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Biomethane Production Plants: a Case Study Aimed at Atex Zones Classification

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Biomethane is the purified version of biogas and it is one of the main renewable gases of the future and available to help decarbonise the European Union (EU) energy system. For these reasons, there is a clear need toincrease **the biomethane production by 2030**, as reported in the RepowerEU (18 May 2022). In particular, the european biomethane production needs to reach **35 billion m3 by 2030. The strategic biomethane importance requires a specific attention to the production plants safety. Indeed, one of the main hazards associated with its production process is the possible formation of potentially explosive atmospheres (Atex zones) due to accidental releases from several components, such as valves, flanges, compressors, etc. In accordance with Atex Directive 99/92/EC, the employer is obliged to classify the workplaces zones, where explosive mixtures could occur. The paper is focused on a biomethane production plant and the goal is the classification of Atex zone, which could be generated by a potential biofuel release from the compressor. In particular, the biofuel compression unit has been examined, because it is the potentially more hazardous place. This hazardousness is due to the exiguous dilution of the natural ventilation (indoor place) and to the maximum biomethane pressure, which strongly increases the released mass flow. In the paper, a specific software has been used to study the biofuel outflow from the potential emission source (compressor) and classify the zone (hazardous or non-hazardous area).**

* 1. Introduction

The European Commission estimates that 350 TWh or 35 billion cubic meters of biomethane could be produced per year in 2030, which equal around 10% of the projected European Union natural gas use (Alberici et al., 2022). This biofuel quantity would save about 110 Mt CO2 emissions or around 6% of the required effort to achieve 55% GHG (greenhouse gases) reduction. This can simultaneously offer environmental and social benefits. Nowadays, this gaseous biofuel is not available in large quantities and needs to be rapidly scaled up to exploit its full potential. Biomethane is a storable and flexible energy source with a high greenhouse gas saving potential. Furthermore, it can be transported through the existing gas infrastructure. With reference to these properties, it becomes an appealing fuel in order to achieve a climate neutral energy system. This scenario requires a particular attention to the potential hazards associated with the biomethane production. One of the main hazards is the possible formation of potentially explosive atmospheres (Atex zones) due to accidental biofuel releases from components (Geng et al., 2020), such as flanges, control valves, compressors, etc. In appropriate ratios, the mixture of air and biomethane has explosive properties. In particular, the biomethane compression is the most hazardous phase of its production process, because it occurs in an indoor place (compression unit) and it is characterized by the maximum pressure values, which can exceed 70-80 bar (Lauri, 2023). Therefore, the choice of operating parameters (air velocity and flow) of the forced ventilation system becomes extremely important for diluting the explosive mixture, decreasing the Atex zones hazardousness and their persistence time. The paper is aimed at investigating the possible biomethane release from the compressor and at classifying the zone (hazardous or non-hazardous area) as function of ventilation flow. In particular, the Atex zones classification has relevant outcomes on industrial processes safety, because it influences the choice of (electrical or non-electrical) equipment, which can be used in hazardous areas, thus decreasing their probability of becoming potential ignition sources. Therefore, the Atex zones classification is a fundamental phase for avoiding explosions in the process industry.

* 1. Materials and Methods

The software Atmosphere Risk Analysis Gas Plus 3.0 is used to study the biomethane outflow from the possible release sources and classify the zone, which could be generated by compressor emission. Software is based on International Standard IEC EN 60079-10-1, which is used to classify the areas (Atex zones), where a potentially explosive mixture could form. The zones classification depends on three following parameters (IEC, 2023):

1. source release grade (continuous, primary or secondary);
2. dilution degree (high, medium or low);
3. ventilation availability (good, fair or poor).

The first parameter is determined by the analysis of components (valves, flanges, compressors, etc.) operating conditions, whereas the others mainly depend on natural ventilation (outdoor places) or forced ventilation (indoor places). The dilution degree is determined (IEC, 2023) by the diagram (Figure 1) reported in the mentioned Standard. In particular, the volumetric release characteristic (Qc) is expressed by the following equation (IEC, 2023):



Where:

* Wg (kg/s) is the overall mass flow of flammable compound (biomethane);
* ρg (kg/m3) indicates the gas or vapour density (the parameter is linked to ambient pressure and temperature) and it is calculated by the ideal gas law;
* LFL (4.4 % v/v) is the lower flammability limit of biomethane.



*Figure 1: Dilution degree assessment (IEC EN 60079-10-1)*

In indoor places, such as the compression unit, with more sources of release, in order to determine the Atex zone typology and extent, the emissions have to be summed (IEC, 2023):

1. the overall continuous release is given by the sum of all continuous emissions (sources of continuous release degree);
2. the overall primary release is given by the sum of some (contemporary) of the primary releases combined with the overall continuous release;
3. the overall secondary release is the biggest secondary release (Wgmax) combined with the overall primary release.

The third condition is calculated by the following equation:



Where:

* Mi (kg/s) is the mass flow released by the potential sources included in the building.

In case of gaseous release, Wg and Mi depend on flow conditions (sonic or subsonic), which are determined by the following equations (Casal, 2018):





Where:

* pin (Pa) is the pressure inside the vessel or component;
* patm (101325 Pa) indicates the atmospheric pressure;
* γ (dimensionless parameter) = cp/cv (heat capacities ratio).

In indoor places, the dilution degree assessment always depends on the comparison between background concentration (Xb) and critical concentration (Xcr). Xb is expressed by the following equation:



Where:

* f (dimensionless parameter) is the ventilation inefficiency factor (it ranges between 1 and 5);
* Qg (m3/s) indicates the volumetric gas flow and it is given by Wg/ρg;
* Qa (m3/s) is the volumetric air flow.

Xcr is about 0.25 LFL (low level alarm threshold of a gas detector). When Xb ≥ Xcr, the dilution degree is low and the diagram, reported in Figure 1, is not necessary to assess this parameter. In case of Xb < Xcr the diagram has to be used to assess the dilution degree. Biomethane LFL is 4.4 (vol/vol %) and therefore Xcr is 0.011. In accordance with Technical Standard IEC EN 60079-10-1, a potential release source could generate non-hazardous or hazardous (Atex zone) area. In case of flammable gas emission, Atex zones are:

1. zone 0 (the most hazardous area): area in which an explosive gas atmosphere is present in continuous way or for long periods;
2. zone 1: area in which an explosive atmosphere is likely to occur periodically or occasionally during normal operation;
3. zone 2 (less hazardous area): area in which an explosive mixture is unlikely to occur during normal operation and if it was generated, its duration would be extremely short.

In case of Atex zone, its extension (hazardous distance) can be estimated by the diagram (figure 2) reported in IEC EN 60079-10-1:

* heavy gas line (vapour/gas density is bigger than air density);
* diffusive line (subsonic release);
* jet line (sonic release).



*Figure 2: Hazardous distance assessment (Atex zone)*

In indoor workplaces, such as the biomethane compression unit, in case of possible formation of potentially explosive atmosphere, its persistence time (td) has to be estimated, because it has remarkable outcomes on safety (Lauri, 2018). Indeed, this parameter indicates the theoretical time required to dilute the flammable substance concentration to values, which are lower than lower flammability limit. In accordance with Technical Standard IEC EN 60079-10-1, the mentioned software uses the following equation to calculate td:



Where:

* C (s-1) is the air changes number per time unit.
	1. The case study: biomethane production plant

The biomethane production plant is located in southern Italy and the compression unit increases the biofuel pressure, which depends on intended purpose. Indeed, in case of biomethane injection into the natural gas network, the pressure can usually vary from 40 bar to 80 bar, whereas, in case of compressed natural gas (CNG) production, it is about 220-230 bar. In the case study, the operating pressure of natural gas pipeline is equal to 30 bar and therefore, because of the pressure drop, the biomethane is compressed up to 36 bar. A multi-stage reciprocating compressor is used to increase the biofuel pressure. On multi-stage machines, intercoolers remove the compression heat from the biofuel and reduce its temperature to value existing at the compressor intake. In particular, the compressor is oil free and water cooling. Its operating parameters are listed in table 1. With reference to reciprocating compressors, the leak is the main source of inefficiency (Matsumura et al., 1992) and it can become dangerous in case of flammable gases releases. Areas of high leak frequency from reciprocating compressors include flanges, valves and fittings located on compressors. However, the highest volume of gas loss is associated with piston rod packing systems and blowdown open-ended lines (Gas Processors Suppliers Association, 2004). The compressor is equipped with two safety valves aimed at limiting the discharge and inter-stage pressure and ensuring a safe machine operating. The safety valves (SV) are set to open at pressures, which are slightly higher than the normal discharge pressure. In particular, valves setting pressures are 17.6 bar (first stage) and 39.6 bar (discharge). The area of valves emission hole is 0.71 cm2 and their discharge is conveyed to the atmosphere. In the case study, according to Purple Book (CPR, 2005), outflow is from a leak with an effective diameter of 10% of the nominal diameter (D=0.95 cm).

Table 1: Compressor operating parameters

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| --- | --- | --- | --- | --- |
| Suction pressure (bar) | Discharge pressure (bar) | Volumetric flow (Sm3/h) | Average speed (rpm) | Initial biomethane temperature (°C) |
| 6 | 36 | 500 | 750-1,150 | 25 |

The compression unit is composed by:

* compressor;
* anti-explosive electric motor;
* cooling unit;
* connection pipeline;
* control valves;
* safety valves;
* blow-down valve;
* control cabinet.

Because of the mentioned components presence, the ventilation inefficiency factor has been assumed to be 3. The compression unit is characterized by the following dimensions (figure 3):

* length (mm) = 6,800;
* height (mm) =2,570;
* width (mm) =3,100.

With reference to classification of Atex zones, the compressor can be considered as a source of secondary grade (the emission is not expected during the normal operating or release duration would be extremely short) release, whereas the safety valves are sources of primary grade release, because their emission can occasionally occur during the operating. The compression unit is a complex engineering system, which can be affected by failures of several components (flanges, control valve, compressor, etc.), which could generate uncontrolled biomethane releases. The compression unit is equipped with a forced ventilation system, which can inject a volumetric air flow ranged between 0.2 m3/s and 0.8 m3/s.



*Figure 3: Biomethane compression unit*

* 1. Results and discussion

In order to classify the (hazardous or non-hazardous) zone generated by the possible biomethane release from the compressor, four values of ventilation flow have been investigated: 0.2 m3/s, 0.4 m3/s, 0.6 m3/s and 0.8 m3/s. The results obtained from the software are reported in table 2. According to equation 2, Xbtot depends on the sum of Xb related to all potential emission sources (safety valves and compressor), because the reciprocating compressor can be considered as secondary grade source. In case of biofuel emission from the compressor, Xbtot is bigger than Xcr (0.011) and therefore, in spite of ventilation flow increase, the dilution degree is low.

*Table 2: Results*

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Qa (m3/s) | Flow | uw (m/s) | Xb1(safety valve/first stage) | Xb2 (safety valve/compressor outlet) | Xb3 (compressor) | Xbtot | Dilution degree |
| 0.2 | sonic | 0.011 | 0.148 | 0.157 | 0.252 | 0.557 | low |
| 0.4 | sonic | 0.022 | 0.037 | 0.079 | 0.13 | 0.246 | low |
| 0.6 | sonic | 0,033 | 0.025 | 0.052 | 0.08 | 0.157 | low |
| 0.8 | sonic | 0.044 | 0.017 | 0.036 | 0.06 | 0.113 | low |

The biomethane outflow is always sonic and therefore it generates a gaseous jet. In case of jet release in small artificially ventilated buildings, such as the compression unit, a remark can be expressed about the dilution. Indeed, the obstacles (process pipes, electric engine, auxiliary equipment, etc.) presence (possible collision) can split up the biofuel jet and so the air amount could increase. The consequent result could be a very diluted jet. Therefore, it is clear that the possible fragmentation of the biomethane jet during a collision is extremely important. Some parameters, which play a fundamental role, are the obstacle dimensions, its geometrical shape and the distance between release hole and obstacle. So far, there are no general criteria for determining the scenario, which could arise. The Qa passage from 0.2 m3/s to 0.8 m3/s causes remarkable decreases of the background concentrations. Indeed, they are equal to 88.5% for Xb1, 77% for Xb2 and 76.2% for Xb3. The Xbtot decrease is about 79.7%. In figure 4, the classification results (biomethane release from compressor) are reported. It has to be highlighted that, because of low dilution, the ventilation availability does not influence the Atex zone typology. Indeed, accidental biofuel emissions from the reciprocating compressor could generate zone 1 and even zone 0 (the most hazardous area). However, zone 0 could occur in case of particularly weak ventilation and continuous presence of potentially explosive atmosphere, but the forced ventilation system and adjustment of its operating parameters make zone 0 formation extremely unlikely. Furthermore, in the biomethane compression unit, the redundancy of ventilation plant components (fan) and gas detectors can ensure uninterrupted air flow availability and continuous monitoring of biomethane concentration, thereby avoiding the zone 0 generation and decreasing the hazardous zone persistence time. Therefore, zone 1 is the most probable scenario, which could be generated by gaseous biofuel release from reciprocating compressor. With reference to the Atex zone extension, in case of Xbtot > Xcr, the overall building has to be considered hazardous area. Finally, the air flow influence on time of Atex zone persistence is reported in table 3.

 *Table 3: Atex zone persistence time*

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| --- | --- | --- |
| Qa (m3/s) | C (s-1) | Persistence time (s) |
| 0.2 | 0.006 | 1,914 |
| 0.4 | 0.012 | 754 |
| 0.6 | 0.018 | 436 |
| 0.8 | 0.024 | 287 |

Its calculation is based on an ideal dilution of the potentially explosive mixture, therefore safety margins (Alves et al., 2019) should be considered to take in account turbulence and uneven biomethane distribution due to the obstacles presence. Qa passage from 0.2 m3/s to 0.8 m3/s causes a significant td decrease, which is about 85%.



 *Figure 4: Results (classification of Atex zone due to release from compressor)*

* 1. Conclusions

Since biomethane is perceived as natural gas substitute and can bring both environmental benefits (reduction in GHG emissions) and economic benefits (higher efficiency of energy contained in biomass), much attention has to be addressed to production process safety. Indeed, a potentially dangerous scenario is the biofuel release in indoor place, such as the compression unit. In order to assess more in detail the obstacles influence on ventilation air movement, computational fluid dynamics (CFD) is recommended for any complex plant, where several components could affect the air movement. In particular, the Atex zones classification has relevant outcomes on industrial processes safety, because it is integral part of explosion risk assessment and it influences the choice of (electrical or non-electrical) equipment, which can be used in hazardous areas, thus decreasing their probability of becoming potential ignition sources. Therefore, the Atex zones classification is a fundamental phase for avoiding explosions in the process industry.

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