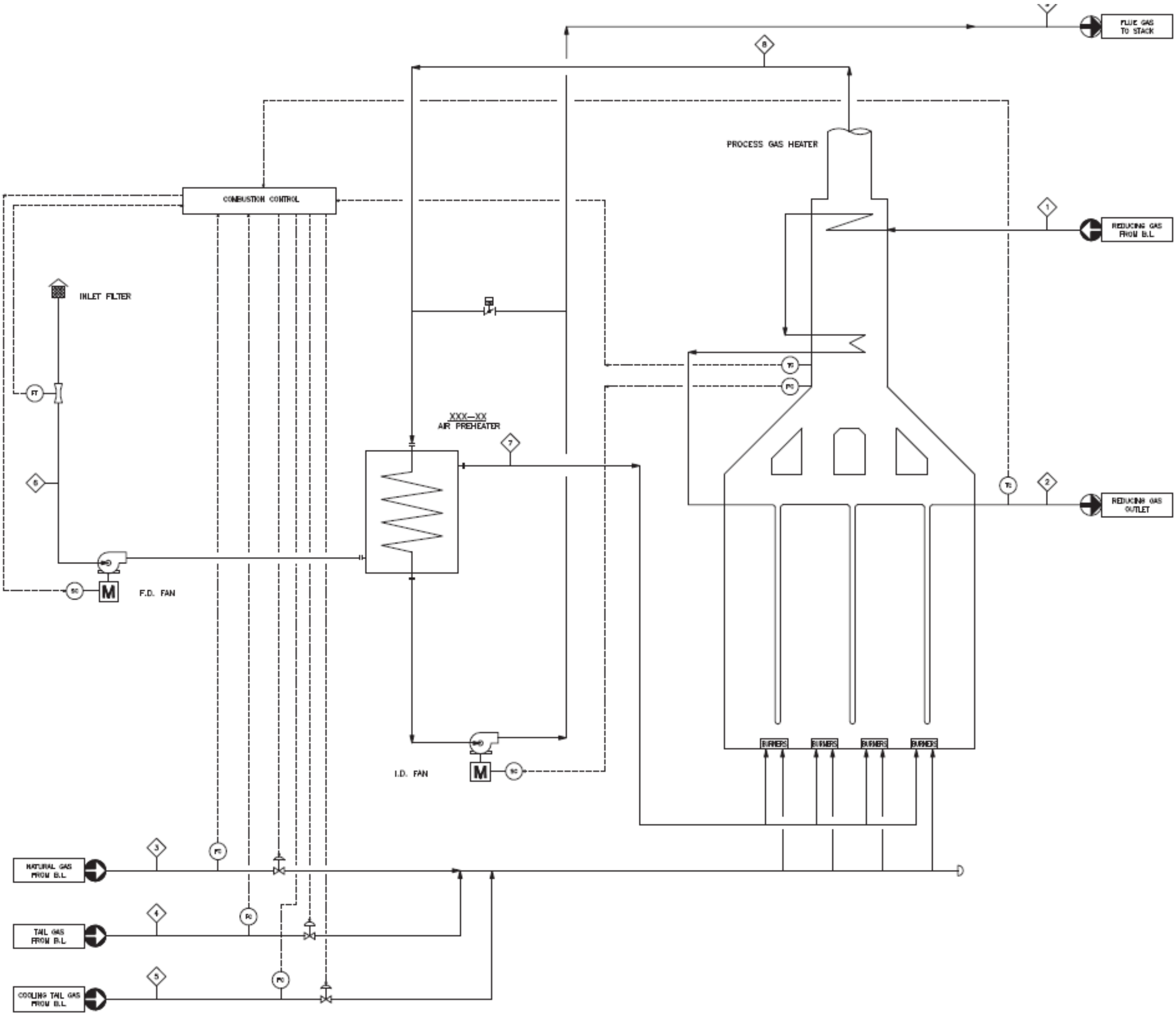


*Figure 6: Process Gas Fire Heater PFD*

Each fuel stream passes through individual control valves before being routed to the burner system, which is controlled by the combustion control system and changes the flow of the fuel supply according to the burners' demand and to maintain an optimal and desired flow rate for the combustion.

To support combustion, air is supplied to the system by a blower, with its flow rate regulated by the combustion control system using control valves on the pipes. Before sending the air to the burners, it passes through a preheater where its temperature rises from atmospheric to the temperature needed for combustion by absorbing heat from the outgoing flue gas from the heater. This process improves energy efficiency by recovering heat from the heating unit, also reducing fuel consumption and operation costs.

The fuel gas feeds multiple burners (in this heater, there are 48 burners) for increasing the temperature of reducing gas to the desired temperature through the vertical convection section and the radiation section. The whole system of the heater is equipped with a distributed control system and is monitored by safety interlocks through BMS (Burner Management System).

The temperature of the reducing gas increases by passing through the tubes inside the heater and is then routed to the blast furnace to reduce the iron through the direct process.

The hot flue gas exits the fired heater and flows through the preheater, where heat recovery is happening and increases the temperature of the incoming air. Also, another option is to cool the flue gas in an indirect way and then discharge the flue gas to the stack with the help of a fan.

Attachment I contains the Process Flow Diagram (PFD) illustrating the Heating Unit layout.

Attachment II presents the Material Balance of the process for different Cases, which shows the unit receives different feeds seasonally and occasionally.

# CHAPTER 4

# METHODOLOGY, CALCULATIONS

Assessing areas that are hazardous or non-hazardous should be done methodically. To ascertain whether hazardous areas exist and to assign hazardous area zones to those locations, risk assessment should be utilized. For the evaluation, it needs to consider steps including:

- The properties of hazardous substances
- The hazardous quantity of those substances
- The work processes and their interactions
- The temperatures and pressures at which the dangerous substances will be handled
- Emission point of dangerous substances
- System of ventilation

These elements work together to identify any zoned area and provide the basis for classifying hazardous areas.

## 4.1 Hazardous substances

Based on material balance, the components in the feeds and the outlet streams are as follows

*Table 4: List of Components(Case of this study)*

| Component | Formula |
|---|---|
| Hydrogen | $H_2$ |
| Methane | $CH_4$ |
| Ethane | $C_2H_6$ |
| Propane | $C_3H_8$ |
| Butane/I butane | $C_4H_{10}$ |
| Pentane/ I pentane | $C_5H_{12}$ |
| Hexane | $C_6H_{14}$ |
| Carbon monoxide | $CO$ |
| Carbon dioxide | $CO_2$ |
| Nitrogen | $N_2$ |
| Hydrogen Sulfide | $H_2S$ |
| Ethylene | $C_2H_4$ |
| Sulfur dioxide | $SO_2$ |
| Oxygen | $O_2$ |

Hazardous substances based on flammability potential are:

*Table 5: Hazardous substances*

| Component | Formula | Ignition Temperature (°C) |
|---|---|---|
| Carbon Monoxide | CO | 605 |
| Hydrogen | $H_2$ | 500 |
| Methane | $C_2H_4$ | 537 |
| Ethane | $C_2H_6$ | 515 |
| Propane | $C_3H_8$ | 450 |
| Iso butane | $C_4H_{10}$ | 460 |
| Butane | $C_4H_{10}$ | 365 |
| Iso pentane | $C_5H_{12}$ | 420 |
| Pentane | $C_5H_{12}$ | 260 |
| Hexane | $C_6h_{14}$ | 234 |

The boiling point and flash point of any flammable liquid, as well as whether any flammable gases or vapors that may form are lighter or heavier than air, represent some of the characteristics of a hazardous material that must be known.

## 4.2 Release Estimation

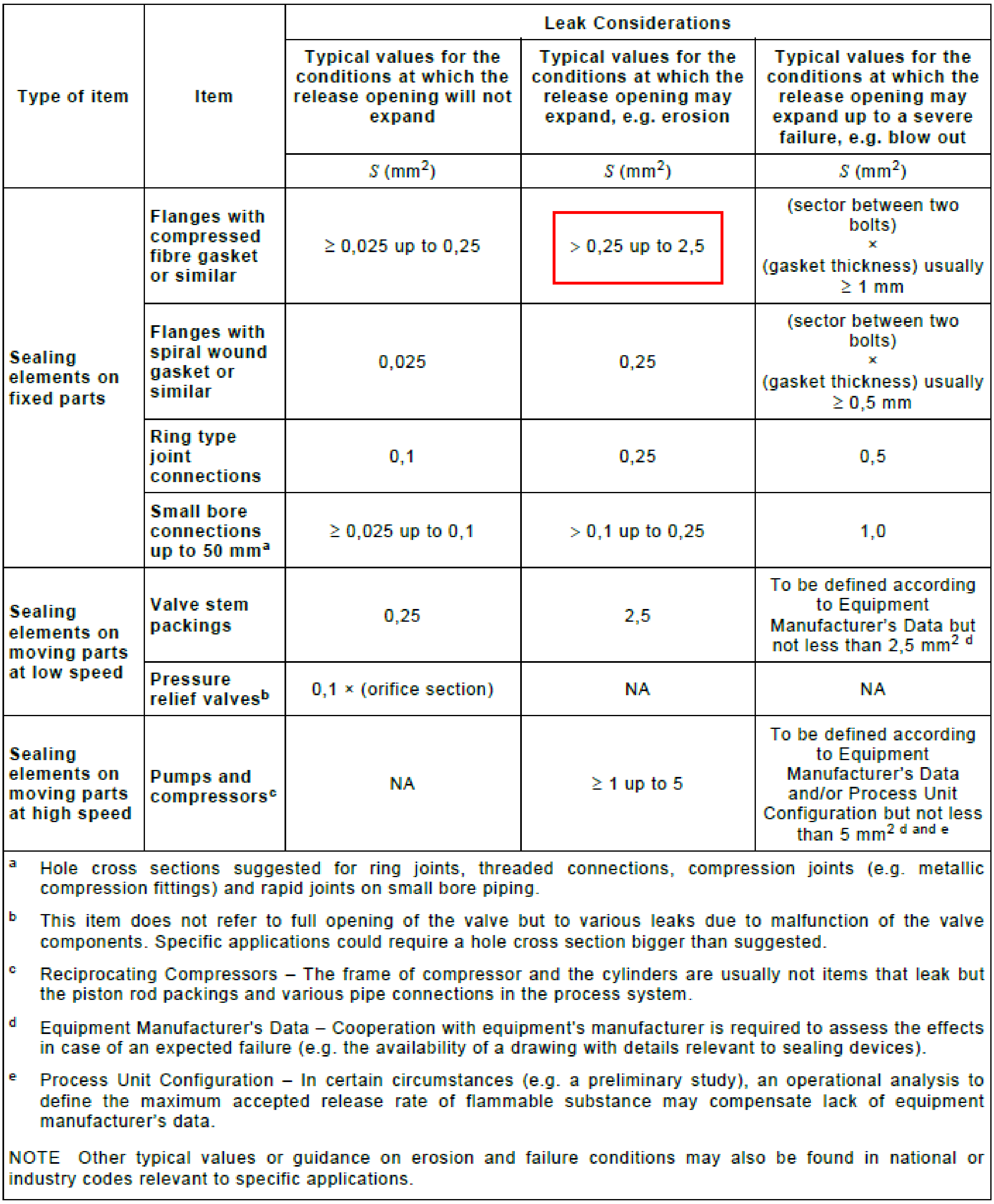
Some possible sources of release may be so minor so do not result in the formation of a hazardous area. This is the situation if the result of an ignition following a release is unlikely to endanger people in the vicinity. However, additional sources of release are not negligible.

One of the most important possible sources of release of flammable liquid or gas/vapors in the petrochemical plants is flanged connections. Flanges pose a serious danger of leaks because of their extensive use in pipelines and their susceptibility to vibration, mechanical stress, and thermal cycling. Specifically, they account for a significant portion of the overall amount of hazardous materials that could be accidentally released. They are therefore regarded as a high-priority node for this study.

The square of the equivalent hole radius determines the release rate. This means that the release rate is a portion of the equivalent hole radius. Therefore, a slight underestimation of this hole size will result in a significant underestimation of the computed release rate value.

The type of release would determine the representative hole size estimation. The size and shape of the release orifice determine the equivalent hole sizes for continuous and primary grades of release. For instance, venting has to do with its output. The equivalent hole size is according to the *(IEC 60079-10-1:2020, 2015),* which is labeled as Table B.1in this standard.

*Table 6: Leak size range of cross section per source of secondary grade release Acc. to IEC 60079-10-1:2020*



| **Type of item** | **Item** | **Leak Considerations** | | |
|---|---|---|---|---|
| | | **Typical values for the conditions at which the release opening will not expand** | **Typical values for the conditions at which the release opening may expand, e.g. erosion** | **Typical values for the conditions at which the release opening may expand up to a severe failure, e.g. blow out** |
| | | $S$ ($\mathrm{mm}^2$) | $S$ ($\mathrm{mm}^2$) | $S$ ($\mathrm{mm}^2$) |
| **Sealing elements on fixed parts** | **Flanges with compressed fibre gasket or similar** | ≥ 0,025 up to 0,25 | > 0,25 up to 2,5 | (sector between two bolts)<br>×<br>(gasket thickness) usually ≥ 1 mm |
| | **Flanges with spiral wound gasket or similar** | 0,025 | 0,25 | (sector between two bolts)<br>×<br>(gasket thickness) usually ≥ 0,5 mm |
| | **Ring type joint connections** | 0,1 | 0,25 | 0,5 |
| | **Small bore connections up to 50 mm**[a] | ≥ 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 | To be defined according to Equipment Manufacturer's Data but not less than 2,5 $\mathrm{mm}^2$ [d] |
| | **Pressure relief valves**[b] | 0,1 × (orifice section) | NA | NA |
| **Sealing elements on moving parts at high speed** | **Pumps and compressors**[c] | NA | ≥ 1 up to 5 | To be defined according to Equipment Manufacturer's Data and/or Process Unit Configuration but not less than 5 $\mathrm{mm}^2$ [d and e] |

[a] Hole cross sections suggested for ring joints, threaded connections, compression joints (e.g. metallic compression fittings) and rapid joints on small bore piping.

[b] This item does not refer to full opening of the valve but to various leaks due to malfunction of the valve components. Specific applications could require a hole cross section bigger than suggested.

[c] Reciprocating Compressors – The frame of compressor and the cylinders are usually not items that leak but the piston rod packings and various pipe connections in the process system.

[d] Equipment Manufacturer's Data – Cooperation with equipment's manufacturer is required to assess the effects in case of an expected failure (e.g. the availability of a drawing with details relevant to sealing devices).

[e] Process Unit Configuration – In certain circumstances (e.g. a preliminary study), an operational analysis to define the maximum accepted release rate of flammable substance may compensate lack of equipment manufacturer's data.

NOTE Other typical values or guidance on erosion and failure conditions may also be found in national or industry codes relevant to specific applications.

- For ideal conditions, like operating at well below design ratings, the standard recommends using a lower value.
- When operating conditions are close to design ratings, or adverse conditions, the standard recommends using Higher values:

In case of simultaneous releases, depending on the type of release, the releases in indoor areas with many release sources may be summed up.

The standard provides a list of equivalent hole sizes for secondary grade releases. As in this case of this thesis, we are in the Secondary grade of release situation.

- To describe the **Secondary grade release**: In normal operations, these releases are not expected, thus it is unlikely that more than one secondary source would release at the same time, so just the largest secondary release should be evaluated.

  For example: compressors and valves where it is not expected that flammable substances will be released during normal operation; flanges, connections, and pipe fittings where it is not expected that flammable substance will be released during normal operation; sample points where it is not anticipated that flammable material will be released during normal operation; relief valves, vents 12, and other openings where it is not expected that flammable material will be released into the atmosphere during normal operation.

- To describe the **Primary grade release**: Although these releases happen during normal operations, it is unlikely that they will all happen at once. Therefore, the installation experience should be used to determine the maximum number of primary grade releases that can be released simultaneously.
- To describe the **Continuous grade release**: Since these sources are expected to be permanently released, all continuous grade releases ought to be summed.

(Quesnel *et al.*, 2024) The researchers had access to several in-house zone sizing methods. These techniques provide hole diameters ranging from 2.50 $mm^2$ to 0.25 $mm^2$ or smaller. The method is predicated on a collection of hole sizes (or classes) that contain the range of sizes utilized in industry standards and procedures, which were primarily relevant to applications in the oil and gas industry.(Quesnel *et al.*, 2024)

The most important source of release of flammable liquid or gas is the flange, which is also the most significant in terms of the quantity of substance released into the environment, the section is 0.25 to 2.5 $mm^2$ as per current technical regulations for flanges and their gaskets leakage.

For a leak in a gasket, the principal severe leak considered is usually the loss of a section of the gasket between two bolts. Information is required on flanges and associated bolts for different pipe sizes.

### 4.2.1 Standard Hole Size Area Classes Proposed By (R. Cox, 1990)

#### 4.2.1.1 Flanges

Flanges can typically be categorized as three groups: Compressed Fibre (CAF), Spiral Wound Joint (SWJ), and Metal-to-Metal Ring Type (RTJ).

Compressed Fibre gaskets have a normal thickness of 1.6 mm. There are further thicknesses of 0.6 mm and 3 mm. The aperture provided by a leak from the Spiral Wound Joint and Metal-to-Metal ring type flanges is significantly smaller. When a gasket fails, the hole size could be the entire space between bolt holes or smaller than that. The hole may be the result of pitting or scoring in a metal-to-metal joint, and it is rare to extend over a whole section. In industrial practice, the sector between bolt holes and the actual gasket thickness are typically used to determine the hole size for a complete section failure of a gasket.

A standard value for a CAF gasket is 2.5 $mm^2$, whereas for an RTJ, it is 0.25 $mm^2$. The SWJ gasket is in the middle of these two values for smaller holes, which are understood as situations that do not involve complete section failure. For a CAF gasket, the sector between two bolts is used to calculate the hole size once the hole width of 1 mm has been specified. For example, the hole size would be 50 $mm^2$ if the arc was 50 mm. A 2.5 $mm^2$ leak is considered to be smaller. The hole width for an SWJ gasket is assumed to be 0.05 mm. The hole size would then be 2.5 $mm^2$ for the same example. A 0.25 $mm^2$ leak is considered to be smaller. A smaller leak is defined as 0.1 $mm^2$ for an RTJ.

#### 4.2.1.2 Valves

*(R. Cox, 1990)* have adopted hole size values of 0.25 $mm^2$ for normal duty valves and 2.5 $mm^2$ for large (>150mm) and severe duty valves. In industrial practice, holes are normally 0.25 $mm^2$, although in more extreme situations, they can be 2.5 $mm^2$.

#### 4.2.1.3 Piping Systems

If a risk-based approach is used, it may not be necessary to classify flanges and valves as causing a danger because the probability of a release from a single item is very low, especially if they are not used at high pressures or temperatures. An area should only be classified if there are several potential leak sources in close proximity to one another. As a general rule, an area should be designated as Zone 2 if there are more than ten leak sources nearby. The more recent versions these studies suggest much larger hole sizes, more than 1 mm, which are considerably bigger than most of the references used for Hazardous Area Classification. in some specific cases, even a size bigger than the pipework size used for the installation is suggested.

## 4.3 Flammable Gases

As can be seen in the composition of streams according to the material balance (Appendix II), hydrogen is not the only flammable gas, but considering the extreme volatility of the gas and even the one with the lowest molecular weight, it is the most dangerous. Additionally, hydrogen tends to escape into the air first in case of failure since it cannot be mixed with other petroleum-derived gases, therefore for greater safety possible the classification is represented by HYDROGEN.

## 4.4 Release rate

As mentioned before, the most important source of release of flammable gas (when we are in the secondary grade of release phase) in this case study and generally in petrochemical plants is by the flange, which is also the most significant in terms of the quantity of substance released into the environment, the section is 0.25 $mm^2$ as per current technical regulations. And it has to be calculated for each stream containing flammable gases, or better to say, hazardous substance, following the calculation procedure based on IEC 60079-10-1:2020

The release rate depends on parameters such as:

a) Nature and type of release

This is related to the physical characteristics of the source of release, for example, an open surface, a leaking flange, etc.

b) Release velocity

For a given source of release, the release rate increases with the release pressure. For a subsonic release of gas, (which a subsonic release occurs when a gas is released at a speed less than the speed of sound, which is typically less than Mach 1 ( less than 343 m/s in air at 20°C) and compared to a sonic (choked) or supersonic release, a subsonic release is typically less violent and Small holes, flanges, valves, or pin-hole leaks can all cause it, especially in systems with low to moderate pressure) the release velocity is related to the process pressure. The size of a cloud of flammable gas or vapor is determined by the rate of flammable gas or vapor release and the rate of dilution. Gas and vapor flowing from a leak at high velocity will entrain air and may be self-diluting. The extent of the explosive gas atmosphere may be almost independent of air flow. If the substance is released at low velocity or if its velocity is reduced by impingement on a solid object, it will be carried by the air flow, and its dilution and extent will depend on the air flow.

c) Concentration

The mass of flammable substance released increases with the concentration of flammable vapor or gas in the released mixture.

d) Volatility of a flammable liquid

This is related principally to the vapor pressure and the enthalpy (heat) of vaporization. if the vapor pressure is not known, the boiling point and flash point can be used as a guide.

### 4.4.1 Release velocity

The following equation calculates the critical pressure, which is different from the thermodynamic critical pressure

$$P_c = P_a \left(\frac{\gamma + 1}{2}\right)^{\gamma/\gamma - 1} \ (P_a)$$

The approximation pc ≈ 1,89 pa will typically work well for a rough estimate for the majority of gases. When compared to most operational pressures noticed in typical industrial processes, critical pressures are often low. Terminal gas supply lines to fired equipment, such as heaters, furnaces, reactors, incinerators, vaporizers, steam generators, boilers, and other process equipment, typically have pressures lower than the critical pressure. *(BS EN IEC 60079-10-1:2021, 2021)* In this thesis, we are in this noted situation. The pressure on the stream with the maximum amount of release rate of hydrogen due to the maximum hydrogen quantity is 9.8 bar, which is higher than Pc.

For an ideal gas, we have:

$$\gamma = \frac{MC_P}{MC_P - R}$$

The release rate of gas will be calculated through this formula:

$$W_g = C_d SP \sqrt{\gamma \frac{M}{ZRT}\left[\left(\frac{2}{\gamma + 1}\right)^{\gamma+1/\gamma - 1}\right]} \quad (kg/s)$$

$C_d$: discharge coefficient, S: cross section of the opening (hole), P: pressure inside the container (Pa),ɣ: polytropic index of adiabatic expansion or ratio of specific heats (dimensionless), Z: compressibility factor (dimensionless), R: universal gas constant (8314,5 J/kmol K), T: temperature of the flammable gas (K);

- discharge coefficient (dimensionless), a characteristic of the release openings that takes into consideration the effects of viscosity and turbulence; it is normally between 0.95 and 0.99 for rounded orifices and between 0.50 and 0.75 for sharp orifices;

The volumetric flow rate of gas in ($m^3$/s) is equal to:

$$Q_g = \frac{w_g}{\rho_g} (m^3/s)$$

Where

$\rho_g = \frac{P_a M}{R\, T_a}$ is the density of the gas (kg/$m^3$)

NOTE: Where the temperature of the gas at the release opening may be below the ambient temperature, it is often used as equal to the gas temperature to provide an approximation for easier calculations, although in most cases, we are around the ambient temperature, except for streams that will be heated in the heater.

Calculation for the hydrogen as the most hazardous substance for the stream which has the most flow, which is stream number 1(ID 1, Case 2). Reducing gas from battery limit, with 51.475% volume fraction of the stream, is described here:

*Table 7: Worst-case Release Rate Calculations*

| | |
|---|---|
| $C_d$ = 0.75 | 0.99 regular-shaped release source |
| | 0.75 Irregular-shaped release source |
| S =$2.5\times10^{-6}$ $m^2$ | hole cross-section for secondary grade of release |
| P = 9.8 bar ≈ 980000 pa | Stream pressure |
| M = 2.01568 kg/kgmol | Molar mass |
| Z=1 | Gas compressibility factor |
| R = 8.314 kj/kg mol k | universal gas constant (8314,5 J/kmol K); |
| T = 81°C ≈ 354.15 k | Stream temperature |
| $\gamma$ =1.400245281 | Considering cp @ 350K = 14.43 kj/kg k |
| $P_a = 101325\ Pa$ | Atmospheric pressure |
| Wg =1.2 × 10-4 kg/s | |

For all the streams, the calculation has been done in the Excel file (Appendix III) in different cases and conditions (Cases 1 to 3). The worst case is the maximum release rate of the hazardous substance. In some processes, stream compositions in a chemical plant are not constant, so this approach is necessary, especially for input feed streams entering the plant from the battery limits, which are typically output streams from other units.

## 4.5 Ventilation and dilution

To identify the type of zone or zones by evaluating the kind and probable extent of gas or vapor emissions and contrasting these elements with the way those gases or vapors are dispersed and diluted by ventilation or air movement.

Due to related standards, it is approved that releases may take many forms and can be dependent by many conditions including: type of substance (gases, vapors or liquids), indoor or outdoor locations, sonic or subsonic jets, fugitive or evaporative releases, obstructed or unobstructed conditions and substance density.

The idea of ventilation is not strictly applicable in outdoor settings, and the risk will vary depending on the source's characteristics, the gas's characteristics, and the airflow in the surrounding area. In open-air settings, air movement is frequently enough to guarantee that any explosive gas environment that forms in the vicinity is dispersed.

In order to assess the degree of dilution, it is necessary to consider basic steps as expected release conditions, including the size of the source and the maximum release rate of hazardous substances.

The interaction of a release's buoyancy and momentum forces with the atmospheric conditions in which it is dispersing determines the dilution of the release. For an unimpeded jetted release, for example, from a vent, the jet momentum dominates and the initial dispersion is dominated by the shear between the release and the atmosphere. However, suppose a jetted release is at low velocity or is impeded to such an extent that the momentum is redirected or dissipated. In that case, the release buoyancy and atmospheric effects become more important.

For small releases of lighter-than-air gas, the dispersion in the atmosphere will dominate, for example, similar to the dispersion of cigarette smoke. For larger releases of lighter-than-air gas the stage may eventually be reached, especially in low wind conditions, when the release buoyancy is significant and the release will lift off from the ground and disperse like a plume, for example, similar to the plume from a large bonfire. For vapor releases from a liquid surface, the vapor buoyancy and local air movement will dominate the dispersion behavior. In all cases, where there is adequate fresh air for dilution of a release to very small concentrations (i.e., well below the LFL), the diluted gas or vapor will tend to move along with the general mass of the air and exhibit neutral behavior. The exact concentration at which such neutral behavior is reached will depend on the relative density of the gas or vapor to air. For greater relative density differences, a lower concentration of the gas or vapor is required for neutral behavior.

If a gas leak exists, the gas must be transported away, or gas buildup will occur. The gas can be transported away by flow induced by the momentum in the gas leak, by buoyancy induced by the gas, or by flow caused by natural or forced ventilation, or by wind.

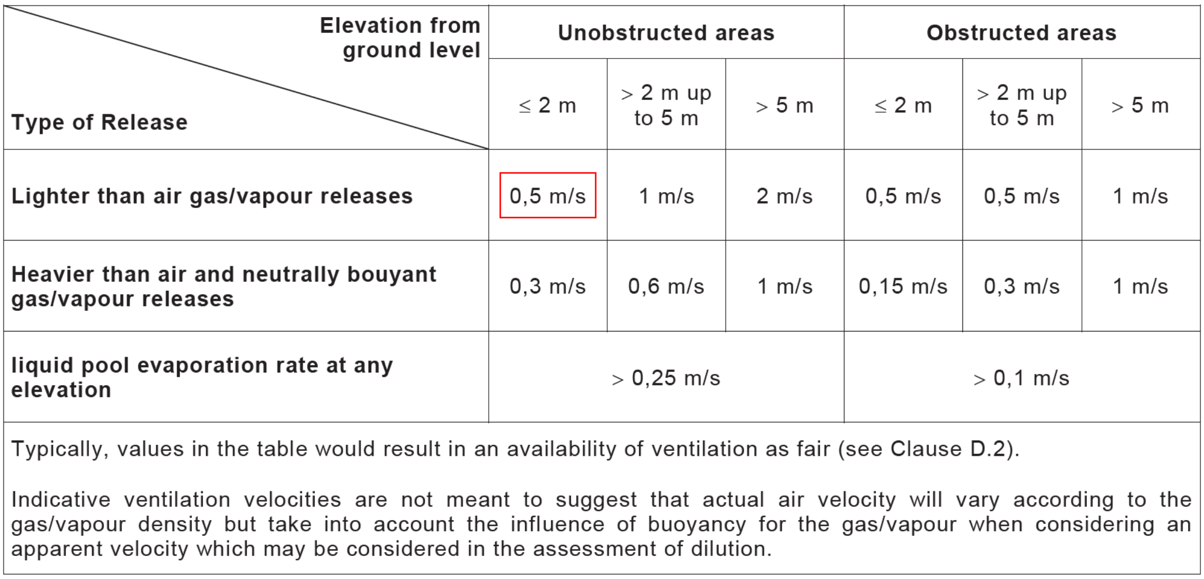
One item that should be identified in ventilation is to clarify if it is FAIR or not. By fair, we mean for spaces with natural ventilation in open areas, if the ventilation velocity exceeded 95 % of the time, the availability of ventilation will be addressed as FAIR

The presence of an explosive gas atmosphere is influenced by the availability of ventilation. Therefore, when choosing the type of zone, it is necessary to consider the availability (as well as the effectiveness) of ventilation. The availability of ventilation have three levels which are described as follow:

- **Good**: There is almost constant ventilation.
- **Fair**: Normal operation is expected to have ventilation. As long as discontinuities are short and infrequent.
- **Poor**: ventilation which does not meet the conditions as fair or good, but discontinuities do not take place over long periods.

Where statistical data are not available, the Table below illustrates a practical approach to defining ventilation velocity values outdoors.*(IEC 60079-10-1:2020, 2015)*

*Table 8: Indicative outdoor ventilation velocities (uw) due to IEC standard*



| **Elevation from ground level** / **Type of Release** | **Unobstructed areas** | | | **Obstructed areas** | | |
|---|---|---|---|---|---|---|
| | ≤ 2 m | > 2 m up to 5 m | > 5 m | ≤ 2 m | > 2 m up to 5 m | > 5 m |
| **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 |
| **Heavier than air and neutrally bouyant 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 |
| **liquid pool evaporation rate at any elevation** | > 0,25 m/s | | | > 0,1 m/s | | |
| Typically, values in the table would result in an availability of ventilation as fair (see Clause D.2).<br>Indicative ventilation velocities are not meant to suggest that actual air velocity will vary according to the gas/vapour density but take into account the influence of buoyancy for the gas/vapour when considering an apparent velocity which may be considered in the assessment of dilution. | | | | | | |

Ventilation velocity in this case study is **0.5 m/s**

### **Assessment of the degree of dilution** *(BS EN IEC 60079-10-1:2021, 2021)*

The following three degrees of dilution are normally recognized:

- **High dilution:** After the release has stopped, the concentration near the source of release rapidly decreases and almost completely disappears.

- **Medium dilution**: When the concentration is controlled, a stable zone boundary is created, keeping the explosive gas environment from continuing unnecessarily after the release has stopped.

- **Low dilution:** Significant concentration exists throughout the release process, and/or an explosive gas environment remains significantly after the release has stopped.

To determine the degree of dilution, it is necessary to know the ventilation velocity, which is already obtained from experimental data, and the volumetric release rate, which can be calculated from a related formula. Then, by referring to Figure 7, the dilution degree can be assessed.

*Figure 7: Chart for assessing the Dilution degree acc. to IEC*

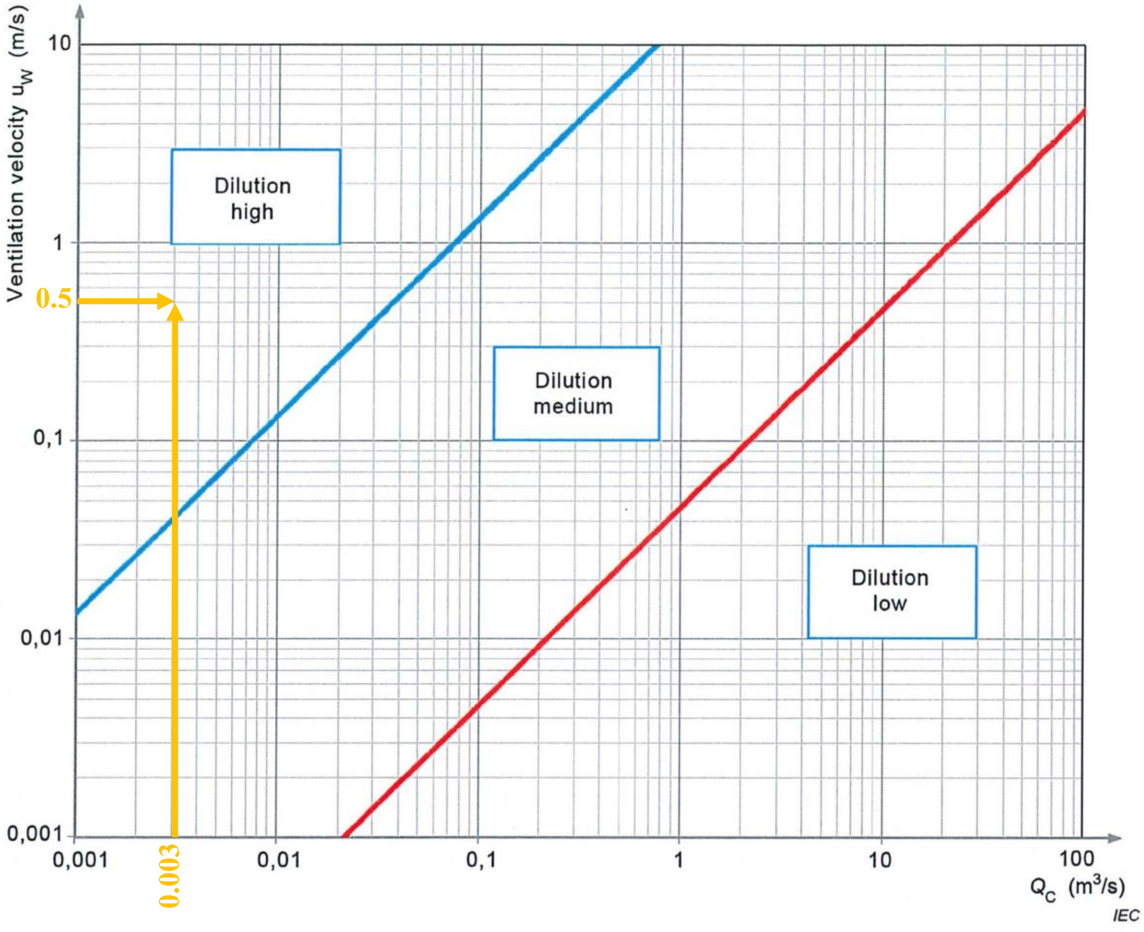


**Figure C.1 – Chart for assessing the degree of dilution**

Where

$Q_C = \frac{W_g}{\rho_g \times LFL}$ is the volumetric release characteristic of the source ($m^3$/s);

$\rho_g = \frac{p_a M}{R T_a}$ is the density of the gas/vapour ($kg/m^3$);

Assessing the Dilution for hydrogen in the worst-case study:

*Table 9: Assessing  Hydrogen Dilution Calculation*

| **EMISSION of Hydrogen from the Flange** | | |
|---|---|---|
| Lower flammability limit, LFL | 4 | % vol. |
| Density of the flammable gas (Hydrogen), ρg | 0.08989 | kg/m3 |
| Hydrogen emission rate, Wg (highest emission) | 0.000122565 | kg/s |
| Safety factor, k = 1 | 1 | k |
| Emission characteristic, Qc= Wg/(ρg × k × LFL) | 0.00340875 | $m^3/s$ |

A specific safety factor is not included due to the latest version of IEC. It should be chosen an proper amount based on the application and any safety considerations applied to other evaluation criteria, such as the estimated release rate.

The safety factor has been considered K=1 in this study. Also, the LFL is 4% for Hydrogen.

*Table 10: Examples of LEL / LFL values in % vol acc. to ISO/IEC 80079-20-1:*

| Gas | LEL / LFL (in % vol) |
|---|---|
| Acetone | 2.5 |
| Acetylene | 2.3 |
| Ammonia | 15.0 |
| Butane | 1.4 |
| Ethanol | 3.1 |
| Hydrogen | 4.0 |
| Isobutylene | 1.6 |
| Methane | 4.4 |
| Propane | 1.7 |
| Propylene | 2.0 |
| Toluene | 1.0 |

Using of Chart with: $u_w = 0.5\frac{m}{s}$ $and\ Q_c$ =0.00340875 $kg/m^3$ we will be in **High dilution** area.

## 4.6 Extent of Hazardous Areas

The release rate, along with a variety of additional factors like flammable gas qualities, release geometry, and surrounding geometry, determines the size of the hazardous area or region where flammable gas may occur.

Areas of the workplace that are connected to the possibility of an explosive atmosphere have been discovered in this study. Determining the immediate hazard zones as well as any nearby regions where an explosive environment might extend is one important step of hazardous area classification. With an effective release area of 2.5 $mm^2$

The most important source of release is found where the process valves and pipes connect which is done by process flanges. All other smaller sources are included in this release source, which is thought to be the main factor in the creation of an explosive atmosphere.

The extent of the hazardous area at different release points can be determined using Figure D.1 from the IEC standard, which is presented as Figure 8 in this thesis. Other methods of calculation or evaluation based on reputable sources could also be used.

CFD simulations for ventilation velocities provide the basis for the curves in this graphic. The chart's distances are provided as the minimum required for the specified release. This has been compared with the distances provided in reputable industrial codes and CFD simulations.

Depending on the kind of release, an appropriate line should be chosen, such as:

**JET**: Happens at a high-velocity, unimpeded jet release (usually a choked release). The 'Jet' curve should be used carefully because the 'Diffusive' curve may be a superior fit for many situations.

**Diffusive**: happens at a low-velocity diffusive jet release (usually subsonic) or a jet that loses momentum as a result of its release geometry or impact with an impingement surface.

**Heavy Gas**: Heavy vapors or gases that disperse over horizontal surfaces, such as the ground.

*Figure 8: Estimating Hazardous Area Distance acc. to IEC*

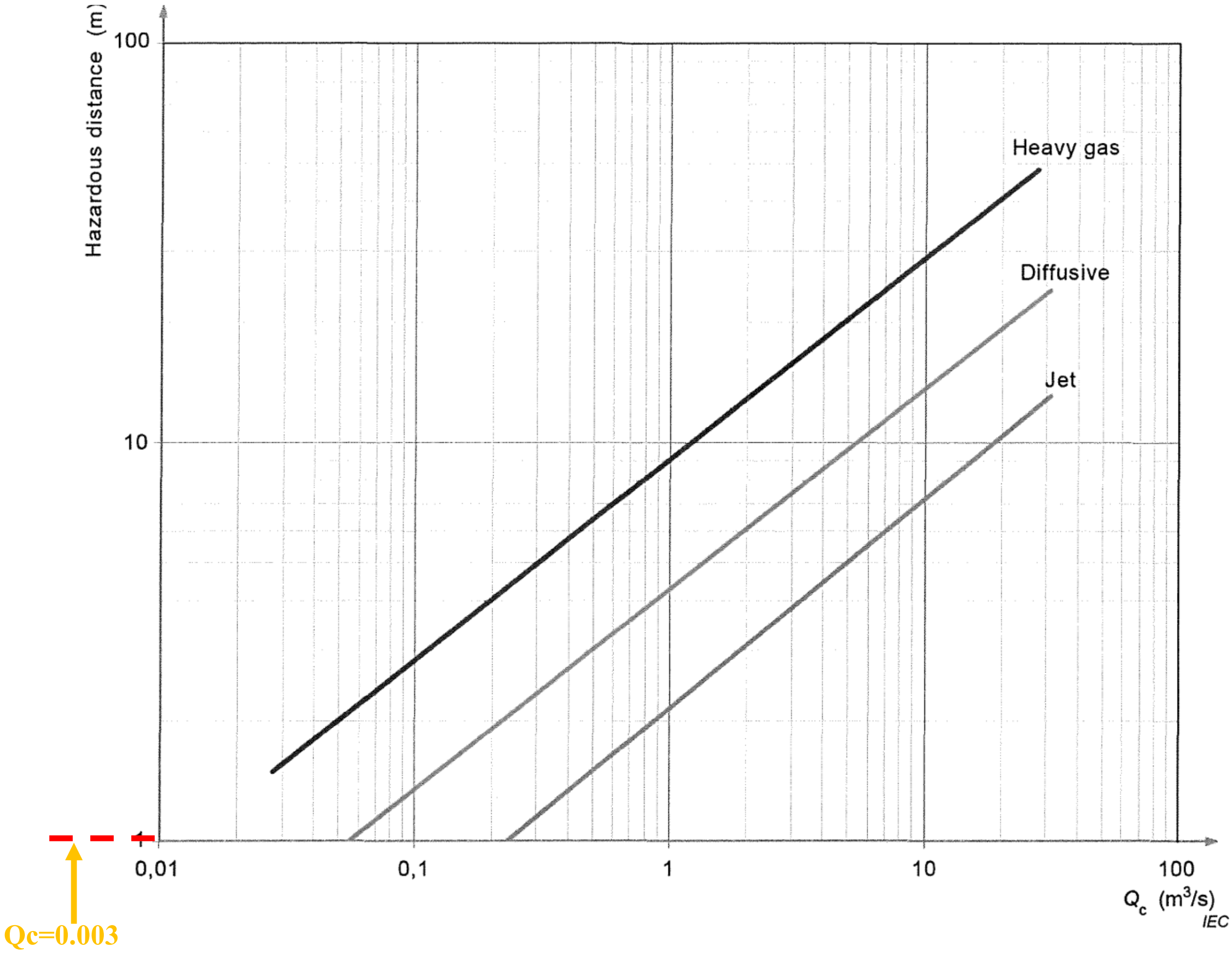


**Figure D.1 – Chart for estimating hazardous area distances**

Zones should be evaluated according to the ventilation surrounding the release source and any variations in release conditions. This graph does not identify different zones.

In this thesis, as the emission volumetric rate is below the range of the graph due to the standard guide for similar cases, the minimum extent of the hazardous area is considered as 1 meter. In an industrial project, after risk analysis studies, this distance would be considered higher according to plant situations.

# CHAPTER 5

# CONCLUSION

## 5. Conclusion

Based on the characteristics of flammable substances, potential release sources, and ventilation conditions, the Direct Reduced Iron (DRI) plant's heating unit's hazardous area classification (HAC) has been thoroughly assessed. The zone, gas group, and temperature class are included in the standard structure for the classification, which is

**Zone 2, Gas Group IIC, Temperature Class T4**.

A clear and organized depiction of the degree of risk associated with each area is provided by this format, which guarantees conformity with international standards like ATEX and IEC. The findings are an essential resource for choosing the right mechanical and electrical equipment, maintaining operational safety, and putting in place proper explosion protection measures.

To assess the establishment of the hazardous area classification, it is necessary to follow the steps below:

- Identification of the sources of release
- Determination of the grade of release
- Determination of the release rate, velocity, etc
- Determination of the type of area (openness)
- Degree and availability of ventilation
- Use of an appropriate code or calculations to determine the extent of zone

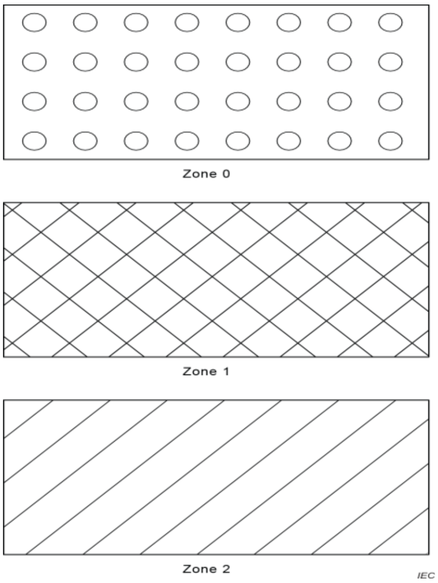
### Identification of the sources of release

As mentioned, the source of release has been identified as Flange connections on the pipelines.

### Determination of the grade of release

In this case study, based on the grade of release, which is less than 10 hours, meaning secondary grade of release, we are in zone 2.

*Figure 9: Preferred Symbols of Zones*



Each zone is represented by a standardized schematic representation in the layout drawings, which visually identifies them using zone-specific patterns.

**Determination of the type of area**

In this specific study for the heating unit of DRI plant, we are in an "open area" because basically there is no roof/ceiling, no walls, and a floor made of grating.

Ventilation is also Natural as there is no fan or blower on the site.

As we are in an "outdoor plant"**, Adequate ventilation** exists because it is defined as ventilation sufficient to prevent the accumulation of concentrations of flammable gas-air.

**Degree and availability of ventilation**

Dilution ventilation shall be sufficient to immediately bring the flammable gas concentration below 25% of the Lower Flammability Limit (LFL) and keep it so all the time

The availability of ventilation is fair.

**Use of an appropriate code or calculations to determine the extent of the zone**

The minimum extent of the hazardous area is considered to be 1 meter

Considering these terms

- Flammable fluid: Hydrogen as the most hazardous substance
- Grade of release: secondary grade
- Ventilation degree: high
- Zone: Zone 2
- Fluid category: IIC, IIB, IIA (considering Hydrogen as the most dangerous for a report, the fluid category will present as IIC)
- Ignition (Auto ignition) Temperature (AIT): According to attachment IV
- Ambient temperature outside: 40 °C (For calculations, temperature has been considered as: +20°C )
- Temperature class: Due to Hydrogen's high flame speed, ultra-low ignition energy, and leak tendency through micro-clearances greatly intensify ignition risk.

In conclusion, the classified areas of the outdoor zone of this site are **Zone 2 IIC T4**.

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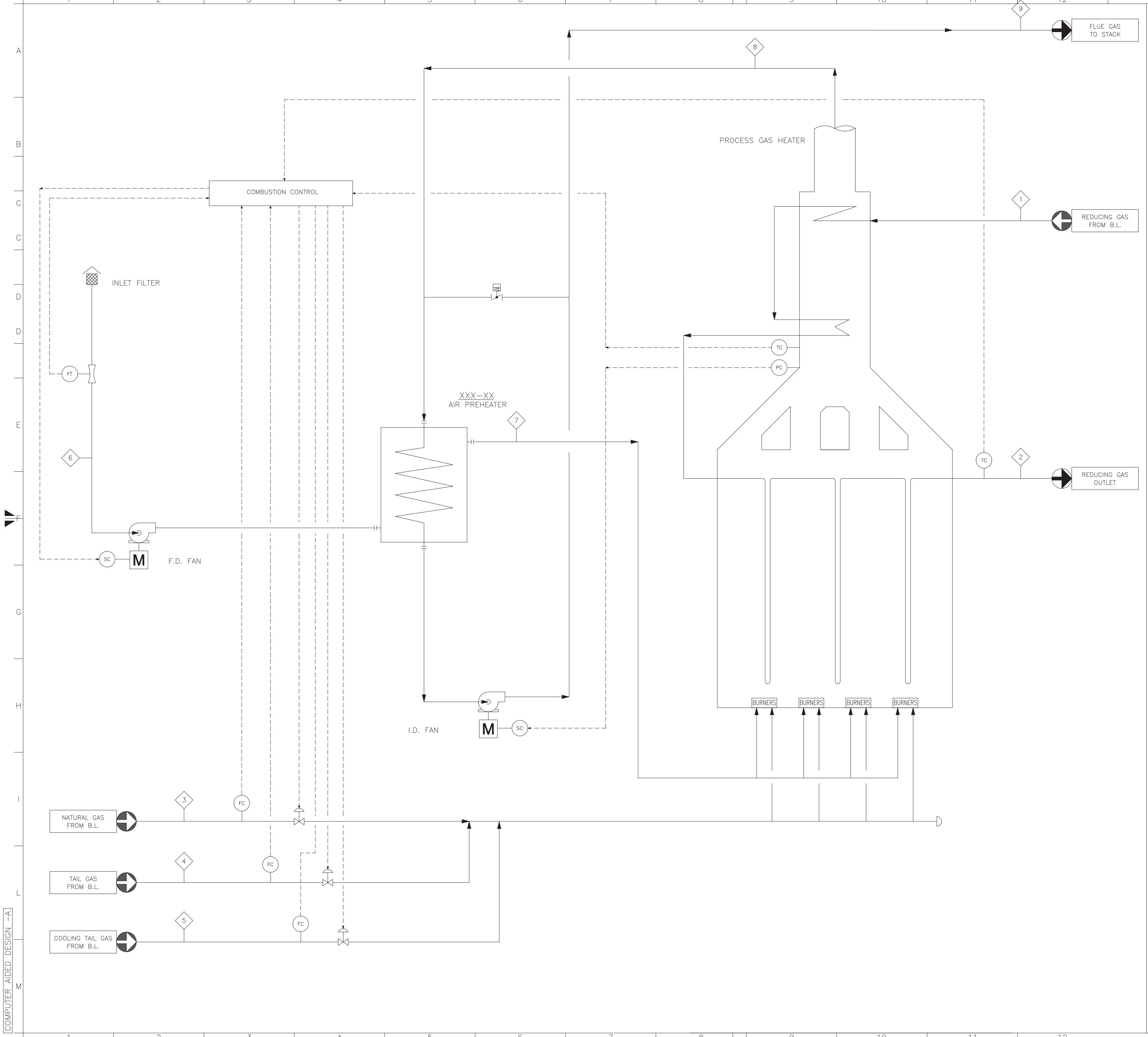
# Attachment List

| | |
|---|---|
| ATTACHMENT I | PROCESS FLOW DIAGRAM |
| ATTACHMENT II | MATERIAL BALANCE |
| ATTACHMENT III | CALCULATION SHEETS |
| ATTACHMENT IV | GENERAL LAYOUT |

# ATTACHMENT I

# PROCESS FLOW DIAGRAM


FLUE GAS TO STACK
9
8
PROCESS GAS HEATER
COMBUSTION CONTROL
1
REDUCING GAS FROM B.L.
INLET FILTER
TC
PC
FT
XXX–XX
AIR PREHEATER
7
6
TC
2
REDUCING GAS OUTLET
SC
M
F.D. FAN
BURNERS
BURNERS
BURNERS
BURNERS
I.D. FAN
M
SC
3
FC
NATURAL GAS FROM B.L.
4
FC
TAIL GAS FROM B.L.
5
FC
COOLING TAIL GAS FROM B.L.
COMPUTER AIDED DESIGN –A

NOTES

1.

## ATTACHMENT II

# MATERIAL BALANCE

**Heat & Material Balance - CASE 1**

| Stream ID |  | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| Stream Name |  | Reducing Gas Inlet | Reducing Gas Outlet | NG from B.L | Tail Gas from B.L | Cooling Tail Gas from B.L |
| Temperature (°C) |  | 85 | 950 | 25 | 38 |  |
| Pressure (barg) |  | 10.15 | 8.35 | 15.00 | 2.50 |  |
| Vapor Frac. |  | 1 | 1 | 1 | 1 |  |
|  | Ignition Temperature (°C) | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % |  |
| Hydrogen | 500 | 46.961 | 46.961 | 0.000 | 50.471 |  |
| Methane | 537 | 24.437 | 24.437 | 93.900 | 15.971 |  |
| Ethane | 515 | 0.257 | 0.257 | 3.260 | 0.000 |  |
| Propane | 450 | 0.059 | 0.059 | 0.690 | 0.000 |  |
| Butane | 365 | 0.018 | 0.018 | 0.270 | 0.000 |  |
| Pentane | 260 | 0.006 | 0.006 | 0.090 | 0.000 |  |
| Hexane | 234 | 0.000 | 0.000 | 0.000 | 0.000 |  |
| Carbon monoxide | 605 | 11.084 | 11.084 | 0.000 | 12.619 |  |
| Carbon dioxide | - | 1.598 | 1.598 | 0.000 | 8.906 |  |
| Nitrogen | - | 10.470 | 10.470 | 1.790 | 11.132 |  |
| H2S | 232 | 0.000 | 0.000 | 0.001 | 0.002 |  |
| Argon | - | 0.000 | 0.000 | 0.000 | 0.000 |  |
| Ethylene | 543 | 0.000 | 0.000 | 0.000 | 0.000 |  |
| SO2 | - | 0.000 | 0.000 | 0.000 | 0.000 |  |
| Oxygen | - | 0.000 | 0.000 | 0.000 | 0.000 |  |

## Heat & Material Balance - CASE 2

| Stream ID | | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| Stream Name | | Reducing Gas Inlet | Reducing Gas Outlet | NG from B.L | Tail Gas from B.L | Cooling Tail Gas from B.L |
| Temperature (°C) | | 81 | 935 | 25 | 38 | |
| Pressure (barg) | | 9.8 | 8.2 | 15.0 | 2.5 | |
| Vapor Frac. | | 1 | 1 | 1 | 1 | |
| | Ignition Temperature (°C) | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % | |
| Hydrogen | 500 | 51.475 | 51.475 | 0.000 | 52.220 | |
| Methane | 537 | 26.108 | 26.108 | 93.900 | 20.793 | |
| Ethane | 515 | 0.211 | 0.211 | 3.260 | 0.000 | |
| Propane | 450 | 0.049 | 0.049 | 0.690 | 0.000 | |
| Butane | 365 | 0.015 | 0.015 | 0.270 | 0.000 | |
| Pentane | 260 | 0.005 | 0.005 | 0.090 | 0.000 | |
| Hexane | 234 | 0.000 | 0.000 | 0.000 | 0.000 | |
| Carbon monoxide | 605 | 7.103 | 7.103 | 0.000 | 8.568 | |
| Carbon dioxide | - | 1.422 | 1.422 | 0.000 | 7.344 | |
| Nitrogen | - | 9.072 | 9.072 | 1.790 | 10.185 | |
| H2S | 232 | 0.000 | 0.000 | 0.001 | 0.002 | |
| Argon | - | 0.000 | 0.000 | 0.000 | 0.000 | |
| Ethylene | 543 | 0.000 | 0.000 | 0.000 | 0.000 | |
| SO2 | - | 0.000 | 0.000 | 0.000 | 0.000 | |
| Oxygen | - | 0.000 | 0.000 | 0.000 | 0.000 | |

## Heat & Material Balance - CASE 3

| Stream ID | | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| Stream Name | | Reducing Gas Inlet | Reducing Gas Outlet | NG from B.L | Tail Gas from B.L | Cooling Tail Gas from B.L |
| Temperature (°C) | | 45.0 | 910.0 | 25.0 | 38.0 | 39.5 |
| Pressure (barg) | | 7.97 | 7.40 | 15.00 | 2.50 | 2.50 |
| Vapor Frac. | | 1 | 1 | 1 | 1 | 1 |
| | Ignition Temperature (°C) | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % | Component Vol. Fraction % |
| Hydrogen | 500 | 92.667 | 92.667 | 0.000 | 89.437 | 6.707 |
| Methane | 537 | 3.030 | 3.030 | 93.900 | 4.368 | 83.805 |
| Ethane | 515 | 0.000 | 0.000 | 3.260 | 0.000 | 0.279 |
| Propane | 450 | 0.000 | 0.000 | 0.690 | 0.000 | 0.038 |
| Butane | 365 | 0.000 | 0.000 | 0.270 | 0.000 | 0.003 |
| Pentane | 260 | 0.000 | 0.000 | 0.090 | 0.000 | 0.000 |
| Hexane | 234 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Carbon monoxide | 605 | 0.394 | 0.394 | 0.000 | 0.568 | 0.001 |
| Carbon dioxide | - | 0.373 | 0.373 | 0.000 | 0.538 | 0.001 |
| Nitrogen | - | 2.939 | 2.939 | 1.790 | 4.237 | 8.324 |
| H2S | 232 | 0.000 | 0.000 | 0.001 | 0.002 | 0.000 |
| Argon | - | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Ethylene | 543 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| SO2 | - | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Oxygen | - | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

# ATTACHMENT III

# CALCULATION SHEETS

# ID1 - CASE 1 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 1 | REDUCING GAS FROM B.L. | Hydrogen | 46.961 | 85 | 10.15 | | | | | | | | | | |
| | | Methane | 24.437 | | | Gas<br>Leak Source: Flange | 1.26E-04 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.257 | | | | | | | | | | | | |
| | | Propane | 0.059 | | | | | | | | | | | | |
| | | Butane | 0.018 | | | | | | | | | | | | |
| | | Pentane | 0.006 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 11.084 | | | | | | | | | | | | |
| | | Carbon dioxide | 1.598 | | | | | | | | | | | | |
| | | Nitrogen | 10.470 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID2 - CASE 1 - Zone Definition

| | | Total Molar Component Vol Fractions | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Name | Vol Fraction [%] | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section $[mm^2]$ | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| 2 | REDUCING GAS OUTLET. | Hydrogen | 46.961 | 950 | 8.35 | | | | | | | | | | |
| | | Methane | 24.437 | | | Gas<br>Leak Source: Flange | 5.71E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.257 | | | | | | | | | | | | |
| | | Propane | 0.059 | | | | | | | | | | | | |
| | | Butane | 0.018 | | | | | | | | | | | | |
| | | Pentane | 0.006 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 11.084 | | | | | | | | | | | | |
| | | Carbon dioxide | 1.598 | | | | | | | | | | | | |
| | | Nitrogen | 10.470 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 :  Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID3 - CASE 1 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 3 | NATURAL GAS FROM B.L. | Hydrogen | 0.000 | 25 | 15 | | | | | | | | | | |
| | | Methane | **93.900** | | | Gas<br>Leak Source: Flange | 5.44E-04 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 3.260 | | | | | | | | | | | | |
| | | Propane | 0.690 | | | | | | | | | | | | |
| | | Butane | 0.270 | | | | | | | | | | | | |
| | | Pentane | 0.090 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 0.000 | | | | | | | | | | | | |
| | | Carbon dioxide | 0.000 | | | | | | | | | | | | |
| | | Nitrogen | 1.790 | | | | | | | | | | | | |
| | | H2S | 0.001 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID4 - CASE 1 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | | | |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 4 | TAIL GAS FROM B.L.. | Hydrogen | 50.471 | 38 | 2.5 | | | | | | | | | | |
| | | Methane | 15.971 | | | Gas<br>Leak Source: Flange | 4.23E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.000 | | | | | | | | | | | | |
| | | Propane | 0.000 | | | | | | | | | | | | |
| | | Butane | 0.000 | | | | | | | | | | | | |
| | | Pentane | 0.000 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 12.619 | | | | | | | | | | | | |
| | | Carbon dioxide | 8.906 | | | | | | | | | | | | |
| | | Nitrogen | 11.132 | | | | | | | | | | | | |
| | | H2S | 0.002 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

## ID1 - CASE 2 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | | | |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 1 | REDUCING GAS FROM B.L. | Hydrogen | 51.475 | 81 | 9.8 | | | | | | | | | | |
| | | Methane | 26.108 | | | Gas<br>Leak Source: Flange | 1.23E-04 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.211 | | | | | | | | | | | | |
| | | Propane | 0.049 | | | | | | | | | | | | |
| | | Butane | 0.015 | | | | | | | | | | | | |
| | | Pentane | 0.005 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 7.103 | | | | | | | | | | | | |
| | | Carbon dioxide | 1.422 | | | | | | | | | | | | |
| | | Nitrogen | 9.072 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID2 - CASE 2 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 2 | REDUCING GAS OUTLET | Hydrogen | 51.475 | 935 | 8.15 | | | | | | | | | | |
| | | Methane | 26.108 | | | Gas<br>Leak Source: Flange | 5.62E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.211 | | | | | | | | | | | | |
| | | Propane | 0.049 | | | | | | | | | | | | |
| | | Butane | 0.015 | | | | | | | | | | | | |
| | | Pentane | 0.005 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 7.103 | | | | | | | | | | | | |
| | | Carbon dioxide | 1.422 | | | | | | | | | | | | |
| | | Nitrogen | 9.072 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID3 - CASE 2 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | | | |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 3 | NATURAL GAS FROM B.L. | Hydrogen | 0.000 | 25 | 15 | | | | | | | | | | |
| | | Methane | 93.900 | | | Gas<br>Leak Source: Flange | 5.44E-04 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 3.260 | | | | | | | | | | | | |
| | | Propane | 0.690 | | | | | | | | | | | | |
| | | Butane | 0.270 | | | | | | | | | | | | |
| | | Pentane | 0.090 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 0.000 | | | | | | | | | | | | |
| | | Carbon dioxide | 0.000 | | | | | | | | | | | | |
| | | Nitrogen | 1.790 | | | | | | | | | | | | |
| | | H2S | 0.001 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID4 - CASE 2 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | | | |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 4 | TAIL GAS FROM B.L.. | Hydrogen | 52.220 | 38 | 2.5 | | | | | | | | | | |
| | | Methane | 20.793 | | | Gas<br>Leak Source: Flange | 4.23E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.000 | | | | | | | | | | | | |
| | | Propane | 0.000 | | | | | | | | | | | | |
| | | Butane | 0.000 | | | | | | | | | | | | |
| | | Pentane | 0.000 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 8.568 | | | | | | | | | | | | |
| | | Carbon dioxide | 7.344 | | | | | | | | | | | | |
| | | Nitrogen | 10.185 | | | | | | | | | | | | |
| | | H2S | 0.002 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID1 - CASE 3 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 1 | REDUCING GAS FROM B.L. | Hydrogen | 92.667 | 45 | 7.97 | | | | | | | | | | |
| | | Methane | 3.030 | | | Gas<br>Leak Source: Flange | 1.07E-04 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.000 | | | | | | | | | | | | |
| | | Propane | 0.000 | | | | | | | | | | | | |
| | | Butane | 0.000 | | | | | | | | | | | | |
| | | Pentane | 0.000 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 0.394 | | | | | | | | | | | | |
| | | Carbon dioxide | 0.373 | | | | | | | | | | | | |
| | | Nitrogen | 2.939 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 :  Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID2 - CASE 3 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [$mm^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 2 | REDUCING GAS OUTLET. | Hydrogen | 92.667 | 910 | 7.4 | | | | | | | | | | |
| | | Methane | 3.030 | | | Gas<br>Leak Source: Flange | 5.71E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.000 | | | | | | | | | | | | |
| | | Propane | 0.000 | | | | | | | | | | | | |
| | | Butane | 0.000 | | | | | | | | | | | | |
| | | Pentane | 0.000 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 0.394 | | | | | | | | | | | | |
| | | Carbon dioxide | 0.373 | | | | | | | | | | | | |
| | | Nitrogen | 2.939 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 :  Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

## ID3 - CASE 3 - Zone Definition

| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Source of Release | | | Ventilation | | | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Name | Vol Fraction [%] | | | | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | | | |
| 3 | NATURAL GAS FROM B.L. | **Hydrogen** | 0.000 | 25 | 15 | | | | | | | | | | |
| | | Methane | **93.900** | | | Gas<br>Leak Source: Flange | 5.44E-04 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 3.260 | | | | | | | | | | | | |
| | | Propane | 0.690 | | | | | | | | | | | | |
| | | Butane | 0.270 | | | | | | | | | | | | |
| | | Pentane | 0.090 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 0.000 | | | | | | | | | | | | |
| | | Carbon dioxide | 0.000 | | | | | | | | | | | | |
| | | Nitrogen | 1.790 | | | | | | | | | | | | |
| | | H2S | 0.001 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | 0.000 | | | | | | | | | | | | |
| | | SO2 | 0.000 | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

# ID4 - CASE 3 - Zone Definition

|  |  | Total Molar Component Vol Fractions |  |  |  |  | Source of Release |  |  | Ventilation |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Name | Vol Fraction [%] | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [mm$^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| 4 | TAIL GAS FROM B.L.. | Hydrogen | 89.437 | 38 | 2.5 |  |  |  |  |  |  |  |  |  |  |
|  |  | Methane | 4.368 |  |  | Gas<br>Leak Source: Flange | 4.23E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
|  |  | Ethane | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Propane | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Butane | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Pentane | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Hexane | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Carbon monoxide | 0.568 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Carbon dioxide | 0.538 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Nitrogen | 4.237 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | H2S | 0.002 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Argon | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Ethylene | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | SO2 | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Oxygen | 0.000 |  |  |  |  |  |  |  |  |  |  |  |  |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

## ID5 - CASE 3 - Zone Definition

| | | | | | | | Source of Release | | | Ventilation | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID | Unit Name | Total Molar Component Vol Fractions | | Temperature [°C] | Pressure [barg] | State of Emission / Leak Source | Emission Flow [Kg/sec] | Grade of Realise | Section [$mm^2$] | Type | Degree | Availability | Enviroment Temperature [°C] | Hazardous Area | Extent of Hazardous Areas [m] |
| | | Name | Vol Fraction [%] | | | | | | | | | | | | |
| 5 | COOILNG TAIL GAS FROM B.L. | Hydrogen | 6.707 | 39.5 | 2.5 | | | | | | | | | | |
| | | Methane | 83.805 | | | Gas<br>Leak Source: Flange | 4.23E-05 | Secondary | 2.5 | Natural Outdoor | Medium | Fair | 40 | Zone 2 | 1.00 |
| | | Ethane | 0.279 | | | | | | | | | | | | |
| | | Propane | 0.038 | | | | | | | | | | | | |
| | | Butane | 0.003 | | | | | | | | | | | | |
| | | Pentane | 0.000 | | | | | | | | | | | | |
| | | Hexane | 0.000 | | | | | | | | | | | | |
| | | Carbon monoxide | 0.001 | | | | | | | | | | | | |
| | | Carbon dioxide | 0.001 | | | | | | | | | | | | |
| | | Nitrogen | 8.324 | | | | | | | | | | | | |
| | | H2S | 0.000 | | | | | | | | | | | | |
| | | Argon | 0.000 | | | | | | | | | | | | |
| | | Ethylene | - | | | | | | | | | | | | |
| | | SO2 | - | | | | | | | | | | | | |
| | | Oxygen | 0.000 | | | | | | | | | | | | |

Note 1 : Although, in the composition of the mixture of flammable gases, hydrogen is not the alone flammable gas , given the extreme volatility of the gas and even the one with the lowest molecular weight is the most dangerous. Furthermore, since hydrogen cannot be mixed with other petroleum-derived gases, it tends to escape into the air first in case of failure. Therefore for greater safety possible the classification is represented by this gas.

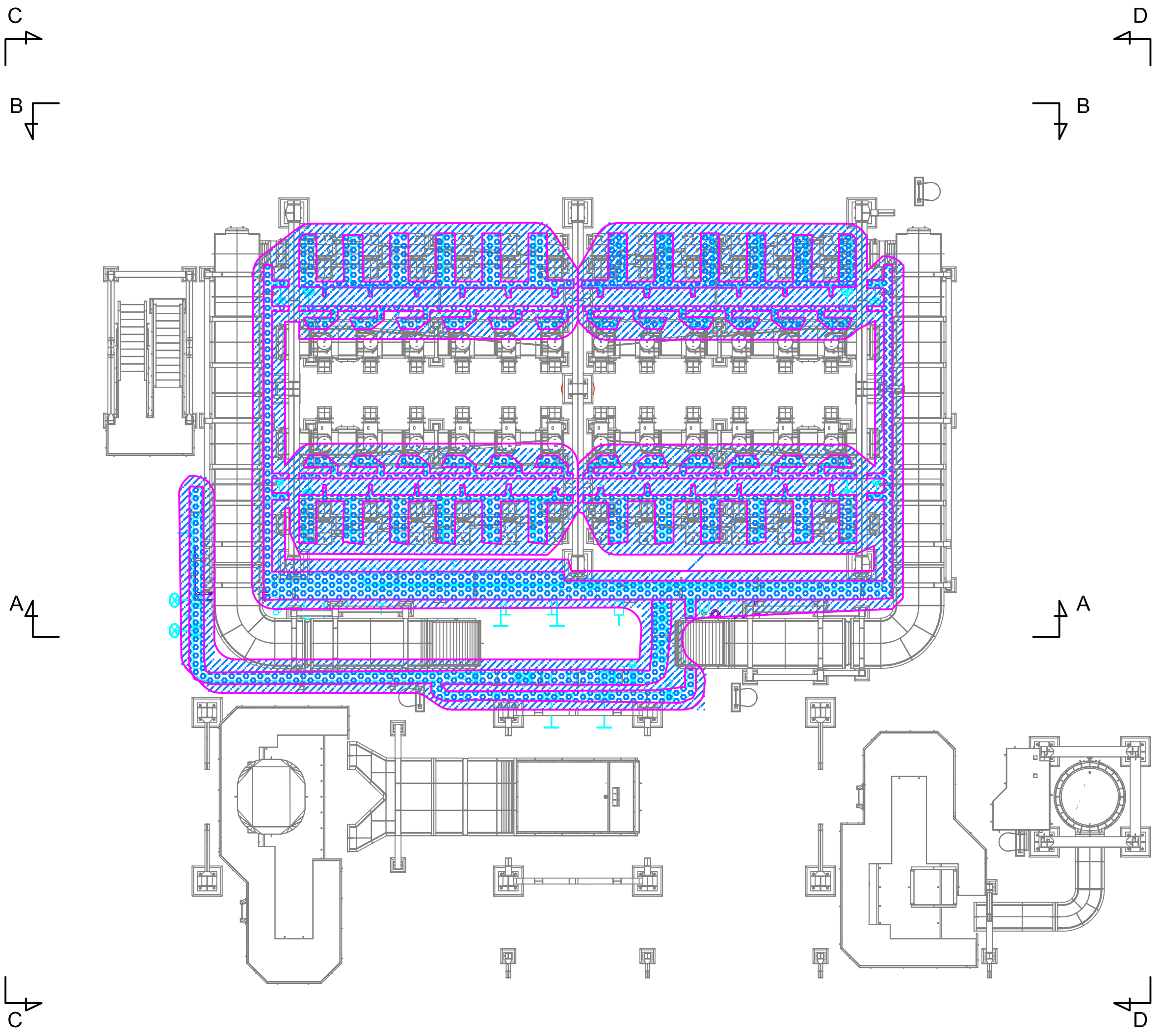
# ATTACHMENT IV

# GENERAL LAYOUTS

# Hazardous Area Classification
# ATTACHMENT "IV"_sh01

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

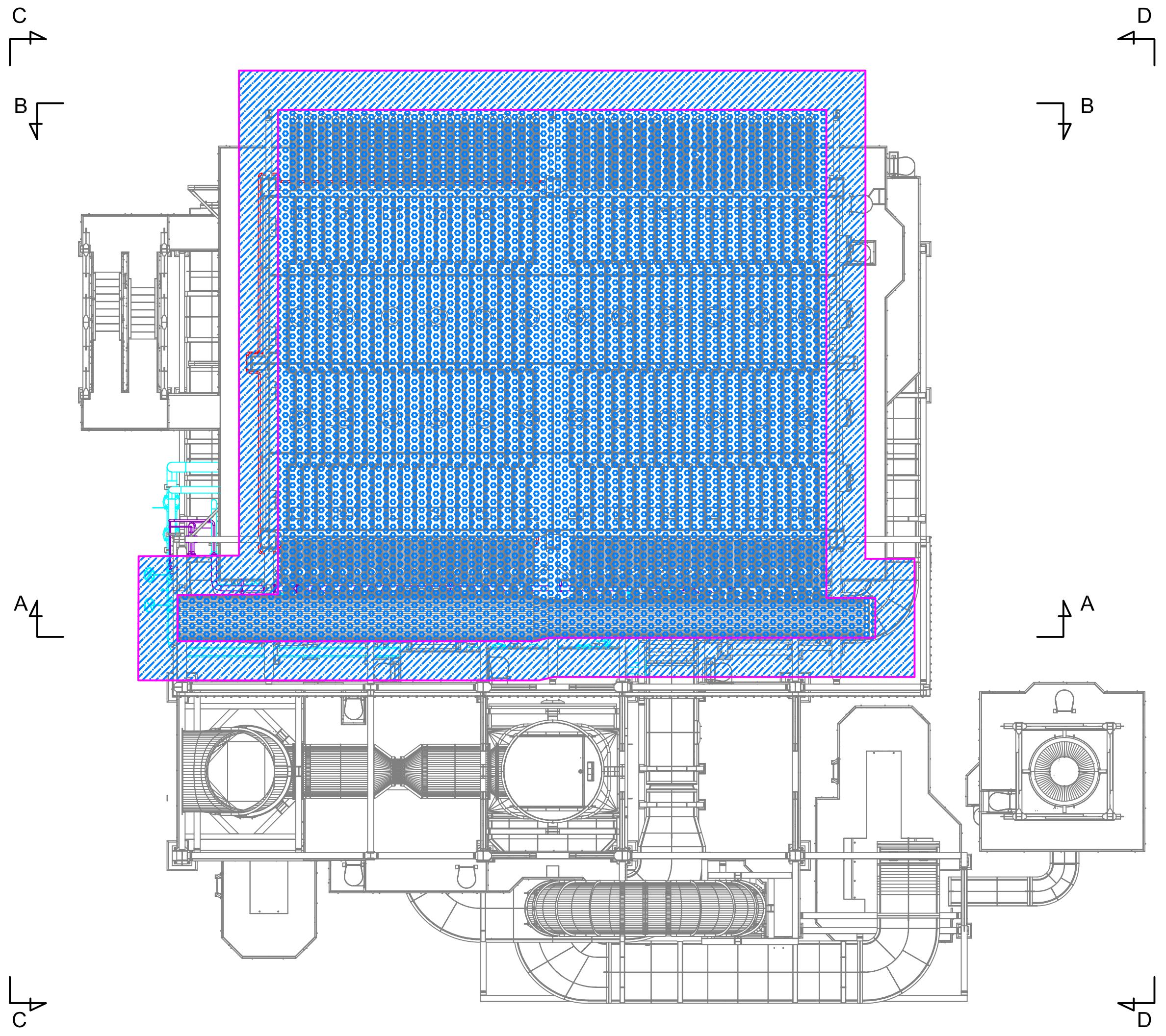


| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
## ATTACHMENT "IV"_sh02

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

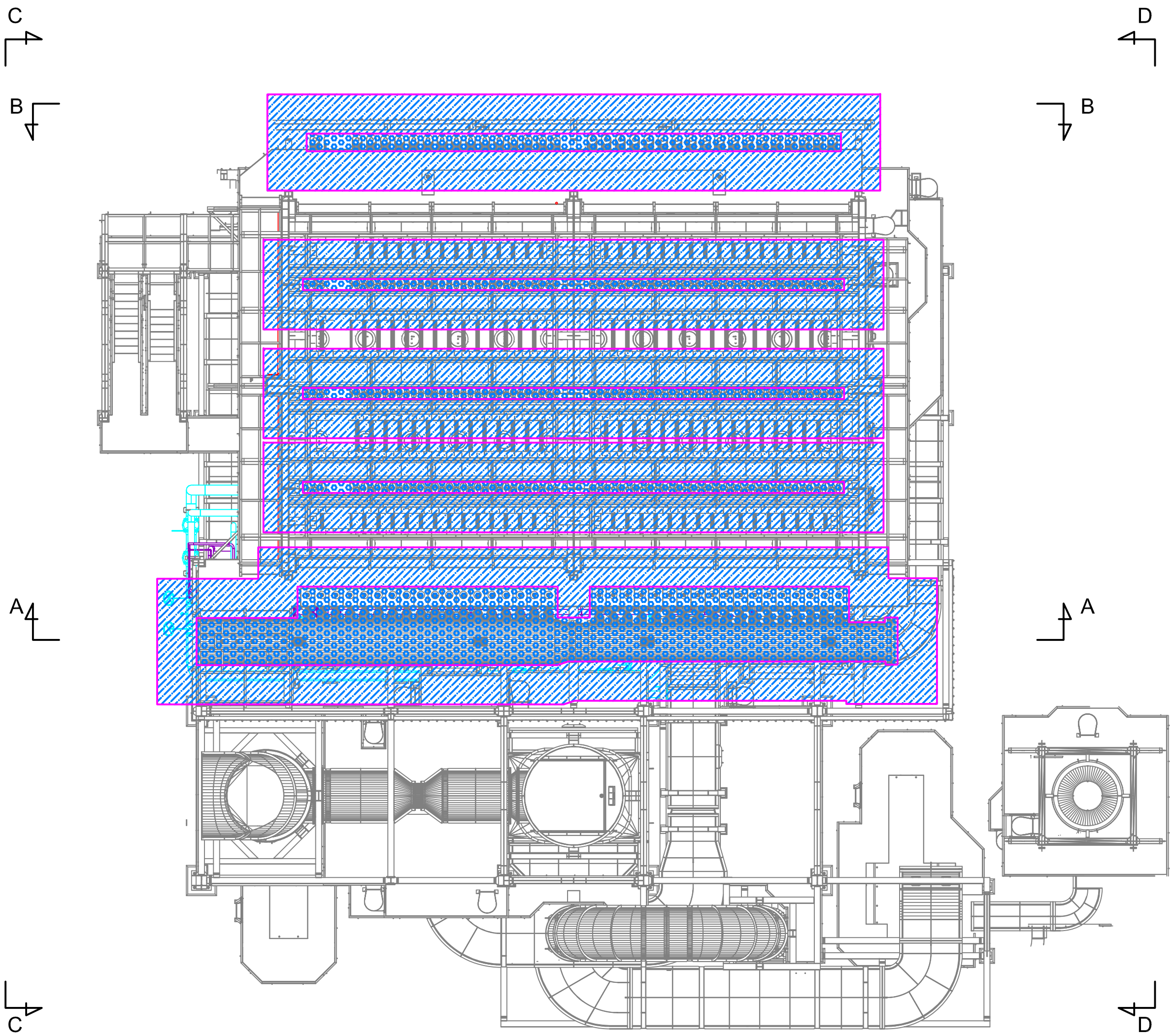


| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
## ATTACHMENT "IV"_sh03

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

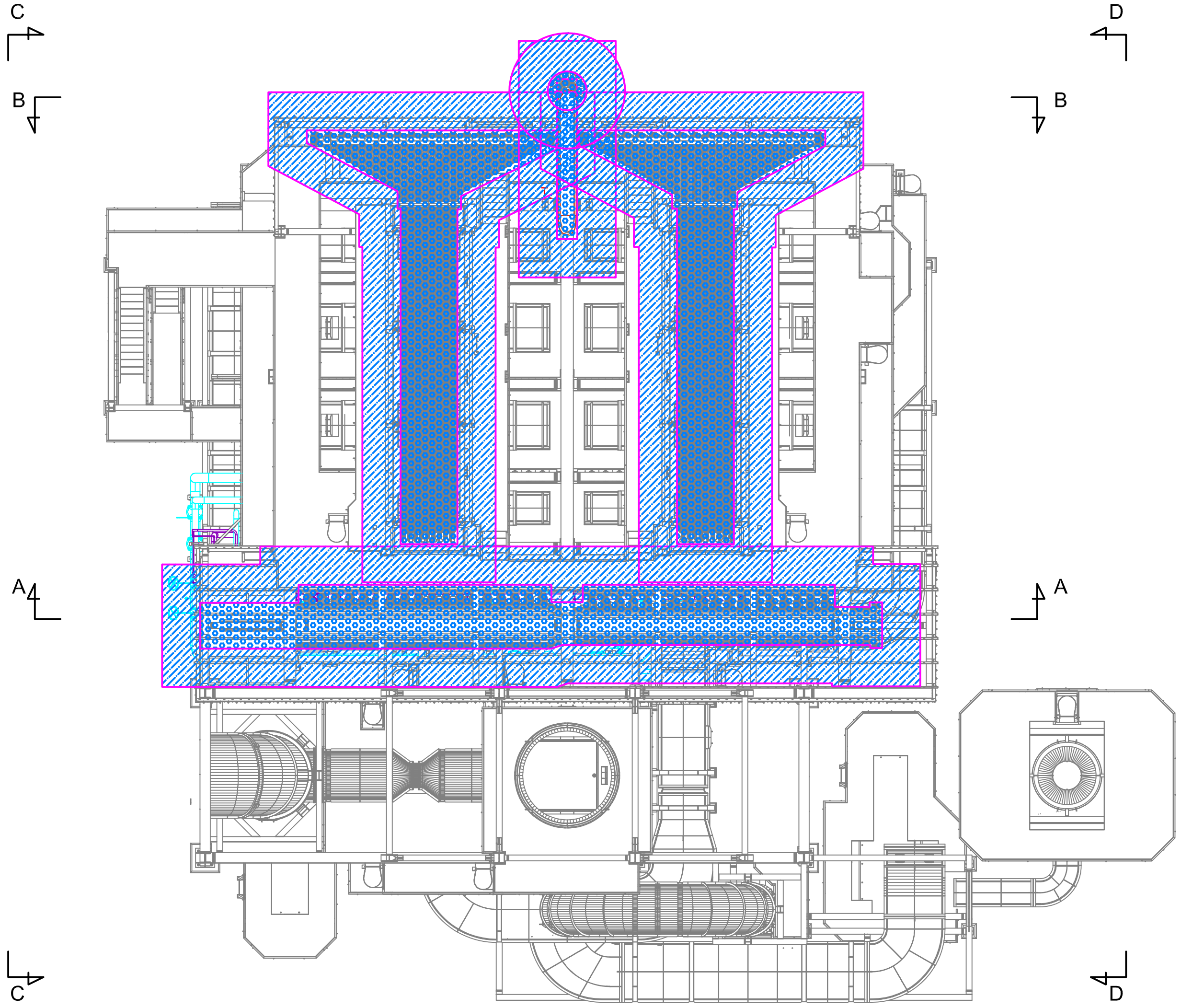
MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS



## LEGEND

| SYMBOLS | DESCRIPTION |
|---|---|
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
# ATTACHMENT "IV"_sh04

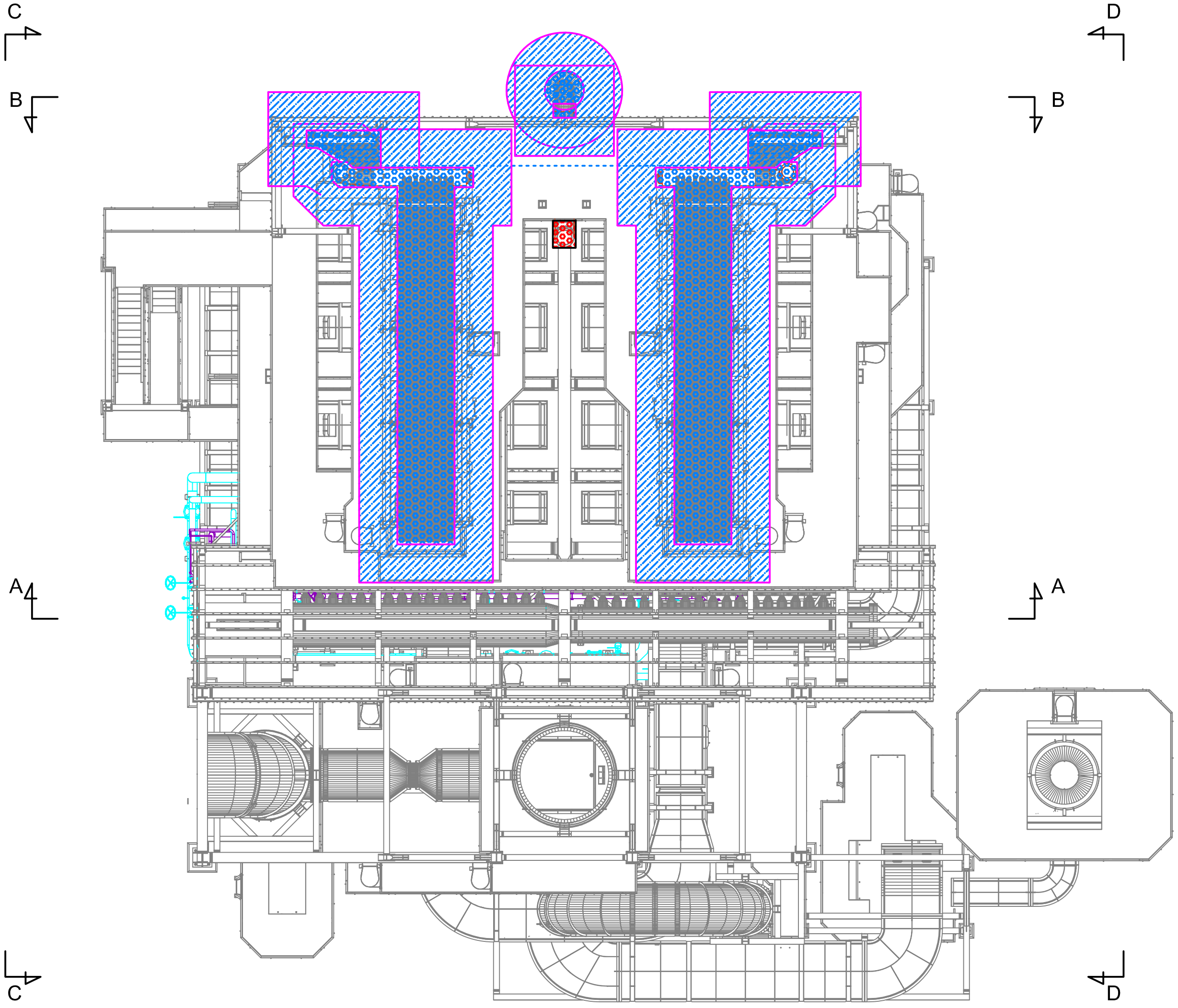


MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
# ATTACHMENT "IV"_sh05

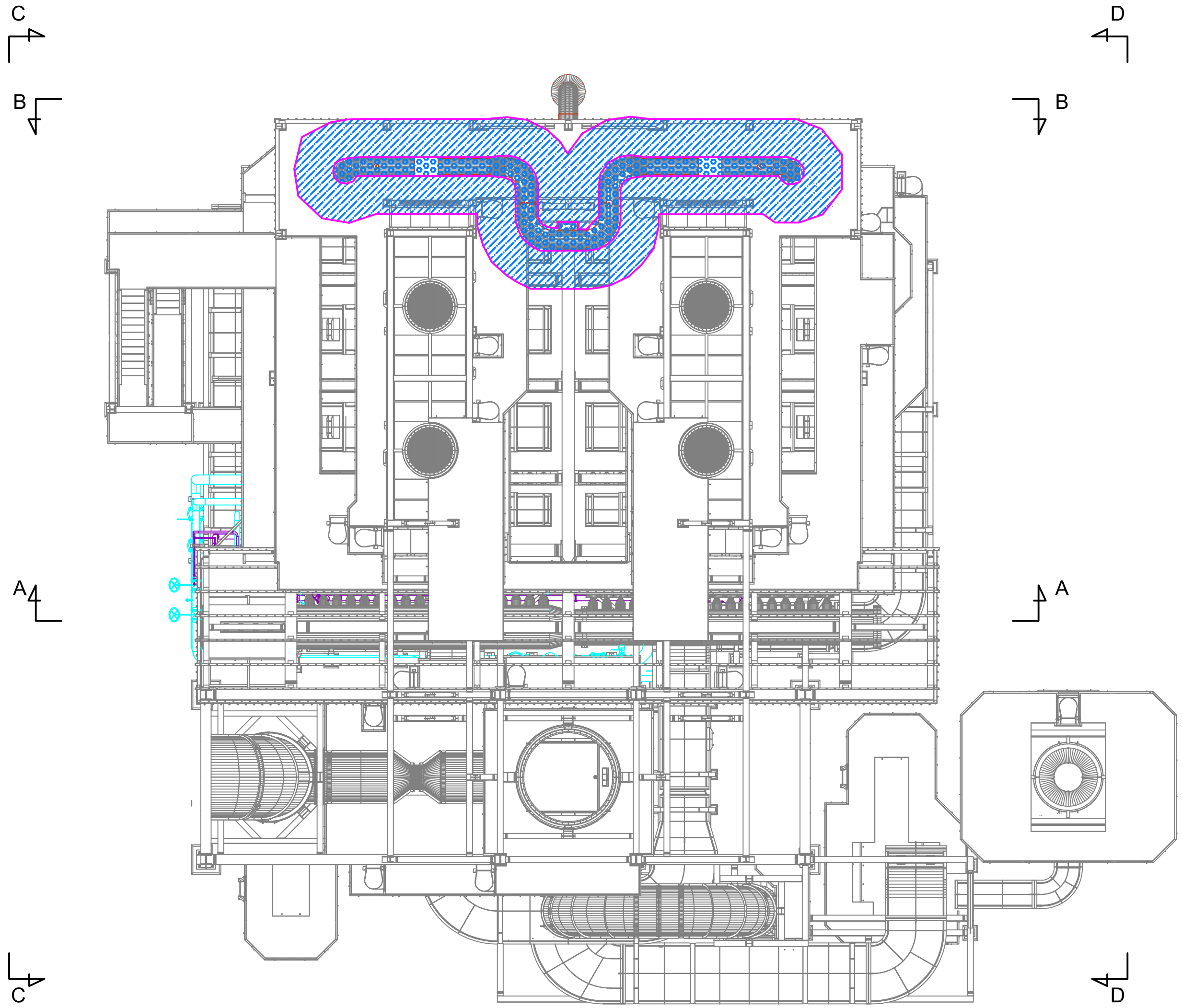


MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR ) GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
# ATTACHMENT "IV"_sh06



MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

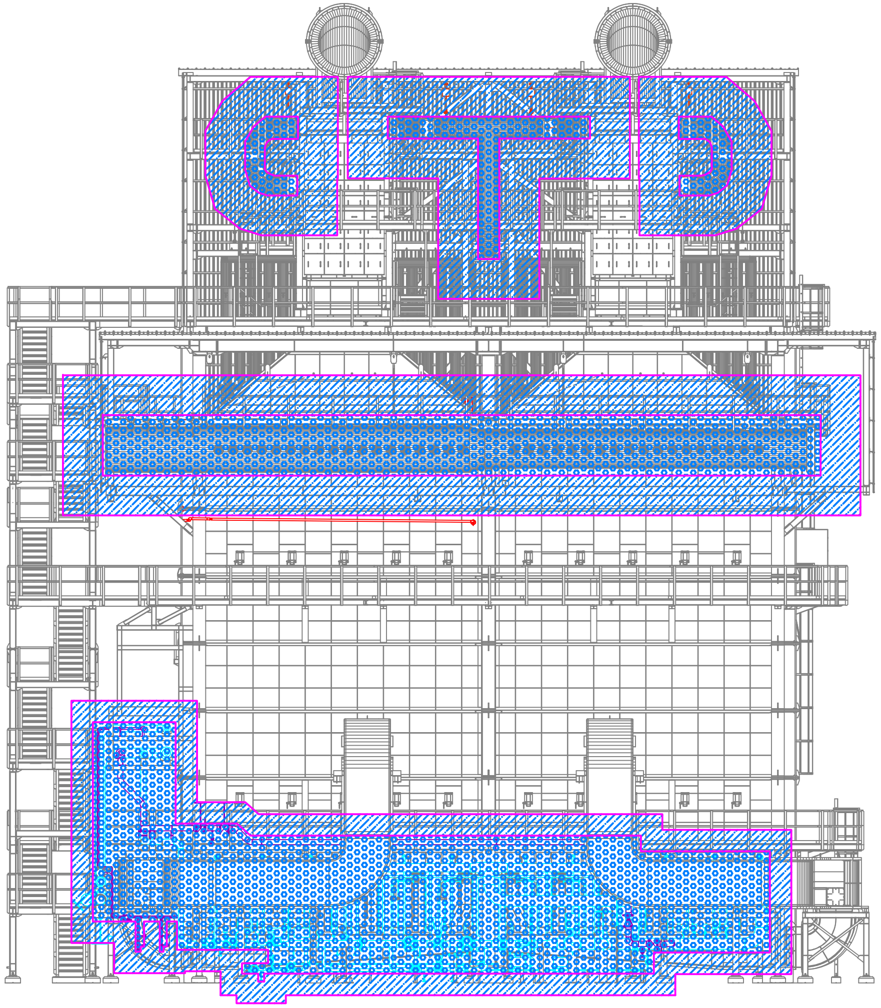
MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
# ATTACHMENT "IV"_sh07

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS



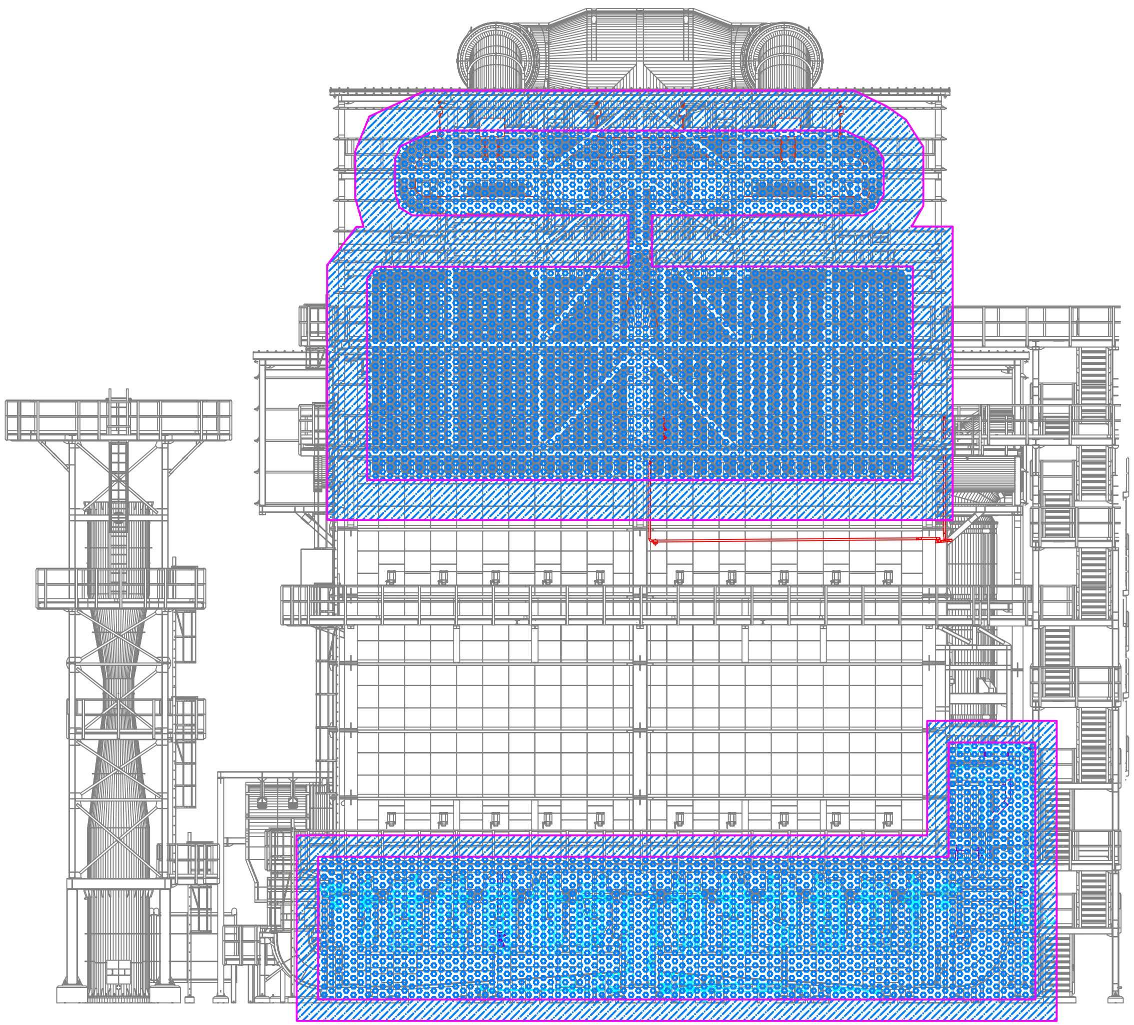
VIEW A-A

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
# ATTACHMENT "IV"_sh08

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS



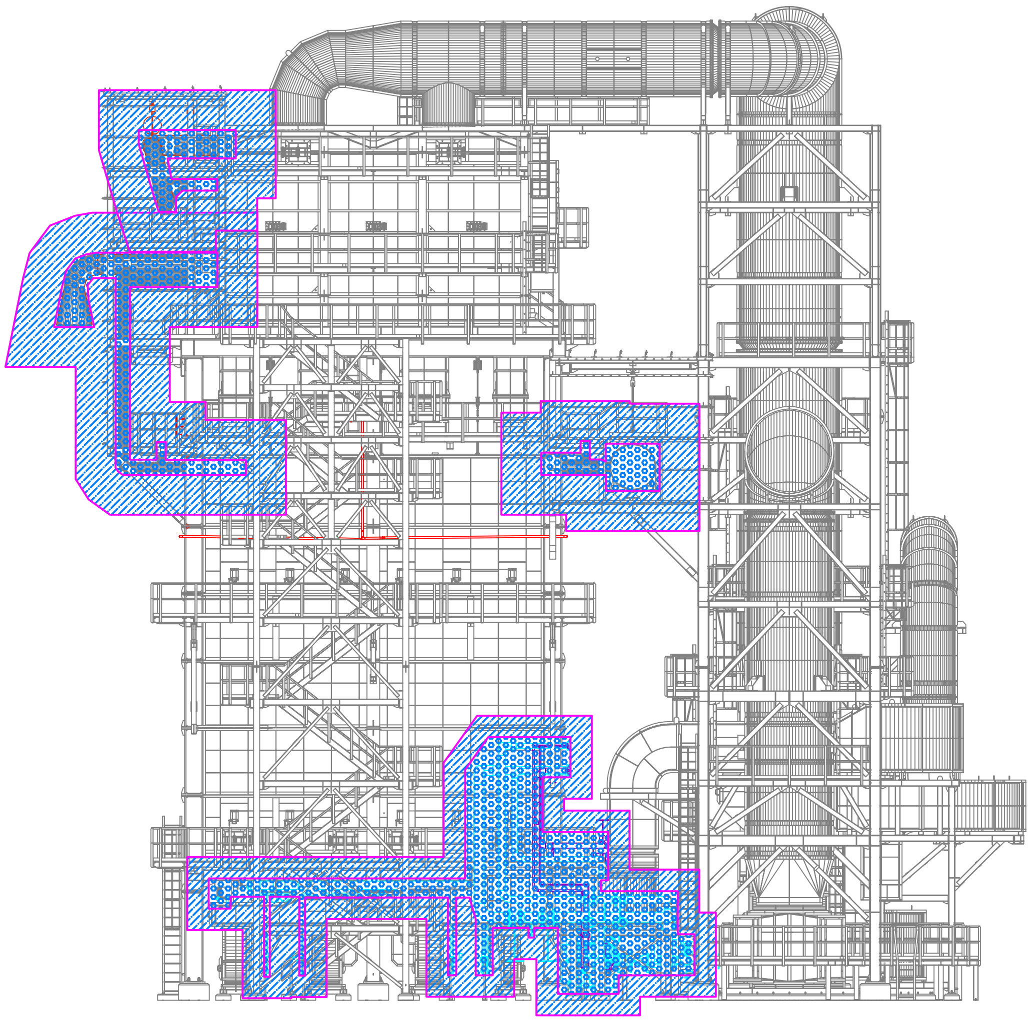
VIEW B-B

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification
## ATTACHMENT "IV"_sh09

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

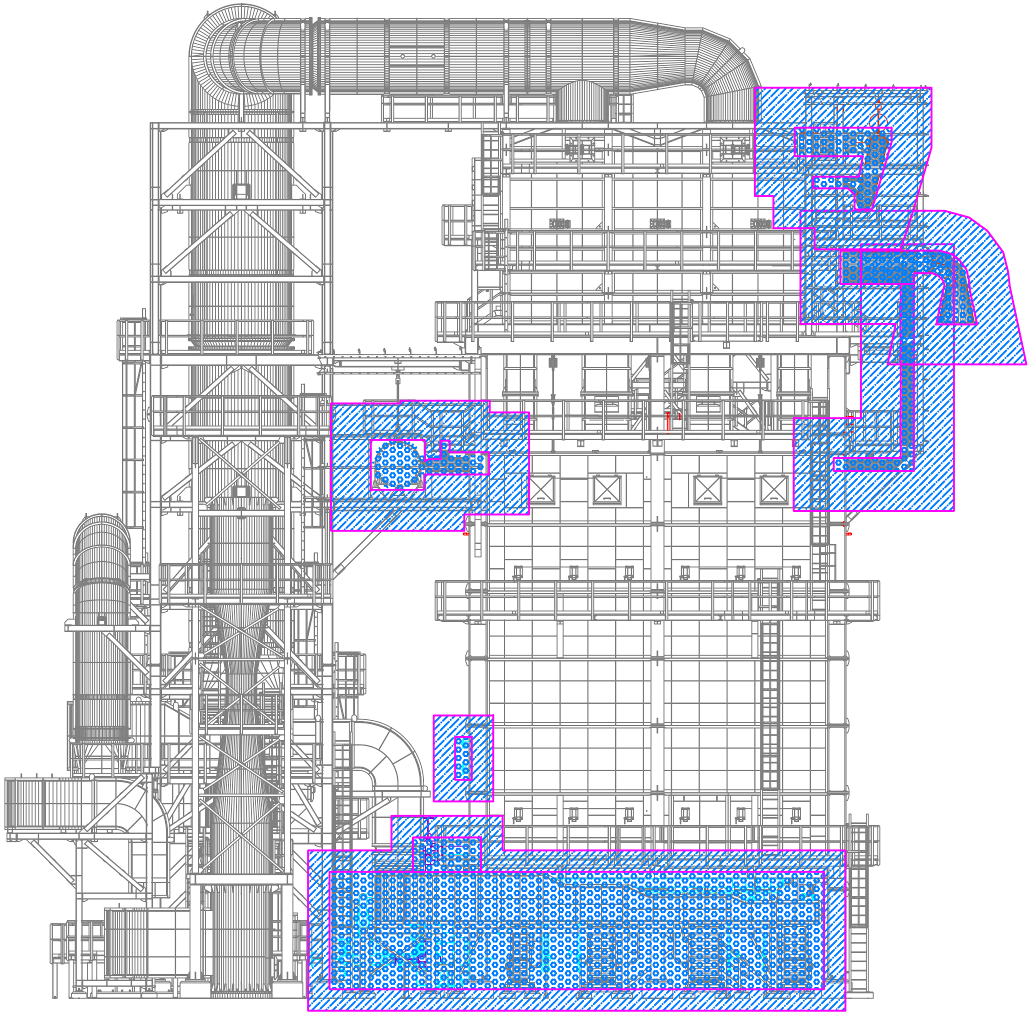


VIEW C-C

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |

# Hazardous Area Classification

# ATTACHMENT "IV"_sh10



VIEW D-D

MAX EXTENSION 1000 mm FROM:
- ID1 REDUCING GAS FROM B.L.
- ID2 REDUCING GAS OUTLET

MAX EXTENSION 1000 mm FROM:
- ID3 NATURAL GAS
- ID4 TAIL GAS
- ID5 COOLING TAIL GAS

| LEGEND | |
|---|---|
| SYMBOLS | DESCRIPTION |
| ▨ | IDENTIFICATION ZONE 2 ( GAS OR VAPOUR )<br>GROUP IIC TEMPERATURE CLASS T4 |
| ○ | IDENTIFICATION ZONE 0 |