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Risk analysis of a biomass combustion process using MOSAR and FMEA methods

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Abstract

Thermal and chemical conversion processes that convert in energy the sewage sludge, pasty waste and other pre-processed waste are increasingly common, for economic and ecological reasons. Fluidized bed combustion is currently one of the most promising methods of energy conversion, since it burns biomass very efficiently, and produces only very small quantities of sulphur and nitrogen oxides. The hazards associated with biomass combustion processes are fire, explosion and poisoning from the combustion gases (CO, etc.). The risk analysis presented in this paper uses the MADS–MOSAR methodology, applied to a semi-industrial pilot scheme comprising a fluidization column, a conventional cyclone, two natural gas burners and a continuous supply of biomass. The methodology uses a generic approach, with an initial macroscopic stage where hazard sources are identified, scenarios for undesired events are recognized and ranked using a grid of Severity × Probability and safety barriers suggested. A microscopic stage then analyzes in detail the major risks identified during the first stage. This analysis may use various different tools, such as HAZOP, FMEA, etc.: our analysis is based on FMEA. Using MOSAR, we were able to identify five subsystems: the reactor (fluidized bed and centrifuge), the fuel and biomass supply lines, the operator and the environment. When we drew up scenarios based on these subsystems, we found that malfunction of the gas supply burners was a common trigger in many scenarios. Our subsequent microscopic analysis, therefore, focused on the burners, looking at the ways they failed, and at the effects and criticality of those failures (FMEA). We were, thus, able to identify a number of critical factors such as the incoming gas lines and the ignition electrode.

Keywords: Risk analysis; Combustion; MADS–MOSAR; FMEA

1. Introduction

Economic and ecological considerations increasingly require us to use thermal conversion processes that yield products with high energy values (so waste energy is salvaged to produce synthetic biofuels or hydrogen for fuel cells) [1,2]. Among these processes (circulating fluidized bed, pressurised fluidized bed, . . .), atmospheric fluidized bed combustion for the heat treatment of sewage sludge [3,4], pasty waste and other pre-processed waste, or even biomass, is currently a promising avenue. The fuel is burnt very efficiently and only very small quantities of sulphur and nitrogen oxides are produced [5].

The hazards associated with using a fluidized bed combustor are various and well reviewed in [6]. Hazards are related to different sources. First, some hazards are due to the fuel (coal, biomass, waste). Secondly, they could be attributed to the exploitation or maintenance phases of the fluidized bed combustion process (from the fuel storage to the combustion process). Finally, some hazards could have as origin the post-combustion process, i.e. hazards related to the gaseous emissions or to the ash. The main hazards associated with using these biomass combustion processes are fires, explosions, contamination, human injury or some odour or diseases.

In the more general context of research into combustion and emitted pollutants, a pilot combustion process has been realised [7]. It uses a circulating fluidized bed combustor that burns different types of coal or biomass, and it is used to develop methods for analyzing the generated pollutants. Since these combustion processes give rise to significant hazards, a general approach to risk management has been adopted [8,9].

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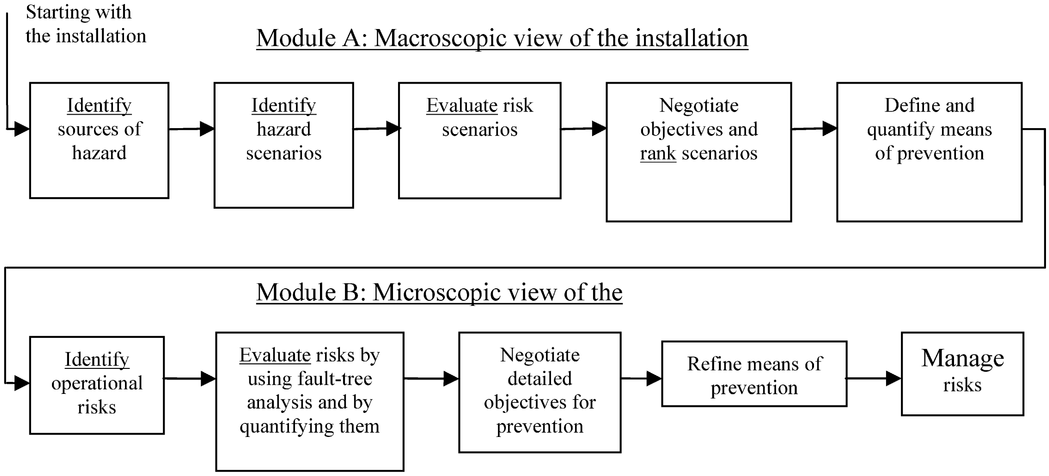


The stages addressed during this study are underlined

Fig. 1. MOSAR (adapted from Périlhon [12]).

Many methodologies have been developed in order to conduce a risk analysis in an industrial environment [10]. The risk analysis discussed here is one that anticipates and prevents undesired events during the implementation of the combustion pilot, using MADS–MOSAR. MADS refers to "*The Analysis Method of Dysfunctional Systems*", and MOSAR refers to "*The Organized and Systemically Method of Risk Analysis*". MADS proposes a general model of hazard, MOSAR builds a global methodology for the risk analysis [11–14].

The MADS model is a systemic approach to unfolding complex systems and evaluate the potential damage in specific targets. It allows to identify and to model the mechanism of danger between sources of hazard and targets. We can conduct a study of the hazard process in which a source of hazard is linked to a target through the phenomena called "hazard flux". This is done in a very specific relation called fields of hazard that takes into account space and time dimensions.

MOSAR is based on MADS model. Its objective is to find dysfunctions and to manage the risks in a complex system. The methodology proposes a structured scheme; exhaustive, progressive and quantitative if necessary. The MOSAR method is a generic approach providing a risk analysis of the system and at the same time, identifying the means for prevention, protection and mitigation necessary to minimize risks [11]. This method allows identification of the hazard sources distinguishing of scenarios of undesired events, providing and evaluating risk analysis and then proposing of safety fences. The hazard sources can be done with a basic list, defined by Périlhon [11] based on the return of experience (REX), it is structured in hazards typologies according to the MADS model.

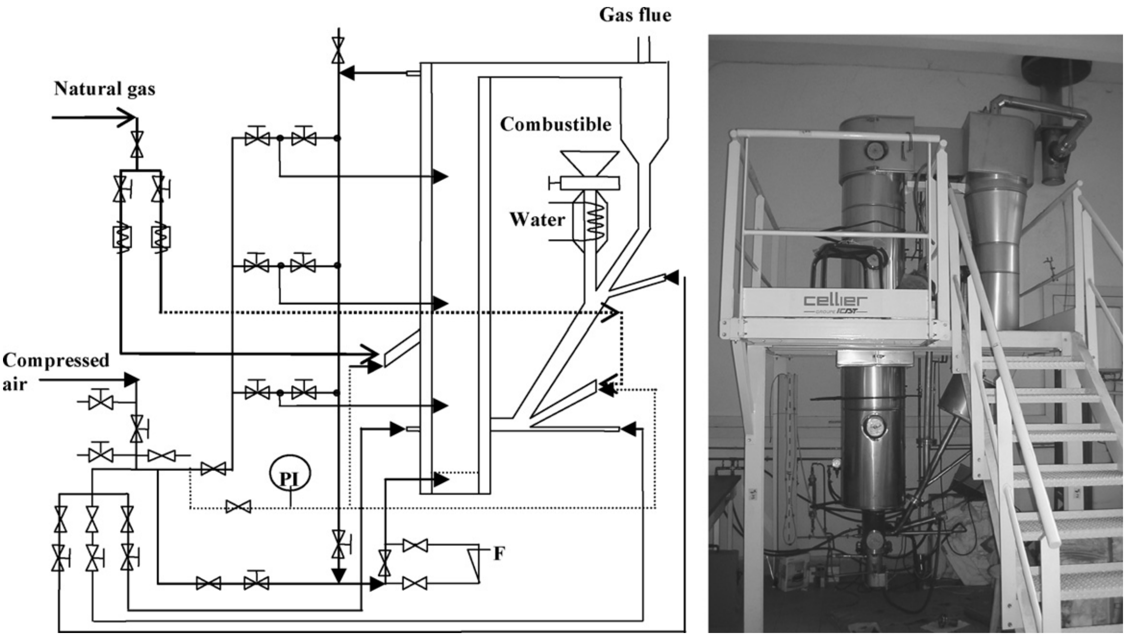


Fig. 2. Outline of the pilot [7].

Table 1
Identification of hazard sources in the subsystems (from the MOSAR grid 1)

Systems with sources of hazard	Initiating events		Initial events		Principal events
	External (active environment)	Internal	Related to the container	Related to the content	
Subsystems under pressure					
Ss1	Mechanical stress	Mechanical stress, over-heating, corrosion	Failure	Over-pressure	Gas leak, material projection, projection of tools
Subsystems in motion					
Ss1, Ss3	Mechanical stress	Malfunction of valves or screw	Blockage in valves, seal or joint failure	Overfilling	Gas leak, clogging, natural gas or biomass accumulation
Subsystems requiring manipulation					
Ss1, Ss3	Mechanical stress, incorrect operation		Blockage in valves	Overfilling	Gas leak, clogging, natural gas or biomass accumulation
Subsystems that are sources of explosions with a chemical origin					
Ss3, Ss5	Error in filling, careless action, non-conforming action	Malfunction of burner	Blockage in valves	Over-pressure	Natural gas or biomass accumulation explosion
Subsystems with a risk of falling from a height					
Ss4	Bad training, tiredness, lack of instructions, dangerous context		Slippery walkway		Injury
Subsystems that are sources of poisons and corrosives					
Ss3	Mechanical stress, incorrect operation	Malfunction of valves, screw or burner		Chemical reaction uncontrolled	Gas leak (CO, NO_x)
Subsystems with hazards that could lead to fire: ignition source systems					
Ss2, Ss3	Incorrect operation	Malfunction of burner	Ignition source		Spark hot materials

The MOSAR method enables us to highlight the main scenarios and to define the barriers of prevention and protection that we have, to set up, to neutralize, or to reduce the occurrence of the undesirable event. The MOSAR method may be also applied to the design of a new installation as well as to the diagnosis of an existing one. It works as a toolbox to assist the decision maker owing to the resulting choices that it provides. The first module (the A module) makes it possible to carry out a risk analysis of the system based on the process presented in Fig. 1. This diagram shows the principal elements and the structure of the MOSAR method. After dividing the system into subsystems, the first step consists of the review of the most relevant release sources for

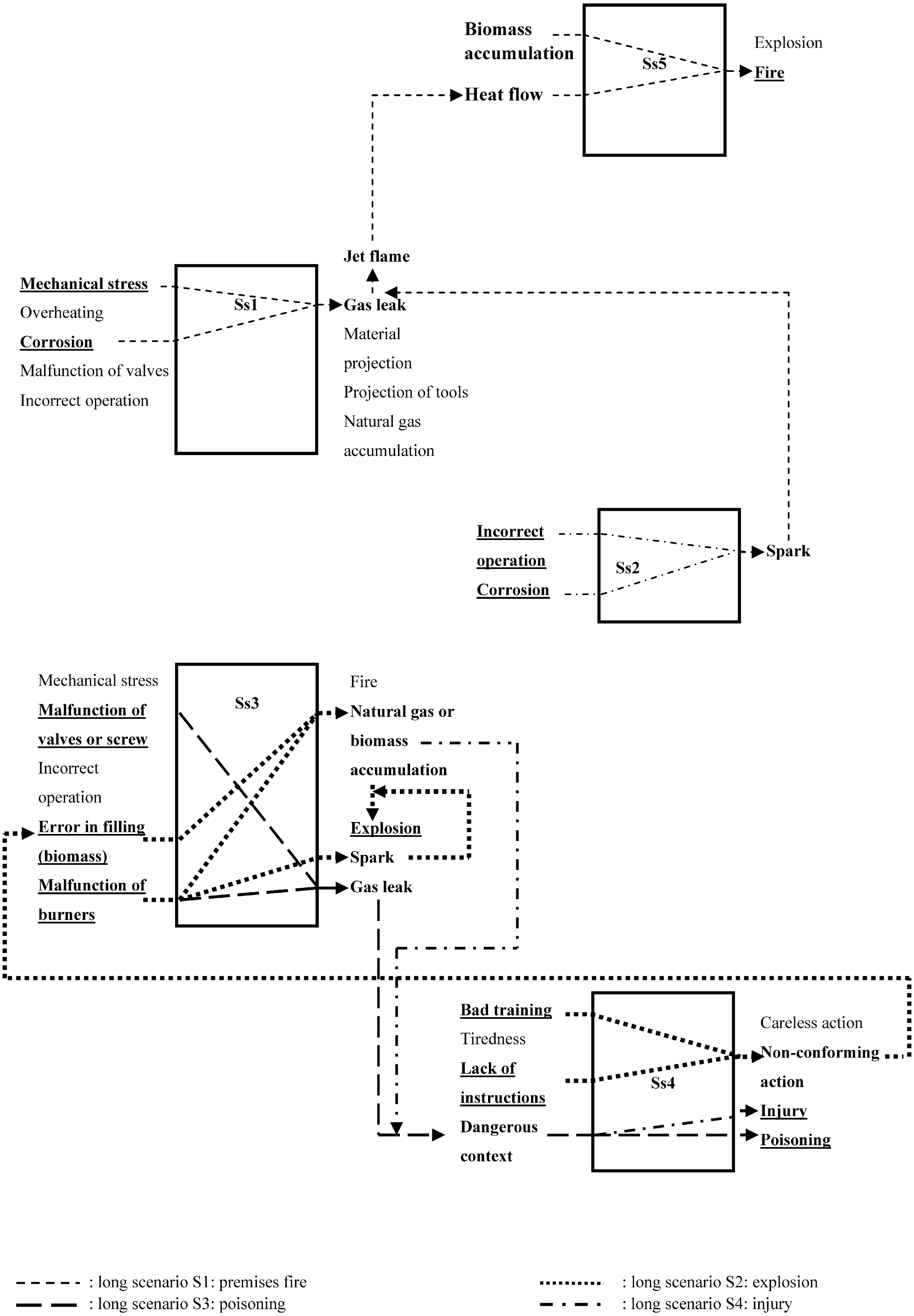


Fig. 3. Long and short accident scenarios.

each subsystem. One refers to a typology grid for the systems that are hazard sources and then uses the MOSAR model that connects them to the targets. This method makes it possible to generate scenarios of risk interference between the subsystems which are gathered for the same event. For each release scenario a set of consequence chains are developed showing the escalation of the events. The set of consequence chains is conveniently represented in the form of the event tree.

This risk analysis method also involves the estimation of the frequency and severity of a range of hazards. The risk of injury is then determined using injury relations which give the probability as a function of the intensity of the physical effect. From a group of expert and the definition of the risk acceptability, we realise finally the scenario's hierarchy. The research of prevention means, i.e. technical barriers and operational barriers, is necessary to neutralize the hazardous scenarios and ensures the prevention of risks. This first module ends in the qualification of the identified barriers.

The second module (the B module), allows a detailed analysis of a specific part of the installation to be carried out and in particular implements the reliability tools to search the technical dysfunctions (like a Fault Mode Analysis) (Fig. 1). It also implements the tools of operational analysis to study the operational dysfunctions. This analysis may use various different tools, such as hazards and operability (HAZOP), failure mode effect analysis (FMEA), etc.

Our analysis is based on FMEA [15]. This is a standard tool used in industrial maintenance and diagnosis [16–18], which also provides a structured and systematic methodology. It is used to detect and assess system failures based on a ranking of failures according to their criticality C, where C = F × S × D (F = Frequency of appearance, S = Severity, D = Detectability). It was directed towards factors identified in module A of the MADS–MOSAR approach. The FMEA is constructed based on a functional analysis of the particular factor and, when it is available, on experiential data.

Carrying out such a safety study and following it up over time provides the basis for better process control (the implementation of a number of preventive and protective barriers, a process operating procedure, and a maintenance procedure) that improves operator safety.

2. Description of the pilot

The pilot combustion process is shown in Fig. 2. It comprises a double-walled fluidization column, acting as a combustor, in AISI 310 steel, 105.3 mm in internal diameter, 4.5 mm thick and 3.58 m high. The fluidization grid is 1 cm thick and perforated with 300 holes 1.3 mm in diameter. Air for the fluidization (flowing at between 20 and 50 $\mathrm{Nm^3/h}$) comes from the compressed air system and from air preheated in the double wall. A sys-

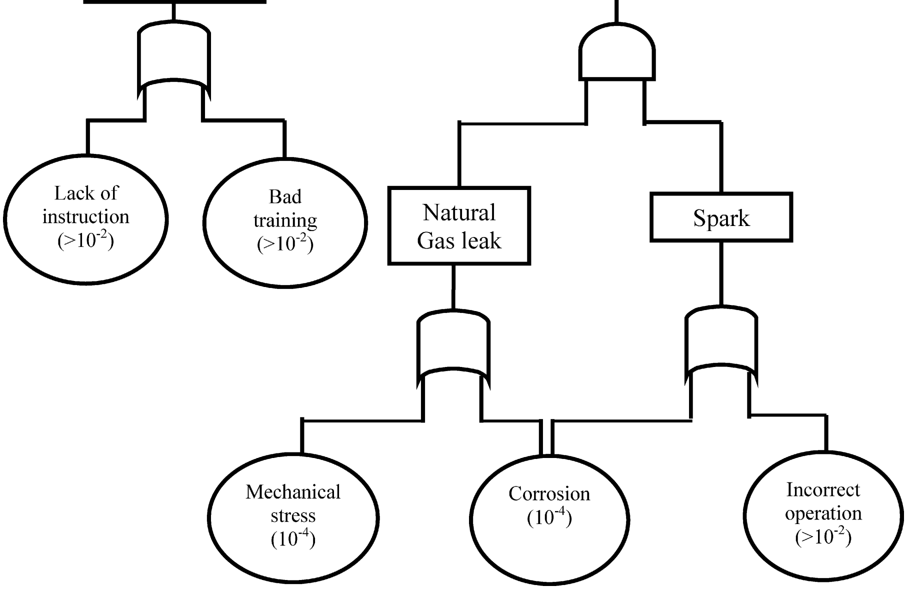


Fig. 4. Long scenario S1 of fire.

tem of valves and piping carries cold or hot secondary air into the reactor. At the exit from the fluidized bed, a conventional cyclone separates partly-combusted particles from those carried away in the smoke (cut-off diameter between 10 and 20 μm). Fuel is introduced into the fluidized bed via an Archimedes' screw. It is then mixed with an inert substance (sand) present in the fluidized bed. Ash is collected at the base of the combustion reactor. Two natural gas (NG) burners are used to start combustion. The pilot assembly is supported by a metal framework, forming a working platform 2 m high. Various studies on the reactor's hydrodynamic behaviour and the chemical processes that occur in the pilot combuster have been used to define the residence time of gases in the reactor, to analyze the levels of CO/CO_2 and NO/NO_2 during combustion, and to identify a number of polycyclic aromatic hydrocarbons (PAH) [7,19,20].

3. Risk analysis

In this study, we focus especially on the risk analysis using MADS–MOSAR coupled with FMEA methods. This analysis is restricted to problems with exploitation or maintenance equipments. Risks related to the quality and properties of biomass used, to the biomass storage or to the fluidization process itself for example [21] are not take into account in this study.

3.1. Implementation of the MADS–MOSAR: macroscopic approach

The first stage of the MOSAR method consists of modelling the pilot for biomass combustion by means of a functional division into subsystems. So that for each subsystem (Ssi) the type of hazard source is identified and the hazardous processes are defined (short and long scenarios). From the previous description of the process, we can distinguish five subsystems:

- supply of natural gas and compressed air (Ss1),
- electricity supply and solenoid valves (Ss2),
- combustion pilot and its equipment (Ss3),
- operator (Ss4),
- environment (Ss5).

The combustion pilot and its auxiliary consist of the fluidized bed, cyclone and burners. Note that the environment corresponds to an unenclosed room.

Table 1 comes from the grid used in the MOSAR [12], and shows the hazard sources identified as those most relevant to our system. This table of the MOSAR method allows the definition of the possible initiating events, initial events and principal events (hazard flux). The initiating event is at the origin of change of state or situation of one system while the initial event characterizes the change of one system which passes from a normal

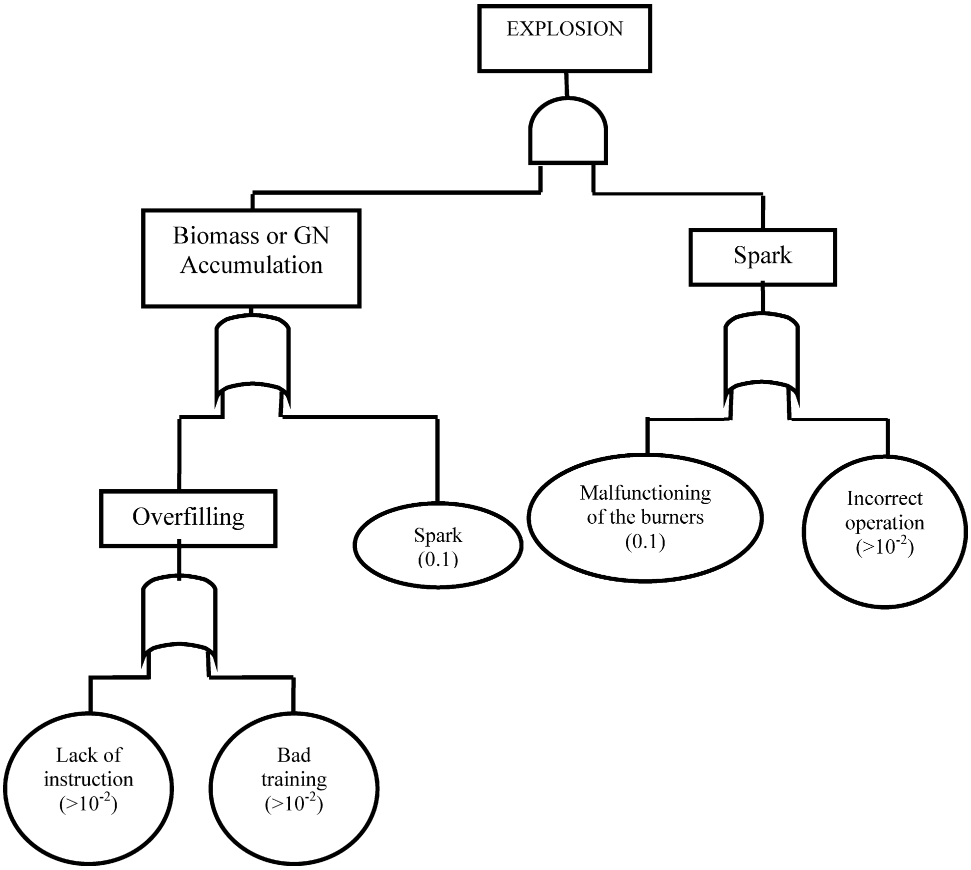


Fig. 5. Long scenario S2 of explosion.

situation towards a failing situation. Finally, the principal event expresses the flows of matter, energy and information emitted by a system in a failing state or situation. Each subsystem in Table 1 is characterized by inputs (initiating events) and outputs (principal events).

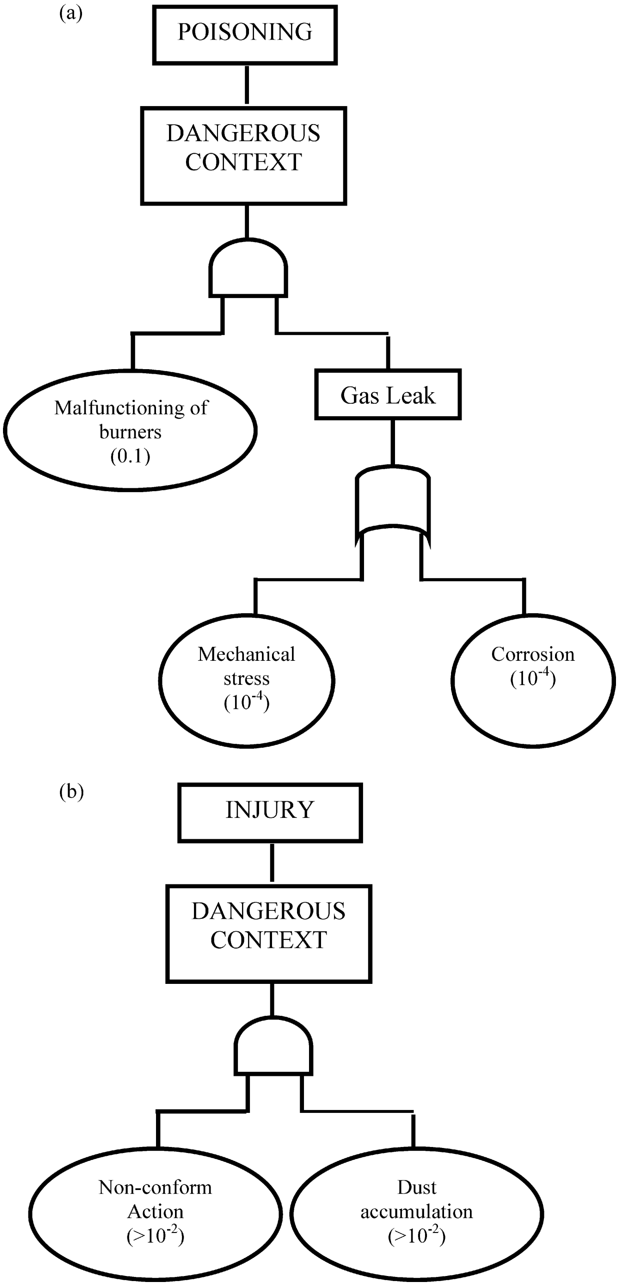


Fig. 6. Long scenarios of poisoning S3 (a) or injury S4 (b) of the operator.

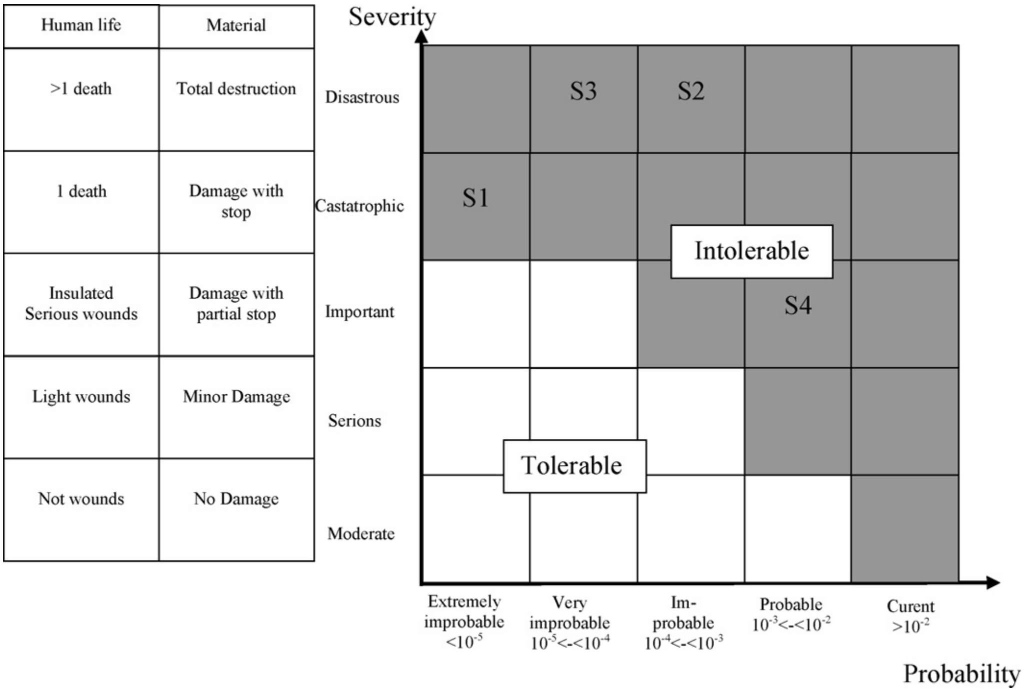
Maintenance of the integrity of the pressure system is the most important loss prevention problem for the natural gas and compressed air supplies (Ss1). With such a subsystem under pressure, it is normal to classify service failure as mechanical failure, through stress, fatigue and corrosion failure, which is a very crucial problem when natural gas is used [22]. From this table, the natural gas and compressed air supplies can be considered as a subsystem under pressure and in motion (i.e. where the gas is moving during the filling), a subsystem sources of physical-induced explosion. The combustion pilot and its equipment are considered as a system sources of chemically induced explosions and in motion. Flammability limits for natural gas, constituted by 88% (mol) of methane, is rather important. The lower flammability limit of methane is 5% (vol.) [23]. So, ignition risk of a flammable mixture should be avoided. The modes of ignitions considered here are principally sparks, hot surfaces, friction or impact and flame torches. The electricity supply and burners of the combustion pilot are system sources of ignition sources.

Each subsystem in Table 1 is characterized by inputs (initiating events) and outputs (principal events). Short scenarios of undesired events can be structured from the links between them. If the combustion pilot as well as the natural gas supply is submitted to mechanical stress, corrosion or fuel loading error, the natural gas or compressed air can vent out.

From Table 1 and short scenarios, we can easily define long undesired scenarios of events (Fig. 3). These scenarios can be identified by connecting the inlets and outlets of the different subsystems. For each release scenario a set of consequence chains are developed showing the escalation of the events. The set of consequence chains is conveniently represented in the form of the event tree included the frequency of each event (Figs. 4–6). We identified a premises fire as a first long scenario S1 (Fig. 4). It would be caused by the presence of inflammable material (biomass, etc.) and a fire source (a leak of ignited NG). In this first case, the accumulation of biomass near the pilot is due to a lack of instruction or a bad training of the operator. The ignition source is related to a jet flame from the natural gas supply. Malfunction of the reactor burners heating the biomass could lead either to a build up of natural gas or to the release of toxic gas such carbon monoxide. It is, therefore, possible to define a long scenario S2 (Fig. 5) involving a natural gas (or dust) explosion in the presence of an ignition source and a long scenario S3 (Fig. 6a) involving poisoning. It is assumed that biomass or natural gas accumulation is responsible for an explosion. This initiating event could be due to an overfilling or a malfunctioning of the burner. The ignition source comes from the electricity supply or burner leading to a possible spark. Carbon monoxide poisoning of the operator has to be also considered. This dangerous context is related to a malfunctioning of the burner associated to a leak on the pilot. The risk of carbon monoxide release depends heavily on the temperature of the fluidized bed, the quantity of oxygen in the gaseous phase of combustion, and on the residence time of gases in the reactor. Lastly, a final long scenario S4 (Fig. 6b) where the operator is injured can be identified if he or she accesses a high part of the pilot system and does not observe the standard safety instructions.

The third stage considers the outcomes of the various scenarios and estimates severities and probabilities (when possible) to obtain a graphical presentation of the risks (Fig. 7). Both deterministic and probabilistic approaches [22] allowed us first to quantify the effects of accidents observed on structures and people.

Accordingly to this graphical presentation, the severity resulting from a fire (scenario S1) can be considered as catastrophic (=1 death). On the contrary, damage due to an explosion or car-



Human life	Material
>1 death	Total destruction
1 death	Damage with stop
Insulated Serious wounds	Damage with partial stop
Light wounds	Minor Damage
Not wounds	No Damage

Fig. 7. The position of the four scenarios on the Severity × Probability grid [24].

bon monoxide poisoning into an enclose zone (scenarios S2 and S3) should be disastrous (>1 death). Finally, it can be stated that the severity of an operator injury is important.

Our experience during this combustion pilot has shown that the reactor burners often malfunction. The frequency of this event could be larger then 1/10 events per year. Moreover, human error is generally considered as a frequent event (>10^{-2}). On contrary, the failure rate of a serious leakage on a pipe or reactor can be estimated lower than 10^{-4}/year [22]. The risk of fire (S1) seems to us very extremely improbable with regard to the frequencies of events. The scenarios of explosion (S2) and poisoning (S3) appears respectively as improbable and very improbable. Lastly, the frequency of the scenario (S4) where the operator is injured, appears as probable.

From a general point of view, this risk analysis, using module A of the MADS–MOSAR methodology, therefore, enabled us to identify malfunction of the reactor burners as an event that precipitates the main accident scenarios. A microscopic approach using FMEA is presented in the following paragraph.

3.2. Using FMEA: Microscopic approach

Following the research developed in module A, the burners were analyzed in more detail. The burners initiate combustion, and, if the system does not do so itself, maintain a constant temperature in the combustor and ensure the biomass is incinerated.

Carrying out a FMEA requires an initial functional analysis. The objective of the analysis is to identify and define clearly the function of the various parts or components making up the burner. The functional analysis will depend on the desired degree of precision, or in other words, on the size of the subsystems selected. Thus, for the burner used in the process (Fig. 8), we identified six subsystems: the natural gas connection (1), the compressed air connection (2), the ionizing electrode (3), the igniting electrode (4), the mixer-injector (5) and the burner's external casing (6).

The role and functions of these subsystems are shown in Table 2. Based on the functional analysis and on experiential

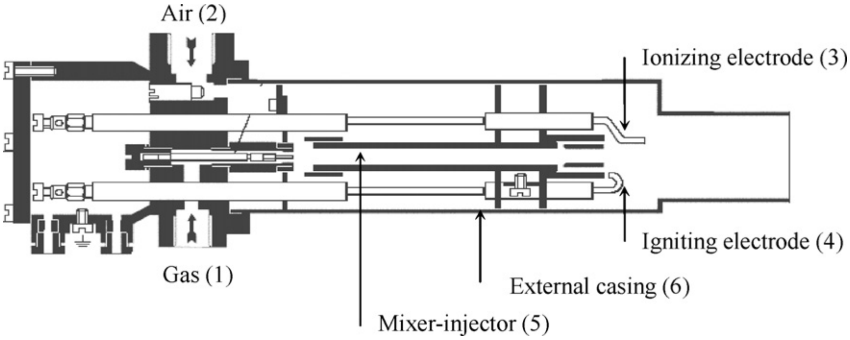


Fig. 8. Diagram of the burners.

Table 2
Functional analysis of the burners

Component (subsystem)	Service function	Technical and design function
Gas connection	Supplies natural gas	Ensures gas is available
Air connection	Supplies air	Ensures air is available
Ionizing electrode	Controls the presence of flame	Controls the presence of free electrons
Igniting electrode	Provides energy for combustion	Creates an electric arc
Mixer-injector	Mixes the combustion gases	Brings the gases into contact and mixes them by injection before combustion
External casing	Protects, insulates and encloses the apparatus	Resists temperature and pressure, confines the gases

data, we reviewed how each component fails, what causes the failure, the effect it has and how it may be detected. Each failure is, thus, associated with a frequency index, a severity index and a detectability index, with the range of values as shown in Table 3. Criticality is defined as the product of these three indices. Components may then be ranked in decreasing order of criticality. A criticality threshold may be set and all items with a criticality above this threshold monitored individually or improved. The FMEA is summarized in Table 4. This table shows the various components ranked in decreasing order of crit-

Table 3
Ratings for the FMEA criteria

F	Frequency		S	Severity	
1	Very low	Very low probability of occurrence (less than once every 6 years)	1	No effect	Line not halted, no quality failures
2	Low	Low probability of occurrence (seen once or twice in 6 years)	2	Significant	Line halted for under 15 min, quality failure but line not halted
3	Medium	Medium probability of occurrence (seen about once a year)	3	Serious	Line halted for between 15 min and 8 h, quality failure and line halted
4	High	High probability of occurrence (seen several times a year)	4	Very serious	Line halted for over 8 h, quality failure not detected in the line
D	Detectability		C	Criticality C = F × S × D	
1	Very easy	Warning sign, automatic alert	1	Minimum	
2	Medium	Warning sign, no automatic alert	8		
3	Low	Warning sign difficult to detect	27	Criticality threshold to be set	
4	Nil	No warning sign	64	Maximum	

Table 4
The FMEA for the burner

Component	Functions	Failure modes	Causes	Effects	Detection	Criticality			
						F	S	D	C
Gas connection	Supplies natural gas	Leak to the outside	Connection loose, Joints worn, Poor connection to the inlet line	Combustion not possible, poisoning, fire	Smell combustion stopped	2	3	2	12
Air connection	Supplies air	Leak to the outside	Connection loose, Joints worn, Poor connection to the inlet line	No or poor combustion	Combustion stopped	2	2	2	8
Igniting electrode	Provides energy for combustion	No electric arc	Transformer fault	No initial combustion, natural gas sent directly to the combustion chamber, fire, explosion	Reactor temperature	1	4	2	8
Ionizing electrode	Controls the presence of flame	Loss of function	Voltage drop stray current	No flame detected	No	1	2	4	8
External casing	Contains the gases	Deterioration Loss of function	External shock Corrosion Poor sealing	Leaks of gas and air to the outside risk of fire poisoning	Smell combustion stopped	1	3	1	3

Table 5
FMEA—recommendations

Component	Recommandation	Criticality			
		F	S	D	C
Gas connection	Check the connection seal, estimate the lifetime of joints and change them periodically	1	3	1	3
Air connection	Check the connection seal, estimate the lifetime of joints and change them periodically	1	2	1	2
Igniting electrode	Dismantle periodically to check the electric transformer	1	4	1	4
Ionizing electrode	Dismantle periodically to check the probe and electrical contacts	1	2	2	4
External casing	Check the seal of both parts of the casing, corrosion pitting	1	3	1	3

icality. In this instance, the FMEA highlights the items where corrective action must be defined, so that a maintenance plan based on the risk assessment may be prepared. In its final form, the FMEA also includes a number of recommendations, aimed at reducing the component's criticality (Table 5). Subsequent to this study, a number of barriers (raising awareness, signage, non-slip matting, etc.) have been implemented, as have preventive maintenance sheets (lists of actions to carry out before starting up the pilot and periodic maintenance). These various barriers may also be described using MOSAR Tables B and C.

4. Conclusions

The study discussed here links two methodologies for analyzing and ranking the risks in a semi-industrial pilot process that chemically converts miscellaneous waste using circulating fluidized bed combustion. The MADS–MOSAR methodology can be used to make a macroscopic study of the installation, comprising a number of stages: selecting five subsystems, identifying hazard sources, constructing scenarios for undesired events, ranking using a Severity × Probability grid, and recommending safety barriers. Detailed study of the scenarios showed burner malfunction to be an initiating process common to a number of anomalous events with potentially catastrophic consequences, including poisoning caused by the release of gaseous combustion products, and fire and explosion also caused by the presence of inflammable material and dust. In the remainder of the study, we carried out a FMEA on the burners; identified the critical factors; and suggested the technological barriers and maintenance instructions that should be implemented to reduce the risks associated with operating the combustion unit. The MADS–MOSAR methodology used to evaluate the risks in a semi-industrial combustion unit is an effective means of identifying scenarios and chains of scenarios (long or short scenarios) that could cause accidents, evaluating their consequences and ranking them. The FMEA, which is associated with it, also offers an effective approach to provide technical and organizational solutions that can significantly reduce the risks associated with operating this system. This type of study is now mandatory (French Decree no.2001-1016 of November 5, 2001) and must be revisited periodically. The overall approach is one of continuous improvement with regular action plans that reduce risk in the workplace and improve working conditions. Thus, the topic presented here will require revising later when experiential data is available for analysis.

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References

[1] P. McKendry, Energy production from biomass (part 1): overview of biomass, Bioresour. Technol. 83 (1) (2002) 37–46.
[2] P. McKendry, Energy production from biomass (part 2): conversion technologies, Bioresour. Technol. 83 (1) (2002) 47–54.
[3] J.-H. Ferrasse, I. Seyssiecq, N. Roche, Les procédés de gazéification comme alternative pour la valorisation de boues de stations d'épuration des eaux usées, Déchets sciences et techniques, la revue francophone d'écologie industrielle, 30 (2003) 20–24.
[4] J. Corella, J.M. Toledo, Incineration of doped sludges in fluidized bed. Fate and partitioning of sic target heavy metals, I. Pilot plan used and results, J. Hazard. Mater. 80 (1–3) (2000) 81–105.
[5] A. Gratias, D. Steinmetz, M. Hemati, S. Dounit, S. Abanades, Incinération des boues humides en lit fluidisé: influence des conditions opératoires sur les émissions des micro-polluants gazeux et métaux lourds, Entropie 243 (2002) 2–15.
[6] J.Y. Hristov, Fluidized bed combustion as a risk-related technology: a scope of some potential problems, IFRF Combustion Journal, article 200208, 1562-479x (2002) 2-34.
[7] P. Baussand, L. Lassagne, V. Jacob, P. Foster, Realisation of pilot using circulating fluidised bed combustion of coal, Fresenius Environ. Bull. 9 (2000) 544–551.
[8] Y. Vérot, Démarche générale de maîtrise du risques dans les industries de procédé, Techniques de l'ingénieur, 2001, fascicule AG 4 605.
[9] J.-M. Flaus, Un modèle de danger unifié pour l'analyse systémique des risques, in: Eds. Lavoisier Tec & Doc, Récents Progrès en Génie des Procédés 90, Paris, 2003.
[10] J. Tixier, G. Dusserre, O. Salvi, D. Gaston, Rewiew of 62 risk analysis methodologies of industrial plants, J. Loss Prev. 15 (2002) 291–303.
[11] P. Périlhon, Analyse des risques, éléments méthodiques, Phoebus, la revue de la sûreté de fonctionnement, l'analyse de risques, 12 (2000) 31–49.
[12] P. Périlhon, MOSAR, présentation de la méthode, Techniques de l'ingénieur, 2003, fascicule SE 4 060.
[13] P. Périlhon, MOSAR, cas industriel, Techniques de l'ingénieur, 2004, fascicule SE 4 061.
[14] Y. Bultel, M. Aurousseau, P. Ozil, L. Perrin, Risk analysis on a fuel cell in electric vehicle using the MADS–MOSAR methodology, Trans. IchemE Part B 85 (B3) (2007) 241–250.
[15] F.I. Khan, S.A. Abbasi, Techniques and methodologies for risk analysis in chemical process industries, J. Loss Prev. 11 (1998) 261–277.
[16] T. Pinna, R. Caporali, G. Cambi, L. Burgazzi, A. Poucet, M.T. Porfiri, Failure mode and effect analysis on ITER heat transfer systems, Fusion Eng. Des. 42 (1998) 431–436.
[17] A. Scipioni, G. Saccarola, A. Centazzo, F. Arena, FMEA methodology design, implementation and integration with HACCP system in a food company, Food Control 13 (2002) 495–501.
[18] P.-X. Thivel, P. Hus, M. Depriester, F. Rougeot, Diagnostic maintenance d'une station d'épuration des eaux usées de papeterie, Déchets sciences

et techniques, la revue francophone d'écologie industrielle, 34 (2004) 27–35.

[19] P. Baussand, L. Lassagne, V. Jacob, P. Foster, Realization of a pilot unit using circular fluidized bed combustion of coal. Study of the temperature influence in PAH formation and NO/NO_x production, in: 10th International Symposium on Environmental Pollution and its impact on life in the Mediterranean region, MESAEP, Spain, 1999, p. 23.

[20] L. Shi, C. Cadet, P.-X. Thivel, F. Delpech, Dynamic modelling for sludge combustion control, Environ. Eng. Manage. J. 5 (4) (2006) 705–716.

[21] J.Y. Hristov, Fluidized bed combustion as a risk-related technology part 2: problems relevant to the equipment damage due to the fluel properties, 4th International Symposium of South-East European Countries on Fluidized Beds in Energy Production, Chemical and Process and Ecolology, ISBN 960-86076-1-2, 2003, 135–141.

[22] R.P. Lees, Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control, second ed., Butterworth-Heinemann, Oxford, England, 1996.

[23] J.-L. Gustin, Management des risques chimiques: explosion de gaz, Techniques de l'ingénieur, 2002, fascicule J 3 894.

[24] A. Laurent, Sécurité des procédés chimiques, connaissances de base et méthodes d'analyse de risques, Edition Lavoisier Tec & Doc. Paris, France, 2003.