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Risk Assessment – Health, Safety and Environment

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1 Introduction

The technology of biomass gasification differs from other energy conversion technologies based on renewable energy sources (e.g. biomass combustion) because it inherently involves the production, treatment and utilisation of flammable and toxic gas mixtures, plant media and utilities. Therefore, an adequate risk assessment is strongly recommended and is often a legal requirement for placing the plant into the market and running it.

A risk assessment is aimed at protecting the workers and the plant itself. Manufacturers/operators have to keep in mind that accidents and ill health can ruin lives and can affect the business too if output is lost, machinery is damaged, insurance costs increase or there is the possibility of prosecution [Ref 7].

A risk assessment consists of a careful examination of what could cause harm to the people and environment in the plant, and the adoption of reasonable control measures. The manufacturers/operators have to produce a complete and well-documented assessment of the risk relative to:

- Health – e.g. hazards to human health, dangers from toxic gases, etc;
- Safety – e.g. explosion hazards, fire hazards, etc;
- Environment – e.g. plant emissions, loss of containment relating to toxic substances, etc.

A risk assessment has to be carried out during the planning phase (for manufacturers) in order to improve the plant’s conceptual design. In existing plants, a risk assessment allows the reduction of the remaining risks by continual updating of the original risk assessment (for manufacturers and operators).

Different methods for risk assessment are available, but procedures for risk assessment are not generally standardised for biomass gasification plants. Some guidance on risk assessment can be found in different case studies from other branches of the industry (e.g. food industry, chemical industry, metal industry, etc.). These examples can only give guidance for finding a methodology and often have to be adapted to be used for biomass gasification plants.
2 Applied risk assessment procedure for biomass gasification plants

Assessing the risks is an extensive task for which comprehensive knowledge of the process and the operational behaviour, as well as the risk assessment methodology itself, is needed. A team that has various expertise is recommended for the risk assessment. The following information is necessary:

- Plant data (process schemes, piping and instrumentation diagram (P&I), reference designation and plant documentation, apparatus design, etc.);
- Predefined plant operation modes (knowledge about start-up, shut-down and normal operation mode), process control strategies;
- Data on plant media, gas mixtures and plant media streams (e.g. waste water, gas cleaning residues, dusts, exhaust gas), as well as their corresponding safety characteristics (toxicity, explosion characteristics etc);
- Desired operation conditions (temperature, pressure, flows and gas compositions);
- Machinery lists, details on construction design;
- Mass and energy balances, process stream information (temperature, pressure, composition and pollutant load, etc);
- Information on the plant’s surroundings (geographical aspects, environmental aspects, etc).

Small-scale biomass gasification being a unique and relatively new technology, no specific risk assessment technique or guidance is available. This guide recommends a risk assessment methodology which is practicable and sufficient to be applied to such plants. The chosen approach is based on functional analysis of the plant [Ref 2-3]. It follows principally the Hazard and Operability Studies (HAZOP) [Ref 4, 9] and Failure Modes Effects and Criticality Analysis (FMEA) [Ref 5] methods, as well as recommendations given by an expert commission [Ref 4, 6].
In many cases, the risk assessment deals with a very complex system, which contains a huge number of mostly independent functions and plant parts. By subdividing the process into process units [Ref 1, 8] (e.g. fuel storage, handling, feeding, gasifier, gas cooling, gas cleaning, gas conditioning and gas utilisation), the complex system is simplified, and a separate analysis of each function (e.g. for the gasifier: fuel supply, gasification utilities supply - i.e. steam and air, temperature control in the gasifier, ash removal, etc) is possible.

On each investigated function, the risk evaluation team has to [Ref 10]:

- Identify the possible hazards and their associated occurrence probability;
- Identify the consequences arising from these possible hazards and their severity;
- Evaluate the risks;
- Apply the suitable reduction/mitigation measures;
- Review and update the risk assessment on a regular basis.

**Figure 2-2 Description scheme for the risk evaluation and assessment within one investigated function**

Figure 2-2 gives a general overview of the principles and methodology underlying a risk assessment. All steps of the assessment must be well-documented to allow traceability.

The following sections give the basis for conducting the hazard identification (Hazard-ID), the risk assessment (RA) itself and implementing concrete risk reduction (RR) measures.

An example of a risk assessment carried out on a whole model process configuration will be given in the software tool manual (D11 – Software tool and Manual).
3 Hazards Identification and Consequences

For each defined function, the risk assessment team has to carry out a hazard identification. This consists of identifying all situations or events that could cause harm to people and environment. These hazardous events can be of different natures:

- Abnormal operation conditions (temperature and pressures);
- Equipment failures;
- Leakage;
- Operator failure;
- Loss of containment;
- Etc.

The approach proposed in this guide follows principally the HAZOP and FMEA analysis, but different hazard identification techniques are available and could be used (see Annex A).

The occurrence probability of each identified hazardous event has to be assessed (e.g. using failure rates of equipment, existing data) [Ref 11, 12]. The investigated hazardous event can itself be caused by different events or situations that have to be taken into account in the calculation of the overall occurrence probability. All these possible hazardous events have to be analysed to determine their possible consequences, such as fire, explosion, emissions, etc. [Ref 12] (see Figure 3-1).

The identification of possible hazardous events and their consequences should be conducted by expert teams consisting of different disciplines. Realistic figures for the estimation of frequency and the severity should be used.
4 Risk assessment

The next step of the procedure consists of evaluating the risk associated to the identified hazardous events. Risk is interpreted as the combination of consequence (severity) and likelihood (frequency). A risk matrix enables this combination to be represented graphically (see Figure 4-1) [Ref 10, Ref 13, Ref 14]. It is an easy method to visualise the spread of risk, to screen hazards, or to conduct a simple risk analysis. The main advantage of the matrix is its easy representation of different risk levels, and the avoidance of more time-consuming quantitative analysis where this is not justified.

For the implementation of the risk matrix, the occurrence probability and the severity determined in the previous step can be classified in several categories. Table 4-1 and Table 4-2 propose a structure that can be used. The risk assessment team can choose a different classification, e.g. by having more categories. However, the chosen classification should not overcomplicate the risk matrix [Ref 14].

![Figure 4-1 Risk matrix for the characterisation and visualisation existing and/or remaining risk potentials](image_url)

Table 4-1 Example for risk characterisation – Probabilities
The risk matrix is subdivided into three areas [Ref 13]:

- **Acceptable region**
  Risks falling into this region are generally regarded as insignificant and adequately controlled. The levels of risk characterising this region are comparable to those that people regard as insignificant or trivial in their daily lives. These risks are typically from activities that are inherently not very hazardous or from hazardous activities that can be, and are, readily controlled to produce very low risks. Further action to reduce risks is often not required.

- **As Low As Reasonably Practicable (ALARP) region**
  Risks in this region are typically activities that people are prepared to tolerate in order to secure benefits, provided that the nature and level of the risks are properly assessed and the results used properly to determine control measures. If the hazardous events fall into the ALARP region, this does not mean that the total risk for the installation is ALARP, but that it should be considered whether further risk reductions are needed. For the remaining risk in the ALARP region, further safety measures might not be economically justifiable and reasonable. In all cases, the risk assessment team must discuss the following points:

### Table 4-2 Example for risk characterisation – Severities

<table>
<thead>
<tr>
<th>Notation</th>
<th>Frequency range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely unlikely</td>
<td>$&lt; 10^{-6}$ per year</td>
</tr>
<tr>
<td>Very unlikely</td>
<td>$10^{-6}$ to $10^{-4}$ per year</td>
</tr>
<tr>
<td>Unlikely</td>
<td>$10^{-4}$ to $10^{-2}$ per year</td>
</tr>
<tr>
<td>Improbable</td>
<td>$10^{-2}$ to 1 per year</td>
</tr>
<tr>
<td>Probable</td>
<td>$&gt; 1$ per year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>minor</th>
<th>significant</th>
<th>severe</th>
<th>major</th>
<th>catastrophic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human beings</td>
<td>light injury</td>
<td>injury</td>
<td>severe injury</td>
<td>disablement, death</td>
<td>death</td>
</tr>
<tr>
<td>Environment</td>
<td>olfactory pollution, elevated emissions (short time)</td>
<td>long lasting olfactory pollution, slightly increased emissions</td>
<td>emission of toxic substances of little amounts</td>
<td>emission of toxic substances of amounts</td>
<td>emission of toxic substances of huge amounts</td>
</tr>
<tr>
<td>Property/goods</td>
<td>no plant shut down, online repairation possible, little costs</td>
<td>plant stop, warm start possible, standstill of the plant &lt; 2 days</td>
<td>plant damage, cold start necessary, standstill of the plant 1 to 3 weeks</td>
<td>critical plant damage concerning the whole plant or plant sections, standstill of plant &gt; 8 weeks</td>
<td>enormous plant destruction/damage concerning the whole plant</td>
</tr>
</tbody>
</table>
• Is the remaining risk acceptable?
• Can additional countermeasures be taken to reduce the risk level?
The risk falling in this region should be reviewed on a regular basis to make sure that they still meet the ALARP condition.

- Unacceptable region
  The risks in this region are unacceptable and must be reduced to an ALARP region by the application of countermeasures.
5 Risk reduction measures

An unacceptable risk requires the implementation of risk reduction measures to move it to the ALARP region of the risk matrix. Practically, this consists of decreasing the frequency and/or the severity of a hazardous event or concern.

The bow-tie diagram shown in Figure 5-1 can be used for this purpose. The column ‘Top event’ in the bow-tie diagram marks the failure of the currently investigated function. This technique is flexible, and any event can be used as a top event. The columns on the left and on the right of the top event contain initiators and consequences of the ‘top event’. The bow-tie diagram can help in determining what can be done to reduce the risk to an acceptable level. Indeed, on the diagram, safety barriers are represented (Figure 5-1):

- The safety barriers between the ‘Hazardous Events’ column and the ‘Top Event’ correspond to prevention measures that act towards the reduction of likelihood/frequency of the top event.
- The safety barriers between the ‘Top Event’ and the ‘Consequences’ columns correspond to the mitigation measures that act to reduce the severity of consequences and/or the likelihood of those consequences.

Different types of countermeasures can be applied:
- **Technical countermeasures**: These consist of the implementation of technical modifications such as change in the process design, addition or replacement of some process parts, etc.
- **Process control countermeasures**: These refer to any changes of the control system routine. This may be the addition of new control devices on the process chain (e.g. temperature sensors, pressure gauges, CO sensors, etc) with the suitable alarm system. The implementation of these new control devices must include setup of the adequate emergency management system.
- **Organisational countermeasures**: These refer to various activities relative to the organisation of the work.

All these countermeasures have to be recorded in the O&M manual. Therefore, the risk assessment procedure should not be taken as a straightforward process. Indeed, the implementation of countermeasures may change the original process. Additional hazardous events may appear. A re-evaluation of risks for the modified process may be necessary.
Figure 5-1 Bow-tie diagram for risk assessment
6 Documenting the outputs of the risk assessment

The documentation of the risk assessment and risk reduction is essential for the traceability. It is commonly done in tabular form, i.e. in structured lists of events and their possible consequences. Such a method may be carried out with the assistance of computer software, which helps considerably with structuring the documentation and with placing cross-references to recurring events and consequences.
7 Software Tool for Risk Assessment

A software tool (called RISK ANALYSER) was developed to facilitate the implementation of the risk assessment proposed in this Guideline. HSE issues of small-scale biomass gasification plants can be treated in a very structured way when the assessment is supported by the software tool.

The target groups of the software tool are, in the first place, manufacturers, project developers, operators, researchers, and implementers of biomass gasification plants. The software can also be used for types of processes other than biomass gasification.

In the software, a recommended risk assessment procedure is implemented, which is practicable and sufficient for the application in small-scale biomass gasification plants. The chosen method, which was presented before, is based on a HAZOP study and is enlarged by additional features specific to biomass gasification plants.

The risk assessment procedure with the software follows the following steps:

1. **Definition of plant basic data**
   The basic information of the investigated plant is given (project name, plant manufacturer, operator, power output of the plant, etc).

2. **Definition of process units**
   The plant is subdivided into process units corresponding generally to the process steps - e.g. gasifier, gas cooling, gas cleaning, gas conditioning and gas utilisation.

3. **Definition of functions**
   The unit functions have to be defined (e.g. fuel supply for section gasifier). They represent the basic data for the risk assessment.

4. **Definition of the operation modes**
   In this step, a short description of the foreseen operation modes for start-up, shut-down, normal operation and emergency shut-down is requested. This will help identify the hazards in different operation modes.

5. **Definition of parts**
   The functions are fulfilled by dedicated parts, which have to be defined. This requires input on:
   - Design parameters (pressure, temperature, flow rates, etc. in all operation conditions, as well as minimum and maximum values);
   - Information on plant media as well as plant utilities (safety characteristics, operation temperature and pressure of the treated media, etc);
   - Information textbox, if necessary (optional).

   This comprehensive documentation of the information should give all the necessary basics for the rest of the risk assessment.

6. **Risk assessment**
   The programme supports the risk assessment with a preset of possible events and consequences. The software tool rates the risk potential according to the proposed risk matrix.

   Important note: within this first risk assessment, the original plant and operation concept is investigated. Countermeasures for risk reduction are added in the next step.

7. **Countermeasures**
   Setting of countermeasures is supported by the tool, giving the possibility of a re-assessment of revised process configurations. The description of countermeasures allows categorising in technical, process control and
organisational countermeasures. An editing of the operation procedure is feasible. Automated system control measures can be documented for each operation mode.

8. Summary
The summary is the final step. It gives an overview of the original plant concept (before applying countermeasures), its functions and parts. The outcomes of the risk assessment are documented for each investigated process function, including the improvement resulting from the countermeasures.

At the end of the risk assessment of the whole process, a report can be generated. This can be used as a documentation of the risk analysis.
8 References


