Risk Solutions

Anaerobic digestion: plant operation risk management

A guide to loss prevention

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Anaerobic digestion plants may experience significant loss events during operation resulting from damage to operational equipment, structural collapse, fire, flood or theft. These events can often result in lengthy periods of process downtime, with a consequential loss of revenue, clean-up costs, risk of local pollution and a resulting drop in local community confidence and support for the project; which can be difficult to rebuild.

A guide to loss prevention

This overview document aims to provide a guide for those operating anaerobic digestion (AD) plants with a view to achieving a loss-free outcome to their commercial enterprise. This guide is not an A to Z of the entire operating and plant management process, but is designed to raise awareness of some of the key practical arrangements and working procedures that should be in place to mitigate the risk of loss or damage. Some examples of major loss events are included in this document to illustrate the risks that can be presented.

A list of the references used in this guide are located at the end of this document.

AD plants are complex process plants. They have many interconnected and interdependent safety and control features aimed at the safe and trouble-free operation of the plant, to avoid equipment damage, and to avoid injury to personnel.

It is essential that all plant operators, and those involved in its maintenance, fully understand the risks that are present on an AD plant, and why these safety and control features are provided. They need to be aware of the consequences of safety feature failures, incorrect plant operation and not following set procedures. Human error is often the root cause of many major loss or damage events.

The risks

The biogas produced by an AD plant consists primarily of the combustible gases methane (50-75%) and carbon dioxide (25-50%)[1]. At normal atmospheric conditions, the volume concentration of methane-in-air required to form an explosive mixture is between 5% Lower Explosive Limit (LEL) and 15% Upper Explosive Limit (UEL). Therefore, allowing air into the biogas containment or pipework to a concentration between 5-15% by volume of methane-in-air will result in an explosive mixture. This can be readily ignited by sparks from welding and maintenance operations, or even by static electricity discharge.

Hydrogen sulphide (H2S) is produced in some AD processes that use certain types of feedstock. Personnel exposed to H2S concentrations of greater than 50 parts per million can suffer long term physical injury and, at higher concentrations, even death. If not controlled or removed, H2S can also cause corrosion of steel pipework and vessels, as well as damage to the biogas engine.

AD plants hold large volumes of liquid digestate and animal waste in tanks which may be constructed of concrete or steel. A catastrophic failure of these tanks due to explosion, corrosion or over/under pressure will result in the release of the vessel contents and a resulting flood of digestate. If not otherwise contained, the digestate can flow onto neighbouring land, causing physical damage as well as environmental damage by polluting land and watercourses.

An experienced, competent plant manager and plant operating team can make all the difference to the safe and trouble-free operation of the plant.

Uncontrolled foaming of the digesters can result in operational disturbances due to the incorrect operation of pressure and level control sensors. Severe foaming could lead to the blockage or jamming of pressure and vacuum relief systems, and gas pipework may also become blocked if liquid is carried over by the foam.

The commissioning and maintenance of a biogas plant is a period when the plant is particularly at risk. During the draining of liquids from tanks, digesters and storage vessels, it is essential that air admission vents are opened before draining starts, so to prevent a vacuum developing in the tank or vessel. Tanks and vessels can implode if subjected to an internal vacuum. It should also be recognised that allowing air into a vessel containing biogas will result in the biogas passing through the LEL and UEL range at some point; creating the risk of a gas explosion. Draining and venting of vessels and tanks should be controlled by a written procedure which has been risk-assessed by a competent engineer.

Operating and maintenance team competence, experience and training

All members of the operations and maintenance team should be well-trained in operating and maintaining the plant, and be familiar with the risks and hazards presented by its processes.

Detailed training should be provided by the process designers and/or technology providers of the plant and should, ideally, include practical hands-on experience gained at an existing operational AD plant. This hands-on training should be supported by classroom-based instruction where the risks and hazards of running the plant can be discussed in depth.

Classroom training should also include discussions on how plant and equipment can be damaged, and how these circumstances can be avoided. Discussions should include how the operator should respond to deviations from normal operating conditions and any other unexpected events.

Site managers should maintain a training matrix which lists all of the skills and competency levels required by individuals, and records of those competency levels being achieved should also be kept. Operator training should remain an ongoing developmental process throughout the life of the plant.

Periodic refresher training is a good way to ensure continued competency of staff.

Operations and maintenance staff should be recruited based on their past experience gained in working on process plants, and they should have an aptitude for the type of tasks that they are expected to perform. This should include an ability to recognise, in advance, the possible consequences of their actions whilst operating and maintaining the plant.

It is not best practice to only have one or two highly-skilled and knowledgeable individuals, who are fully familiar with the process, to instruct the rest of the team with operations and maintenance duties. This is particularly important if those skilled individuals are not present on the site at all times.

Procedural and management controls

Risk and hazard assessment: To establish a safe system of work, as required by health and safety legislation, it is essential that the hazards and risks associated with every task required to operate and maintain the plant are assessed beforehand, and that a safe method of carrying out these tasks is developed.

Apart from keeping personnel safety in mind, as that remains the first priority, risk assessments need to consider protecting business continuity by assessing how the plant could be damaged, and what the resulting consequences would be for the business (e.g. complete loss of production, production downtime, financial losses due to equipment replacement or repair, etc).

Standard operating procedures (SOP): These should be written for every task by setting out how each task should be performed, what controls should be in place, and the risks and hazards that are present. SOPs should be internally audited regularly to ensure that they are still relevant and up to date.

Permit to work: Each AD plant should operate a documented permit to work (PTW) system, incorporating a lock-out-tag-out (LOTO) system; with plant isolations, draining, venting and purging carried out by senior authorised and competent persons.

AD plant management should ensure all service, contract and vendor personnel employed to undertake specific maintenance and inspection work are aware of the risks and hazards presented by carrying out their tasks at a particular AD plant. While they may be familiar with their 'own' equipment, they may not be fully aware of how it is specifically utilised in the AD process for a particular site; hence, they should never be allowed to work unsupervised. They should not be permitted to carry out plant isolations and/or issue their own PTW.

Hot work permit: A separate hot work PTW system should also be in place to control any work which may present a source of ignition taking place in potentially explosive biogas zones or near combustible materials; including buildings and certain types of thermal insulation.

A 60-minute fire watch, followed by fire monitoring (of up to three hours), is recommended. Precautionary measures prior to hot work should also be documented, along with the prohibition of hot work near combustible construction.

Fire prevention: Ignition by static electricity should also be considered. Portable flammable atmosphere testing equipment should be provided to confirm that the work area, system or vessel being worked on does not contain a flammable atmosphere, and has been safely vented and purged to air or inert gas atmosphere.

All staff employed on the site should receive training in fire prevention and first attack firefighting with portable fire extinguishers. They should also be trained to effectively use any other firefighting systems provided on the site.

Maintenance and inspection: A maintenance, inspection, testing and calibration schedule should be established for all plant items; including control systems and process safety devices. The inspection schedule should include annual testing of pressure and vacuum relief valves on the digesters, internal and external corrosion monitoring, and side wall thickness checks of steel digester tanks.

Contingency plans: Site management should prepare written disaster recovery and contingency plans to ensure a rapid and effective response to worst case scenario events. These events could typically include:

- failure of the outgoing power transformer or a biogas engine
- digester side wall rupture and major digestate release
- pollution of adjacent land
- a major fire or explosion on site
- uncontrolled biogas release
- severe weather

These plans should include immediate, medium and longer term responses to the worst case scenario events, and include the appropriate contact details for each circumstance.

Case study 1

During routine maintenance, an activated carbon filter used to remove hydrogen sulphide from biogas was left open to atmosphere overnight. The filter subsequently ignited, resulting in a major fire which spread to the building structure. The building structure included a large amount of timber. The engine room and electrical switch rooms suffered major damage as a result of the fire, which shut down the entire site.

The AD plant site was not normally manned overnight, but the process control system automatically sent plant alarm messages to an on-standby plant operator. The fire detection system was not linked to the plant control system and, thus, the plant operator was not made aware of the fire.

Lessons learned

The manufacturer's guidance manual for the activated carbon filters gave clear warning of the risks of spontaneous combustion when exposed to the atmosphere. This applied to both new and used carbon filter elements.

The contractor employed to maintain the filter was not aware of the risks associated with this type of filter, and had not read the manufacturer's safety guidance. The plant owners and operators were also unaware of the risks.

No risk assessment, method statement or safe system of work had been prepared for the maintenance task and the contractor had performed his own plant isolation. The task was not completed in the same working day and the filter body was left open overnight. A PTW should have been issued by the plant operators, and the filter should not have been left 'opened up' overnight without additional inspection at the end of each working day.

At unmanned sites, fire detection systems should be connected to the process control alarm system and to an off-site monitoring service or the local fire services.

Combustibles used in the construction of buildings adds considerably to the damage caused during a fire. This also applies to combustible thermal insulation materials (e.g. polystyrene) which are often used to insulate digester tanks. Once ignited, it is extremely difficult to extinguish combustible tank insulation due to the metal cladding usually used to provide mechanical protection.

Case study 2

During testing and commissioning at an AD plant, a storage tank was being prepared for hydrostatic testing to check for leaks and structural integrity. This involved filling the tank with water and purging the space at the top of the tank with nitrogen to allow pneumatic testing of the seals and roof space. This required all pressure and vacuum relief valves and the atmospheric vents to be isolated for the duration of the test.

The test was successfully completed and the tank depressurised, but commissioning of the tank was delayed for two weeks. During this time, the tank remained purged with nitrogen, with all of the relief valves and vents remaining isolated. External atmospheric variations and a decrease in air temperature caused a reduction in pressure within the tank, which lead to an implosion of the tank due to external atmospheric pressure.

Lessons learned

Despite the robust appearance of AD plant tanks and vessels, they are designed to withstand the internal pressure of liquids, but are not designed to withstand the external atmospheric pressure caused by an internal vacuum. Any action likely to reduce the pressure inside a tank below atmospheric must be prevented. Vacuum relief valves are provided for this specific purpose, but are of no use if isolated.

If a tank or vessel is being drained of liquid, particular care should be taken to ensure that, as the tank contents is drained out, a corresponding volume of air or inert gas is allowed to enter the remaining space to maintain atmospheric pressure inside the tank. This should be done by manually opening top-space vent valves rather than relying on vacuum relief valves; which may not be working correctly. Some form of internal pressure monitoring should be available throughout the drain-down process.

If the tank contains biogas, care should be taken that when allowing air to enter the tank, an explosive atmosphere is not created by mixing air with residual biogas. Before allowing air to enter, the tank should be purged to an inert atmosphere with nitrogen or carbon dioxide.

A clear written procedure for tank draining and venting should be in place which sets out all of the risks and hazards that are to be avoided.

Case study 3

A concrete digester tank cracked and collapsed, causing 500m3 of digestate to spill out. The digestate overwhelmed the combined heat and power (CHP) plant, putting it out of action for three months. The digestate tank took four months to rebuild, and a further two months to restart the process.

The failure was caused by fatigue of the concrete walls due to repeated over-pressurisation of the tank. The over-pressurisation occurred because pressure-sensing instrumentation had been incorrectly calibrated. Furthermore, unlike other tank designs, the tank was not fitted with pressure relief valves; therefore relying solely on sensors to control the pressure within the tank.

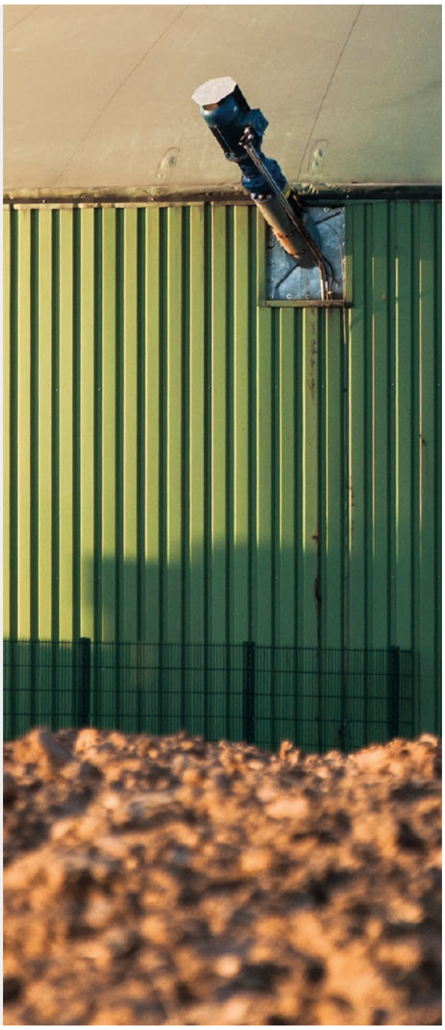
The resulting claim to rebuild the digester, repair the damage to the CHP plant and cover the loss of revenue while the plant was shut down was close to GBP £5 million.

Lessons learned

It is unusual for a digester tank to not be fitted with a pressure relief valve, as was the case here. The design philosophy for protecting AD plant tanks and vessels against over pressure (and under pressure) needs to be clearly understood to ensure safety. They should be designed with suitable pressure control and pressure relief devices, and pressure fluctuations in the digester should be carefully monitored.

If process control instrumentation is calibrated incorrectly, readings will be incorrect; no matter how precise the measurement is. Calibration and testing should be carried out by a competent person in accordance with the manufacturer's instructions and at recommended frequencies.

Operator training is vitally important so that operators are prepared to respond to deviations from normal plant operating conditions. In emergency cases, where the tank or vessel is subject to pressures outside of its design limitations, plant operators need to be well trained so that they are able to respond to alarms and take appropriate measures to prevent a situation from escalating out of control.



Preventing a major loss

The importance of human element programmes in loss control, such as operator training and management systems, were covered earlier in this document. The following guidance provide further points aimed at preventing a major loss incident at an AD plant.

Fire prevention

During the design phase of an AD plant, it is important to work with qualified fire protection system designers to address appropriate fire prevention measures. For example, incorporate safe separation distances, as much as feasible, between plant items which present a high fire hazard, and install automatic fire protection systems appropriate to the risk presented.

If the plant has a process for drying digestate solids using heat, a risk assessment of the process should be carried out to determine if the dried digestate could become combustible during drying and be ignited by the process or through an external heat source. If found to be the case, some form of automatic fire protection may be required to fight any resulting fire. Expert advice should be sought for designing adequate fire protection systems for the site. A leading, specialist insurer like HSB Engineering Insurance can provide advice and technical assistance to the plant designers and constructors.

Some feedstock materials have a potential for spontaneous combustion when stored in large piles or silos. Extinguishing a fire in large piles of combustible material can be very difficult, even for the fire services. Stock piles should be inspected daily for signs of smouldering, and action taken immediately to extinguish any smouldering areas. Ideally, fire hoses should be made available close to large stockpiles where a spontaneous ignition risk is present.

The local fire service and your insurer can be a valuable source of help and provide advice in avoiding or fighting a major fire in combustible stockpiles and silos.

Waste food is often used to supplement the feedstock, with the packaging removed during processing. If this packaging is then allowed to dry out in the storage bin or skip prior to removal from site, it may become combustible. Bins and skips of waste packaging should be removed from site as soon as they are filled, and should not be stored inside buildings. If there is a delay in removal from site, the bins or skips should be stored outside and away from any buildings or process equipment.

Smoking should be prohibited in all areas of the site, and any hot work on site should be controlled by a documented Hot Work Permit system; with a risk and hazard assessment carried out before starting each task.

Firefighting

The following highlights best practices for effective firefighting:

- Adequate portable firefighting equipment should always be available close at hand, and must be inspected and tested regularly by an approved servicing company.

- Any automatic firefighting systems must also be inspected and tested at least annually by an approved company.

- If there are no fire hydrants or a firewater ring main on the site, there should be an adequate source of water nearby that the fire services can access to fight a major fire.

- The fire services should be invited to visit the site to familiarise themselves with the plant, and be made aware of the hazards and risks present on the site.

- In the event of a fire, there should be a system in place to meet and guide the fire services to the fire; even when the site is unmanned. There should also be a system in place to give the fire services access to buildings, etc, during an emergency. There should be a designated person(s) who will adopt the role of major incident controller during a major incident.

Biogas explosion prevention

Biogas is explosive when mixed with air between the LEL and UEL limits. From design through to operational and maintenance stages of the AD plant, the Health and Safety Executive Dangerous Areas and Explosive Atmospheres Regulations – 2002[2] (DSEAR) and associated Approved Code of Practice L138[3] must be followed.

During maintenance and tank draining operations, there is a risk of air being admitted into the system; potentially resulting in an explosive mixture. A risk assessment should be carried out for any task which may lead to air being mixed with biogas.

All sources of ignition should be removed/relocated while working on hazardous zones at a biogas plant. As defined in DSEAR, hazardous zones are “any place in which an explosive atmosphere may occur in quantities such as to require special precautions to protect the safety of workers”.

All tanks, pipework and process equipment must be adequately earth-bonded to reduce static electricity build-up.

In enclosures and rooms where biogas may be present, all electrical equipment must be to ATEX[4] standard for potentially flammable or explosive atmospheres.

Vessel implosion/explosion prevention
A SOP must be in place to control the process of vessel drain-down to prevent a vacuum being formed inside the vessel.

Vacuum relief valves should be pressure tested and calibrated annually to ensure they are working correctly.

Pressure and temperature sensors must be correctly calibrated and regularly tested to prove correct operation.

Atmospheric vents must be kept clear of obstruction, such as digestate build-up, etc.

Operations and maintenance staff must be made aware of the risk of tank implosion and explosion, and the methods of avoiding this risk.

Vessels which cannot be readily shut down or drained for maintenance (e.g. digesters) should always be provided with spare relief valve capacity (e.g. a changeover valve to ensure that at least one out of two pressure/vacuum relief valves (PVRV) is always in service if one PVRV has to be removed for maintenance or testing).

The setting and operation of PVRVs should be tested at least annually by trained and competent personnel.

Some pressure relief systems employ a simple water-filled manometric loop on the digester tank top. If the water in the manometric loop freezes during cold weather, the pressure relief function is lost. Trace heating may be required, or possibly a liquid which does not freeze may be used.

Foaming of digester tanks can result in the obstruction of process sensors, pipework blockage and possible liquid carryover; which may damage process plant. The addition of anti-foaming agents to the digestate, as advised by the process designers, must not be ignored.

Prevention of malicious damage, theft or arson
The AD plant site should be securely fenced to prevent opportunistic intruders, thieves and arsonists.

As most AD plant sites are unmanned overnight, CCTV cameras should be installed and monitored by an external security agency, or by other suitable 24/7 monitoring systems.

An intruder entering the site at night should be detectable and an alarm raised. All doors and windows should be fitted with intruder detection and the system monitored by an external security agency when the site is unmanned. A system should be in place to respond to intruders during unmanned hours.

All buildings, vehicles and the main gates must be securely locked when the site is unmanned.

Site vehicles
Even when not in use, site vehicles, such as front loaders, forklifts, etc, can cause fires due to electrical faults. They should not be garaged in process buildings where a fire could spread to combustible material and/or damage process equipment.

Site vehicles parked overnight should be stored in a two-hour fire-resistant building and away from process plant.

During unmanned hours, site vehicles must be locked and immobilised, with keys held in a secure key safe inside the main buildings. Ideally, site vehicles should be fitted with tracking devices.

Dust explosion prevention
Dust explosions result from the ignition of dusty explosive atmospheres. A risk assessment should be carried out to consider the risk of dust explosion caused by the feedstock if it is a dry and dusty material type.

If the feedstock can generate a dusty explosive atmosphere, a programme of housekeeping specifically designed to remove dust accumulations on ledges, building structures and process equipment should be in place.

Note: the use of compressed air to blow dust off ledges, etc, itself produces a dangerous dust-laden atmosphere. Industrial vacuum cleaners are available and recommended for use as these are designed for applications in flammable or dusty atmospheres.

References and guidance

(1) The Practical Guide to AD (available at www.adbioresources.org)

(2) HSE: Dangerous Areas and Explosive Atmospheres Regulations 2002 (available from the HSE UK)

(3) HSE: Dangerous Substances and Explosive Atmospheres 2002 - Approved Code of Practice L138 (ISBN 9780717666164) (available from the HSE UK)

(4) Equipment for Potentially Explosive Atmospheres (ATEX) Directive 2014/34/EU (available at www.ec.europa.eu)

– Code of Practice for On-Farm Bio-Gas Production and Use (Piggeries) – 2013 by National Institute of Water and Atmospheric Research Ltd, New Zealand

– RC48 Risk Control 'Arson Prevention - The Protection of Premises from Deliberate Fire Raising' (available at www.stoparsonuk.org)

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