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Identification of Major Accident Hazards in Industrial Biological Processes

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The present work focuses on process safety related to bioprocess engineering, meant as the integration between chemical engineering and biotechnology. A specific checklist has been created in order to perform a first step in bioprocesses hazard identification aimed at meeting not only personnel safety issues, but also process safety ones. The bioprocess of biogas production from anaerobic digestion of livestock slurry was taken as a case study to show the methodology.

1. Introduction

In recent years, industrial biological processes are increasingly used in the chemical industry, spacing from pharmaceutical to food or energy production. The increase in the number and potentiality of bioprocess facilities associated to the scale-up to industrial production, as well as to the industrial implementation of innovative processes and technologies, is generating an emerging risk (CCPS, 2011). Bioprocesses are often perceived as safer and having a lower impact than conventional chemical processes. However, recently several unexpected severe accidents were reported for biological processes, in particular in the energy sector (e.g. biogas production and biofuel processing in Casson Moreno and Cozzani, 2015; Rivière and Marlair, 2010). In particular, unexpected operating conditions in the biological process resulted in the formation and release of hazardous substances (Casson Moreno et al., 2015). Such scenarios were not considered in the safety assessment of the process, revealing some limitations of conventional hazard identification techniques for biological processes.

Our review of the state of the art on existing risk assessment methods shows that there are no specific techniques for hazard identification in bioprocesses, especially addressing process safety problems. Until now, specific checklists, hazard identification procedures and tools for biological processes focused mostly on personnel safety. On the other hand, conventional hazard identification techniques often may overlook the specific issues posed by biological reactions.

The present study shows preliminary results obtained in the identification of bioprocess hazards.

A specific checklist, to screen the possible criticalities related to bioprocesses has been created; it has been tested and tuned on a real case study; a biogas production plant from anaerobic digestion of livestock slurry was analysed, giving interesting results and rising the issue about the need for a complete hazard identification methodology specific for the sector.

2. State of the art in bioprocess hazard identification

A bioprocess is a process that uses microorganisms, living cells or their components to obtain products or complete a chemical transformation. At present, the scientific community identifies the risk related to bioprocesses (the so-called biohazard or biological hazard) to the use of biohazardous materials, defined as infectious agents that present a risk, or potential risk, to the health of humans, animals or environment. The prevention of the exposure or accidental release of biohazardous materials is the task of the biosafety. With respect to conventional chemical engineering processes, biohazard is a new element specific of bioprocess

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manufacturing sites (CCPS, 2011). However, as any other chemical process, bioprocesses have also traditional risks to manage, in addition to the specific ones.

Process safety management (PSMS) system is historically focused on the classical chemical industries (petroleum, natural gas, chemicals and polymers production). Recently also others production industries (such as pharmaceutical industries, Angel et al., 2015) profit of PSMS even if no regulations (but Seveso III in Europe) require it (CCPS, 2011). The European Directive 2000/54/CE (European Parliament, 2000) has the goal to protect workers from risks for their safety and their health from exposure to biological agents at work, including the prevention of such risks. The Directive applies to food industry, to agricultural and healthcare business, to all kind of laboratories, to wastewater treatment and waste management. On the basis of the Directive, many countries defined their own biological risk assessment methods (Bassett et al., 2012; Caskey et al., 2010; EPA, 2007; Giudici et al., 2011; HSE, 2013). There are just few studies in literature about the use of conventional methods for risk assessment (e.g. FMEA, HAZOP, bow-tie analysis) in bioprocesses (Harms et al., 2008; Mollah, 2005; Pietrangeli et al., 2013; Pinkenba and Statement, 2006). In particular, Pietrangeli et al. (2013) also concluded that biosafety is focused on individual protection only.

3. Bioprocess checklist

The creation of a checklist is the first step toward the creation of a full methodology aimed at hazard identification of bioprocesses. The checklist here proposed is designed to recognize the criticalities related to the bioprocess, the hazardous substances involved and on how they could be formed during the process itself; in addition to standard checklists, the possible presence of pathogen agents has been considered.

The checklist was developed with the purpose of collecting as much information as possible on the bioprocess itself; this tool allowed us to make a first screening on the process parameters, on the substances and on all the conditions to monitor, becoming preparatory for future development of the methodology.

Our checklist is mainly focused on the hazardous substances, intended as chemical substances that can be toxic, flammable, but especially on pathogenic agents. In addition, particular attention was paid on the operating conditions that influence the formation of these substances (Canadian Society of Chemical Engineering, 2012).

The checklist is divided into two different sections: a process specification section (Engineering Process), and a more general section (General). The first section helps the identification of parameters that need a deeper analysis and of conditions to monitor; in the second section, some questions related to PHAs are proposed. The structure of the proposed checklist for bioprocess hazard identification is shown in Figure 1.

A) ENGINEERING PROCESS

Some questions on the single unit operation, useful to understand the role of the different operating parameters.

A.1) Hazard classification of substances

The substances involved are classified according to the Globally Harmonized System (GHS, United Nations, 2011).

A.2) Biohazard

Microorganisms are classified according to European Directive 2000/54/EC (European Parliament, 2000), specifying information on mode of transmission, diseases and symptoms that they can induce; questions about medical countermeasures and about preventive and protective measures are present.

A.3) Toxicity and Ecotoxicity

In this section all toxicity and ecotoxicity information are reported, including dangerous concentrations and effects on human and environment; questions about medical countermeasures and preventive and protective measures are present.

A.4) Flammability and Explosivity

All data about flammability ranges, temperatures to monitor, minimum ignition energy, etc.; questions about preventive and protective measures are present.

B) GENERAL

Some general questions about the site.

B.1) Operating procedures

Questions used to highlight possible deficiencies on personnel operating procedure, due to lack of information.

B.2) Plant layout

Some questions useful to point out risks that a wrong layout can introduce:

- Emergency/ongoing program
- Management-Process Hazard Analysis (PAH)

Figure 1: Structure of the proposed checklist for bioprocess hazard identification.

4. Results and discussion

An anaerobic digester for the production of biogas form livestock slurry have been taken as a case study. The choice was driven by the existing emerging risk in the sector of production of energy from renewable sources (Casson Moreno and Cozzani, 2015; Casson Moreno et al., 2015) and because the authors are familiar with the process and existing plant.

Biogas is a mixture of methane and carbon dioxide that can be produced by anaerobic digestion of different kind of wastes, deriving from agricultural, food or urban waste, sewage or manure and animal residuals. Usually, besides methane and carbon dioxide, others components are present in very small quantities, depending on the substrate used for the production (Scarponi et al., 2015). The most important substances from a process safety standpoint are hydrogen sulfide and ammonia; then there are traces of carbon monoxide, hydrogen, nitrogen, and oxygen.

The focus of our analysis is on the reactor (the so-called anaerobic digester), because it is the equipment where the production of biogas takes place and mainly where the microorganisms are. It is where toxic substances could be formed, so the analysis is limited to it and few connected equipment, fundamental for the normal operations. Due to the limited space available, the results are shown below with focus on the part of the checklist in which bio-aspects have been integrated in the Engineering Process section of the checklist (Figure 2 to Figure 5).

Designing and filling out the checklist raised the following issues:

- Deviation from normal operating conditions of specific parameters (such as flow, pressure, temperature, and composition of feed) can induce operability as well as safety problems. By changing the above mentioned conditions, microorganisms could die (creating an operability problem) or they could increase the production of toxic substances (safety problem).

Therefore, standard deviations induce consequences that are somehow new with respect to conventional chemical processes. The relationship cause-consequences, bio and not, needed a deeper investigation with a more sophisticate technique such as HAZOP. This will be a further development of the present work.

- A very detailed knowledge of the bioprocess is required.
- The method should be tuned and tested with bioprocesses involving microorganisms of risk group II, III and IV in order to prove the effectiveness of the dedicated Biohazard section of the checklist.

5. Conclusions

Industrial bioprocesses pose both conventional process hazards and those more specific related to the use of microorganisms (biohazard) or to the influence of microorganisms on process parameters.

The checklist created in the present work was aimed at highlighting the criticalities of the equipment under analysis and was built in order to be a screening tool that can be used in different types of bioprocesses.

The main results of its application was stressing the fact that some process parameters play a significant role in the production of hazardous substances. This, in turn, reveled the need for a deeper analysis of the process and equipment involved.

Our future work will be focused on the development of a complete methodology for hazard identification in bioprocess. The basic idea behind it will designing a tool able to identify hazards related to a bioprocess, to perform a screening to select equipment that needed a more detailed analysis and to propose some protective and preventative measures. The checklist here presented will be the first step of it, allowing us to collect as much information as possible on the process, making a first screening on the process parameters, on the substances and on all the conditions to monitor, becoming an introduction to some more specific analysis such as HAZOP.

CHECKLIST for BioPROCESSES (A. SINGLE UNIT OPERATION)

ENGINEERING PROCESS

What is the equipment in analysis? Digester

What are the substances present in main quantity? CH_4 CO_2 H_2S NH_3

What is the maximum quantity of substance processed? 1150 Nm^3/day of biogas

What is the frequency of use? Continuously

Are any products hazardous from a toxic or fire standpoint? × yes ? no

Could their quantity introduce an additional hazard to the process? × yes ? no

Are hazardous reactions possible due to mistakes or contaminations/impurities? ×yes ?no

What could be the other products of the reactions? An higher production of H_2S and NH_3
In which cases can be developed unwanted reactions?? improper storage ? impact or shock × contaminant materials × abnormal process conditions (e.g., temperature, pH) × abnormal flow rates ? missing ingredients or disproportioned reactants or catalysts ? mechanical failure (e.g., pump trip, agitator trip) ? improper operation (e.g., started early, late, or out of sequence) ? sudden or gradual blockage or buildup in equipment ? overheating residual material in quipment

Which deviation of the following operating parameters can introduce a hazard/operability issue?

	Operability	Safety		Operability	Safety
Flow	×	×	Level	×	
Pressure	×	×	Mixing	×	
Temperature	×	×	Separation		
Composition of feed	×	×	Addition		
Time			Viscosity	×	
pH	×				

Is hazard possible from loss of utility? × yes ? no

Does the process work in sub atmospheric pressure? ? yes × no

Are the following present? × Relief systems × Flare systems × Vents × Drains × Other process equipment
Are liquid seals protected against freezing? × yes ? no

Does the process work in or near the flammable range? ? yes × no

Can the process reach temperature lower than the ductile/brittle transition temperature??yes×no

Hazard classification of the substances :

? Biohazardous substances

? Unstable explosives ? Explosives, divisions 1.1, 1.2, .3, 1.4 ? Self-reactive substances and mixtures, types A, B ? Organic peroxides, types A, B

× Flammable gases, category 1 ? Flammable aerosols, categories 1, 2 ? Flammable liquids, categories 1, 2, 3 ?Flammable solids, categories 1, 2 ? Self-reactive substances and mixtures, types B, C, D, E, F ?Pyrophoric liquids, category 1 ?Pyrophoric solids, category 1 ?Self-heating substances and mixtures, categories 1, 2 ?Substances and mixtures, which in contact with water, emit flammable gases, categories 1, 2, 3 ?Organic peroxides, types B, C, D, E, F

? Oxidizing gases, category 1 ? Oxidizing liquids, categories 1, 2, 3 ? Oxidizing solids, categories 1, 2, 3

? Compressed gases ? Liquefied gases ? Refrigerated liquefied gases ? Dissolved gases

? Corrosive to metals, category 1

× Acute toxicity (oral, dermal, inhalation), categories 1, 2, 3

? Skin corrosion, categories 1A, 1B, 1C ? Serious eye damage, category 1

? Acute toxicity (oral, dermal, inhalation), category 4 ? Skin irritation, categories 2, 3 ? Eye irritation, category 2A ? Skin sensitization, category 1 ? Specific target organ toxicity following single exposure, category 3 ?Respiratory tract irritation ? Narcotic effects

? Respiratory sensitization, category 1 ? Germ cell mutagenicity, categories 1A, 1B, 2 ? Carcinogenicity, categories 1A, 1B, 2 ? Reproductive toxicity, categories 1A, 1B, 2 ? Specific target organ toxicity following single exposure, categories 1, 2 ? Specific target organ toxicity following repeated exposure, categories 1, 2
Aspiration hazard, categories 1, 2

? Acute hazards to the aquatic environment, category 1
? Chronic hazards to the aquatic environment, categories 1, 2

Figure 2: Checklist for bioprocesses applied to the case of biogas production, Engineering Process section.

BIOHAZARD
Microorganism involved
What is the pathogen agent involved? examples: *Methanococcus, Desulfovibrio, Acetobacter*
How and where much substrate is manually manage? Premixing tank
What is the frequency of use? Continuously
What is/are the class of the pathogen agent/s? × Bacteria ? Cell lines ? Fungi ? Parasites ? Human blood and tissue ? Prions ? Recombinant DNA ? Toxins ? Viruses ? Zoonotic pathogens
Risk group of the organism: × I ? II ? III ? IV
Consider only if the risk group is higher than 1
What is the standard mode of transmission? ? inhalation ? ingestion ? skin contact ? blood What is the infectious dose, if known?
Describe the hazards associated to the microorganism: list of disease/symptoms of intoxication.
Is there a vaccination available? ? yes ? no
Have the employees done the vaccination? ? yes ? no
Has the microorganism been inactivated by a tested procedure during processing? ? yes ? no
Is there known or suspected drug resistance of biological agent(s) to be used? ? yes ? no
Is there an emergency countermeasure/ antidote in case of exposure? ? yes ? no
Are there any pre-existing medical issues that increase the risk associated with this biological agent(s), e.g. pregnancy, immunosuppression etc.? ? yes ? no
Do agents attenuated or do they have increased pathogenicity during the process? ? yes ? no
Have occasions of potential occupational exposure been identified and documented??yes ?no
Details of others who may be affected by the work activity, e.g. maintenance operators, cleaners, ...
Are the required preventative and protective measures in place? ? yes ? no
Are all equipment and work environment cleaned and disinfected after contact with potentially infectious materials when required? ? yes ? no What ability has the biological agent(s) to survive, e.g. resistance to chemical disinfection?
In biohazardous areas: are all entrances properly labelled and restrictions followed? ? yes ? no
Are personnel instructed on the necessity to report immediately any release or event that might cause exposure to biohazards agents? ? yes ? no
Are spill control system in place? ? yes ? no
Do workers know how to decontaminate counters, spilled materials, equipment, etc.? ? yes ? no
Are necessary Additional control measures? (description)

Figure 3: Checklist for bioprocesses applied to the case of biogas production, Biohazard section.

TOXICITY & ECOTOXICITY
Toxic substances
What is/are the toxic/s present/s in the main quantity? H_2S
What is the frequency of use? Continuously
What is the IDLH? 100 ppm
Other threshold limits? ? TLV-C ?TLV-STEL ? TLV- TWA ? PEL ? LD50 × Other: ERPG-2: 30 ppm
How are potential health effects? × acute ? chronic
Is there evidence based on studies of animals or humans that the substance is one or more of the following? ? yes × no ; ? carcinogen ? mutagen ? teratogen
How does this substance enter the body (routes of entry)? × inhalation ? skin contact ? ingestion ? eye contact
Describe the hazards associated to the substance: list of disease/symptoms of intoxication. Eyes irritation , caught , loss of consciousness
Has the concentration of the substance in the workplace air been tested? × yes ? no Is the operator exposed to other chemicals at the same time? Can they have a combined effect? ? yes × no
Preventative & Protective measures
Are gas detector used? ? yes × no
Are all employees required to use personal protective equipment when handling chemicals? × yes ? no
Are eyewash fountains and safety showers present in the working area? × yes ? no
Are operators included in a medical surveillance program appropriate for the types of chemicals to which they are exposed? × yes ? no
Do the operators have any medical conditions or take any drugs that might interact with chemicals? **N. A.**
Is any medical test recommended? If so, list. **N. A.**
Are operators trained in the use of first aid procedures? × yes ? no
Ecotoxicity
Are the substances ecotoxic? × aquatic ? terrestrial How is the substance? ? persistent × biodegradable
Is the substances potentially bio accumulative? ? yes × no
Is mobility in soil possible? ? yes × no
Is any other adverse effects known? If so, list them. ? yes × no

Figure 4: Checklist for bioprocesses applied to the case of biogas production, Toxicity and Ecotoxicity section.

FLAMMABILITY & EXPLOSIVITY
Flammable substances
What is/are the combustible/s present/s in the main quantity? CH_4
What is the frequency of use? Continuously
What is the phase of the combustible? ? compressed gas × atmospheric gas ? dust ? compressed liquid ?atmospheric liquid
What are the low and the upper flammability limits? UFL (UEL): 1 7,5 % LFL (LEL): 3,93 %
What is the flash point temperature [°C]? - 188
What is the auto ignition temperature [°C]? ˜ 600
What is the operating pressure [bar]? 1,013
What is the operating temperature [°C]? 38-39
What is the minimum ignition energy [mJ]? 0,29
What are the conditions to avoid? ? static discharge ? shock ? vibrations
Preventative & Protective measures
Are proper storage methods used to minimize the risk of fire and spontaneous combustion? × yes ? no
Are all connections on drums and combustible liquid piping (vapor and liquid) tight? × yes ? no
Have practices and procedures been established to control potential fire hazards/ignition sources? × yes ? no
Is there any ATEX zone? × yes ? no
Do measures include? ? Flame arresters ? Relief valves ? Safe venting location × Flares ? Carbon dioxide × Sprinklers ? Emergency spill kits ? Gas detection ? Electrostatic discharge design ? Ex-rated equipment ×Grounding/earthing × Emergency vents ?Fireproofing supports ? Dikes and drainage ? Inerting atmospheres ? Foam ? Dry chemicals ? Explosion walls ? Isolation ? Confinement × Good ventilation ? Pressurization of rooms
Does the company have a written fire prevention plan? × yes ? no
Is the local fire department well acquainted with company facilities, location, and specific hazards? × yes ? no
Are operators trained in the use of extinguishers and fire protection procedures? × yes ? no

Figure 5: Checklist for bioprocesses applied to the case of biogas production, Flammability and Explosivity section.

Reference

Angel, M., Herrera, D.O., Severino, A., Carlos, A., Monte, E., Lemes, B., 2015. A structural approach to the HAZOP e Hazard and operability technique in the biopharmaceutical industry. J. Loss Prev. Process Ind. 35, 1–11. doi:10.1016/j.jlp.2015.03.002

Bassett, J., Nauta, M., Lindqvist, R., Zwietering, M., 2012. Tools for Microbiological Risk Assessment.

Canadian Society of Chemical Engineering, 2012. Process Safety Management. doi:10.1201/b11069-30

Caskey, S., Gaudioso, J., Salerno, R., Wagener, S., Risi, G., Kozlovac, J., Halkjær-knudsen, V., Prat, E., 2010. Biosafety Risk Assessment Methodology.

Casson Moreno, V., Cozzani, V., 2015. Major accident hazard in bioenergy production. J. Loss Prev. Process Ind. 35, 135–144. doi:10.1016/j.jlp.2015.04.004

Casson Moreno, V., Papasidero, Salvatore Giordano Emrys, S., Daniele, G., Cozzani, V., 2015. Analysis of accidents in biogas production and upgrading. Renew. Energy IN PRESS. doi:10.1016/j.renene.2015.10.017

CCPS, 2011. Guidelines for Process Safety in Bioprocess Manufactoring Facilities.

EPA, 2007. A Compendium of Prior and Current Microbial Risk Assessment Methods.

European Parliament, 2000. Directive 2000/54/EC.

Giudici, P.D.E., Guillam, M., Segala, C., 2011. Microbiologie et déchets : évaluation des risques sanitaires.

Harms, J., Wang, X., Kim, T., Yang, X., Rathore, A.S., 2008. Defining process design space for biotech products: case study of Pichia pastoris fermentation. Biotechnol. Prog. 24, 655–62. doi:10.1021/bp070338y

HSE, 2013. An update on HSE's work to consolidate legislation on human pathogens, animal pathogens and genetically modified organisms following the Callaghan and Löfstedt Reviews [WWW Document].

Mollah, A.H., 2005. Application of Failure Mode and Effect Analysis (FMEA) for Process Risk Assessment. Bioprocess Int.

Pietrangeli, B., Lauri, R., Bragatto, P.A., 2013. Safe Operation of Biogas Plants in Italy. Chem. Eng. Trans. 32, 199–204. doi:10.3303/CET1332034

Pinkenba, P., Statement, I.A., 2006. Proposed Pinkenba Ethanol Bio-Refinery.

Rivière, C., Marlair, G., 2010. The use of multiple correspondence analysis and hierarchical clustering to identify incident typologies pertaining to the biofuel industry. Biofuels, Bioprod. Biorefinering 4, 53–65. doi:10.1002/bbb

Scarponi, G.E., Guglielmi, D., Casson Moreno, V., Cozzani, V., 2015. Risk Assessment of a Biogas Production and Upgrading Plant. Chem. Eng. Trans. 43, 1921–1926. doi:10.3303/CET1543321

United Nations, 2011. Globally harmonized system of classification and labelling of chemicals (GHS), Nihon eiseigaku zasshi. Japanese journal of hygiene. doi:10.1265/jjh.65.5.