CHEMICAL ENGINEERING TRANSACTIONS

VOL. 32, 2013

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Chief Editors: Sauro Pierucci, Jiří J. Klemeš

ISBN 978-88-95608-23-5; **ISSN** 1974-9791

DOI: 10.3303/CET1332034

Safe Operation of Biogas Plants in Italy

Biancamaria Pietrangeli*, Roberto Lauri, Paolo A. Bragatto

INAIL – Settore Ricerca Certificazione Verifica – Via Urbana 167, 00184 Rome – Italy
b.pietrangeli@inail.it

This paper presents a few results of a work aiming at providing the biogas industry with practical tools to protect workers and environment. Biological contamination, Fire and Explosive Atmosphere are the main hazards. The technical and organizational measures, aiming at preventing or mitigating them, have been identified and classified by means of the “bowties” technique. From this analysis, a structured safety check list has been derived. The checklist is a valuable support for the plant operator to evaluate periodically the actual effectiveness of the overall safety measures and to address a safer management of the plant.

1. Introduction

Biogas industry development is driven by important issues, including the decreased availability of fossil resources, and the climate change (Čuček et al. 2011).In Italy this industry is rapidly growing, thanks to intensive Research & Development support complemented by public incentives. In Italy, increasing numbers of biogas plants use food waste and manure as energy sources: 542 biogas plants (61 under construction) have been identified in 2009 by CRPA[1], of which 235 plants producing biogas from livestock effluent in co-digestion with energy crops or agro-industrial waste. In the present paper the focus is on a biogas plant that is installed at livestock farms, as the most popular type of installation.

1.1 The biogas plant

Even though biogas plants are considered quite simple installations, they are featuring a variety of items. As there are many feedstock types suitable for digestion in biogas plants, there are various techniques for treating these feedstock types and different digester constructions and systems of operation. The core component of a biogas plant is the digester. Common characteristics of digesters are that they have a feedstock feeding system as well as digestate output. The size of digesters determines the scale of biogas plants and varies from few cubic meters in the case of small household installations to several thousands of cubic meters, like in the case of large commercial plants. Constant process temperature inside the digester is one of the most important conditions for stable operation and high biogas yield. In order to achieve and maintain a constant process temperature and to compensate for eventual heat losses, digesters must be insulated and heated by external heating sources. The most used source is waste heat from the CHP (combined heat and power) unit of the biogas plant. Agricultural biogas plants (Figure 1) usually operate with six process stages: 1) transport, delivery, storage and pre-treatment of feedstock, including liquid manures, maize silage, etc; 2) biogas production in the digester (A.D. anaerobic digestion); 3) biogas storage in the gasholder; 4) digestate storage; 5) biogas cleaning (desulphurization, filtration and dehumidification); 6) combined heat and power production. When biogas is utilized in a CHP unit, the demand for biogas can vary during the day. Therefore it is necessary to store it in appropriate storage facilities. The simplest solution is the biogas storage established on top of digesters. For safety reasons the gasholders must be equipped with safety valves (protections against under-pressure and over-pressure) to prevent damages and safety risks. Explosion protection must be guaranteed and an emergency flare is required. When biogas leaves the digester, it is saturated with water vapor and contains, in addition to methane (CH_4) and carbon dioxide (CO_2), various amounts of hydrogen sulphide

[1] CRPA (Centro Ricerche Produzioni Animali),”Bovini da latte e biogas. Linee guida per la costruzione e la gestione degli impianti”, 2012.

Please cite this article as: Pietrangeli B., Lauri R., Bragatto P., 2013, Safe operation of biogas plants in italy, Chemical Engineering Transactions, 32, 199-204 DOI: 10.3303/CET1332034

(H_2S). Water vapor and hydrogen sulphide can cause damages to the CHP unit (corrosive effects) and so it is necessary to desulphurize and dehumidify the biogas in order to observe the targets, which are set by the engines producers.

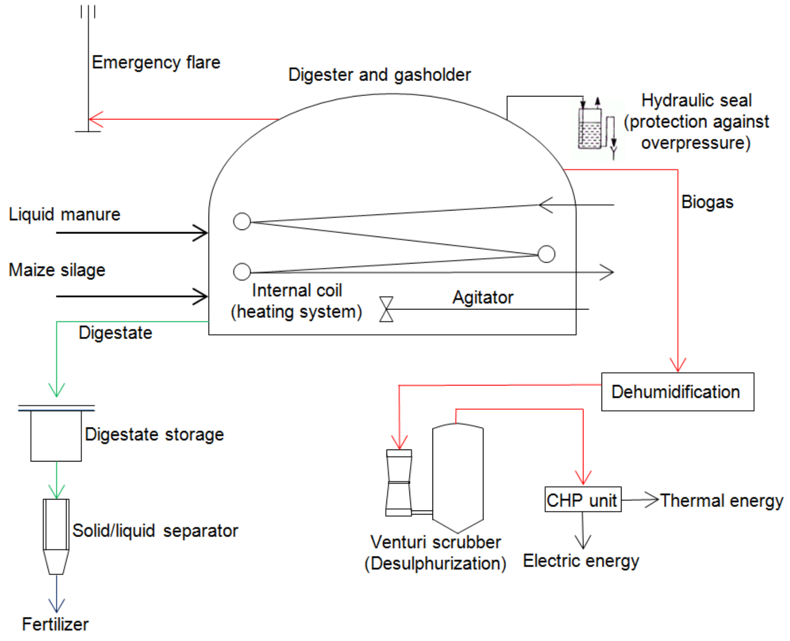

Figure 1- A typical Biogas plant

2. Methods

The adopted methods for developing the required tool is based on the well known bow-tie approach. In the bowtie approach must be identified the initial event, which could cause an adverse effect on workers (injuries or diseases). Then measures must be identified in order to prevent that a person is hit by a potential "initial event". The safety measures must be subsequently identified to reduce the "dose" , which is received by a worker following an "initial event". The mitigation event can be aimed to (a) minimize amount/intensity of hazardous agent; (b) protect person from hazardous phenomenon; (c) minimize duration of exposure. It is usually called "bowtie method" because preventive barriers, events and mitigations are organized according to a diagram, looking as a bowtie (Ale et al. 2008). The discrimination of protective and preventive barriers is highly valuable to prioritize safety measures, evaluate and monitoring safety levels, making adequate decisions about training and maintenance programming and safety investments. The adopted methods includes six steps, including a) identification of hazard and relevant safety barriers identification; b) safety measure classification (regulatory, organizational, procedural, technical systems); c) building for each hazard a bow tie with preventive and protective measure; d) derive from the bowties a check list, that aims at evaluating the actual efficiency of the safety measure. It has to be stressed that the efforts for the check list included three visits at a biogas plant, where inspections and audits activites have been simulated, in order to verify the real feasibility.

3. Results

Fundamentals of safety for biogas plants are discussed in §4.1 §4.2, whilst the specific safety measures are shown in detail in the diagrams, which are discussed in §4.3. The check lists are presented in §4.4.

3.1 Hazard and safety measures identification (Biological Hazard)

Biohazard related to biogas technology may be presented by the feedstock and by the digestate. Wastes of animal and human origin contain various pathogenic bacteria (e.g *Salmonella, Enterobacter, Clostridia, Listeria* ecc), parasites (e.g. *Ascaris, Trichostrangylidae, Coccidae*), fungi, viruses (Ritari et al. 2012, Sahlstrom 2003) and could represent an occupational and environmental biohazard. Biogas production from co-digestion of animal manure and biogenic wastes may not result in new routes of pathogens and diseases transmission among animals, humans and the environment by standardized veterinary and sanitary measures. Effective control of pathogens can be done through applying the measures, which are 1) livestock health control. No animal manure and slurries should be supplied from any livestock with health problems; 2) feedstock control. Biomass types with high risk of pathogen contamination must be excluded from AD; 3) separate pre-sanitation of specific feedstock categories (animal carcasses, parts of carcasses, or products of animal origin not intended for human consumption), by pasteurization or pressure sterilization, is mandatory as stipulated by European Regulation EC 1069/2009 [2]. In the case of feedstock categories which don't require separate pre-sanitation, the combination of AD process temperature and a minimum guaranteed retention time will provide an effective pathogens reduction/ inactivation in digestate (Kearney et al. 1993) and in biogas plants these process variables are taken into account using several checkpoints. The efficiency of pathogens reduction must not be assumed, but verified by using one of the accredited indicator organism methods. Indicator bacteria are preferably non-pathogenic bacteria, easily detected and counted and in large numbers in human and animal intestinal tracts. Enterococci are usually used to evaluate the hygienic treatment of biowaste in BGPs (Larsen et al. 1994), even though an indicator, that is good to give an overall picture has not yet been found (Sahlstrom 2003). The microorganisms taking part in the fermentation process are mainly assigned to the group 1 risks and to a small extent to the group 2, according to the Italian Decree 81/2008 and no special protection devices are necessary, but the observance of hygiene regulations is crucially important during work in biogas plants. If the specified hygiene and other protective measures are properly taken, complaints are not normally encountered. However if employees suffer headaches, dizziness, diarrhoea or skin irritation, the observance and efficacy of the protective measures must be immediately checked. Personal hygiene measures include the disinfection or washing of hands before breaks. Eating, drinking and smoking must be forbidden in the workplace (plant area). Work clothing must be separately stored from private clothing in accordance with good practice for preventing the propagation of pathogens. A skin-care plan is also important. It includes the provision of facilities for washing and disinfection, and of skin protection and care products. Furthermore employees must receive instructions on hazards and protective measures before assuming their tasks and subsequently at regular intervals. In biogas plants, during the different operations (biomass storage, loading and unloading) workers could be exposed to bacterial endotoxins. Acute lung function changes, which are associated with endotoxin levels, have been measured in different occupationl environments: pigs farming, animal feed, grain processing, waste and compost industry, and agricultural seeds (grass, cereal, or vegetable). The source of endotoxins is the lipopolysaccharides (LPS) in the cell walls of Gram-negative bacteria derived from decaying wastes. At low concentrations (<200 Endotoxin Units (EU)/m^3), endotoxins can induce fever, and at high concentrations (>200 EU/m^3) a stimulation of the mucous membrane; respiratory diseases up to chronic inflammations of the respiratory system can be evoked. Relatively low endotoxin levels of 50-500 EU/m^3 over 8 h may cause a decline in lung function. An exposure limit of 50 EU/m^3 has been recommended (ICOH 1997). In biogas plants increased endotoxin concentrations (>50 EU/m^3) could be related to operations with aerosol formation, e.g., when a chamber filter press is cleaned, etc. Furthemore, at biogas plants, large amounts of agricultural feedstock are often handled and there is a high exposure to inhalable fungal spores and bacteria including actinomycetes in the air at working areas. Evidence from both epidemiological and experimental studies supports the hypothesis that these exposures are associated with development of hypersensitivity pneumonitis, organic dust toxic syndrome, decline in lung function, severity of asthma, respiratory symptoms and airway inflammation (Douwes et al. 2003). Personal protective equipments (PPE) are the first lines of defence in order to prevent the intake via the respiratory tract.

3.2 Hazards identification and safety measures (Fire and Explosion)

Biogas plants process large quantities of combustible and toxic gases, which pose increased fire and explosion hazards in case of faults in design, material or control. Methane is highly flammable and forms explosive mixtures in combination with the oxygen in the air. Therefore explosion protection is very important in biogas plants. For these reasons biogas must be prevented from entering working areas. Specific safety measures must be guaranteed during construction and operation of biogas plants. The risk of explosion is particularly high close to digesters and gasholders (overpressure safety devices). In Europe explosion safety measures are stipulated in the European Directive 1999/92/EC. Spaces with risk of explosion are graded in zones according to the probability of the occurrence of an explosive atmosphere. Sources of ignition must be prevented and so a small positive pressure prevents the penetration of air into the bioreactor. A minimum overpressure is fixed to avoid this event. Pressure inside the biogas storage tank is measured and transmitted to the control center. The safety devices are intended to prevent an increase in pressure to amounts that could result in the destruction of the gasholder membranes.

[2] EU Regulation n. 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption

Therefore biogas plants are usually equipped with an hydraulic overpressure valve. Furthermore in situations where there is an excess of biogas, which cannot be stored or used, emergency flare is the ultimate solution to eliminate gasholder overpressure risk. Safe and reliable operation of a flare requires a number of features, in addition to a burner and an enclosure. Essential safety features include a flame arrestor, fail-safe valve and an ignition system that incorporates a flame detector. The pilot flame must be controlled by an automatic guard and when the gasholder pressure is reduced to the fitted operation value, the biogas feeding to the flare is automatically interrupted. Insufficient attention is often paid to protection during maintenance works. If maintenance works are necessary in danger zones, measurements must be always performed at the beginning of these operations. In particular during welding, abrasive cutting and soldering, suitable fire extinguishers must be made available. These extinguishers must be instantly seen, easy to reach in case of fire and working. As the responsibility to ensure the safety of biogas facilities rests with the operators, they must assess the possible hazards in accordance with the Italian Legislation on Occupational Safety (D.Lgs. 81/08) and implement appropriate safety measures. Safety equipment and the planning of the building and technical systems (fire resistance of gasholder membranes, etc.) must be tailored to the specific plant and inspected at regular intervals. However operators should not solely focus on safety precautions, but should also take into account organizational measures (schedule of extinguishers maintenance), which are frequently neglected in practice. In fact emergency response plans, routes for fire brigade vehicles and escape routes must be accurately designed. To ensure an effective emergency response system, the sensors (gas and fire detectors) must be appropriately positioned, calibrated, wired and maintained. For larger plants recurrent emergency exercises show whether the alarm is able to alert all persons in and around the facility at all times and prove the efficiency of escape and rescue plans.

3.3 Safety measure classification and bowties

As it has been briefly discussed in § 4.1 and 4.2, for each hazard (BIO, FIRE and ATEX) there are well known preventive and protective measures. For each measure a basic efficiency level has been evaluated. Three levels, which range from 1 to 3 (the highest), have been considered. Table 1 summarizes the adopted classification criteria.

Table 1. *Classification criteria for the safety measures.*

<table>
<tr><th>Level</th><th>short description</th><th>Non exhaustive list of measures</th><th>class</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Generic measure. It has a higher failure probability or lower mitigation capability;</td><td>Mandatory actions defined by law. They must be authorized and may be under periodical verifications by Competent Authorities.</td><td>regulatory</td></tr>
<tr><td>Personnel Resources. Organization chart, Training, Information, Culture and Behaviour.</td><td>Organiza-tional</td></tr>
<tr><td>Internal Procedures, Operating Instructions, and relevant Modules in force at the plant.</td><td rowspan="2">procedure</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Technical measure subject to some degradation mechanisms, that require periodical verification;</td><td>Audited procedures; Certificate delivered by external bodies</td></tr>
<tr><td>Personal and Collective Protective Equipment, Portable Instruments, Removable and provisional barriers.</td><td>portable system</td></tr>
<tr><td>Equipment, Safety Valves, Electrical Electronic and Programmable Instrumentation, Control and Block System, Alarms and Signals.</td><td rowspan="2">fixed system</td></tr>
<tr><td>3</td><td>Inherent/permanent Safety measure.</td><td>Layout and Installations designed according to safety criteria,</td></tr>
</table>

The safety measures have been discriminated as preventive, mitigatory or protective. For each identified hazard (BIO, FIRE and ATEX) a diagram with the relevant measures has been built, according to the bowtie model. Each measure, as individuated in the analysis phase, has been represented in a single box: the position in the bowtie depends on type of measure, the number on right side represents the efficiency levels, as in table 1. Figure 2 shows a synopsis of the three bowties. The figure is self-explaining, but it's interesting to stress that whilst biosafety is focused on individual protection, fire and explosion safeties trust more in engineering containment system, as well as on firefighting preparedness. The sums of the evaluated efficiency levels are, anyway, adequate to control the three main hazards.

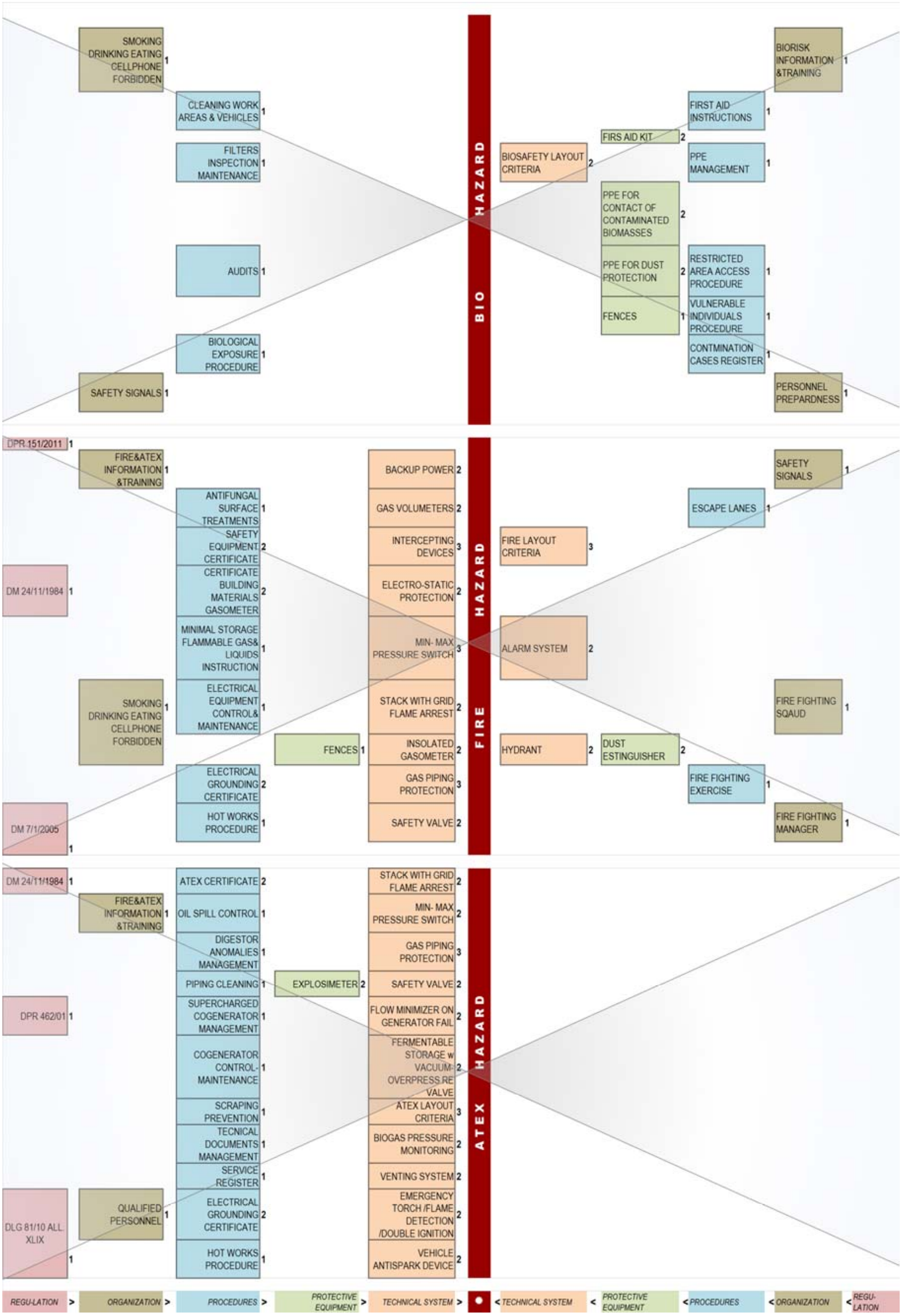

Figure 2- Bowties representation of the safety measures for BIO, FIRE and ATEX hazard.

3.4 Safety Check list

From the safety measures, which are organized according to the bowtie schema, it was easy to derive a structured check list. For any single measure represented as a box in the bowtie there is a single item in the check list. The check list is aimed at auditing the plant safety and evaluating the actual safety level. It may be applied in a modular way. Design criteria should be checked just at the first time. It has to be stressed that the efficiency levels of the equipment are subjected to degradation processes. Thus even though they are initially assumed equal 2, they must be evaluated through periodical inspections, which must be carried out by qualified person, on behalf of the plant's operator. The check list has been organized according modules (regulatory, organizational, procedural, technical). In such cases the operator is able to control any safety issue. For any issue there are specific activities (audit, exercitation, test or non destructive controls), that may be scheduled according the operation needs, the available resources and the results of previous control activities. There is not room in the paper for a full description of the check-list, and the structure may be just shown.

Table 2: The Check list for evaluating the safety level of a biogas plant.

Check List Issue		Periodical Control Activity
Law and regulation compliance (7 items)		audit
Organizational issues (11 items)		audit
Safety procedures and operating Instructions (28 items)		
	Preventive FIRE and ATEX procedure	audit
	Preventive BIO Hazard procedures	audit
	Firefighting procedures (protective)	exercitation
Personal Protective and other portable Equipment (6 items)		verification
Technical System (24 items)		
	Safe Design Criteria	just a first verification
	FIRE prevention system	in situ Inspection
	ATEX prevention system	in situ Inspection

4. Conclusions

The check lists, as designed starting from a scientific analysis of preventive and protective measures, are adequate to evaluate the actual safety levels of the whole plant and to support the operators in the safety assessment management. Risk levels are not so high and operator may operate the plants in a profitable way by means of simple tools, such as the proposed check list.

5. Acknowledgement

The work is supported by the National Centre for Diseases Prevention and Control (CCM) of the Italian Ministry of Health (Project n°36/2011). The Authors thank the Maccarese S.p.a. for its kind cooperation.

References

Čuček, L., Klemeš, J. J., Varbanov, P., & Kravanja, Z., 2011, Life Cycle Assessment and Multicriteria Optimization of Regional Biomass and Bioenergy Supply Chains. Chemical Engineering Transactions, 25, 575-580.

Ritari J., Koskinen K., Hultman J., Kurola J.M., Kymalainen M., Romantschuk M., Paulin L., Auvinen P., 2012, Molecular analysis of meso-and thermophilic microbiota associated with anaerobic biowaste degradation. BMC Microbiology 12, 121-135.

Ale B.J.M., Baksteen H., Bellamy L.J., Bloemhof A., Goossens L., Hale A.R., Mud M.L., Oh J.I.H., Papazoglou I.A., Post J., Whiston J.Y., 2008, Quantifying occupational risk: the development of an occupational risk model. Safety Science 46 (2), 176–185.

Sahlstrom L., 2003. A review of survival of pathogenic bacteria in organic waste used in biogas plants. Biores Technol 87,161-166.

Douwes J., Thorne P., Pearce N., Heederik D., 2003. Bioaerosol health effects and exposure assessment: progress and prospects. Ann. Occup.Hyg. 47(3),187-200.

ICOH Committee on Organic Dust, 1997, Endotoxin in the environment: a criteria document, Int. J. Occup. Environ. Health 3(suppl.), 1-48.

Larsen H.E., Munch B., Schlundt J.,1994, Use of indicators for monitoring the reduction of pathogens in animal waste treated in BGPs, Zentralbl.Hyg. Umweltmed 195, 544-555.

Kearney T.E., Larkin M.J., Levett P.N., 1993, The effect of slurry storage and anaerobic digestion on survival of pathogenic bacteria, J. Appl. Bacteriol 74, 86-93.