An enquiry into the causes of an explosion accident occurred in a biogas plant

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Abstract

Biogas is a versatile carrier of renewable energy produced by means of the digestion of crops, residues, or other wastes, and storage of the gas in dedicated plants. Safety regulations impose operational and technical restrictions to areas interested by the presence of the biogas in order to limit the explosion risk. Conversely, other areas of the plant are not subject to strict safety requirements. Nevertheless, explosions can be triggered in these areas as well, as the present investigation confirms. In the specific case, the production of biogas by anaerobic digestion in a storm-water tank and its infiltration and accumulation into a technical building through a pipe connection caused the explosion of the building itself. The authors describe the procedures adopted for the enquiry and suggest possible improvements to the safety regulations for biogas plants.

KEYWORDS
anaerobic digestion, explosion, leachate, storm-water drainage

1 | INTRODUCTION

The number of biogas plants has been growing in the last decade, particularly in Europe, where incentives have been introduced. Unfortunately, the number of serious accidents in these facilities has also increased.[1-3]

Notwithstanding a rich literature on risk assessment and prevention in this sector, risk identification and analysis is still matter of research. According to Reference [4], risks in biogas plants may be due to several reasons, such as leakages in storage tanks and distribution networks, accidental effluent discharges, sewage system overflow due to control failures or exceptional downpours, dangerous substance in the biogas raw materials, and so on. Explosion risk management is usually focused on areas where biogas is actually present as in production, storage, distribution, and utilization, while auxiliary systems and storm-water drainage networks are mainly considered as sources of pollution risk.[5]

The present case study reports on the accidental explosion of a technical building, hosting the biogas production monitoring and control equipment, and causing a several-month production stop and significant economic loss. The unexpected explosion was caused by an inadequate risk analysis: an unusual yet significant anaerobic digestion activity in the storm-water drainage system, seeping into the monitor and control building, through the electrical piping system, triggered by devices that are inadequate according to the European ATEX directive. Considering that the typology of the storm-water drainage is rather common in these plants, the authors hope to raise alertness and awareness among plant managers and designers on the subject.

2 | THE PLANT FACILITY

The investigated plant processes maize silage (16 600 t/y) and cattle slurry (4000 t/y) by anaerobic digestion. It produces biogas for electric power (8.3 GWh/y) and heat (7.4 GWh/y) generation. The substrates' digestion is carried out at 40/42°C within two digesters at a total volume of 6200 m^3. The digestate (16 000 t/y) is stored in two tanks (total capacity of 6200 m^3) and from here, it was collected and used as fertilizer. The overall plant size is roughly 100 × 220 m (see Figure 1), two-thirds of which are occupied by bunker silos' digesters and post-digesters. The rest is occupied by the combined heat and power unit

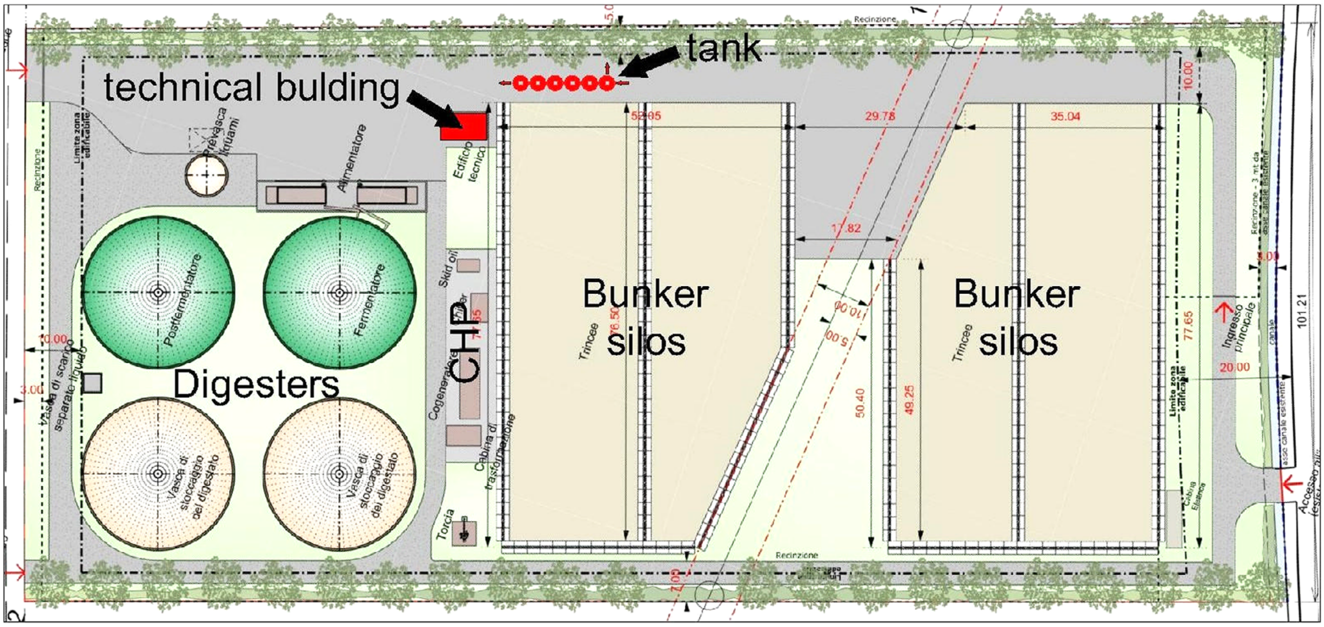

FIGURE 1 Layout of the biogas plant (the technical building is highlighted in red) [Color figure can be viewed at wileyonlinelibrary.com]

(CHP) and by the prefabricated building where office, personnel room, and monitoring/control devices are located.

The biogas production process starts with corn ensilage, carried out in bunker silos, with a relevant production of leachate, especially during the early stages of production. This is collected through a specific drainage system, pumped into a leachate tank, from where it is reinserted in the biogas production cycle in due time. Since a quantity of leachate can cover the plant yards, in the first phases of rainy events, the

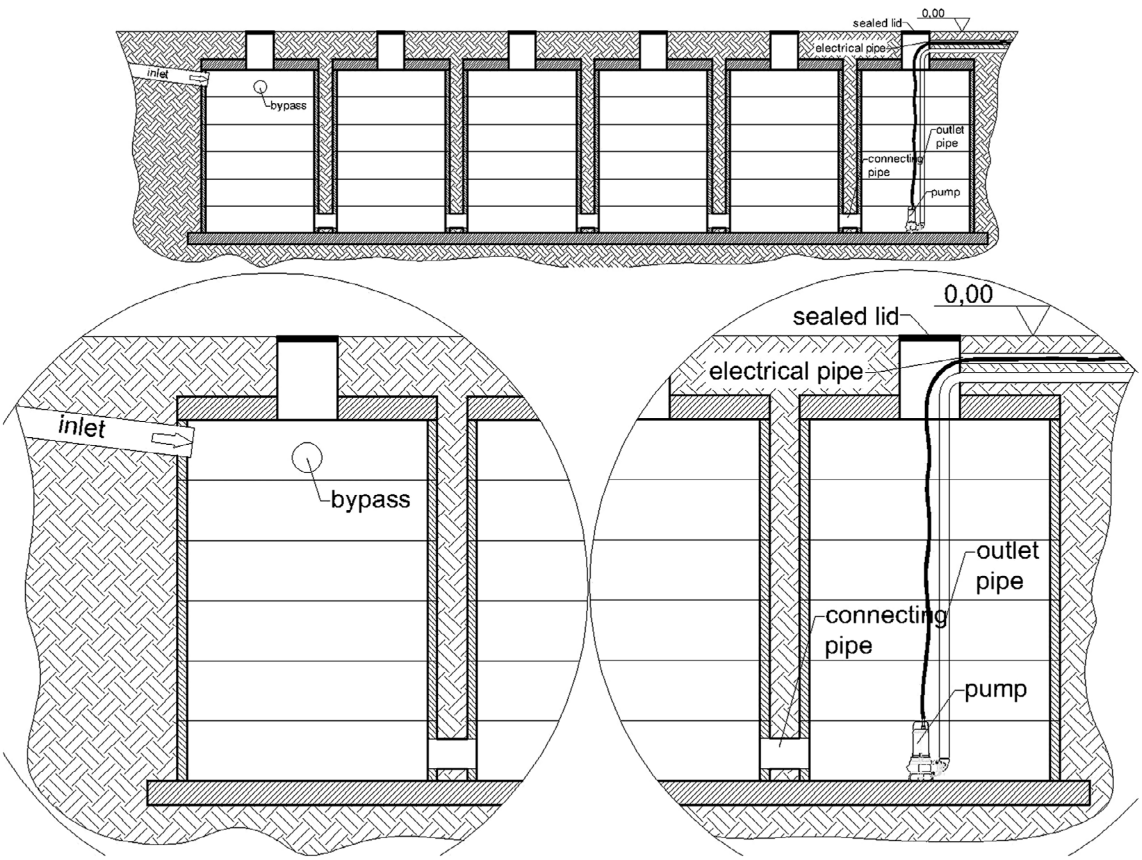

FIGURE 2 Cutaway view of the leachate tank

drainage system will convey the storm-water, rich of leachate, to a dedicated retention tank. When the tank is full, the subsequent storm-water, with negligible quantity of leachate, bypass it and reaches the ground. The system is effective when the tank is empty at the beginning of the rain, and it needs to be emptied within 48 hours after the beginning of the downpour, as the plant's operational guide foresees, with a submersed pump in the leachate tank, consisting of six interconnected concrete basins (total capacity 55 m^3) (see Figure 2).

3 | THE RISK OF EXPLOSION AND THE ACCIDENT

The plant was subjected to risk analysis as detailed in the EN 60079-10-1 regulation. In particular, the technical building where the explosion occurred was classified as Zone2 ("explosive atmosphere not likely to occur in normal operation and if it does occur, it will exist only for a short time"), given its distance from the areas where high concentrations of biogas are present (digesters, biogas piping network, and CHP). For indoor spaces classified as Zone2, the norm forbids open flames, imposes fire alarm and portable fire extinguishers, and allows 3G category appliances and equipment.

The explosion, as by the surveillance system data, occurred at 05.00 AM in the prefab where the changing room and monitoring and control equipment were located. The explosion resulted in the dislocation of the flooring of the building and the electrical equipment laying on it and the side walls (Figure 3). Inside the building, burnt furniture evidenced the presence of fire after the explosion. The fireman's record confirmed biogas presence in the electric manholes and the electrical room, which is located in a container roughly 200 m away from the building where the explosion occurred. The firemen extinguished the fire and, to prevent further biogas formation, opened all the digesters. Given the presence of biogas in the electrical piping network, all the manholes were opened as well.

FIGURE 3 The technical building after the accident [Color figure can be viewed at wileyonlinelibrary.com]

4 | RESULTS OF THE INVESTIGATION

About 20 days after the accident, during the inspection of the plant, methane traces could still be found in the inspection manholes of the underground electrical piping system. The examination of the damaged building suggested that the explosion took place inside it, likely due to an explosive biogas mixture detonated by the electrical appliances. The enquiry aimed to find the path through which biogas could have reached the technical building, since there were no evident connections between the building, the underground distribution network, and the biogas production facilities (digesters, CHP, etc.), which were not affected by the explosion.

After an unsuccessful search for leakages along the underground distribution network, attention was focused on the storm-water tank, where anaerobic digestion might have occurred for the possible presence (to be confirmed by evidence) of leachate and silage through bunker silos' losses. Notwithstanding the operational requirements, a number of evidence showed that the tank had not been emptied for at least a month. Furthermore, the dimensioning of the tanks had not properly considered the amount of rainfall that could be fed to the digesters without compromising the overall biogas production.

Another relevant aspect was the unusual leachate routing from the bunker silos. As shown in Figure 4, the manhole grates present a protrusion that prevent the catch basin from collecting the leachate waters, which can thus bypass the leachate tank and flow directly into the storm-water tank. The storm-water tank, along with a water-tight manhole, constitutes a hermetically sealed system, where anaerobic conditions are met and methane production can set.

As reported, the storm-water tank is emptied with a dedicated pump. This is connected to the damaged building through an 80-mm-diameter pipe containing power and control lines. Such a pipe could route biogas from the storm-water tank to the technical building, provided no obstructions are present.

Although 20 days had already passed since the accident and all manholes had been temporarily opened after the explosion, the presence of an anaerobic digestion process and biogas concentration in the storm-water tank needed to be assessed, since the tank was continuously fed

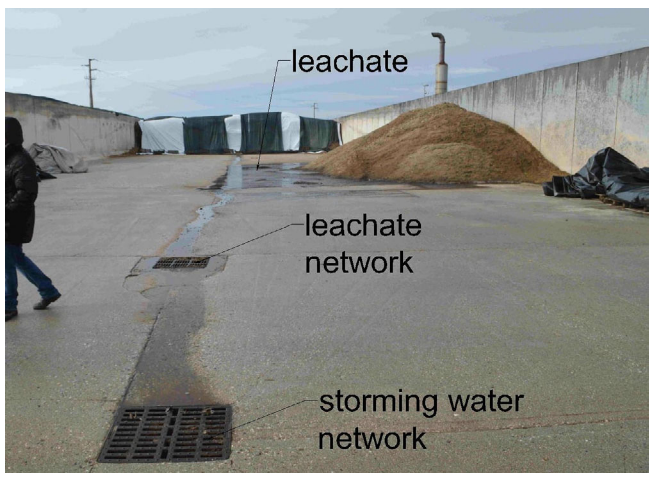

FIGURE 4 Storm-water and leachate catch basins [Color figure can be viewed at wileyonlinelibrary.com]

FIGURE 5 The analyzer probe during measurement [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Concentrations of gas in the storm-water tank

Basin	CH_4 (%Vol)	CO_2 (%Vol)	O_2 (%Vol)	H_2S (ppm)
1	32	Nil	Nil	Nil
2	22	25	19	Negligible
3	2	9	18	Negligible
4	9	25	11	Negligible
5	2	8	15	Negligible
6	32	22	8	19

by the leachate flow. The assessment was carried out analyzing the composition of the gas present in the storm-water tank, inserting the analyzer probe in all six basins, by slightly lifting the sealed manhole lids (see Figure 5). Measurements were taken immediately after the probe insertions to limit the dilution effects (Table 1). To verify the connection between the storm-water tank and the building through the pipe, CO_2 was injected in the service manhole close to the tank and fumes at the other end of the pipe were detected.

5 | DISCUSSION

The enquiry confirmed the presence of methane in all six basins. The presence of hydrogen sulphide (H_2S) and carbon dioxide (CO_2) was also recorded. The water temperature measured inside the storm-water tank, 20 days after the accident, was 15.1°C. Because of the thermal inertia, high volume, and the season, it is reasonable to assume that the temperature prior to the accident was about the same or higher. The gas composition measures showed oxygen concentrations sensibly lower than those normally present in the atmosphere (although not null). The carbon deposition on the sealed manhole walls was also evidence of low oxygen digestion process.

These considerations support the presence of an anaerobic activity inside the tank, and it is reasonable to assume that the observed oxygen concentrations were mostly due to the measuring procedure. The findings fit with a psychrophilic anaerobic digestion process,[6,7] which can develop in a 30/90-day-range period (longer than mesophilic and thermophilic digestion). This time interval is compatible with the inaccurate emptying of the storm-water tank as testified by the water level. It is also worth noting that organic material layers, deposited at the bottom of the basins, cannot be completely removed, and most likely act as inoculum, reducing the activation time and fostering the psychrophile digestion process.

As for the measurements taken in the first basin, which is actually the only one directly connected with the technical building through the control and power line (to activate the submerged pump), a methane concentration of 32 mol% was recorded. Such concentration is sufficient to form an explosive mixture when diluted with air.[8]

In conclusion, it is likely that the explosion is related to the spontaneous and uncontrolled development of a psychrophile anaerobic digestion process in the storm-water tank. Such biogas, evidently routed to the damaged building through the electrical piping system, produced an explosive mixture ignited by one of the various electric devices.

6 | CONCLUSIONS

The enquiry allowed to assess, with a high level of confidence, the accident dynamics, the causes of which were an uncontrolled anaerobic digestion process in the storm-water tanks and the lack of adherence to the operating prescription, thus suggesting a negligent operating behavior. Such circumstances, coupled with heavy rainfall, cannot be considered exceptionally rare and therefore should be subjected to risk analysis.

It is thus mandatory to derive some guidelines to prevent the future occurrence of similar events, particularly focused on (i) reducing the explosion trigger and (ii) preventing the formation of explosive mixtures.

As for point (i), it is natural to suggest a different ATEX classification for the different areas of this kind of plant upgrading from 2G to 0 for technical rooms and electric transformer cabins. This would increase the costs of the electrical and electronic appliances and yield to serious operational limitations.

As for point (ii), the formation of an explosive mixture in the technical rooms and electric transformer cabins should be avoided. To this aim, notwithstanding the somehow negligent operating behavior, it must be said that, according to the inherent safety operational approach,[9] the adoption of a grated manhole rather than a sealed one would have avoided the explosion. The grated manhole would have prevented the anaerobic biogas formation while allowing biogas dilution and dispersion in the atmosphere. It seems thus natural to conclude that a reconsideration of the security levels of all the underground electrical piping and their proper aeration is needed.

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