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Accident Analysis of European Biogas Stations

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The number of biogas stations continues to grow. Biomass is currently a very important source of renewable energy in Europe and bio-energy will play a key role in achieving the ambitious targets. It is generally known that the number of accidents increases with higher number of biogas units; therefore the role of their safety is increasingly important. The history of production of biogas in the industrial scale is relatively recent; there is not so much experience with safety as it is with other industrial processes. Experience can be taken from similar units, mainly from chemical industry. This paper is intended to describe a probability of possible major accidents associated with the operation of biogas stations. For 13,171 European biogas stations, more than 800 accidents were found out within the last 10 y, but most of them were accidents without any serious consequences; only three of them were serious with consequences for human lives.

1. Number of European biogas stations

The existing biomass resources on our planet can give us an idea of the global potential of biogas production. Probably only a very small part of this potential is utilised today; thus there is a real possibility to significantly increase the actual production of biogas. The European Biomass Association (AEBIOM) estimates that the European production of biomass-based energy can be increased from 72 Million tons in 2004 to 220 Million tons in 2020.
It is clear that biogas stations form a very dense network in some countries. The densest network in Europe can be found in Germany where one biogas station is attributable to every 45 km^2 of total area of land. The second densest network is in Switzerland; however a mountainous landscape forms 60 % of territory of this country. In reality, the network of biogas in Switzerland is much denser than in Germany.
Biogas sources vary distinctively among the members of the European Union. Germany, Austria and Denmark produce the largest share of their biogas in agricultural plants using energy crops, agricultural by-products and manure, whereas the UK, Italy, France and Spain predominantly use landfill gas (European Biogas Association, 2009).
Thus, for the reasons of safety, the operation of biogas stations becomes a very important issue and in terms of safety, biogas stations deserve more and more attention. The amount of biogas applications in the respective countries in Europe in 2014 is stated in Table 1. Information from Germany, Austria and Switzerland are from (Fachverband Biogas e.V. Branchenzahlen, 2013), information from Czech Republic are from (Czech Biogas Association, 2014) and the other data are from (European Biogas Association, 2013). Data were calculated using the Eurostat database information (Eurostat, 2014).

2. Biogas accidents

The analysis of accidents in biogas stations was conducted in 2011 by INERIS for the Ministry of the Environment in France. The aim was to gather a comprehensive feedback on the methanization activity from

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Table 1: Numbers of biogas stations in individual countries in European Union in 2012.

Country	Number of biogas stations	Number of inhabitants per one biogas station	Area attributable to one biogas station (km^2)
Germany (2013)	7,874	10,345	45
Italy	1,264	48,077	238
Switzerland	606	13,047	68
France	557	117,480	982
Czech Republic	481	21,925	164
Austria	436	19,309	192
UK	312	202,660	785
Netherlands	252	66,548	165
Sweden	242	39,061	1,859
Poland	186	205,462	1,681
Norway	185	25,361	1,747
Denmark	176	31,670	245
Belgium	119	92,504	273
Slovakia	92	59,130	533
Finland	78	69,064	4,335
Hungary	50	199,240	1,861
Latvia	37	54,729	1,743
Slovenia	33	62,181	614
Luxembourg	33	15,667	87
Ireland	27	166,185	3,127
Portugal	26	409,115	3,553
Spain	22	2,101,590	22,944
Greece	22	513,818	5,997
Lithuania	21	142,190	3,105
Cyprus	15	74,437	616
Croatia	12	367,250	4,712
Romania	7	3055,714	33,928
Estonia	3	446,667	15,075
Bulgaria	3	2,492,000	36,970

different national and international databases such as the databases ARIA from BARPI in France or ZEMA in Germany (Salvi, 2012).

The INERIS study provides, for the first time, a detailed analysis of accidents in France and in Germany (Evanno, 2012).

Typical accidents of biogas plants identified from INERIS study were as follows:

- Leakage in the storage tank and / or distribution network of the biogas,
- Leakage following the completion of work on site, storage, and distribution of biogas,
- Accidental release of H_2S, especially in mixtures of septic waste,
- Water pollution caused by effluent discharge,
- Overflowing sewage systems or storm-water control due to exceptional downpours, equipment failures in the event of massive influx of fire-water suppression,
- Presence of dangerous products in the raw material used to produce biogas,
- Overflow, freezing of valves, high pressure inside the digester.

The next source of accident information was the ZEBEC commissioned PROjENBioEnergy Analysis (Gornal, 2011).

Our study also involves an internet word search on a set of words related to European biogas accidents in different European languages. It was used as search terms on Google internet search engine. The terms brought to light newspaper reports of accidents in the language local to the accident.

For 13,171 European biogas stations, more than 800 accidents were found out in the last 10 y, but most of them were accidents without any serious consequences; only three major accidents resulted in consequences for human lives. The first was from Czech Republic (Czech Biogas association, 2013), the second one was from Germany (Delsinne, S., 2010) and the last was from Latvia (The Baltic Course, 2014). All of the identified serious accidents were caused by escaped biogas.

From the obtained data the frequency of major accidents was calculated. Frequency is denoted by the number of accidents per year. Calculated frequency of major accident is $1.5 \times 10^{-5}\ y^{-1}$. Calculation of frequency is very conservative - the number of biogas stations was lower in the past and there could be more major accidents (not described in the reports).

3. Description of analyzed biogas station

In the next step we will use an analytical approach and calculate the frequency of major accidents from widely used HAZOP, FTA and ETA methods.
For the analysis we assumed a typical wet biogas station (Figure 1).

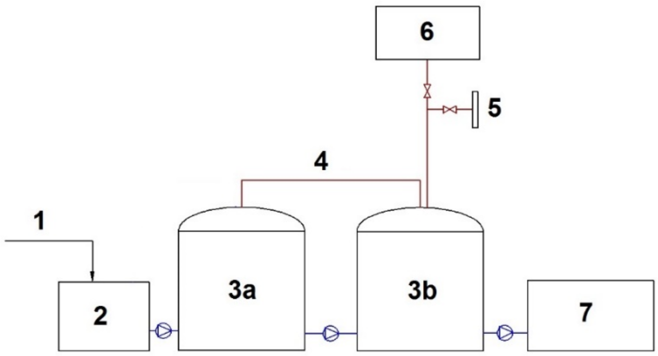

Figure1: Basic technological scheme of wet-process biogas station

Figure 1 shows a simple technological scheme of biogas station with two reactors. This is a two-step process which is very often used for treatment of farm products. Naturally, a biogas station with one-stage process or three-stage process can also be used. Every step represents the next reactor involved in the process.
A description of the process is the following. At first the processed material (1) enters a homogenization tank (2) where it is mixed because the batch often consists of various kinds of material and it is very important to mix them before they enter the reactor (feedstock is described in the next chapters). The mixed material is transported to the first anaerobic reactor (3a) by a screw conveyor. In the reactor the material is heated to a given temperature, which varies in dependence on the kind of process. A mesophilic process is ensured by the temperature of approximately 35 °C. The following process is a thermophilic process when the temperature can reach up to 55 °C (Stuckey, 1994). In the top part of the reactors, a gasholder is located. Reacted material is pumped to the second stage reactor (3b) where the secondary reaction runs and produces biogas. However, the intensity of production is lower than that in the reactor of the first stage (3a). Only low overpressure is in the pipe system - approximately 5 kPa (Kouďa, 2008). Due to this pressure, biogas is transported by pipes to a cogeneration unit (6) or gas torch (5). This torch serves in the case of outage of the cogeneration unit where biogas is burned. However, biogas is usually burned in the gas-engine of cogeneration unit where electrical energy and heat energy are produced. In the end, the reacted material from the reactor (3b) is pumped to the reservoir (7). The contents from this reservoir (7) are then transported to the field.

4. Identification of accident scenarios

The key part of risk analysis is to identify possible scenarios and their causes and to select representative scenarios of accident events (where risk sources with the most serious impact on health and human lives and property are included), which can lead to a serious accident. We have used the standard HAZOP method, which represents a structured and systematic technique of risk analysis where the objective is to identify the potential sources of risk in the system. These hazards can include the following:

- hazards, which are only related to immediate vicinity of the system,
- hazards with a wider impact (for example some environmental hazards).

This method also enables to find a potential problem with system operability which can lead to an accident.
The HAZOP study is particularly useful for identification of the lacks in systems or series of events or activities, which are planned in the sequence, and for determination of procedures, which control this sequence (Kotek, 2012).
We have identified the following scenarios:

- break of inlet piping,
- leakage from cogeneration unit,
- rupture of reservoir.

5. Estimation of frequency of hazardous events

To estimate the frequency of occurrence of hazardous event, the Fault Tree Analysis (FTA) was used. The FTA method is the most often used for the estimation of frequency of accident scenario. It is a model which shows various combinations of device failure and human errors, which can lead to a serious event, the so-called top event.
The fault tree can be considered as a qualitative model which can be quantitatively evaluated (CPR 12E, 1997). The advantage of fault tree technique is clearly a representation of development of the disorder in the system and identification of all causal links between elements and the disorder. This is carried out for chosen level of complexity of the system with the use of Boolean logical operators (AND, OR, NOT).
The important advantage of FTA methods is their system compatibility with methods for evaluation of faults of operators. A properly assembled fault tree represents all reasonable combinations of the elements faults and fault phenomena, which can lead to a specified peak phenomenon.
The fault tree for biogas leakage from the reservoir of biogas station is shown in Figure 2.

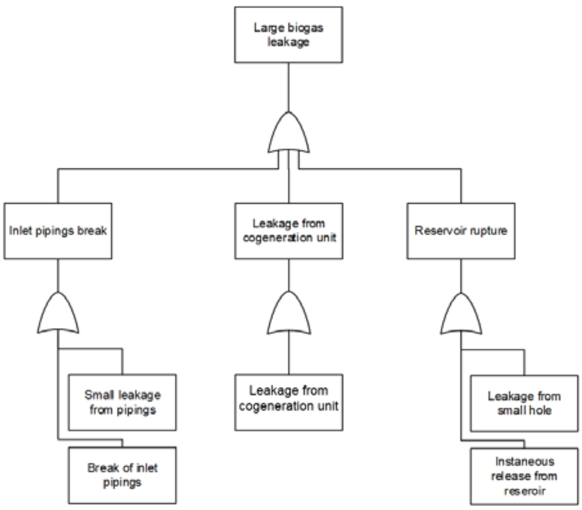

Figure 2: Fault tree for biogas leakage event

For these situations, RIVM suggested to consider the typical fermenter, cogeneration unit and reservoir as 'normal' atmospheric vessels for which defined scenarios are available (Heezen, 2013). Frequencies of these scenarios (piping rupture, vessel rupture) are taken from the Reference Manual Bevi Risk Assessments (Table 2).

Table 2: Scenarios for single containment atmospheric storage tanks (RIVM, 2009)

Scenario	Frequency (y^{-1})
Instantaneous release of entire contents	5×10^{-6}
Release of entire contents in 10 min in a continuous and constant stream	5×10^{-6}
Continuous release from a hole with an effective diameter of 10 mm	1×10^{-4}

We can obtain also the information about frequency of piping rupture (RIVM, 2014) from the Reference Manual Bevi Risk Assessments (Table 3).

Table 3: Scenarios for pipelines above ground (RIVM, 2009)

Scenario	Frequency ($m^{-1}y^{-1}$)
Rupture in the pipeline	3×10^{-7}
Leakage with an effective diameter of 10% of the nominal diameter, up to a maximum of 50 mm	2×10^{-6}

We can calculate the frequency of occurrence of large biogas leakage. The frequency is $4 \times 10^{-5}\ y^{-1}$.

6. Estimation of probability of scenario development

Frequency of occurrence of top accident scenario (leakage of gaseous substances) does not reflect frequency of harm for human population or environment by accident consequences. An explosive mixture does not have to be initiated because leakage can be caught in an accident reservoir or registered by operators, the source of leakage can be disconnected, etc. For this reason, the estimation of probability of developing an accident scenario should follow. The ETA method (Event Tree Analysis) is often used in major accident risk analysis.
The event tree graphically displays the information about possible development of accident sequences from the top event using the sequence combination of success and failure of safety elements (e.g. equipment failure, human error). The scenarios of accident are the result of ETA analysis; i.e. a set of faults or errors that lead to an accident.
The event tree is based on binary logic where the equipment safety function either works or fails, or the operator either intervenes or not. Theoretically, the number of accident sequences is twice the number of safety functions. The resulting frequency of occurrence of accident consequences is obtained with ETA analysis. The event tree for biogas leakage from the reservoir of biogas station is shown in Figure 3.

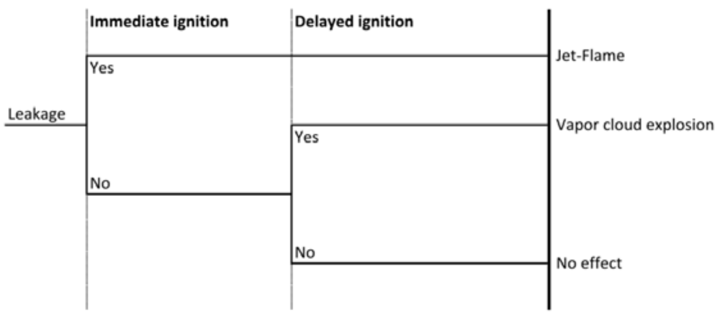

Figure 3: Event tree for biogas leakage event

In the case of Jet-Flame, the immediate initiation occurs during leakage of biogas. A slender, directionally oriented flame with a very distinct thermal radiation into the environment is formed. The pressure impact of this type of accident is not significant but the heat flux can cause injury. Because of low pressure of biogas, the consequences of this scenario are very limited.
The vapour cloud explosion (VCE) or Flash Fire is a very serious accident. Formation of cloud of dangerous substances, which can explode when mixed with air, is a primary condition of VCE or Flash Fire. This occurs above all during leakage of biogas in gaseous state in confined spaces. A transition from a burning cloud to a detonation occurs after initiation when specific physical conditions are met. The formed pressure wave spreads to the surrounding area. All of the identified serious accidents were caused by explosion of escaped biogas.
We can calculate the frequency of scenarios development. For these situations, RIVM suggested to consider the probability of delayed ignition caused by the presence of an ignition source. The assumed probability of immediate and delayed ignition is shown in Table 4.

Table 4: Probability of ignition (RIVM, 2009)

Scenario	Probability (-)
Immediate ignition	0.5
Delayed ignition	0.5

The calculated frequency of explosion in the wet biogas station is $1\times 10^{-5}\ y^{-1}$.

7. Conclusions

This paper presents an overview of safety situations related to biogas production. We conducted a detailed study of accidents in biogas stations. For 13,171 European biogas stations, more than 800 accidents were found out over the last 10 y, but most of them were accidents without any serious consequences; only three of them were serious with consequences for human population.
It means that the frequency of major accidents was $2.3 \times 10^{-5}\ y^{-1}$. Using the analytical approach, the calculated frequency of explosion in the wet biogas station was $1 \times 10^{-5}\ y^{-1}$.
Biogas stations do not represent as high a risk as chemical plants; it is necessary to emphasize that the impact of accident in biogas stations is rather of a local character. However, the accident in the biogas plant can have serious consequences. Therefore a proper application of basic principles of risk evaluation method can be a helpful tool for reduction of the frequency of accidental events; this should prevent damage to property and above all loss of lives.

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