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RISK ASSESSMENT AND SAFETY CONCEPTS FOR COGENERATION BIOGAS PLANTS

Abstract: *The topic of this paper is risk assessment and protection concepts for cogeneration biogas plants using functional HAZOP and FMEA methods with 5x5 AS / NZS 4360: 2004 matrix. The assessment was based on the ISO 31010 Risk Assessment Standard, Guidelines for the Safe use of Biogas Technology issued by the German Biogas Association (FNR), and Overall survey of engineering insurers for potential hazards at biogas installations issued by the German Insurance Association (GDV). The paper analyses all potential hazards that can occur during the regular operation of a biogas plant, how hazards can affect the occurrence of a harmful event, as well as how harmful events can affect all vulnerable resources. According to risk assessment and hazard analyses, a unique protection concept was proposed through a set of different measures. The final part of the paper is concerned with the development of the biogas industry and the occurrence of harmful events across Europe.*

Keywords: Cogeneration biogas plant, Risk assessment, HAZOP and FMEA method, matrix 5x5 AS / NZS 4360: 2004, Safety concepts.

INTRODUCTION

The production and use of biogas have been growing and developing rapidly around the world for the past twenty years. In our country, biogas production has been on the increase for the past ten years. The main aim of producing electricity from renewable resources is to reduce the dependence on the import of fossil fuels and to protect the environment.

Building a plant, obtaining the use permit, acquiring the status of the privileged producer of electricity and signing the power purchase agreement is only one stage in the business. Real challenges begin later.

The payback period for cogenerative biogas plants is at least eight years. During that period plants should be able to operate efficiently with 8200 h a year in order to earn sufficient income for regular servicing and further development. The investors are aware of the fact that this aim is not easily achieved because there are numerous problems on the way.

The production process inevitably entails hazards and their consequences. Therefore, it is extremely important to identify all risks and establish a proper protection concept that will comprise technical, organizational, financial and personal measures so that biogas plants could function safely.

COGENERATIVE BIOGAS PLANTS

Biogas is produced by anaerobic digestion (decomposition of organic matter in the absence of oxygen) of different kinds of biomass. Biogas is a mixture of gases containing methane CH_4 (50%-70%), carbon dioxide CO_2 (20%-50%), hydrogen sulfide H_2S (0.01% to 0.04%), ammonia NH_3, hydrogen H, nitrogen N and carbon monoxide CO.

A cogenerative biogas plant, i.e., a plant for combined simultaneous production of heat and power (CHP) converts the chemical energy of biogas into electrical and heat energy using an engine connected to the generator [1].

The biogas industry, as a combination of the chemical and energy industry, is prone to numerous harmful events. Managing the production process in these circumstances is an enormous challenge. Therefore, it is crucial that the plants are protected from all non-economic damage.

RISK ASSESSMENT

Risk can be managed after it has been identified, analyzed and evaluated i.e. assessed [2]. Only then can it be said whether that risk is acceptable or something needs to be changed to make it acceptable.

Theoretically, a risk assessment would be more accurate if it involved more parameters [3]. On the other hand, it makes the assessment more complex and more difficult to implement, very often having a nonlinear relation between those parameters [3].

The most widely accepted theory is that risk is the probability of harmful consequences or losses resulting from a given hazard over a specified time period [2, 4-8]. A better definition could be the one which says that risk can be viewed as a function of several components: hazard, vulnerability, exposure, and resilience [3, 9].

Hazard frequency and magnitude indicate that we are talking about risk [5]. Therefore, to assess risk adequately, data about the underlying hazardous event should be collected first [3,10].

Hazard is a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation [2].

In industrial systems, hazardous events include the release of chemicals and toxic substances, radioactivity, the release of energy in the form of fires and explosions, spillage and leakage of waste. These events are the result of failures in the industrial system, that is, a technical or human error, or are the result of events in nature such as earthquakes, landslides, floods, atmospheric discharges. The redundancies are most often sudden and intense with extensive damage that is not only limited to property but also to injuries to employees, often with fatalities, as well as to disruption of their regular operations.

Risk assessment in cogenerative biogas plants

For the assessment of risk in cogenerative biogas plants, according to ISO 31010 recommendations, it is necessary to choose proper methods of risk assessment. For that purpose, the combination of functional methods HAZOP and FMEA with 5x5 AS/NZS 4360:2004 matrix was used.

HAZOP is an acronym for HAZard and OPerability method of structured and systematic evaluation of a planned or an existing product, process, procedure or system. It is a technique for detecting risks that people, equipment, property, environment or organisational goals are exposed to. Failure mode and effects analysis (FMEA) is a technique used for detecting cases where components, systems or processes cannot fulfill their purpose [11]. The assessment was performed using a 5x5 matrix with the 5x5 AS/NZS 4360:2004 matrix in which consequences for people, environment and properties, and frequencies of an event were categorised.

Based on the assessed values of consequences C and frequency of exposure F, the level of risk is calculated as the product of these two parameters:

$$R = C \times F \qquad (1)$$

The levels of risk in the matrix were qualitatively determined as very high (VH), high (H), medium (M) and low (L).

The purpose of this kind of assessment is an observation of all risks, identification of the most significant risks and elimination of the less significant ones from the analysis. However, low risks with a high frequency of occurrence and significant cumulative effect should not be eliminated.

Depending on the characteristics of the technological process, facilities and equipment, a total of 49 hazards/failures were identified. The following events entail very high risk and cause extreme damage to all categories of the vulnerable resources or individual categories of the vulnerable resources:

- Formation of an explosive atmosphere as a result of putting the plant into operation, maintenance, regular release of biogas by means of overpressure valves, ruptures of the gas membrane, increased concentration of methane in the exhaust of the cogeneration or sudden failure of the burner. Coming into contact with an ignition source (spark), all these lead to explosions and fires which have a devastating effect;
- Self-ignition of the raw material as a result of improper storage conditions leading to fires, as well as fires resulting from ignition of other flammable materials in the plant;
- Release of hydrogen sulphide H_2S as a component of biogas from the mixing pit and pre-digestion pits, small concentrations of which can be fatal;
- Leakage of various biological substances.

Injuries caused by traffic accidents, by working with equipment that carries high voltage or with faulty equipment, and those caused by maintenance. Injuries happen when procedures are not followed and when protective equipment is not used or is used carelessly.

Analysis of events which cause fires

Cogenerative biogas plants store different flammable materials and explosive gases. In biogas plants, fires can occur both inside and outside the plant. Depending on the place of occurrence, fires can be medium or big. In a cogeneration biogas plant, depending on the kind and amount of combustible materials, the following classes of fire can be expected:

- Class **A** fire is related to solid combustible materials such as corn silage, straw, wood (furniture and stationery in the administration building with the pumping station), paper and cardboard in the administration building. These fires are extinguished with water, sand, foam, halon and some kinds of powder;
- Class **B** fires are fires in flammable liquids such as different greases for technological equipment and cogeneration unit, oils in the substation, various paints, plant oils, thinners, etc. The main extinguishers here are powder, carbon dioxide and foam;
- Class **C** fires are fires of flammable gases such as methane CH_4, hydrogen sulphide H_2S and ammonia NH_3. These gases are generated in the production process. The main extinguishers are powder and carbon monoxide, whereas the best way to extinguish fire in gas installations is to shut off the inflow of gas.

Class **E** fires are fires in electric equipment and installations (machines, electric motors, substations). The main extinguishers are powder and carbon dioxide.

Analysis of events which cause explosions

An explosion is a sudden chemical reaction of an explosive, flammable matter with oxygen, during which an enormous amount of energy is released and dispersed in different ways [12], through the creation of the pressure wave, bursting of vessels, thermal radiation, physical displacement of equipment and secondary fires. An explosion occurs in an explosive atmosphere (with particular concentration and under particular pressure) in the presence of oxygen and an ignition source. There is a danger of explosion when the concentration of biogas is in the range between 6% and 22%. An explosive atmosphere is formed when gas leaks from the technological equipment or due to incomplete gas combustion which happens as the result of faulty machines or different problems with buildings where biogas is processed and stored.

Analysis of events which cause release of pollutants, dangerous and toxic substances into the environment

Activities which take place in cogenerative biogas plants can affect the environment through the release of substances into the soil, water and air. These activities include disposal of drainage water from trench silos and disposal of the biological substrate from pre-digestion pits, mixing pits and digesters.

Analysis of events which cause failures and different hazards connected to the use of technological and electrical equipment

A cogenerative biogas plant uses various kinds of equipment in the process of producing heat and power. The most frequent failures are breakdowns of mixers, pumps and CHP unit and are induced by the quality of the substrate, chemical compounds in the process and the quality of biogas - all of them damage and corrode the material of which the equipment is made. The dangers related to the technical and electrical equipment are dangers of explosion, electric arc and static electricity. These dangers occur if the equipment is not periodically controlled or maintained, or if safety procedures are not adhered to. Within the technological process, injuries occur while manipulating the raw materials all the way from trench silos to hoppers, during work at height and as a consequence of non-compliance with safety procedures.

CONCEPTS OF PROTECTION

Cogenerative biogas plants are complex systems. In order to produce biogas and convert mechanical energy into electrical energy, they need to have appropriate facilities and equipment. All facilities must have a use permit and proper equipment. Different procedures have to be followed and different protective measures considered. In order to reduce risk, it is necessary to establish a system of protection through technical, organisational, financial and personal measures and to monitor the work of the whole plant using appropriate documentation.

Risk reduction by means of technical protective measures

Risk prevention tends to reduce the number of damages or completely eliminate them [12, 13] and primarily depends on the specific risk with which an organization may be encountered. The causes of damage, and in particular damage from fires, explosions and other accidents, fall into the categories of damage that science and the profession can predict and which can be prevented, i.e. managed.

In parts of a biogas plant in which gas is stored and transported, Ex zones must be classified. The facilities are protected using:

- a hydrant network with aboveground fire hydrants (which have a specific reservoir volume and a pressure booster) aimed at fighting primary fires;
- portable and transportable fire extinguishers, type S-6, S-9, S-50;
- warning boards.

The equipment used for storing and transporting biogas must be checked for possible leakages and the formation of an explosive atmosphere. Devices used for this purpose are cameras and laser methane detectors. If the electricity supply goes off, the unburnt gas must not be released into the atmosphere. It has to be burnt with the burner.

Risk reduction by means of organisational and personal protective measures

Before putting the plant into operation, the operator should create a register of sources of danger and pollution that would contain information on types, amounts, way and place of entry, release and disposal of pollutants in the gaseous, liquid and solid state, or on the release of energy (noise, vibrations, heat, ionizing and non-ionizing radiation) [14]. If the environment is harmed in the process of work of a cogenerative biogas plant, the legal entity is responsible for repair and remediation [14].

It has been shown in practice that precautions against fires improve when each operator is in regular contact with the concerned fire brigade and when fire drills are practiced so that the fire brigade can take proper action in case of fire.

It is necessary to wear adequate equipment while the plant is working. Personal protective equipment includes:

- safety glasses;
- masks with filter;
- protective helmets;
- earmuffs;

- protective clothing and boots;
- protective gloves;
- safety harness for working at heights and in closed spaces.

Transfer of risk by means of financial protective measures

Financial resilience to hazards is a preventive financial measure that helps individuals or communities to quickly recover from financial shocks that hazardous event brings [9].

Insurance, as a financial instrument, ensures financial security to the affected individuals and companies [15]. By taking the risk within the insurance portfolio, the insurance company takes responsibility for damages that might arise from the risk realization [15,16].

Generally, the transfer of risk to insurance companies could mitigate the effects of natural disasters in two ways: first, the insured is motivated to take appropriate preventive measures in order to be entitled to a more acceptable insurance premium and second, the insured is compensated for the damage by insurance companies immediately after the harmful event [17,18]. This way, financial liquidity of the affected individuals and firms is achieved, contributing to the reduction of vulnerability, i.e. to increased resilience [17].

Cogenerative biogas plants are exposed to various risks: fire and explosion, gas or liquid leakages, stock self-ignition, bad weather hazards, machine breakdowns and staff injuries. Considering the above-mentioned, the best solution for these plants is the All risks insurance contract. With all risks insurance, one policy is taken out for a precisely defined number of risks where standard risks can be expanded so that the property and business activities of a company are best protected. This policy has to be carefully formulated. It has to be unambiguous so that specific property or risk would not be accidentally excluded. All risks policy should cover the following risks:

- physical damage to property;
- faults in electrical and mechanical parts of equipment;
- lost profit (including the loss of feed-in tariffs);
- fire and explosion;
- accidents, illness and injuries of the employees;
- decay of raw materials;
- responsibility for pollution;
- responsibility of managers and operators;
- theft and deliberate destruction of property.

Documentation as a special measure of risk management

Documenting for cogenerative biogas plants is performed by writing:

- Project technical documentation, essentially a report on danger zones and the main fire safety project;
- Documentation on risk assessment;
- Instructions on the safe use of equipment and work of the plant;
- Instructions on the maintenance of the equipment and the plant;
- A plan for preventive and regular maintenance;
- Procedures in case of accidents, fires, explosions, power failures, injuries at work;
- Instructions on the training of all employees by the supplier of technology before the plant are put into operation;
- A record showing that putting the plant into operation was done with the supplier of technology;
- Register of dangerous substances.

DEVELOPMENT OF BIOGAS INDUSTRY AND HARMFUL EVENTS

With the development of engineering and technology, the global demand for bioenergy has been on the increase during the past ten years. The projections are that the demand will be increasing until 2035, as a result of strategies aimed at reducing air pollution.

According to information and databases such as E MARS, INFOSYS and ARIA, an investigation [19] was carried out in the period from 2006 to 2016, including 208 harmful events in different European countries.

The most frequent harmful events out of these were fires - 123 (59%) and then 45 explosions (22%), 23 events harmful to the environment (11%), 11 gas leakages (5.29%) and 6 poisonings of employees (2.88%) [19]. Financial damage was recorded in 95 events and the average value of damage was 400,000€ [19]. The average financial damage caused by the fire was around 250,000 €, and the average financial damage caused by the explosion amounted to 960,000€ [19].

Between 2006 and 2016, four harmful events resulted in the loss of life [19]. There were 21 cases of accidents with severe injuries, whereas major injuries occurred in 16 cases (76%) as a result of biogas explosion [19].

Analysing the reports on the recorded harmful events from the available databases of biogas plants, it can be concluded that the data is incomplete and of questionable quality. The questionnaires were carelessly or only partially completed and not supported by photographs which captured the harmful event. Apart from this, not all harmful events were recorded in the MARS database. A considerable number of data can be found only in INFOSYS or only in the ARIA database.

CONCLUSION

Although today all risks in the process of converting and generating energy are known, and specific engineering standards adopted, harmful events continue to happen. This is due to inadequate technological solutions, non-compliance with rules, poor organisation of work, lack of safety procedures, lack of adequate standards for the training of operators, and lack of awareness of the risks on the part of managers of biogas plants.

After twenty years of intensive development, it is necessary to adopt specific technical standards and rules for this industry because the process of production and conversion of biogas is unjustifiably seen as safer than classical chemical processes.

The analysis showed that it is necessary to update the information from reports on harmful events and liaise with insurance companies in order to obtain information about real damage inflicted on vulnerable resources. Only comparable results in combination with a sufficient number of analysed plants will enable a better understanding of harmful events from the whole sector and the creation of a reliable database.

Finally, the concept of safety can only be developed when both preventive engineering and a set of technical, organisational, personal and financial protective measures are applied.

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BIOGRAPHY

Gorana Milinčić Stančić was born in Čurug in 1983. She defended her master's thesis at the Faculty of Technical Sciences, Department of Engineering Management in June 2007. She has worked as an expert assistant in the SGS company since October 2007. She has been an engineering expert witness in the field of mechanical technology – the assessment of equipment, installations and vehicles since 2014. As an employee of the SGS company, she has participated in the process of supervision of building biogas plants. She is a member of the Serbian Biogas Association.

PROCENA RIZIKA I KONCEPTI ZAŠTITE KOGENERATIVNIH BIOGAS POSTROJENJA

Gorana Milinčić Stančić, Snežana Živković

Rezime: *Tema ovog rada je procena rizika i koncepti zaštite za kogenerativna biogas postrojenja primenom funkcionalnih metoda HAZOP i FMEA sa matricom 5x5 AS/NZS 4360:2004.Procena je rađena na osnovu Standarda za procenu rizika ISO 31010, Smernica za bezbednu upotrebu tehnologije biogasa koje je izdalo Nemačko biogas udruženje (FNR) i Istraživanja o biogas postrojenjima i potencijalu tehničkih opasnosti koje je izdalo Nemačko udruženje za osiguranje (GDV). U radu su analizirane sve potencijalne opasnosti koje je javljaju tokom redovnog rada kogenerativnog biogas postrojenja, kako one utiču na pojavu štetnog događaja, kao i kako štetan događaj utiče na sve ranjive resurse. Po izvršenoj proceni rizika i analizi svih opasnosti dat je predlog za jedinstven koncept zaštite primenom seta različitih mera. Na kraju rada je sagledan razvoj industrije biogasa i pojava štetnih događaja na teritoriji Evrope.*

Ključne reči: Kogenerativna biogas postrojenja, procena rizika, HAZOP, FMEA, matrica AS/NZS 4360:2004, koncepti zaštite.