Grant Agreement Number: EIE/06/078/SI2.447511

Project acronym: **Gasification Guide**

Full title of the action: Guideline for safe and eco-friendly biomass gasification

Intelligent Energy – Europe (IEE)

Key action: ALTENER

Deliverable D17:

State Of The Art from Case Studies and Good Design Principles

Final Version 09 December 2009

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The project is co-funded by the European Commission

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1 Introduction

This report briefly describes the potential dangers associated with the design, operation and maintenance of biomass gasification plants (BGPs). It is an essential prerequisite for the complete risk assessment process to first analyse the hazards and then go on to assess the risks that they present and determine what, if any, ameliorating measures should be taken.

It is good practice to apply a number of good engineering principles that apply to design as a hierarchy, by aiming to eliminate a hazard in preference to controlling the hazard, and controlling the hazard in preference to providing personal protective equipment.

A holistic approach is important in order to ensure that risk-reduction measures that are adopted to address one hazard do not disproportionately increase risks due to other hazards, or compromise the associated risk control measures. Where appropriate, consideration should also be given to the balance of risk between workers and the public, and to the risks n case of an emergency case.

In the “Guidance on ‘as low as reasonably practicable’ (ALARP) decisions in control of major accident hazards (COMAH)”, the following three important principles are defined *[ref. 27]*:

Principle 1

"HSE starts with the expectation that suitable controls must be in place to address all significant hazards and that those controls, as a minimum, must implement authoritative good practice irrespective of situation based risk estimates".

Principle 2

"The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits in the expectation that:

- the nature and level of the risks are properly assessed and the results used properly to determine control measures;
- the residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle); and
- the risks are periodically reviewed to ensure that they still meet the ALARP criteria, for example, by ascertaining whether further or new controls need to be introduced to take into account changes over time, such as new knowledge about the risk or the availability of new techniques for reducing or eliminating risks."

Principle 3

"both the level of individual risks and the societal concerns engendered by the activity or process must be taken into account when deciding whether a risk is acceptable, tolerable or broadly acceptable’ and ‘hazards that give rise to …. individual risks also give rise to societal concerns and the latter often play a far greater role in deciding whether risk is unacceptable or not".

2 Primary safety considerations

Occupational hazards relate to hazards or risks inherent in certain employment or workplaces. Occupational health and safety issues should be considered to be part of a comprehensive hazard or risk assessment, including, for example, a hazard identification study [HAZID], hazard and operability study [HAZOP], or other risk assessment studies. BGP's presents several occupational hazards of different nature: physical, chemical, biological, environmental, mechanical, psychosocial, etc. Most of them are not specific to BGPs, for instance: slips and trips, collisions, falls from height, struck by objects, workplace transport, electricity, noise, vibration, lighting, compressed air/high pressure fluids, confined space, cold stress, heat stress, crushing, cutting, friction and abrasion, vehicle movements, impact, moving parts, work related stress, etc.

The operator must be aware of these different aspects of occupational hazards, and also of the national regulations related to them, and take appropriates measures.

The Health and Safety Executive (UK) provide on its website (www.hse.gov.uk/) a list of possible hazards to be considered in a workplace. Some guidance on how to prevent and manage these hazards is also given.

The French institute competent in the area of occupational risk prevention (INRS) also gives some guidance on the different areas of occupational hazards on the following website (document in French):

www.inrs.fr/htm/frame_constr.html?frame=/INRS-PUB/inrs01.nsf/IntranetObject-accesParReference/ED%20840/$File/Visu.html.

Similar guidance in German language is available ("Ratgeber zur Ermittlung gefährdungsbezogener Arbeitsschutzmaßnahmen im Betrieb") on the website of the German Federal Institute for Occupational Safety and Health (BAuA):

http://www.baua.de/nn_12456/de/Publikationen/Sonderschriften/2000-/S42.html?__nnn=true

Each activity can have some inherent and specific occupational hazards. This chapter highlights the hazards specific to the gasification process, such as: fire, explosion/deflagration, toxic substances, etc.

The focus in this chapter will be to identify precautionary measures to be taken for health and safety. These measures are based on available expertise within the consortium, external advisors, using generally available information and information gained from case studies. As mentioned in Chapter 1 (Introduction), some target groups may have conflicting interest such as end-user versus the permitting authority, or manufacturer versus plant owner. Therefore, it is necessary to have as complete as possible insight into all HSE concerns and best practices accepted by the international community.

3 Good engineering and operation practice

Good design engineering and construction based on a decent risk assessment and/or HAZID/HAZOP study are compulsory to put a biomass gasifier plant on the market. Most risk assessments provide a general overview and are not intended to be comprehensive in every aspect. They can create liability issues and give a false sense of security. The following paragraphs provide a general overview of good engineering practices, and are not compulsory to each gasifier design, e.g. the safety issues are different whether the gasifier operates at overpressure or underpressure, etc.

3.1 Good design practice related to plant building construction

When designing the gasification plant buildings, a number of health, safety and environmental measures should be considered:

- The fuel storage facility must be separated from the gasification building or divided using a high performance fire curtain.
- For safety reasons, the control and staff rooms must be separated from the remainder of the plant due to fire, explosion and toxic gas release hazards.
- The control rooms should have positive pressure ventilation (special attention must obviously be paid on where the inlet air is taken from).
- The gasification building must be well ventilated and the flows monitored or verified across critical operational areas.
- There should be two escape routes from each point within the gasifier building to the outside.
- The ATEX directive requires that all areas classified as hazardous shall be identified with a warning sign. The sign must be triangular, black on yellow with the text EX to be displayed at points of entry into explosive atmospheres. It is recommended that a study to identify the areas appropriate to be controlled to this standard be undertaken.
- Equipment exceeding a certain noise level, like compressor or engine, should be placed in acoustically insulated cabins.

3.2 Good engineering practice related to process equipment

Good engineering practice related to process equipment is the responsibility of the manufacturer. If the plant is designed properly according to the Machinery Directive, the basic hazards should be eliminated.

Choice of material

- Reactor vessels, valves and piping materials should be constructed from good quality materials;
- Heat resistant stainless steel or other appropriate material shall be chosen for the gasifier and gas cooling device;
- Chemical resistant stainless steel is recommended for gas scrubbing and washing media circulation.

Gas tightness

Gas tightness is important to avoid gas escape and air intake, which may lead to the formation of explosive mixtures and/or the release of toxic gas. The following engineering practices are suitable to ensure gas tightness:

- The use of welded connections is preferred above flanges, in particular for hot pipes above 500°C. In all cases, proper flange sealing like chemical and thermal resistant material need to be used;
- All pipes, aggregates, measurements devices have to be of proper materials;
- Proper material should be used with regard to chemical resistance, temperature and pressures, corrosion, particle size.

Valves

- All air inlets and gas outlets to/from gasifier, including fuel feeding section, flare and engine should be equipped with block devices or anti-backfiring valves in series (after the other in the same line);
- When valves are in contact with pyrolysis or gasification gas they may get stuck;
- Valves used to ensure a safe mode in case of failure and emergency stop must be of the fail safe type;
- Valves at air pipes, filters and cyclones should have position micro switches;
- Faulty settings of manual valves should not be possible. Malfunction of critical valves should be detected.

Electrical devices

- It is recommended to electrically ground all gas conducting parts.
- PLC should be properly grounded in order to avoid malfunction and accidents.
- Galvanic separation of electrical supply of measurement devices is strongly recommended.
- It is recommended to supply PLCs with uninterrupted power supply units (UPS).
- Duplicate plant key operation measurement points (critical temperatures, pressures, etc.) are recommended for monitoring using a secondary measurement system during emergency case or in case of failure of the main PLC system.
- Gas/air inlet into engines should be earth grounded, and shielded cables should be used to avoid electrical breakdowns that could cause backfiring in the inlet system.
- In equipment where there may be a gas-air mixture, instrumentation and electrical equipment should be for Zone 1, otherwise the equipment should be secured; in the gasifier itself equipment should be for Zone 2. A study to determine the relevant zone rating for each area is highly recommended as many plant have been designed for open areas and the Zone classification is highly dependent upon building ventilation.
- There should be safety switches and local circuit breakers on:
    - rotating parts and switches;
    - access panels;
    - pressure relieve equipment;
    - critical valves with access to gas containing equipment such as feeders, cyclones and ash outlet.
- The use of area E-Stops should be considered.

Control and safety devices

- CO detectors, giving indication and alarm at about 25/50 ppm CO, must be installed in rooms with equipment containing pyrolysis or gasification gas.
- Pressure and temperature sensors included in the safety concept should be duplicated or tripled. The failure probability regarding the influence of operation/installation must have been estimated.
- Heat exchangers between gas and air form a possible hazard source in case of leaks between the media due to e.g. thermal cracks or corrosion. Similarly for expansion joints in long welded pipes. Hazards from this possible malfunctioning should be avoided by well designed equipment and by temperature and oxygen sensors downstream to be able to detect leakages.
- It should not be possible to tamper safety related devices.
- All alarm values should be specified in the manual before start-up of the plant.
- Temperature sensors should be installed before and after the main plant reactor system components. Preferred and allowable operating temperatures shall be available for the operators in plant manuals and secured with proper alarm levels.

The movable or rotating parts

- The plant movable parts, such as conveyor belts, motors, engines could generate a risk of gas explosions. They should be shielded and equipped with ‘visible’ signs and emergency stop.
- At standby, gas blowers and other rotating equipment in the product gas line should be maintained, otherwise it may corrode or seize through the condensation of tar, which will lead to break down.

Hot surfaces

- The plant can have several hot surfaces. These could generate a risk of gas or dust explosion and also present a risk of accidental contact with operators. The plant equipments that can pose an occupational risk due to high temperatures should be adequately identified and protected (shielded) to reduce risks.
- Training should be provided to educate operators regarding the hazards related to hot surfaces and the use of personal protective equipment (e.g. gloves, insulated clothing, etc).

Gas flaring system

- The flare or a similar device for burning the gas is used when the gas quality is poor and can not be used in the gas engine, or in case of engine failure.
- In case where valves in contact with pyrolysis or gasification gas get stuck, the gas should automatically be flared.
- Gasifiers will have to vent gases as they purge pipe-work from the gasifiers to the engine. At start-up, the gas will always pass through and LEL and UEL.
- The flare should be equipped with:
    - an automatic ignition system;
    - flame monitoring with alarm;
    - water seal.

A HAZOP study is recommended to understand the issues relative to the gas flaring system and then identify the suitable counter-measures, for instance inert gas purging.

Safety equipment

The following safety equipment or tools should be present in each separate part and/or building of the gasifier plant:

- Fire detection and suppression equipment that meets internationally recognized technical specifications for the type and amount of flammable and combustible materials stored at the facility;
- CO detection system;
- Fire fighting equipment;
- Personal protective equipment: ear protectors, eye glasses, gloves, respiratory equipment, personal CO detectors;
- Emergency equipment: shower, first aid kit.

3.3 Recommendations regarding operating and monitoring procedures

Important operating and monitoring procedures to be considered include the start-up procedure (cold and hot start-up), normal operation, normal shutdown procedure and emergency shutdown. These should be considered within the HAZOP study and described in the O&M manual.
It is recommended to develop and implement start-up, normal operation and shutdown routines for the entire gasification plant (preheating, gasifier ignition, normal operation, etc.) to avoid human error in manual operation. Fail-Safe routines have to be part of the plant operation concept.

Normal start-up and shutdown procedures

- At start-up it is recommended to remove the oxygen inside the plant by inertizing the system with for instance nitrogen.
- Experience shows that most accidents take place at start-up and shutdown. Therefore, operators should be instructed not to stay unnecessarily close to system components (gasifier, cyclone bins, filters, etc.) containing flammable materials during start-up and shutdown.
- At start-up and emergency shutdown or in the case where valves get stuck, the gas must be flared.
- If the gas engine were to be shutdown for whatever reason, any residual gas should be immediately flared by switching valves by the automation and control system. If the engine can not be re-started (after two attempts), the emergency stop procedure should be initiated.

Normal operation procedure

- Procedures for manual intervention during operation of the plant should be documented properly in the O&M manual.

Emergency shut down procedure

- The development of the plant operational manual and appropriate scada control must consider the implications identified within the Hazid and Hazop. Each emergency shutdown procedure is therefore highly specific and customized to the individual application.
- Typical emergency shutdown measures include:
  - stop feeding to the gasifier;
  - stop air supply to the gasifier;
  - direct the gas to the flare;

  - o note: inerting the gasifier with nitrogen is not effective as the gasifier normally contains a lot of fuel and charcoal.
- ➢ Evacuation procedures must be in place.
- ➢ Proper training in evacuation and emergency procedures for operators and visitors at induction must be in place.

Maintenance procedure

- ➢ Schedules should be developed for start-up checks and regular inspection of sensor devices for accuracy. For instance, when pressure transmitters pipes are blocked by tar or dust, sensors may show wrong readings, etc. Procedures should be available for inspection even if the sensors are functioning properly.
- ➢ During plant maintenance, the operators should avoid contact and inhalation of either toxic or suffocating gases or toxic liquids. All plant maintenance procedures should be well documented while operators should routinely follow procedures.

3.4 Supplementary precautions

The adoption of the following supplementary precautions is recommended:

- ➢ Operators must be aware that condensation of tarry compounds and steam inside producer gas piping, reactor vessels and valves is likely to be a frequent occurrence. The plant design and maintenance procedure should deal with this issue. It is recommended that operators have a clear understanding of the effect of temperature and pressure on condensation of gaseous components.
- ➢ At the fuel gas-air mixer before the gas engine, there is a possibility of condensation when for instance the outside temperature is low, or the air is very humid. Condensate may cause hammering (= knocking) with damage to the gas engine. It is good practice to monitor the air temperature – and preheat the air, if necessary – and monitor the humidity of the gas entering the gas-air mixer. For modern engines with full electronic control, this is less relevant.
- ➢ Besides overpressure, plant components should also be able to withstand under-pressure for example the full design pressure of the main gas fans. Vacuum conditions may form during cooling after plant shutdown.

4 Safety related issues in practice

Several hazardous events may occur, having different consequences. A checklist is provided in Annex A. The most critical safety issues during the operation and/or maintenance of gasifier plants are related to:

- Asphyxiation/toxic issues like unplanned release of potentially hazardous gas and liquids;
- Explosion / deflagration hazards;
- Fire hazards;
- Operator failures.

For each safety issue, a description is given in the following paragraphs on:
- When and where to address these issues
- Potential impact of these issues, and
- Possible corrective measures to implement best practices.

4.1 Explosion / deflagration

When:
- Gas explosion at biomass gasification facilities can occur when a mixture of combustible gases (mostly CO, H_2 and higher hydrocarbons) and oxygen within the flammability limits meets an ignition source.
- A gasifier plant routinely pass through the Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL). The limiting oxygen concentration depends on the producer gas composition, the moisture, the temperature and the pressure. For hydrogen and carbon monoxide at room temperature and ambient pressure, the limiting oxygen concentration is about 4%. In particular, a dangerous situation may occur during plant start-up, at shutdown and in an emergency case of uncontrolled air intake, for instance due to leakages.
- A combustible vapour cloud can be formed after the spillage of flammable liquids. This depends on the volatility of the liquid, the flash point, the vapour density. Attention should be given to the auxiliary media stored on site.
- Dust explosion from small biomass and char particles can occur at BGPs when a mixture of dust and air in a proper concentration meets an ignition source. The severity of the explosion depends on several parameters such as the size of the dust particles, the degree of confinement of the building, etc.
- Specific attention should be paid to hybrid mixtures, where there is a combination of a flammable gas and dust.
- Ignition sources can be sparks resulting from the build-up of static electricity, glowing particles (char, partially converted biomass), lightning electrical or mechanical sparks (from an electromotor of the blower for instance), hot work (welding, cutting, grinding and sawing), hot surfaces, self-ignition in dust layers and open flames.
- Product gas from gasification can auto-ignite at temperatures above ca. 600-650°C. If a small amount of air is added to gas at high temperature - or vice versa – a quiet combustion will take place at the air/gas interface. If gas and air can be mixed without immediate reaction and subsequently set on fire by an external source such as e.g. a spark or a glowing particle, gas explosion may take place,

the reaction velocity and the peak pressure depending on the degrees of turbulence and confinement of the gas mixture.

Where:

- In plant sections where pressure build up exists (i.e. after a blower), there is a risk of gas escape to the atmosphere, which may lead to a toxic atmosphere, a fire or an explosion on the outside of the particular plant section. Similarly, at under-pressure there is a risk of air ingress and the explosion may occur inside a particular plant section.
- Backwards flowing producer gas is a potential hazard in case for instance valves are not properly functioning.
- Although the gasifier reactor is operated at under-stoïchiometric conditions, locally higher oxygen levels may occur, which can result in rapid temperature increase and explosive mixtures. However, at high temperatures the maximum explosion pressure decreases and classical low-speed deflagration or “Verpuffung” may occur.
- In the gas cleaning section, explosion can be more severe with large volume gas. In most cases, the ignition source would be burning pieces of charcoal/ashes, entrained with the raw gas.
- In the gas flare, back-firing can cause the flame to travel backwards into the gas cleaning section.
- In the gas feeding to the engine, in case of back-firing of the engine takes place.
- In the ash removal section, in case carbon rich ash is generated.
- During repairs (in particularly during welding, cutting, grinding and sawing) explosion can occur if there is still gas inside the system.
- In the fuel storage, feeding section and at places where excessive dust is present, explosions may occur when clouds of dust are formed, depending on the processed biomass and on fuel particle size.
- Attention should be given to auxiliary media such natural gas/propane gas storage and piping. As they are stored under pressure, a risk of leakage exists.

What happens:

- In most cases, there is a minor explosion called low-speed deflagration or in German “Verpuffung”, caused by “unstable” operation, where a local explosive mixture may be present for a short time.
- From theory and practice it is known that pressure in the system due to explosion depends on the producer gas composition and the developed temperature, where explosions/deflagration occur.
- The explosion pressure of (wood) dust/air mixtures is similar to that of flammable gas/air mixtures. Dust explosions could be severe mainly due to the large volume of explosive mixture that can be formed when extensive dust gets dispersed in air. The severity of explosions will depend on the degree of confinement, which – in case of BGPs – is the highest inside equipment, where gases are present (and not dust).
- A gas or dust explosion can cause significant damage to the building, the equipments and the personnel.
- A gas or dust explosion can initiate a fire.

Possible reduction measures:
The following measures are specific to gasification facilities:

- o Gasification facilities should be designed, constructed, and operated according to international standards for the prevention and control of fire and explosion hazards, including provisions for safe distances between tanks in the facility and between the facility and adjacent buildings.
- o Safety procedures must be implemented for operation and maintenance, including use of fail safe control valves and emergency shutdown and detection equipment.

According to ATEX, there are three principle ways to reduce the explosion risk:

- o primary measures which consist in avoiding the occurrence of an explosive atmosphere,
- o secondary measures which consist in avoiding the ignition source, and,
- o tertiary measures which consist in mitigating the effects of explosions.

Furthermore, some general measures are to be considered.

- ➢ Primary measures: avoidance of explosive atmospheres.
  - o At plant sections where over-pressure exists, gas leaks will lead to CO and H_2 escaping to the atmosphere. On the contrary at under-pressure, O_2 will enter into the plant section. Therefore, an oxygen sensor must be installed to monitor the O_2 level in the plant system, and CO monitors must be installed to measure the CO level around the plant. The maximum value of O_2 at the sampling point must be defined with consideration of determined flammability limits and dispersion effects due to the geometry of the equipment. Reference is made to the normative standard BGR 104[7], where design practices are given in terms of flanges to be used, type of sealing, etc.
  - o At start-up, explosive atmosphere can be avoided by operation in combustion mode or purging with nitrogen.
  - o After shutdown and cooling, the whole system should be inertized with nitrogen. Purging with air is used as well, but this is not recommended because in that case the ignition source have to be eliminated which is a secondary protection measure.
  - o The control of dust is an important consideration to avoid the formation of an explosive atmosphere:
    - ▪ Good housekeeping is the key to avoid dust explosions. This includes removing dust deposits and maintaining a clean working floor.
    - ▪ The facility should be well ventilated.
    - ▪ Flooding with inert gas can also be considered when relevant.
- ➢ Secondary measures: avoidance of ignition sources:

[7] BG-Regel 104 „Berufsgenossenschaftliche Regeln für die Sicherheit und Gesundheit bei der Arbeit - Explosionsschutz-Regeln“, Ausgabe Juli 2008, SMBG

- Proper grounding will prevent static electricity build-up and lightning hazards (including formal procedures for the use and maintenance of grounding connections).
- The use of intrinsically safe electrical installations and non-sparking tools is recommended.
- The implementation of permit-to-work system and formal procedures for conducting any hot work (welding, cutting, grinding and sawing) during maintenance activities, including proper tank cleaning and venting, is highly recommended. Flammable material and explosive mixtures or atmospheres must be removed or prevented when performing such work.
- Backfiring from a flare can be prevented by using a water seal acting as a flame arrestor (Reference to EN 12874).
- Application of hazardous area zoning for electrical equipment in design is required. Ex-zoning will determine which type or category of equipment is allowed. When ex-zones have been defined, it will be necessary (in a second step) to assess all potential sources of ignition in these areas. Zoning of places where hazardous explosive atmospheres may occur has to be applied according to ATEX directive 1999/92/EC – the following plant sections are recommended to be considered for the occurrence of an Ex-Zone[8].
  - Fuel storage and feeding with respect to dust explosions;
  - Fuel intake;
  - Ash and dust removal system;
  - Waste water removal system;
  - Flare and auxiliary firing systems (e.g. misfiring);
  - Engine and exhaust gas system;
  - Man/hand holes and sampling ports;
  - Measurement and instrumentation points;
  - Liquefied petroleum gas tanks or cylinders.

Ex-Zoning requires a risk based approach. A study to determine the relevant zone rating for each area is highly recommended as many plant have been designed for open areas and the Zone classification is highly dependent upon building ventilation.

- There are tertiary measures which may be appropriate for gasification plants:
  - to construct the whole system to withstand explosion pressure. For a single vessel (not interconnected) the explosion pressure has been assessed to be around 8 bars. When calculating the maximum explosion pressure, one must take into account any possible pressure pilling effects in interconnected vessels. The maximum explosion pressure in inter-

[8] Explosive mixtures at non-atmospheric conditions, e.g. at increased temperature, are outside the scope of Directive 1999/92/EC, and Ex-zoning may not be appropriate in this case. Conditions for the formation of such mixtures and appropriate safeguards need to be addressed separately.

connected vessels would indeed be higher than the value calculated for a single closed vessel;
- to use of flame arresting devices preferably in the form of water seals;
- to use explosion venting devices to relieve the explosion pressure[9]

- Other general measures:
  - Smoking in the facilities should be banned, and clear ‘no smoking’ signs in the facilities must be installed with staff instructions/training.
  - The whole system should be purged before ignition at start-up by either using excess air or inert gas at 6 times the system volume.

[9] Devices like bursting discs are not preferred due to the small surfaces and they can be expensive. With such devices, ATEX requires decoupling of the particular plant section from the other parts by flame arrestors before and after the particular plant section. This makes the whole system quite complicated. In practice also spring-loaded doors are applied at the gasifier reactor, but they are not preferred since they may get blocked after a while due to sticking of tar and dust. Reference is made to the standards EN 14994 (Gas explosion venting protective systems - 2006) and EN 14797 (Explosion venting devices – 2005).

4.2 Fire

When and where:
- An explosion can initiate a fire.
- Self-ignition of moist and high piles biomass feedstock can lead to a fire. Spontaneous ignition of piles of biomass feedstock can result from the heat accumulation in a relatively large mass where combustion starts deep inside the pile. A small amount of biomass feedstock is not likely to lead to self-heating, but this can occur in huge piles and lead to a fire.
- In cases where the maximum allowable temperatures are exceeded.
- Sparks from hot work (welding, cutting, grinding and sawing) can initiate a fire.
- At the removal of hot ashes, a fire can be initiated.
- In the case where, the decelerating of the engine occur with the wrong ignition timing, a very rich mixture can form in the exhaust manifold. This mixture is hot enough to self-ignite, if the amount of air is enough to support the ignition. If the timing is too late a backfire through the carburetter may happen. If the timing is too early backfiring through the intake valve may occur, which could burn the intake valve. It is to be noted that with the use of modern engines using integrated control systems, this is less likely to happen.
- Failure of the anti-backfiring system (valve-, rotary valve system, double sluice) due to unexpected foreign material, failure in the fuel dosing routines and apparatus, etc may lead to a fire.
- The spillage of flammable liquid could lead to a fire, if an ignition source is present.

What happens:
- Physical injury to human being.
- Damage or destruction of the BGP and other buildings.
- May act as an ignition source for an explosion.
- Release of toxic fumes.

Possible reduction measures:
- Fuel should be stored in a closed container, fire isolated, or in a separate room or building.
- A fire-resistant separation (with a specified fire resistance time) between the fuel storage and the gasifier may be required according to local fire-protection regulations.
- The installation of anti back-firing system at reactor, flare and the air inlet to the engine may be required according to national regulations. A humidification system at the ash removal in order to prevent fire hazard from glowing particles or nitrogen inerting on ash removal screws.
- It is recommended to monitor the temperature in the fuel storage pile.
- Ample ventilations is recommended, preferably natural ventilation.
- Fire detection and suppression equipment that meet internationally recognized technical specifications for the type and amount of flammable and combustible materials stored at the facility should be used.
- Accommodation areas should be protected by distance or by fire walls.
- The ventilation air intakes should prevent smoke or gas from entering accommodation areas.

- A formal fire-response plan supported by the necessary resources and training, including training in the use fire suppression equipment and evacuation, must be prepared. Procedures may include coordination activities with local authorities or neighbouring facilities.
- Fire-extinguishing system like fire extinguishers and/or Sprinkler system should be used (Note: Regulations on the construction of the fire protection system must be coordinated with the pertinent fire-protection expert of the licensing public authority). Fixed systems may also include foam extinguishers and automatic or manually operated fire-protection systems.
- All fire systems should be located in a safe area of the facility, protected from the fire by distance or by fire walls. The detection equipment specified needs to be suitable for use in a dusty environment to prevent false alarms or accidental discharge.

4.3 Toxic liquid escape

When:

- In case of leakage in the gas cooling section.
- In case of leakage in storage or holding tanks containing toxic liquids.
- During the maintenance of gas cooling section.

Where:

- Condensed water and tar vapours can be toxic. This could be particularly relevant at wet scrubbing systems.
- Scrubbing liquor and other media used for dissolution or lubrication of tar covered moving parts (including some industrial degreasers) can be toxic and caustic.

What happens:

- Contact with the toxic/caustic liquid can lead to physical injury, suffocation, irritation to eyes or irritation after inhalation.
- The liquid may evaporate with subsequent risk of inhalation of the associated toxic vapours like PAH, (some PAH are carcinogenic).
- Toxic liquid escapes can lead to environmental hazards and pollution.
- If the liquid is also flammable, a risk of formation of a combustible vapour cloud can exist.

Possible reduction measure:

- Wear safety (chemical resistant) hand gloves, glasses and safety shoes.
- Wear suitable respiratory equipment to prevent the inhalation of the toxic vapours.
- Ample ventilation of the surrounding work area.
- Storage in bin/tank to be collected and treated by certified company, as prescribed in the permit document.
- Reduce inventory of toxic/caustic liquid onsite.
- Spill cleanup kits available.
- Use of non-sparking tools in the facilities.
- Regular inspections of the stock of toxic/caustic liquids.

4.4 Toxic gas escape (in particularly CO)

When:

- Toxic gas escapes can occur in case of leakages and an over-pressure in the system. In particular, when a plant is shut-down, the whole system is filled with toxic gas. It is important to understand that after a planned or emergency shut-down, the gasification reactions still continue for quite some time, which may result in an over-pressure in the system if the gas is not safely vented. This is in particular valid to fixed-bed gasifiers containing large volumes of fuel
- During plant maintenance.
- In case volatile toxic liquids escape.

Where:

- Water seals in case of over-pressure.
- Leakages where over-pressure can occur.
- Exhaust gas emission.

What happens:

- CO poisoning.
- There is also an explosion hazard with CO (see 5.4.1).
- Suffocation (CO, PAH,…).
- Toxicity, both short term and long term as some components of the syngas e.g. PAH are carcinogenic.
- Irritation to eyes, inhalation.

Possible reduction measures:

- Gas-tight construction, see also par. 5.5.
- Wear portable CO monitors during operation and maintenance and install fixed online CO detectors in fuel storage buildings, gasifier building and gas engine room, giving an indication and alarm at about 25/50 ppm.
- The control rooms should have positive pressure ventilation.
- Ample ventilation of gasification building.
- In case volatile toxic liquids escape, the reduction measures cited in 5.4.3 also apply.

4.5 Operators failures

Only skilled and qualified personnel are allowed to operate and maintain the plant. They should be trained by the technology supplier or on-the-job using the original O&M manual. However, there are several potential risks due to failures of operators, like:

- (Un)authorised re-programming of the alarm settings. These set-points must be reset again after the problem is solved.
- Safety-related changes to the process control system must be performed by trained personnel and properly documented. The operation manual must clearly indicate and address this type of actions (e.g. changing alarm setpoints, re-programming, etc.).
- Operational procedures should be in place, which indicates whether the plant should be operated by only one or two operators.

5 Norms and Standards

As for construction and operation of BGP's, different regulations and norms exist. Applicable directives are listed in Chapter 3. An up-to-date list of harmonized standards relating to European Directives can be found at:
http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist.html.
Regulations for operation can typically be found in national legislation, technical rules etc. These are not defined in norms or standards (like EN or ISO standards).

Gasification plants must be approved for the design, construction and safe operation by the local fire department and permitting authority, and sometimes supplemented by third-party inspectors, expert opinions and/or environmental authorities. The exact types of approval vary between EU countries (Chapter 3), and will depend on plant parameters like thermal capacity, gasifier feedstock, plant location and the like.

5.1 A norm for gas tightness

A couple of standards is used in the chemical industry for a safe handling of hazardous substances (toxic and flammable) in pipes and vessels. Norms for gas tightness relate to "good practices" regarding the methods for avoiding leakages, methods of detection, etc.
Technical measures regarding the use of piping standards and the design and maintenance of piping systems can be found on the Health and Safety Executive website. These are good practices for COMAH (Seveso II) sites:
http://www.hse.gov.uk/comah/sragtech/techmeaspipework.htm

Even if the Seveso II regulation is not relevant to BGPs, these recommendations in terms of gas tightness could be considered as applicable to BGPs (such as the values of frequencies and severity for the risk assessment part). The standards showed in Table 5.1 might be relevant.

In German regulations, a few definitions and remarks on "technically leakproof" units are available:

- in the non-binding Guide on directive 1999/92/EC, cf. the glossary of that Guide and chapter 3.2.1/remarks on zone 2
- in the
  - German Technical Rules on Industrial Safety: TRBS 2152 part 2, chapter 2.4.3,
  - German Technical Rules on Hazardous Substances: TRGS 722, and in
  - technical rules of the German "Berufsgenossenschaften" (employers' liability insurance associations / professional organisations): BGR 104 "Explosion Protection" (very similar definitions and descriptions appear in these documents).

German Technical Rules make a difference between units that are "technically leakproof" ("= technisch dicht") and "permanently technically leakproof" (= "auf Dauer technisch dicht"). In the latter case, no hazardous release of flammable material is anticipated, and there is no need to classify a hazardous area around such

equipment. TRBS 2152-2 etc. give some examples of the types of connections which are deemed "permanently technically leakproof", e.g. certain types of flanges used in pipe connections.
In some cases, technical measures combined with regular inspection and maintenance may also result in equipment being regarded as "permanently technically leakproof".

With equipment regarded only as "technically leakproof", releases are anticipated on rare occasions, and this will typically lead to a zone 2 classification around such equipment / such connections.

With a view to environmental protection, there are some requirements on permissible leak rates of flange connections and gaskets in TA-Luft (chapter 5.2.6.3). These refer to gaseous emissions of certain (volatile or hazardous) organic liquids, however, and do not formally apply to producer gas.
Concerning technical requirements, TA-Luft refers to regulation VDI 2440 (for technically leakproof flange connections) and to EN 1591-2 for selection and design of flange connections.
These standards could also be useful for flange connections in pipes with hazardous gases.

5.2 Literature regarding zoning and explosion protection measures

The Health and Safety Executive website gives general information about:

- Fire and explosion:
www.hse.gov.uk/fireandexplosion/index.htm

- ATEX regulation (called DSEAR in United Kingdom)
www.hse.gov.uk/fireandexplosion/atex.htm

- Short guide to the ATEX regulation:
www.hse.gov.uk/pubns/indg370.pdf

- Zone classification:
www.hse.gov.uk/fireandexplosion/zoning.pdf

Some guidance is also given by different sources compiled in Table 5.2. These different sources contain information on explosion protection measures (for instance: EN 1127-1:2007).

Table 5.1: Standard for gas tightness that might be applicable

Source	Name	Description
American Society of Mechanical Engineers (ASME) http://www.asme.org/	B31.3-2002 Process Piping	Petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals. Content and Coverage (a) This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping. (b) This Code applies to piping for all fluids, including: (1) raw, intermediate, and finished chemicals; (2) petroleum products; (3) gas, steam, air, and water; (4) fluidized solids; (5) refrigerants; and (6) cryogenic fluids. (c) See Fig. 300.1.1 for a diagram illustrating the application of B31.3 piping at equipment. The joint connecting piping to equipment is within the scope of B31.3. Packaged Equipment Piping. Also included within the scope of this Code is piping which interconnects pieces or stages within a packaged equipment assembly. Exclusions. This Code excludes the following: (a) piping systems designed for internal gage pressures at or above zero but less than 105 kPa (15 psi), provided the fluid handled is nonflammable, nontoxic, and not damaging to human tissue as defined in 300.2, and its design temperature is from -29°C (-20°F) through 186°C (366°F); (b) power boilers in accordance with BPV Code2 Section I and boiler external piping which is required to conform to B31.1; (c) tubes, tube headers, crossovers, and manifolds of fired heaters, which are internal to the heater enclosure; and (d) pressure vessels, heat exchangers, pumps, compressors, and other fluid handling or processing equipment, including internal piping and connections for external piping.
IGEM www.igem.org.uk	IGE/UP/1/New Edition 2 2003 Guide to non-domestic gas tightness testing and purging standards.	IGE/UP/1 (Edition 2) gives practical guidance to gas operatives when engaged in strength testing, tightness testing and purging gas pipework used in the non-domestic sector.
IGEM Energy Institute Publications http://www.igem.org.uk/Technical/energyinstitute.asp	IP Model Code of Safe Practice Part 13: Pressure piping systems examination	The purpose of this Code is to provide a guide to safe practices in the in-service examination and test of piping systems used in the petroleum and chemical industries. The Code gives general requirements regarding the provision and maintenance of adequate documentation, in-service examination, the control of modifications and repairs, examination frequency, protective devices and testing of piping systems. In many countries statutory requirements exist, both local and national, pertaining to the in-service examination of pressure vessels and, where this is so, this Code should be regarded as being complementary to such requirements.

British standards	BS 3636:1963 Methods for proving the gas tightness of vacuum or pressurized plant	Ten methods for application to evacuated plant, seven to pressurized plant. Five involve direct measurement of quantities but are insensitive or lengthy. Others use search gas and detectors sensitive to such gas. Four use vacuum gauges which may be able to serve another purpose on plant. Each method describes apparatus, special precautions, procedure, interpretation of results, working principles, sensitivity. Design of plant; contracts; blockage of capillary leaks; leak rates of different fluids; worked examples; safety precautions; bibliography; methods of leak location.
British standards	BS 4504-3.3:1989 Circular flanges for pipes, valves and fittings (PN designated). Specification for copper alloy and composite flanges	Types of flanges from PN 6 to PN 40 and in sizes up to DN 1800. Facings, dimensions tolerances, bolt sizes, marking and materials for bolting and flange materials with associated pressure/temperature ratings.
API	API 570 2nd Edition 1998 Piping Inspection Code	Covers inspection, repair, alteration, and rerating procedures for in-service metallic piping systems. Establishes requirements and guidelines that allow owner/users of piping systems to maintain the safety and mechanical integrity of systems after they have been placed into service. Intended for use by organizations that maintain or have access to an authorized inspection agency, repair organization, and technically qualified personnel. May be used, where practical, for any piping system. Piping inspectors are to be certified as stated in this inspection code.
API	API 510 - "Pressure Vessel Inspection Code: Maintenance Inspection, Rating, Repair, and Alteration"	Addresses the maintenance inspection, repair, alteration and re-rating procedures for pressure vessels used in the petroleum and chemical process industries.
API	API RP 572 - "Inspection of Pressure Vessels"	Addresses the inspection of pressure vessels. It includes a description of the various types of pressure vessels and the standards that can be used for their construction and maintenance.
API	API RP 574 - "Inspection Practices for Piping System Components, June 1998"	Addresses the inspection practices for piping, tubing, valves (other than control valves), and fitting used in petroleum refineries and chemical plants.
API	API RP 575 - "Inspection of Atmospheric and Low-Pressure Storage Tanks"	- Addresses the inspection of atmospheric storage tanks that have been designed to operate at pressures from atmospheric through 0.5 psig and inspection of low-pressure storage tanks that have been designed to operate at pressure above 0.5 psig but less than 15 psig.
Health and Safety Executive	Web site	http://www.hse.gov.uk/chemicals/spctechgen33.htm#App2

Table 5.2: Guidance for ATEX

<table>
<tr><th>Source</th><th>Name</th><th>Description</th></tr>
<tr><td>Energy Institute

(leading professional body for the energy industries)

http://www.energyinst.org.uk/index.cfm?PageID=1005#whatis</td><td>Model Code of Safe Practice Part 15:
Area Classification Code for Installations Handling Flammable Fluids</td><td>Model code of safe practice Part 15: The Area classification code for installations handling flammable fluids (EI 15, formerly referred to as IP 15) is a well-established, internationally accepted publication that provides methodologies for hazardous area classification around equipment storing or handling flammable fluids in the production, processing, distribution and retail sectors. It constitutes a sector-specific approach to achieving the hazardous area classification requirements for flammable fluids required in the UK by the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002 and in doing so, provides much more detail than BS EN 60079-10 Electrical apparatus for explosive gas atmospheres: Classification of hazardous areas. Note that the scope of EI 15 excludes hazardous area classification arising from dusts.</td></tr>
<tr><td>SHAPA

(SHAPA has been the UK's leading specialist association for the solids handling and processing industry since its formation in 1981)</td><td>Practical Guidance for Suppliers and Operators of Solids Handling Equipment for Potentially Explosive Dusts

Compliance with legislation implementing the ATEX Directives.

http://www.shapa.co.uk/atex.php</td><td>The purpose is to provide practical guidance to manufacturers, suppliers and operators, when manufacturing, installing and operating equipment or systems that may require compliance with standards under the ATEX Directives, particularly in dusty atmospheres. A brief description of the two relevant ATEX Directives is included, together with their purpose and scope.

Pdf document: http://www.shapa.co.uk/pdf/atex.pdf</td></tr>
<tr><td>Bundesministerium für Arbeit und Soziales (German Federal Ministry of Labour and Social Affairs)</td><td>TRBS 2152 "Gefährliche explosionsfähige Atmosphäre" (Technical Rules on hazardous explosive atmosphere)</td><td rowspan="2">TRBS 2152 (TRBS = Technische Regeln für Betriebssicherheit, Technical Rules on Workplace Safety) describe rules for protection against hazards from explosive atmospheres in the workplace. If these rules are followed, compliance with the German Regulations on Workplace Safety and Regulations on Hazardous Substances is assumed.
TRBS 2152 is referred to in BGR 104, which gives a comprehensive description of the formation and prevention of hazardous explosive atmospheres, on potential sources of ignition and their prevention, and on constructive measures to mitigate the effects of explosions. BGR 104 contains a detailed list of practical examples of ex-zones and safeguards, taking various factors (e.g. ventilation, source strength) into account.</td></tr>
<tr><td>DGUV (Deutsche Gesetzliche Unfallversicherung), (former HVBG)</td><td>BGR 104: Explosionsschutz-Regeln (EX-RL) – Regeln für das Vermeiden der Gefahren durch explosionsfähige Atmosphäre mit Beispielsammlung (explosion protection rules with practical examples)</td></tr>
<tr><td>European commission</td><td>Guidance on ATEX Directive 94/9/EC</td><td>http://ec.europa.eu/enterprise/atex/guide/index.htm

Harmonized guideline: http://ec.europa.eu/enterprise/atex/guide/atexguidelines_august2008.pdf</td></tr>
</table>

		Considerations PAPERS by the ATEX Standing Committee on How to apply the Directive: http://ec.europa.eu/enterprise/atex/standcomm.htm
European commission	Guidance on ATEX Directive 1999/92/EC	COMMUNICATION FROM THE COMMISSION concerning the non-binding guide of good practice for implementing Directive 1999/92/EC of the European Parliament and of the Council on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres: **http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0515:FIN:EN:PDF** [available in other languages, too; search http://eur-lex.europa.eu for COM(2003) 0515 document]
European standard	EN 1127-1 Explosive atmospheres - Explosion prevention and protection - Basic concepts and methodology	Explosive atmospheres, Fire risks, Explosions, Hazards, Classification systems, Ignition, Surfaces, Flames, Electric sparks, Gases, Particulate materials, Electrostatics, Electric current, Lightning, Electromagnetic radiation, High frequencies, Ignitability, Ionizing radiation, Ultrasonics, Chemical hazards, Design, Ventilation, Protected electrical equipment, Hazardous areas classification (for electrical equipment), Dust, Fire safety, Flame traps, Safety measures, Instructions for use, Marking, Hand tools, Control equipment, Electrical safety, Risk assessment
European standard	EN 60079-10 Electrical apparatus for explosive gas atmospheres Part 10: Classification of hazardous areas	The standards EN 60079-10 and EN 61241-10 explain the basic principles of area classification for gases and vapours and for dusts, respectively. These standards form a suitable basis for assessing the extent and type of zones, and can be used as a guide to complying with the national requirements towards explosion protection. However, they cannot give the extent and type of zone in any particular case, as site-specific factors should always be taken into account
European standard	EN 61241-10 Electrical apparatus for use in the presence of combustible dust - Classification of areas where combustible dusts are or may be present	

For the purpose of the Gasification Guide, the names of the European (EN) standards have been quoted, but the various national translations have been omitted, as the list would have become lengthy otherwise.

6 Documentation

6.1 *Operation and Maintenance manual*

- Technical process description of the main plant sections (as in chapter 2), including the process flow diagram (PID)
- Description of the automation and control strategy and process
- Main technical specifications
- Contact details of manufacturer
- Procedures for operation and maintenance
  - Start-up
  - Normal operation, including display and set-point overview
  - Unmanned operation
  - Shutdown
  - Emergency procedures
  - Check lists (inspection and maintenance tables: what to do, where and when)
  - Troubleshooting
  - Maintenance
- HSE instructions
  - Skills of operators
  - Description of hazards
  - During normal operation
  - During inspection and maintenance
  - During repairs or modifications

Most of this documentation has to be supplied by the manufacturer. For some documents – like the permit – the manufacturer has to supply information upon request. The operator and plant owner are responsible for keeping the information updated in case of modifications to the plant or changes in O&M procedures like adjustments of set-points, etc.

6.2 *Other documentation*

- Emergency procedures
  - Check lists (what to do, where and when)
  - Description of escape routes
  - Contact addresses in case of accident
- Accident register
- Spare parts lists
- Log book (if electronic it must have a safe back-up system)
- Training manual
- Detailed plant description (Design book)
  - Process description
  - PID of each main process step (unit operation)
  - List of components (I/O listing)
  - HAZOP analyses
  - Risk assessment analyses report
  - Arrangement drawings
- Component documentation and drawings
- Permits (building, environment, CE marking, etc.)

Table 5-3 shows which parts of the documentation have to be provided by the manufacturer and which parts are to be drafted by the operator/owner.

Table 5-3: Target group responsible for documentation

Document	***Manufacturer***	***Operator***
Operation and Maintenance Manual	*X*	
Training Manual	*X*	
Updating the O&M Manual		*X*
Description and map of escape routes		*X*
Detailed plant description (Design Book)	*X*	
Accident register		*X*
Logbook		*X*

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