Environment Agency

How to comply with your environmental permit. Additional guidance for:

Anaerobic Digestion

Reference LIT 8737

Report version 1.0 and November 2013

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We operate at the place where environmental change has its greatest impact on people's lives. We reduce the risks to people and properties from flooding; make sure there is enough water for people and wildlife; protect and improve air, land and water quality and apply the environmental standards within which industry can operate.

Acting to reduce climate change and helping people and wildlife adapt to its consequences are at the heart of all that we do.

We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

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Forward; our guidance

This Sector Guidance Note is one of a series of three additional guidance notes for biowaste treatment installations and waste operations that require permits under the Environmental Permitting Regulations 2010 (EPR) and The Environmental Permitting (England and Wales) Amendment) Regulations 2013. It sets out, both for operators and regulators, indicative Best Available Techniques (BAT) or appropriate measures (environmental standards of operation) for the anaerobic digestion (AD) of biodegradable wastes. It specifically applies to facilities carrying out those anaerobic digestion and associated activities which require an environmental permit as waste operations or listed Part A(1) Schedule 1 installation activities under the EPR. Here after both installations and waste operations are referred to as anaerobic digestion (AD) facilities.

This Guidance has been produced by the Environment Agency. The guidance is supported by Natural Resources Wales (NRW), Northern Ireland Environment Agency (NIEA) and Scottish Environment Protection Agency (SEPA) - each referred to as “the Regulator” in this document. Its publication follows consultation with industry, Government departments and non-governmental organisations. This technical guidance document is targeted at anaerobic digestion operations. It is also targeted at AD operations carried out as part of Mechanical Biological Treatment (MBT) and Mechanical Heat Treatment (MHT) operations.

You should use this guidance in addition to the standards and measures described in the general guidance note ‘How to comply with your Environmental Permit’ (EPR 1.00) to demonstrate how you will meet the objectives of your permit. You may also need to consult the ‘horizontal’ guidance that gives in depth information on particular topics such as, emissions, odour or noise. They are listed in Part 3 of EPR 1.00

The structure of this guidance

The structure and contents of this guidance have been largely informed by the findings of the ‘Anaerobic Digestion Technical Guidance – Literature Review (2012)’. This review identifies current established technical standards for operating and controlling environmental and health impacts from different types of treatment processes. It is not a design guide, but does contain considerations for infrastructure design, commissioning, process control and maintenance, which we consider to be BAT. It is envisaged that this guidance will be revised within 12 months of publication or when further information becomes available.

Part 1: This provides and introduction to the role of permitting anaerobic digestion, the various rules that apply and the high level principles and standards expected. It also sets out the timeframes for new and existing plant and identifies the main issues associated with anaerobic digestion.

Part 2: Sets out the technical overview of the anaerobic digestion process. It explains in detail the biochemistry that takes place and defines the process parameters that are fundamental to achieving good operational control. Following the process as described will result in stable digestates and optimise biogas production in terms of both quantity and quality.

Part 3: Provides comprehensive guidance on ensuring the feedstock for the process is well characterised even before arrival on site. It details the verification, the handling and storage of feedstock on site to prevent process issues and environmental incidents.

Part 4: Details the design parameter of the digester systems. How to start-up the process, how to remove any contaminants and how to optimise the treatment of the various feedstock including mixing, heating and pasteurisation. Anyone thinking of designing a new system may want to look at this chapter first as it is a very useful guide on the fundamental design.

Part 5: Is concerned with biogas treatment essential for protecting the equipment used to obtain energy from the gas. This section also covers those occasions when biogas flaring may be needed in times of emergency or maintenance situations.

Part 6: Here there is plenty of information on biogas upgrading to biomethane which is all about increasing the calorific value as well as pressure needed for grid injection. This section will help operators in ensuring optimum energy is recovered from the plant

Part 7: Details not only digestate treatment and storage arrangements but also covers the main environmental considerations to prevent emissions from all the storage and processes taking place on site. There is an emphasis on the protection on groundwater and surface waters through the provision of secondary containment. Odour management and abatement and other amenity management techniques also feature strongly.

Part 8; Covers the essentials of what should be in a documented management system for the smooth operation of an anaerobic digester.

Part 9 & 10: We have highlighted the monitoring standards expected from the operation of anaerobic digesters and place an emphasis on the importance of obtaining good data. This goes hand in hand with assessing the environmental impact of the site on any nearby receptors such as habitat sites.

Link to permit conditions

EPR permit conditions describe the objectives (or outcomes) that we want you to achieve. They do not normally tell you how to achieve them. These conditions give you a degree of flexibility. This guidance indicates what we consider are appropriate measures. You may need to apply other higher environmental standards of operation or appropriate measures if the objectives of your permit condition are not being met.

This note may state measures which are mandatory because they are currently required by BREF for installations or they are legislative requirements.

Industrial Emissions Directive (IED) and BAT

The IED requires you to take all appropriate measures to **prevent** or, where this is not practical, to **minimise** emissions to the environment, in particular (but not solely) through applying best available techniques (BAT).

BAT requires that the techniques and measures employed provide an appropriate level of environmental protection taking into consideration the likely costs and environmental benefits of the measures and set in the context of what can be afforded in each sector. We cannot permit an installation where its operation would cause significant pollution.

This technical guidance has been developed to provide guidance on indicative environmental standards for both installations and waste operations. It includes the technical components, process control, and management of the activities. These will be applied unless departure (which may include stricter standards) can be justified for a particular activity. In addition it provides the benchmark levels for emissions. Departures from those benchmark levels can be justified at the site level by taking into account the technical characteristics of the process operation, its geographical location and the local environmental conditions.

If any mandatory EU emission limits or conditions are applicable, they must be met as a minimum.

Steps are required to be taken to prevent emissions - unless prevention is not practicable in which case they must be reduced. If it is economically and technically viable to reduce emissions further, or prevent them altogether, then this should be done. We are required to consider the environment as a whole and it’s not to be used as a recipient of pollutants and waste which can be filled up to a given level, instead all that is practicable should be done to minimise emissions and their impact. This approach first considers what emission prevention can reasonably be achieved and then checks to ensure that the local environmental conditions are secure.

Ultimately, the process will only be permitted to operate if it does not cause significant pollution.

We encourage the development and introduction of innovative techniques that advance indicative environmental standards, i.e. techniques which have been developed on a scale which reasonably allows implementation in the sector, which are technically and economically viable and which further reduce emissions and their impact on the environment as a whole. One of the main aims of the legislation is continuous improvement in the overall environmental performance as a part of progressive sustainable development.

BAT standards are usually based on an assessment throughout the European Union of the typical costs and environmental benefits of techniques and their viability within the sector as a whole. The EU BREF for biological treatment has not yet been developed. The standards in this guidance have been developed, drawing on existing agreed industry standards and peer reviewed literature, having regard to all relevant legal considerations, and following consultation.

Waste operations

We consider that the environmental standards set out in this guidance represent appropriate measures for waste operations under the Waste Framework Directive, as well as for installations under the IED. They may be applied, where necessary, in the development, delivery, operation and regulation of AD facilities where pollution is a risk or where pollution is ongoing or has been occurring.

The Industrial Emissions Directive (IED) extends the scope of the Directive on Integrated Pollution Prevention and Control (IPPC) to include treatment of more than 100 tonnes of non hazardous waste per day for recovery or a mix of recovery and disposal and 100 tonnes per day for disposal. This threshold value of 100 is reduced if there is more than just an anaerobic digestion operation taking place. If you are treating less than the threshold quantities described above the activity will be regulated as a waste operation. Clarity can be found in our 'Regulatory Guidance Note Number 2, understanding the meaning of regulated facility.' This guidance is directly applicable to AD facilities in England.

Key issues

Site location

Selecting an appropriate site location is fundamental for the delivery of a successful operational facility. This fact cannot be over emphasised. General concerns about odour and bio-aerosols from biological processing may require sites to be located away from sensitive receptors.

Digestion of wastes

Consistency of waste feed, sampling and monitoring during the digestion process, residence time and good agitation are some of the critical factors in managing the efficiency of the digestion process, maximising biogas and producing a fully stabilised digestate.

Poor design, the introduction of waste types without proper evaluation, and poor process control can severely reduce the efficiency of the digestion process and gas production.

Odour

The handling and processing of waste or any substance that is or may contain a volatile organic compound (VOC) or other substances which may contain sulphur may potentially lead to odour noticeable beyond the site boundary, even at concentrations that may be well below benchmark emission limit values.

Odours may arise from the waste reception and handling area, from open top tanks, from pressure relief valves, condensate handling and storage of the biogas. Failure to adequately inspect and maintain plant and equipment is a contributory cause to fugitive emissions.

AD facilities may produce odours as a result of normal operations and odours can become significant if there are local sensitive receptors. Recognising where the potential release of odorous compounds may arise is paramount in order to design such releases out or manage and minimise odours from the site.

Loss of containment

Loss of containment can give rise to contamination of groundwater, boreholes, streams and other water bodies as well as give rise to odour. Losses can arise from poor handling of material, overfilling tanks, foaming events and failure of equipment. Tank failure may arise through corrosion and other extreme events such as agitators breaking from their housing and puncturing the tank. All foreseeable events should be planned for and secondary containment is usually required to prevent pollution. For small and micro AD facilities (falling within the exempt scale of EPR) where there are no direct pathways to water bodies then alternative protection measures to secondary containment may be acceptable however consultation with the local Environment Agency office is recommended.

Releases to air

Apart from fugitive releases of odorous compounds, burning of biogas in gas engines will give rise to releases to air. Releases of oxides of nitrogen and sulphur are of particular interest. An adequate stack height, release temperature and velocity will give good dispersion characteristics, which will ensure that the impact is usually acceptable. Care should be taken however to ensure designated ‘Air Quality Management Zones’ are avoided.

We do not support routine flaring of biogas. Auxiliary flares should only be used during plant maintenance or to safeguard the plant.

Systems and procedures

We require the operation of an environmental management system. An operator with such a system will not only find it easier to meet good environmental standards for management of the AD process but also many of the technical/regulatory requirements listed in this guidance. What your management system needs to contain depends on the risk your site poses to the environment, the size of your site, the waste types digested and therefore the complexity of your process. Your management system must identify these risks and the measures you will take to prevent or minimise those risks from your site and not cause pollution.

Executive summary

The Anaerobic Digestion Technical Guidance is based on established practical and reliable evidence, and is intended to provide advice and guidance to a wide range of stakeholders. The principal audience are operators of existing and developers of new Anaerobic Digestion facilities. The Environment Agency's regulatory staff will use this guidance as a framework for assessing new developments and current operations when assessing compliance with permitted activities. This guidance will be revised as EU Best Available Techniques (BAT) reference documents (BREF documents) are developed. It is the hoped that together with industry we can stimulate and encourage best practice across the UK.

Contents

Introduction

1.1. Understanding Best Available Techniques and Appropriate Measures

BAT requires that the techniques and measures employed provide an appropriate level of environmental protection taking into consideration the likely costs and environmental benefits of the measures and set in the context of what can be afforded in each sector. We cannot permit an AD installation or a waste operation where its operation would cause risk of significant pollution.

When considering what measures are appropriate for a waste operation, the same considerations apply. Practically, there is little difference between measures that are indicative environmental standards of operation and measures required by BAT. We refer to these collectively as appropriate measures in this document.

This technical guidance has been developed to provide guidance on indicative environmental standards for both installations and waste operations. It includes the technical components, process control and management of the activities. These will be applied unless departure (which may include stricter standards) can be justified for a particular activity and will take into considerations site specifics. The document is produced by the Environment Agency England and on behalf of Natural Resources Wales.

Departures from those benchmark levels can be justified at the site level by taking into account the technical characteristics of the process operation, its geographical location and the local environmental conditions. If any mandatory EU emission limits or conditions are applicable, they must be met as a minimum.

We are required to consider the environment as a recipient of pollutants and operators are required to do all that is practicable to minimise emissions and their impact. Steps are required to be taken to **prevent emissions** - unless prevention is not practicable in which case they must be **minimised**. If it is economically and technically viable to reduce emissions further, or prevent them altogether, then this should be done. This approach first considers what emission prevention can reasonably be achieved and then checks to ensure that the local environmental conditions are secure.

The Regulations allow for expenditure beyond indicative BAT and appropriate measures where necessary – if for example an environmental quality standard is threatened. Ultimately, the process will only be permitted to operate if it will not cause significant pollution.

We encourage the development and introduction of innovative techniques that advance indicative environmental standards, i.e. techniques which have been developed on a scale which reasonably allows implementation in the sector, which are technically and economically viable and which further reduce emissions and their impact on the environment as a whole. One of the main aims of the legislation is continuous improvement in the overall environmental performance as a part of progressive sustainable development.

Where AD is permitted as an installation, EPR will deliver the requirements of Industrial Emissions Directive (IED). Under the IED all appropriate preventative measures **must** be taken to protect against pollution, in particular best available techniques (BAT) must be used and no significant pollution must be caused.

Where they are available, the European BAT reference documents (BREFs) set out conclusions on what constitutes BAT for the sector concerned and the emission levels associated with their use. The current BREF on waste treatment also applies to AD however, this document will be reviewed as work progresses towards a revised BREF for waste treatment, due to be published in 2016. You should ensure you are working with the most recent version of this guidance, it provides our current view on indicative BAT.

Where AD is permitted as a waste operation, appropriate measures will need to be taken to avoid the risk of harm to human health or the environment based on consideration for site-specific locations.

1.2. AD regulatory context

1.2.1. European Regulatory Context

The majority of environmental regulation in the UK is driven by the requirements of European legislation. European Directives are transposed into National legislation through Acts of Parliament and associated Statutory Instruments which are enforced accordingly. In England and Wales, the key European Directives that underpin UK legislation with respect to the regulation of the Anaerobic Digestion of wastes are as follows:

The Revised Waste Framework Directive (2008/98/EC): Established the waste hierarchy and set targets that prioritised recycling over recovery. This Directive and preceding Waste framework directives also require a system of permitting and regulation of facilities that manage the disposal and/or recovery of wastes.

The EU Landfill Directive (1999/31/EC): The Landfill Directive defines technical standards for the disposal of waste and sets targets for the reduction of biodegradable municipal waste disposal to land. These targets are the primary driver for initiatives on biodegradable municipal waste treatment as they require increasing diversion of biodegradable municipal waste from landfill when measured against a 1995 baseline at specific dates. The upper limit demands 75% diversion of biodegradable municipal waste by 2020. This Directive has been one of the key drivers for the development of alternative waste management operations to landfill, including AD.

The Industrial Emissions Directive (2010/75/EU): Combined seven existing directives (including the Integrated Pollution Prevention and Control Directive) into one Directive. Some larger scale waste recovery facilities (those with a treatment capacity exceeding 100 tonnes per day) will be regulated (via their Environmental Permit) under the requirements of this Directive.

The EU Animal By-Product Regulation (EC) No. 1069/2009: The regulations include sanitary requirements for the handling and treatment in an AD plant of waste containing animal by-products. This includes food waste from commercial and household sources. The nature of the sanitary requirements can influence the suitability of feedstock or processes at AD sites.

1.2.2. The UK regulatory requirements

The regulation of AD activities which involve waste materials is undertaken by both Local Authorities, via the planning regime and statutory nuisance, and, in England by the Environment Agency, and by Natural Resource Wales (NRW) in Wales, through the Environmental Permitting regime (in Scotland this role is undertaken by the Scottish Environment Protection Agency, in Northern Ireland by the Northern Ireland Environment Agency).

Further regulatory controls can be applied by Animal Health (should the AD process involve any wastes covered by The Animal By-Products (Enforcement) (England) Regulations 2011) or, in

Wales, The Animal By-Products (Enforcement) (Wales) Regulations 2011) and the Health and Safety Executive.

The main purpose of this section of the document is to provide guidance on our current regulatory requirements in England and Wales, however information is also provided concerning the requirements of other regulatory bodies where there is an overlap or they integrate with our regulatory requirements.

This section of the guidance primarily applies to the AD of materials consisting of or including wastes. The Government has provided guidance on the meaning of waste in the Waste Framework Directive in Chapter 3 of its Environmental Permitting Guidance "The Waste Framework Directive" (see links in Appendix D).

Whilst all the regulatory information within this document is correct at the time of publication, it is recommended that anyone wishing to develop and operate an AD facility should check whether there have been any applicable new regulatory requirements applied since publication. Information on any such changes should be available by reference to the Statute Law database (see links in Appendix D.

1.2.3. Environmental permitting for AD facilities in England and Wales

The following section provides an overview of environmental permitting (EP) in England and Wales and how it applies to AD operations. Additional information can be found in the Environmental Permitting section of our website (see links in Appendix D).

In England and Wales, the permitting requirements and standards of the revised Waste Framework Directive (WFD) and the Industrial Emissions Directive (IED) are applied by the Environmental Permitting (England and Wales) Regulations 2010 (EPR 2010) and their associated amendments (The Environmental Permitting (England and Wales) (Amendment) Regulations 2011 and The Environmental Permitting (England and Wales) (Amendment) Regulations 2012) and The Environmental Permitting (England and Wales) (Amendment) Regulations 2013.

The EP regulations define AD as: "The mesophilic and thermophilic biological decomposition and stabilisation of biodegradable waste which (a) is carried on under controlled anaerobic conditions, and (b) results in stable sanitised material that can be applied to land for the benefit of agriculture or to improve the soil structure or nutrients in land."

AD facilities in England and Wales that process waste materials or burn biogas above the specified threshold will require an environmental permit issued under the Environmental Permitting (England and Wales) Regulations 2010 (as amended). These permits are issued and regulated by the Environment Agency in England and NRW in Wales. It is necessary to apply for and obtain an environmental permit from the regulator before operations commence. The application will either be for a *waste operation* in accordance with the requirements of the revised Waste Framework Directive (rWFD) or as an *installation* in accordance with the requirements of the Industrial Emissions Directive (IED).

In accordance with the EPR, AD facilities currently require planning permission before an environmental permit can be issued.

In order for an environmental permit to be granted, the regulator must be satisfied that the activity will be operated in a manner so as to prevent pollution of the environment and harm to human health. The permit conditions indicate what needs to be done to prevent different types of pollution, e.g. odour pollution will be assessed differently from groundwater pollution. Guidance document "How to Comply with your Environmental Permit" provides more information; this is available from the environmental permitting section of our website (see links in Appendix D).

For waste operations permitted under the WFD, operators are required to demonstrate that they will take all appropriate measures to minimise and prevent unacceptable pollution of the environment and harm to human health. This includes offence to senses and loss of amenity.

For AD installations permitted under the IED, operators must demonstrate that their activities satisfy the criteria of Best Available Techniques (BAT), providing an assessment and justification of their proposals against this sector technical guidance note (SGN) and BAT Reference Standards (BREF).

A table summarising the main authorisations that are likely to be applicable for AD processes at the time of writing can be found at Appendix B.

Further information and guidance on what type of permit a proposed AD facility may require can be found at the environmental permitting section of our website.

This provides details of all current exemptions and standard rules permits, plus guidance on how to make an application for an environmental permit.

1.2.4. Exemptions from requiring an environmental permit

Exemptions have a simple registration process, do not attract a fixed fee and last for three years. There are a range of criteria that must be satisfied in order for an activity to be able to operate under an exemption, including restrictions that are associated with the location, waste types and quantities. Any AD facility that registers for an exemption must meet all the requirements in full. Otherwise a permit is required.

Operators should be aware that the types of exemptions and the criteria that apply to exemptions, can be changed or new ones added. To check on the current position with regard to available exemptions for AD facilities, and to find guidance on how to register an exemption please refer to the waste exemptions page of our website (see links in Appendix D).

1.2.5. Standard rules permits

Standard rules environmental permits (SRPs) are available where the size/scale, location and types of operation are such that the Environment Agency has determined that the level of environmental risk from the operation is suitable for control by such an environmental permit. They have a simpler application process than bespoke environmental permits applications and also attract a lower fixed application fee and subsistence charges.

There are a range of criteria that must be continually satisfied in order for an activity to be able to operate under a SRP, including restrictions that are associated with the location, waste types and quantities. If all the standard rules cannot be met, a bespoke permit is required.

Operators should be aware that the criteria for permits can be changed or new ones added. To check on the current position with regard to SRPs for AD facilities, please go to the standard permits page of our website (see links in Appendix D).

Guidance on applying for a SRP can be found in the Environmental Permitting section of our website.

1.2.6. Bespoke Permits

Where an AD facility does not meet the criteria for an exemption or an SRP, then a bespoke environmental permit (also known as a Tier 3 permit) will be required. Applications for bespoke environmental permits require a significant amount of additional and supporting information to be provided in comparison to an SRP and specialist assistance may be required to produce some of the required information. Guidance on applying for a bespoke permit can be found in the environmental permitting section of our website (see links in Appendix D).

We have produced a number of horizontal guidance documents, the purpose of which is to provide information relevant to all sectors regulated under the Environmental Permitting Regulations (EPR), for example, noise, odour, energy efficiency, and protection of land. These are available on our website (see links in Appendix D).

An understanding of the areas which are controlled under the EPR and the requirements to comply is strongly recommended prior to proceeding with initial site design as it may inform the process. Please refer to Section 3 for further information.

One of the key elements of a bespoke Environmental Permit application is the requirement to undertake and submit environmental risk assessments to support the application. Risk assessments should be undertaken in accordance with the H1 process.

Information on the requirements for a bespoke Environmental Permit application can be found on our website (see links in Appendix D).

1.2.7. Energy crops

Any crop which is grown specifically for use as a fuel for heat, combined heat and power (CHP) or power generation is not a waste. Digestion in an AD plant, to produce energy, meets this requirement. If the main purpose of the plant is to recover energy from biogas, the biogas will also always be a non-waste. In order to be considered as non-waste, other output material must meet three criteria;

- certain to be used
- without any prior processing and,
- be part of a continuing process of production (i.e. this does not apply to wastes produced as an incidental part of the operation, for example clean down wastes).

In these circumstances a permit or exemption is not required for the AD process.

Crops grown for food and other purposes but are diverted to an AD facility, for example there is a crop surplus, they become spoiled or there is a failure to move them off-farm in time, are considered waste and therefore must go to a permitted site.

1.2.8. Animal By-Product (ABP) Compliance

If there is a requirement for a site to comply with ABP guidance, the operator must keep records of any animal by-product or food waste that is delivered to site. This must include the following information:

- The date of delivery
- The quantity and description of material
- The name of the haulier and
- For food waste only, details of how meat was kept separate at the source.

The supervisor should keep records of the dates of treatment, quantity treated, a description of the material treated, the results of any checks completed and the inclusion of sufficient information that shows material has been treated within the correct quality parameters. Details of the movement of material off-site must also be recorded and retained for a period of at least two years.

Further information regarding the ABPR approval process can be found on the Animal Health and Veterinary Laboratories Agency website (see links in Appendix D).

1.2.9. Applying for an environmental permit

It is strongly recommended that operators contact us to undertake a pre-application discussion with the Area Environment Management Team regarding the location and operation of a proposed AD facility. They will be able to provide advice on the type of permit that should be applied for, the application process and any relevant local environmental issues that may affect the application. Advice can also be sought from our National Permitting Service. It should be noted that there is a maximum 15 hour limit for free advice (one hour for standard rules permits), following which, charges may apply. Although operators are not obliged to undertake pre-application meetings if these are not carried out it can result in delays to the permitting application process or even refusal where all the considerations of the proposed site and activity have not been taken into account.

1.3. Timescales

1.3.1. Permit review periods

Permits are likely to be reviewed as follows:

- for individual activities not previously subject to regulation under EPR or waste management licensing, a review should be carried out within four years of the issue of the EPR permit
- for individual activities previously subject to regulation under EPR or waste management licensing, a review should be carried out within six years of the issue of the EPR permit.

However, where discharges to groundwater of hazardous substances and non-hazardous pollutants have been permitted, or where there is disposal of any matter that might lead to a discharge of hazardous substances and non-hazardous pollutants, a review must be carried out within six years as a requirement of the Environmental Permitting (England and Wales) Regulations (EPR, 2010). (See Section 7.8 Point source discharges to groundwater).

These periods will be kept under review and, if any of the above factors change significantly, they may be shortened or extended.

1.3.2. Upgrading timescales for existing plant

Unless subject to specific conditions elsewhere in the permit, upgrading timescales will be set in the improvement programme of the permit, having regard to the criteria for improvements in the following two categories:

1. Standard “good-practice” requirements, such as, management systems, waste, water and energy audits, bunding, measures to prevent fugitive or accidental emissions, good waste handling facilities, and adequate monitoring equipment. Many of these require relatively modest capital expenditure and so, with studies aimed at improving environmental performance, they should be implemented as soon as possible.
2. Larger, more capital-intensive improvements, such as major changes to reaction systems or the installation of significant abatement equipment. Ideally these improvements should also be completed within 3 years of permit issue, particularly where there is considerable divergence from relevant indicative BAT standards, but where justified in objective terms, longer time-scales may be allowed by the regulator.

Local environmental impacts may require action to be taken more quickly than the indicative timescales above and requirements still outstanding from any upgrading programme in a previous permit should be completed to the original time-scale or sooner. Where an activity already operates to a standard that is close to an indicative requirement a more extended time-scale may be acceptable.

Unless there are statutory deadlines for compliance with national or international requirements, the requirement by the regulator for capital expenditure on improvements and the rate at which those improvements have to be made, should be proportionate to the divergence of the AD facility from indicative standards and to the environmental benefits that will be gained.

The Operator should include in the application a proposed programme in which all identified improvements (and rectification of clear deficiencies) are undertaken at the earliest practicable opportunities. The regulator will assess BAT for the AD facility and the improvements that need to be made, compare them with the operator's proposals, and then set appropriate Improvement conditions in the permit.

Technical overview of AD process

2.1. General principles and definitions

The Anaerobic Digestion (AD) process has been defined as "a natural process in which microorganisms break down organic matter, in the absence of oxygen, into biogas [a mixture of carbon dioxide (CO_2) and methane (CH_4)] and digestate (a nitrogen-rich fertiliser). The biogas can be used directly in engines for Combined Heat and Power (CHP), burned to produce heat, or cleaned and used in the same way as natural gas or as a vehicle fuel. The digestate can be used as a renewable fertiliser or soil conditioner."

The AD process is used for the stabilisation of organic matter within high organic strength waste waters (as defined by their biochemical or chemical oxygen demand; BOD, COD) and for the digestion of organic sludge generated from the treatment of municipal wastewater. Sludge digestion at sewage treatment works has been practised and researched for over a century and as such the understanding of the basic microbiological processes is well developed. AD's use as a technique for treating solid biowastes is more recent, although the basic ecology and degradation processes are the same, with the bacterial action occurring within the aqueous phase irrespective of whether the process is referred to as a high solids or low solid/aqueous process.

Feedstocks for AD have traditionally included sewage sludges and industrial waste waters. More recently government policies to reduce Biodegradable Municipal Waste (BMW) sent to landfill and the anaerobic digestion action plan have resulted in the technique being applied to the treatment of household food wastes. The Government Waste Strategy in 2011 (Government Review of Waste Policy in England, Defra 2011) also identified Commercial and Industrial (C&I) wastes for improved recycling. This includes organic material that may contain meat products.

Typical feedstocks include:

- Sewage and wastewater sludge,
- Organic fraction of MSW,
- Commercial and Industrial organic waste,
- Livestock farming wastes,

- Agricultural plant wastes, and
- Energy Crops.

Additionally co-digestion has been applied to mixtures of these waste streams. Properties and definitions for each these feedstocks are provided in the Glossary (Appendix E). The table below shows indicative biogas potential of examples of each feedstock which will vary the complexity of interacting factors that will determine the actual biogas production.

Feedstock type	Dry Matter (DM)	Volatile solids % of DM	,Biogas, m³/tTS	Biogas, m³/tVS	Biogas, m³/t fresh weight
Dairy cattle slurry	9%	80%	300	375	22
Beef cattle slurry	9%	80%	300	375	22
Pig slurry	5%	90%	600	667	26
Poultry/layers	30%	75%	490	653	110
Poultry broilers	65%	75%	490	653	239
Sugar beet waste	18%	80%	560	700	81
Wheat silage	38%	94%	540	574	193
Maize silage	30%	94%	523	556	148
Grass silage	21%	88%	600	682	111
Vegetables	20%	90%	560	622	101
C&I food wastes	23%	90%	500	556	104
H-H food waste	23%	90%	500	556	104
Garden waste	35%	80%	540	675	151

TS = total solids; assumes biogas = 65% CH_4, 35% CO_2

Table 1 Feedstock and Biogas potential for Anaerobic Digestion (source: AEA-ADAS, 2011)

The configuration and design of an AD process will vary with the feedstocks that are to be processed. It is imperative that any new waste streams are properly evaluated before they are added to a digester. Different types of feedstock material will have a range of physical and chemical characteristics. However despite these different configurations the microbial processes within AD reactors are broadly similar.

AD systems for solid wastes can be classified in a number of different ways, these include;

- By the solids content of the feedstock material
- By the temperature of digestion
- By the loading procedure or waste flow regime within the process (continuous flow or batch processing)
- By the number of digestion stages used in the system.

The classification of AD processes based on solids content is commonly used and it provides a distinction between the type of AD design and the treatment of different kinds of feedstock material.

For example, types of AD process optimised for the digestion of industrial effluents and waste water may not be suitable for the treatment of food waste which has a much higher solids content.

Figure 1 provides an overview of the classification of AD processes based on the solids content of the feedstock material.

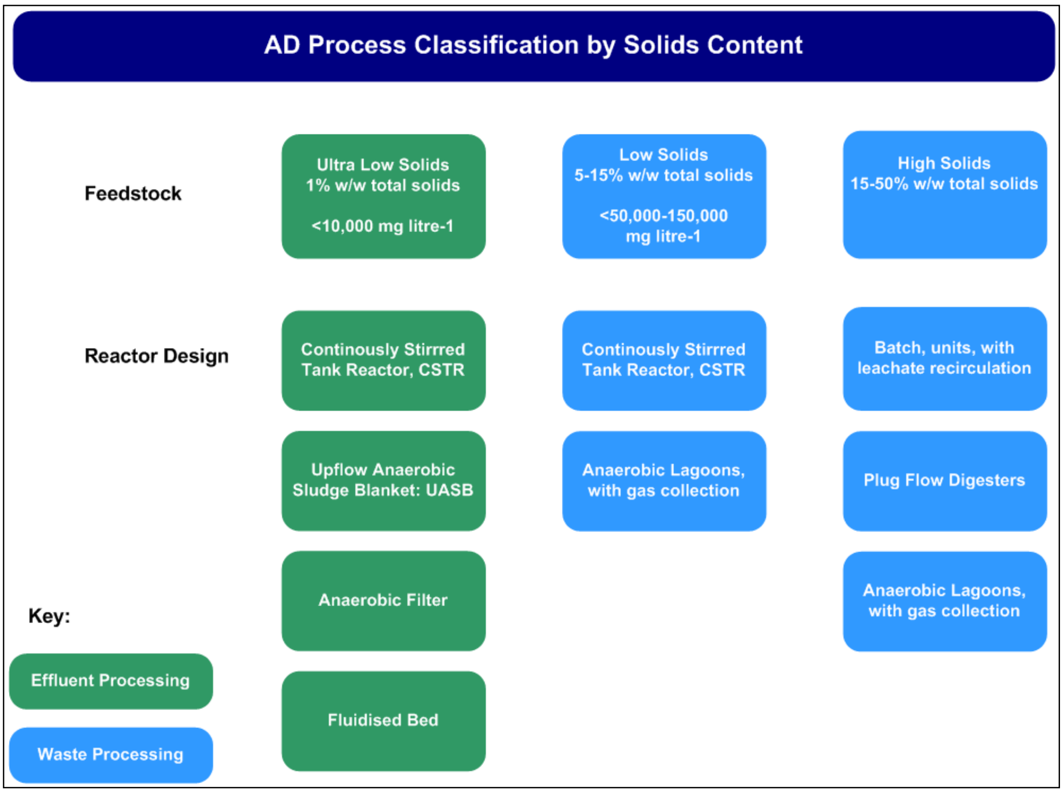


Figure 1 AD Process Classification by Solids Content (N.B. Coloured key)

Ultra low solids feedstocks are industrial effluents with high dissolved organic carbon content and are often treated at or near the point of generation. The classification is broad and practically most effluents will have solids content of less than 10,000 mg litre^{-1}.

A wide range of industries produce wastewaters amenable to AD processing including those from food and drink preparation, processing of organic chemicals, and pharmaceutical and fermentation industries.

A range of reactor designs are available for the treatment of ultra low solids effluents and these systems operate at hydraulic residence times which are much lower than those used in the treatment of low solids and high solids biowastes, however biomass is kept in the system by separation and recycling for continuously stirred tank reactors (CSTR) or integrated separation in the form of an upflow anaerobic sludge blanket (UASB) in a suspended biomass layer. As effluent treatment processes, these reactor designs are not considered in detail in this guidance. However, many topics covered in this document apply to all three types of processes. There are also instances of system designs where ultra low solids effluent treatment is applied to liquors produced from high solids AD systems. Within biowaste processing, low solids processes may also be referred to as “wet” processes and high solids processes as “dry” processes.

The further classification of AD systems is based on the temperature of digestion, feeding or loading regime and the number of digestion stages. These represent a form of optimal AD plant to match the intended application whilst taking into consideration any operational or economic factors. The separate classifications are not mutually exclusive; for instance a low solids digester may be designed to operate at mesophilic temperatures, with a continuous loading regime, using a single stage digester design.

Consideration of the optimal digester design requires an understanding of the microbiological pathways and processes involved in anaerobic digestion which may vary with feedstock characteristics. Section 2.2 below introduces the different stages of microbial activity that are required to achieve efficient digestion of feedstock.

2.2. Key stages of the biological process

This section illustrates the biological processes that occur during the anaerobic digestion of feedstock once it has been fed into the reactor. An understanding of the processes and their requirements will allow operators to optimise the production of biogas and the stabilisation of organic wastes. In addition to these stages there will also be requirements for pre-sorting of waste feeds, pre-treatment (cutting/mixing) of waste feeds, treatment (drying, sulphur control) of biogas and any processing of digestate and these are discussed in Sections 3 to 7.

The microbial consortia responsible for AD comprise several groups and each performs a specific function in the digestion process. Together they achieve the conversion of organic matter into biogas through a sequence of stages. The main stages within an AD process are:

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

The key stages are shown in Figure 2.

During the initial stages, short chain Volatile Fatty Acids (VFA) are generated. The final stage is methanogenesis (methane formation) where intermediate compounds such as acetic acid and hydrogen are converted to methane and carbon dioxide. The specific bacteria within a process will reflect the innoculum used in “seeding” the reactor during the early stages of operation and will adapt according to the feedstock being processed.

Some microbial groups can function within environments that are both aerobic and anaerobic (referred to as facultative anaerobic microorganisms). However the key stages of AD, particularly methanogenesis, are performed by strict anaerobes which are capable of functioning in an environment characterised by a low redox potential. Oxygen is effectively toxic to these strict anaerobes. This can be an issue when, for example, inspection lids are lifted during maintenance operations.

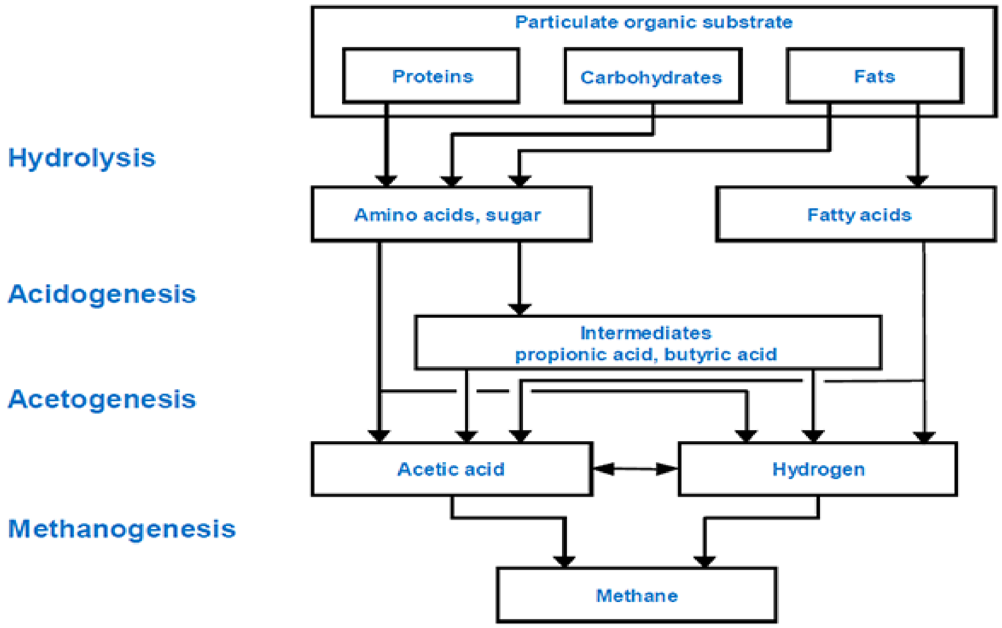


Figure 2 Key Stages of Anaerobic Digestion

The energy within the feedstock is largely transferred to the biogas which consequently has value as a fuel. A very small quantity of the organic feedstock will be transformed in to microbial biomass (i.e. new bacteria). This is approximately 10% of that observed in aerobic systems. Overall the digestion process brings about a reduction in the amount of solid residue. Depending on the operating temperature and ambient temperature, there is often a need to provide heat to the digester to maintain it at an optimal temperature. This is why lagging of the digester improves overall energy efficiency of the process.

The stages are introduced below using a carbohydrate feedstock to illustrate the principles of the process. As organic material undergoes anaerobic degradation the exact mix of intermediates formed will depend upon factors such as the chemical characteristics of the feedstock, operating parameters, and the micro-organisms contained within the process. In general, as the carbon content within the feedstock increases so does its energy content.

When compared to lower energy feedstock, higher energy feedstock will yield higher gas volumes and biogas with a higher methane content for the same degree of anaerobic stabilisation. The theoretical relationship between C, H,O,N and S content in feedstock and the quality of biogas has been understood since the 1950s and was defined by Buswell (1952). When applied, it shows palmitic acid ($C_{16}H_{32}O_2$ - the fatty acid released from the hydrolysis of palm oil) will yield a biogas with 72% methane compared to 50% from glucose ($C_6H_6O_6$). It should also yield 2.5 times the amount of methane per g of feedstock stabilised. Many mass transfer factors moderate this theoretical example in full scale plants. Principally sugars are more available and more readily degraded than fats which allows the rate of stabilisation to be higher. However the general principle holds that different feedstock will yield differing volumes and composition of biogas and this needs to be understood prior to full scale design.

2.2.1. Hydrolysis

During hydrolysis, bacteria and saprophytic microorganisms transform the particulate organic substrate into liquefied monomers and polymers, i.e. proteins, carbohydrates and fats are transformed to amino acids, monosaccharides and fatty acids respectively. For some feedstocks, including fats and complex carbohydrates, hydrolysis may be the rate limiting step. This may reflect particle size, micro-biological growth and poorly soluble materials in the feedstock that need to enter solution to be hydrolysed. Examples of poorly soluble material are hard fats or cellulose, which although degradable are not readily soluble in water and are only slowly hydrolysed by extracellular enzymes. Depending on the feedstock this may be addressed by inclusion of a primary hydrolytic reactor in the design and is covered later under pre-treatment. This is a good example of why the type of feedstock impacts on AD design.

Equation 1 shows an example of a hydrolysis reaction where organic waste is broken down into a simple sugar, in this case glucose. Similar reactions occur to degrade proteins into their constituent amino acids and fats into long chain fatty acids and glycerol. Not all hydrolytic microorganisms are strict anaerobes.

Equation 1: $[C_6H_{10}O_4]n + 2nH_2O \rightarrow n[C_6H_{12}O_6] + nH_2$

2.2.2. Acidogenesis

In the second stage, acidogenic bacteria transform the products of the first reaction into short and long chain VFAs, ketones, alcohols, hydrogen and carbon dioxide. The principal acidogenesis stage products are propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), acetic acid (CH_3COOH), formic acid ($HCOOH$), lactic acid ($C_3H_6O_3$), ethanol (C_2H_5OH) and methanol (CH_3OH).

Other intermediates arise e.g. succinic acid from the degradation of unsaturated feedstocks (e.g. unsaturated fats), and inorganic elements which are mineralised. The exact mix of intermediates will depend on many factors including the source of the original innoculum and makeup of the microbiological consortia. From these products, the hydrogen, carbon dioxide and acetic acid will skip the third stage, acetogenesis, and be utilised directly by the methanogenic bacteria in the final stage (see Figure 2 Key Stages of Anaerobic Digestion

Equations 2, 3 (Ostrem, 2004) and 4 (Bilitewski et al. 1997) represent three typical acidogenic reactions, where glucose is converted to ethanol, propionate and acetic acid, respectively.

Equation 2: $C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$

Equation 3: $C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$

Equation 4: $C_6H_{12}O_6 \rightarrow 3CH_3COOH$

2.2.3. Acetogenesis

A critical process step as the precursor for methane formations where propionic, butyric and higher chain acids and alcohols are transformed by acetogenic bacteria into hydrogen, carbon dioxide and acetic acid (Figure 2).

Hydrogen plays an important intermediary role in this process, as the reaction will only occur if the hydrogen partial pressure is low enough to thermodynamically allow the conversion of all the acids. Such lowering of the partial pressure is carried out by hydrogen scavenging methanogenic bacteria (hydrogenotrophs). Thus the low hydrogen concentration of a digester is an indicator of its health and hydrogen only appears as a trace component of biogas in AD plants.

Hydrogenotrophs are pH sensitive and where conditions within the digester result in a drop in pH (for example through the introduction of an inhibitory material, or sudden increase in loading) the ecology will respond by storing hydrogen within propionic acid in a reversal of the reaction shown in Equation 3.

As observing partial pressure of hydrogen is technically challenging, monitoring the propionic: acetate ratio is a means of forecasting digester problems. A ratio of not >1 is used as a guideline to healthy digestion.

Equation 5 represents the conversion of propionate to acetate, only achievable at low hydrogen pressure. Glucose (Equation 6) and ethanol (Equation 7) among others are also converted to acetate during the third stage of anaerobic fermentation.

Equation 5: $CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2$

Equation 6: $C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$

Equation 7: $CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+$

2.2.4. Methanogenesis

The fourth and final stage in the digestion process is called methanogenesis. During this stage, microorganisms convert the hydrogen and acetic acid formed by the acid formers to methane and carbon dioxide (equations 8, 9 and 10). The bacteria responsible for this conversion are called methanogens which are strict anaerobes. Stabilisation is accomplished when methane and carbon dioxide are produced.

Equation 8: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Equation 9: $2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$

Equation 10: $CH_3COOH \rightarrow CH_4 + CO_2$

The degradation process yields bicarbonate which, within a balanced digestion, establishes a stable pH and in most cases there is no need for pH control, pH is discussed further in Section 2.1.7

2.2.5. Sulphur and Nitrogen

Sulphur and nitrogen are reduced in the anaerobic process to sulphide and ammonia. The broadly neutral pH of the anaerobic systems means that the sulphide is distributed mainly into the biogas as hydrogen sulphide and the ammonia mainly as ammonium into the digestate. When sulphur is present as sulphate it provides an alternative electron acceptor to carbon dioxide and thermodynamically the reduction of sulphate to sulphide is more favourable. This stimulates the growth of sulphate reducing bacteria (SRB) and where it is present, hydrogen sulphide is formed.

Although hydrogen sulphide has a considerable energy value, it is corrosive and is typically removed to protect the energy recovery plant. The stoichiometry of the sulphate reducing reactions yield equivalent amounts of H_2S volumetrically as methane where the carbon feedstock is metabolised by SRB. This equates approximately to 230 litres of methane being lost from the biogas and replaced with 230 litres of H_2S for every 1kg of sulphate within the feedstock.

Nitrogen is the inorganic nutrient required in the largest concentrations for the growth of microorganisms. Under anaerobic conditions, nitrogen as nitrite and nitrate is unavailable as it is reduced to nitrogen gas and released to the atmosphere. Reduced forms of nitrogen and ammonia present in the feedstock from the degradation of proteins are the main sources of nitrogen used by microorganisms.

2.3. Biomass growth

The anaerobic digester is a vessel (reactor) that provides an oxygen free environment in which microorganisms can degrade organic feedstock to methane and carbon dioxide. The capacity of a given digester to degrade the organic feedstock depends primarily on the amount of viable (living) biomass within the digester.

Where the carbon feedstock (and nutrients) are not limited, the bacterial population within the digester responds (following a lag phase) to feeding (loading) through an increase in the microbial population. This is shown in Figure.3:

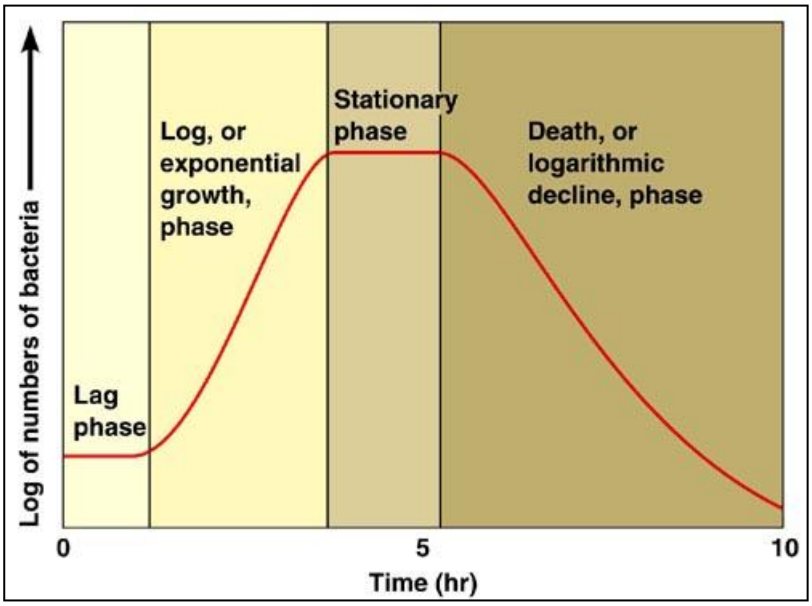


Figure.3 : Bacterial Growth Curve

Some microbes will be lost from the digester with the digestate and others will die off. If, when combined with the growth rate, an increase in the overall population occurs, then the capacity of the system to process feedstock material will also increase.

This is the situation observed in the start up of an AD process where the inoculum in the digester is developed through steadily increasing the rate of feeding until the population reaches a steady state where the rate of biomass removal is equivalent to the rate of growth. At this point the biomass within the system should be sufficient to achieve the required level of organic treatment and the digestion process has reached stabilisation.

All rates of growth for each group of microorganism are proportional to nutrition in the broadest sense (carbon and essential elements) and are therefore first order. The constant of proportionality, however, differs for each bacterial grouping (hydrolytic, acidogens, acetogens and methanogens). Therefore, when stimulated to grow by an increase in load the groups within the consortia respond at different rates. The ecology and therefore the rates also depend on environmental factors including the type of the feedstock.

The growth rates of each of the groups of bacteria are often described in terms of generation or doubling times [g]. This is time taken for the biomass to double in population. For most groupings within the anaerobic consortia the microorganisms have doubling times of around 2-4 days.

If the microbial system is disturbed (or “shocked”) as a result of a change in loading or adverse environmental factor, the balance between these groups may be disturbed. An understanding of the doubling times will allow operators to understand the potential recovery times for the system following a disturbance to the ecology.

Typical doubling times for anaerobic microorganisms are given in Table 2 below:

Microbial Function	Doubling Time [g] days
Hydrolysis:	1 - 1.5
Acidogenesis	1 - 1.5
Acetogenesis	1 – 4
Methanogenesis	5 – 15

Table 2 Microbial Doubling Times (source: Gerardi 2003)

2.4. Environmental considerations

Microbial activity within an AD plant is influenced by the following environmental factors:

- Nutrient Content
- Temperature
- pH and Alkalinity
- Any inhibition and toxicity

All of these factors have an influence on the growth and viability of the microbial population within the digester and it is absolutely vital that environmental conditions are monitored and managed carefully as part of the operation of an AD plant. Failure to maintain optimal environmental conditions within the digester can potentially lead to disruption of the digestion process and ultimately failure of the digester characterised by cessation in methane production.

Variations in digester design are largely aimed at optimising environmental conditions for the growth of anaerobic microorganisms.

The influence that each of these environmental factors has on the digestion process are explored in further detail in the following sections.

2.4.1. Nutrient requirements

The contents of a digester must provide a sufficient source of nutrients in order to support the growth of anaerobic microorganisms. Nutrient requirements can be defined as macro nutrients (nitrogen, phosphorous and sulphur) that are required in significant quantities and also micro nutrients or trace elements, both of which are required in sufficient quantities.

Optimum methane production is expected where the carbon: nitrogen (C:N) ratio lies between 20-30:1. Above this, nitrogen availability will limit the process and result in decreased gas production and a digestate containing increased amounts of unstabilised feedstock. Digester failure may occur where the C:N ratio increases beyond 50:1, although in practice this is rare.

Nitrogen deficiency usually leads to sub-optimal performance which may be addressed before complete failure occurs. At the other extreme, nitrogen rich feedstocks will deliver high concentrations of reduced nitrogen as ammonia in the digester, increasing the pH and potentially inhibiting the microbiology. This may limit the degree to which liquor may be recycled (as this will tend to accumulate ammonia). In such circumstances the addition of a feed supplement such as glycerine or co-digestion with a carbon rich feedstock, may be required in order to achieve an optimal C:N ratio.

Phosphorous and sulphur and a range of trace metals, including iron, zinc, nickel, copper, cobalt, molybdenum, selenium and tungsten are also essential to achieve optimal digestion, particularly in relation to supporting the growth of methanogens. Depending on the feedstock to be processed operators may need to supplement the feed with trace or micronutrients in order to sustain the digestion process, particularly if the feedstock is from a single source.

There is still no formula for the optimum composition of trace elements within an AD process. Research conducted for Defra identified that selenium, cobalt and molybdenum are key elements essential for the long-term stability of digestion that may be limited where food waste is the sole feedstock. Some nutrients may also be recycled through the process by reusing some of the digestate liquor, this is chiefly done to improve mixing and in some cases to recycle biomass.

2.4.2. Temperature

Temperature affects biological processes in two ways by influencing:

- The microbially mediated enzymatic reaction rates and
- The diffusion rates within a substrate.

Both of these factors impact on the rate at which microbial growth can occur and in general an increase in temperature will correspond with an increase in microbial growth rate up to an optimal level. The effect of temperature also influences the ecology of the methanogens that are responsible for biogas production. The separate microbial ecologies have different temperature preferences and are defined according to the temperature range within which they operate.

Ecologies that function at ambient temperatures, generally between 5-15°C, are referred to as psychrophilic; at temperatures between 25-45 °C are referred to as mesophilic and at higher temperatures, between 50-60°C, are termed thermophilic.

This effect of temperature on microbial activity of methanogens is shown in Figure 4. This indicates the optimal range of temperatures for microbial growth within each of the three described temperature regimes.

It can be seen that the maximum growth rate for a regime increases with temperature, i.e. the maximum growth rate for thermophiles is greater than that for mesophiles. In addition an overlap between the tolerances of the differing ecologies can be seen with mesophiles overlapping both psychrophiles and thermophiles.

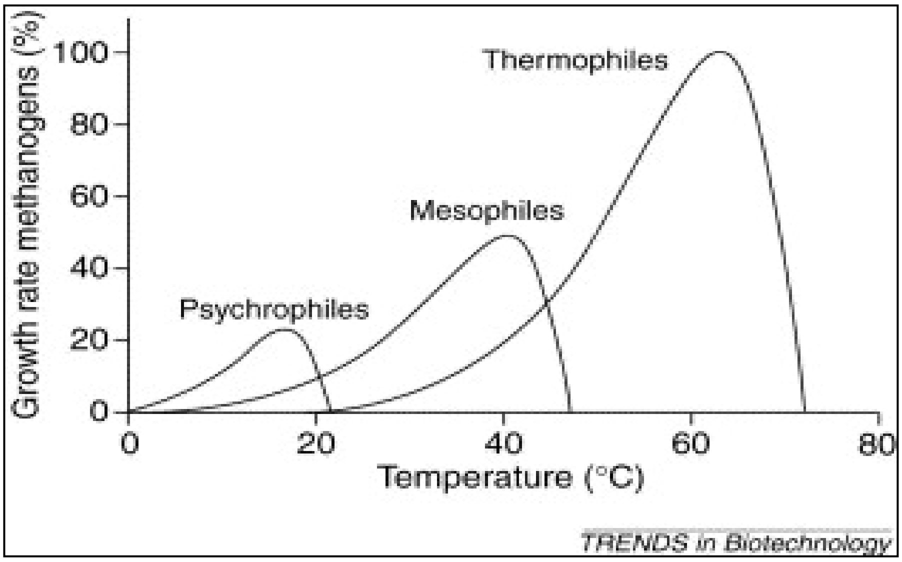


Figure 4: Influence of Temperature on Biomass Growth Rate (source: Van Lier et al, 1997)

Temperature variations can have significant effects on the process, for example, at mesophilic temperatures the maximum bacterial growth rate decreases by 11% per ºC below 30 ºC. Above the ideal temperature, proteins and enzymes become denatured and microbial decay overtakes synthesis. Given the overlap in ecologies the overall gas production may continue, but at a significantly reduced rate.

The classification of AD systems according to operational temperature reflects the temperature profiles at which the different ecologies operate. An understanding of the optimal temperature ranges for the microbial ecologies also demonstrates the importance of maintaining a consistent temperature within a digester and ancillary pipework.

Temperature shocks to a system are likely to cause an imbalance in the bacterial population, particularly temperature increases as these will increase the rate of physical processes and substrate availability whilst reducing the rate of growth.

Temperature also affects the thermodynamics of transformations within the degradation process and the dissociation of species such as ammonia.

The rate of reaction determines the speed and therefore time it takes for the AD process to occur. The same level of decomposition can be achieved through a low reaction rate occurring for a long time as for a fast reaction in a short time.

Most AD plants are designed in the mesophilic range and there is considerably more operational experience of mesophilic plants than thermophilic. Practical experience is also that there is a considerable loss of process efficiency with temperature deviation from the optimum. Therefore most mesophilic plants aim to achieve a design temperature of 35-37 °C to deliver optimal performance and reduce unnecessary capital costs. Designs aim to maintain this temperature throughout the reactor through the use of a high standard of insulation and a high degree of mixing.

2.4.3. pH and alkalinity

Measurement of pH is conducted by taking a representative sample from the digester at regular intervals or is continuously monitored in the digester using probes. The pH can be monitored using pH strips or analyzed using a pH electrode and meter. The pH electrode needs to and should be calibrated regularly. The pH of a sample is preferably measured shortly after sampling because biological processes continue in the sample, thereby affecting the pH.

Many practitioners recognise that alkalinity is more informative and important than pH as a measure of digester stability.The digester should contain substantial amounts of alkalinity which will buffer the system from increases in VFA which may arise routinely e.g. when the reactor is fed. More problematic increases in VFA may not yield a significant change in pH but will erode alkalinity significantly to the point where additional VFA will yield a severe drop in pH. It is for these reasons that the FOS/TAC (see later) ratio of VFA (FOS) to Alkalinity(TAC) is the most useful means of monitoring digester stability.

Alkalinity can be measured by a range of standard methods either by titration or potentiometrically. For simple systems it may also be used to provide a coarse assessment of VFA concentrations without the need for on-site gas chromatography or off-site analysis.

There are strong relationships between alkalinity, pH and volatile acid concentrations; as such these are equally important to the control and operation of anaerobic processes. The pH affects the process:

- Directly: affecting for example, the enzymes activity by changing their proteic structure.
- Indirectly: by affecting the availability of certain toxic elements and compounds.

The methane producing organisms have optimum growth in the pH range between 6.6 and 7.4, although stability may still be achieved in the formation of methane in a wider pH range (between 6.0 and 8.0). pH values below 6.0 and above 8.3 will inhibit the methane producing bacteria.

Table 3 indicates the optimum pH ranges for different substrates.

Substrate	Optimum pH
Formate	6.8 – 7.3
Acetate	6.5 – 7.1
Propionate	7.2 – 7.5

Table 3 Optimum pH ranges for Different Substrates (source: Lettinga et al, 1996)

In general the acid producing organisms involved in the earlier stages of AD are much less sensitive to pH than the methanogens, for example the acidogenic bacteria can still be very active at pH 4.5. In practice this means that any form of perturbation which produces a reduction in methanogenic activity will quickly be aggravated by the hydrolysis and fermentation of feedstocks if loading the reactor continues.

The operation of an anaerobic reactor constantly outside of pH 6.5 – pH 8.0 can cause a significant decrease in methane production due to chronic inhibition. In addition the tolerance of the system to further shocks is also eroded. Recovery from a pH shock will depend on a series of factors related to the impact the shock has on the population and whether this is permanent or temporary.

The recovery from a pH shock will be quicker if the:

- pH deviation was not significant
- Duration of the pH shock is short
- VFA concentration during the pH shock remains low (acid shock).

Within anaerobic systems, the degradation process generates three species, ammonia, carbon dioxide and VFA which provide buffering capacity within the liquor. This capacity allows the system to resist changes in pH. Each species (in the case of VFA group of compounds) buffers around a different pH, the pKa at which the buffering species are in equilibrium.

$NH_3 + H^+ \Leftrightarrow NH_4^+$, pKa 9.3

$HCO_3^- + H^+ \Leftrightarrow H_2CO_3$, pKa 6.4

$CH_3CO_2^- + H^+ \Leftrightarrow CH_3CO_2H$, pKa 4.8

In the pH range 6.0-7.5 the buffering capacity in the process depends almost entirely on the bicarbonate equilibrium. The alkalinity provided by the VFA is of little importance in maintaining ideal conditions and indeed the bicarbonate alkalinity needs to neutralise the VFA to hold the system at an optimal pH for methanogenesis.

The potential alkalinity within a system will depend on the:

- Feedstock strength as this will provide the potential for acid generation; and
- Proportion of proteins, fats and carbohydrates as each has a different potential for the generation of alkalinity.

Characterising alkalinity is carried out by titration to an end point which reflects the titratable bases (ammonia, bicarbonate and acetate) to be determined. Total alkalinity is usually quoted to pH 4.3, but by calculating the alkalinity at pH 5.75 and then to pH 4.3 allows the VFA alkalinityto be determined and a reasonable approximation of VFA concentration but not their distribution.

More commonly referred to in the industry is the ‘FOS/TAC’ determination. Titrating down to pH 5,0 using sulphuric acid indicates the TAC (buffer), noting the more acid that is needed to lower the pH-value the more buffer systems are available. Then continuing to titrate down to pH 4,4 for FOS (total amount of organic acids). The more acid needed to lower from pH 5.0 to pH 4.4 indicates that more VFA’s are present in the sample. Division of both parameters gives you the FOS/TAC ratio.

Properly operating digesters have alkalinity within the region of 2000-4000 mg $litre^{-1}$.

In designing AD plants an assessment has to be made as to whether the intrinsic alkalinity within the feedstock added to the forecast alkalinity within from the degradation will provide adequate buffering within the reactor. This can be modelled within wastewater (ultra low solids) on consistent, well characterised feedstocks. For low and high solids systems it may be determined empirically. Where it is deemed insufficient, pH adjustment is required typically by adding a base into the feedstock. Lime, caustic and sodium bicarbonate may be used but care must be taken to prevent a build up of high salt concentrations.

2.4.4. Volatile fatty ccid and ammonia concentration and speciation

The measurement of VFA and ammonia levels within a digester and digestate provides important information regarding process stability. An increase in VFA concentrations can be indicative of an overload in the OLR (Organic loading rate). Indicative functional ranges for VFA concentrations have been defined as 500 to 3000 mg $litre^{-1}$.

VFA concentrations can be used as an indicator of the balance between acetogens and methanogens in the digester. If VFA concentrations follow a notable increase, it indicates that methanogens are not able to consume the substrate as fast as it is produced by the acetogens. Acetic acid is usually present in higher concentrations than other VFAs during anaerobic digestion, although propionic and butyric acids are considered more inhibitory to methanogens.

The relation between propionic acid and acetic acid can be used for early recognition of process imbalances. In general process disturbances appear where the propionic to acetic acid ratio exceeds a value of 1, and where propionic acid concentration exceeds 1,000 mg $litre^{-1}$. Propionic acid concentrations over 3000 mg $litre^{-1}$ have been shown to cause digester failure, although propionic acid has also been found to be an effect rather than a cause of inhibition.

Measurement of the possible wide ranges of ammonia concentrations within the process is also important because these high ammonia concentrations can be inhibitory to a digestion process. This is attributed to differences in substrates and inocula, environmental conditions (temperature, pH), and acclimation periods. Experimental Total Ammonia Nitrogen (TAN) concentrations that cause a 50% reduction in methane production range from 1,700 to 14,000 mg $litre^{-1}$

VFA’s should be measured on site in a laboratory. If no onsite laboratory is available, samples may be taken and sent for analysis. Samples for VFA should be filtered or centrifuged to remove suspended solids and stored refrigerated for a maximum of 1 day. When a small laboratory is available on site, VFA can be determined with the titration method or by measurement of organic acids with bespoke kits.

Combining VFA concentrations and Total Alkalinity (TA) measurements in a ratio referred to as FOS/TAC is a useful tool to monitor digester stability, since the ratio can indicate if the acids are out of balance with the alkalinity. For municipal wastewater solids digested at mesophilic temperatures, a conservative ratio of 0.1 VFA to Total Alkalinity or less has been used as a safe operational range. Ratio trends are monitored regularly to assess digester stability.

2.4.5. Inhibition and toxicity

Inhibition of the anaerobic ecology is affected by many different materials and conditions beyond pH. Given the implications of inhibition and reactors failing (process down time, unanticipated costs, loss of revenue), it is commercially incumbent upon the operator to understand what is within their feedstock and to manage their process within the known operational envelope. However, a well designed and operated AD process should comfortably be able to withstand seasonal and other expected variations in feedstock.

Feedstocks other than those already agreed in the AD Quality Protocols and Standard Rules Permit's need to be fully assessed for suitability which includes addressing inhibition factors (see link to organic waste framework guidance in Appendix D.).

Inhibition is determined by examining the effect of introducing a new material or change in operation from a steady-state system at laboratory scale.

The impact of the change on the activity is reflected in the rate of biogas production. This is measured against a control which remains at the pre-established steady state. For substances, the inactivity concentration (IC) which results in a 50% reduction in activity is termed the IC50.

Potential causes of inhibition in the AD process is set out in Table 4

Inhibitor	Description	Threshold
Oxygen and Light	Oxygen and light are poisons for certain bacteria. A high amount could inhibit the activity of methane producing bacteria.	All digesters operate in an oxygen free environment without any light.
Sulphate/Sulphide	As described in Section 2.2.5, in anaerobic digestion, sulphate is reduced to sulphide by sulphate reducing bacteria (SRB). Two stages of inhibition exist as a result of sulphate reduction. Primary inhibition is due to competition for common organic and inorganic substrates from SRB, which suppresses methane production. Secondary inhibition results from the toxicity of sulphide to various bacteria groups. Sulphide is toxic to methanogens as well as to the SRB themselves.	Inhibitory sulphide levels reported in the range of 100–800 mg $litre^{-1}$ dissolved sulphide or approximately 50–400 mg $litre^{-1}$ unionised H_2S.
Light metal ions	High salt levels cause bacterial cells to dehydrate due to osmotic pressure. Light metal ions including sodium, potassium, calcium, and magnesium may be released by the breakdown of organic matter or added as pH adjustment chemicals. They are required for microbial growth and, consequently, affect specific growth rate like any other nutrient. While moderate concentrations stimulate microbial growth, excessive amounts slow down the growth, and even higher concentrations can cause severe inhibition or toxicity. Excessive amounts of calcium lead to precipitation of carbonate and phosphate, which may result in • Scaling of reactors and pipes • Scaling of biomass and reduced specific methanogenic activity • Loss of buffer capacity and essential nutrients for anaerobic degradation.	Significant variations are reported in toxicity levels for light metal ions.
Heavy Metals	Heavy metals identified to be of particular concern with regards to inhibition include chromium, iron, cobalt, copper, zinc, cadmium, and nickel. A distinguishing feature of heavy metals is that, unlike many other toxic substances, they are not biodegradable and can accumulate to potentially toxic concentrations.	
Ammonia (NH_3)	Ammonium ion (NH_4) and free ammonia (NH_3) are the two principal forms of inorganic ammonia nitrogen in aqueous solution. Free ammonia has been suggested to be the main cause of inhibition since it is freely membrane-permeable. The hydrophobic ammonia molecule may diffuse passively into the cell, causing proton imbalance, and/or potassium deficiency. Among	Ammonia concentrations below 200 mg $litre^{-1}$ are believed to be beneficial to anaerobic process since nitrogen is an essential nutrient for anaerobic

Inhibitor	Description	Threshold
	the four types of anaerobic microorganisms, methanogens are the least tolerant and the most likely to cease growth due to ammonia inhibition. A high ammonia concentration could be caused by high nitrogen and ammonium (NH_4) concentrations under certain circumstances (e.g. temperature).Therefore, substrates with high nitrogen content like chicken manure, slaughterhouse waste, other waste rich in proteins and occasionally pig slurry or manure are diluted or mixed with nitrogen-poor substrates. In this case ammonia and ammonium must be analysed regularly during operation	microorganisms. A wide range of inhibiting ammonia concentrations have been reported in the literature, with the inhibitory Total Ammonia Nitrogen (TAN) concentration that caused a 50% reduction in methane production ranging from 1,700 to 14,000 mg litre^{-1}. Studies have indicated that where there was ammonia at concentrations in the range of 4000–5700 mg NH_3–N litre^{-1}, acidogenic populations in granular sludge were hardly affected while methanogenic population lost over 50% of its activity. The significant difference in inhibiting ammonia concentrations can be attributed to differences in substrates and innocula, environmental conditions (temperature, pH), and acclimatisation periods.
Volatile Fatty Acids	An excessive input material addition (or feeding) could restrain the digestion process. By adding to much material at one time an accumulation of VFA could be possible and affect gas production.	
Toxicants	Disinfectants, herbicides or antibiotics such as those found in poultry/chicken manure and pig, can disturb the process in high concentrations. At low concentrations, biodegradation of some toxicants can prevent inhibition; higher concentrations of toxicants generally lead to significant inhibition. With higher biomass concentration, digesters exhibit greater process stability in the presence of toxic shocks. At equal solids concentrations, younger microbial cultures were proven to be more robust and resistant to toxicants than older cultures. In the majority of agricultural wastes these compounds are in very low concentrations (less than 30 ppm) and are generally not inhibitory. However, some synthetic chemotherapeutics such as Olaquindox which is used in the treatment of animal diseases, may be strongly inhibitory even at 1 mg litre^{-1}	Inhibition concentration ranges vary widely for specific toxicants. Parameters that affect the toxicity of organic compounds include toxicant concentration, biomass concentration, toxicant exposure time, cell age, feeding pattern, acclimation, and temperature.
Surfactants	e.g. alkyl dimethylbenzylammonium chloride: 6.7; sodium alkyl ethersulfate: 11 litre-1. Surfactants may be used in cleaning in process routines (CIP) to clean process vessels and pipework in food and drink plants.	

Inhibitor	Description	Threshold
Alcohols	Short chain alcohols are generally less toxic than long chain alcohols. Short chain alcohols may occur in high concentrations in distillery wastes (spent mash).	22-43000 mg $litre^{-1}$

Table 4. Selected typical IC50 concentrations for selected inhibitors

2.4.6. Loading rate and retention Time

Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT) are key control parameters within an AD system and are fundamental considerations in ensuring the system is designed and operated to achieve optimal digestion. They correlate to the amount of biomass held within the reactor and the efficiency of stabilisation.

Loading rate is defined both in terms of the Hydraulic and Organic Loading Rate. In a fully mixed digester (CSTR) hydraulic and solid retention are the same. Digestion systems for liquid feedstocks operate with low hydraulic RT and high solids RT to achieve operational stability. There is a close correlation between these factors that depends on the design of the system.

The Hydraulic Loading Rate (HLR) represents the total volume of material that is fed into the digester over time and is expressed in m^3 or tonnes of feedstock per digester unit volume per day.

The Organic Loading Rate (OLR) represents the mass of feedstock that is loaded into the digester, and for low and high solids systems it is expressed in terms of Volatile Solids (VS) in kg per unit volume per unit time i.e. kg VS m^{-3} day^{-1}. For low solids systems where most of the organic matter is dissolved the energy content in the organic matter is measured chemically by oxidation (Chemical Oxygen Demand) to yield an OLR expressed as kg COD m^{-3} day^{-1}

The Hydraulic Retention Time (HRT) is defined as the working volume of the digester divided by the rate of feeding as volume per unit time and is expressed in days. It is a fundamental design parameter and is a determining factor in sizing the AD plant.

Bacterial growth and system performance is related to the Solids Retention Time (SRT). The longer the SRT the lower the growth rate and the larger the microbial population within the reactor. This in turn allows for a high level of stabilisation at higher loading rates.

SRT is defined as the mean biomass concentration expressed as kg VS (Volatile Solids) within the reactor divided by the biomass lost in the effluent expressed as kg VS per unit time. For simpler systems applied for the treatment of low and high solids feedstocks within stirred tanks, lagoons or similar reactor designs, SRT = HRT as the concentration of biomass in the solid material or effluent removed is equivalent or close to the mean concentration within the vessel. As a result, in low and high solids process, in order to achieve the desired SRT, an equivalent HRT is required. HRT for low and high solids processes are much greater than for ultra low solids and reactor sizes are much bigger as a result.

More advanced systems applied to ultra low solids feedstocks are differentiated by their ability to retain biomass within the reactor through the use of packing media or the development of a blanket of biomass which is retained within the reaction vessel. In the case of the Upflow Anaerobic Sludge Blanket (UASB) the biomass blanket is granular, rapid settling and allows the retention of very high biomass concentrations.

In ultra-low solids processes, the majority of the active biomass is retained within the reactor and the effluent biomass concentration is much lower than the mean biomass concentration in the reactor. As a consequence, SRT is then greater than HRT and this drives down reactor size and increase loading rates.

Measurement of the VS content of the digestate compared to the feedstock VS will indicate the level of Volatile Solids Destruction (VSD) in the process. VSD is used to monitor the efficiency of the process. The stabilisation of organic material must be maintained within the minimum levels indicated, which are provided in Table 5. This is an excellent measure of AD efficiency.

Biogas production can be deliberately controlled to a considerable extent by regulating the organic loading rate. The loading can also be changed to some extent by changing the HRT.

2.4.7. Other design considerations

Although there are many kinetic models describing the relationships between bacterial growth, biomass yield and organic stabilisation, which relate hydraulic and solids retention time, these are not used to provide key design parameters for low and high solids systems.

Such models remain unable to map the performance of the system closely enough to take account of the availability and conversion of substrate and nutrients within a complex feedstock.

A further complication in applying theoretical models to low and high solids systems is understanding the reactor biomass concentration which is key to applying this sort of approach. This is because the reactor liquor in low and high solids systems contains substantial Volatile Suspended Solids (VSS) from the feedstock which change as they are hydrolysed and fermented.

Design information is therefore usually derived from trials and full scale plant data using the intended feedstock or an analogue. This will yield performance curves on stabilisation, gas yield, solids removal, and alkalinity at a range of HRTs and OLRs.

The basic design of a digester is a balance of technical and economic considerations. There are a number of essential functions that must be realised in the digester:

- the continuous provision of nutrients to the bacteria and the removal of metabolic products from the viable biomass;
- adequate retention times for the feedstock organic matter; and
- prevention of uncontrolled accumulation of solids in the digester and of blockages in the material flow through the digester.

For all anaerobic systems, digester capacity is directly related to the design retention time, the operating temperature and the quantity of material processed.

Longer retention times within the reactor releases more biogas, provides a more stable digestate (with lower liquor VFA concentrations) and cuts down post digestion methane and odour release.

However, excessive retention times increases capital costs and challenge the viability of AD projects. Therefore, installed capacity becomes an economic balance between the capacity cost and the biogas production.

2.4.8. Monitoring and control considerations

A suitable monitoring system, both manual and instrumental, is essential to ensure stable reactor operation (especially for thermophilic plants) and to minimise operational difficulties, such as foaming, which may lead to odour and aesthetic problems. Additionally, excess foam in the digester content makes dewatering very difficult.

The key factors to be monitored during the digestion process itself include:

- Alkalinity and pH
- Temperature and temperature distribution
- Organic Loading Rate including Total solids and Volatile Solids Fractions
- Concentration of VFA
- Ammonia
- C:N ratio and other nutrient and key feedstock data
- Gas production and composition
- Gas pressure
- Gas H2S concentrations

Alkalinity is also useful to understand as it will correlate information on VFA and pH if carried out by titration (FOS/TAC). The distribution of VFA and in particular the relationship between the higher VFA and acetate provides the opportunity for potential problems with the system to be recognised early before the balance of the system and the gas production is significantly impacted. However this is likely to require analysis of the liquor using gas chromatography.

Temperature, gas production, pressure and the composition of the bulk components are monitored in real time in most commercial plants and this information is relayed to the process control panels. The pH of the liquor is also measured at least daily by withdrawing a sample. Other parameters will require discrete monitoring equipment and chemical analysis.

The operator needs to understand and monitor the above parameters, making changes in the feed stock and micro nutrient dosing to maintain the biomass at an optimum level. Small deviations in any of the above can have large impacts on the microbiology, and in a worst case scenario the biomass can be destroyed, or produce unwanted by-products, potentially giving rise to increased pollution risk.

For example; if the organic load is raised too quickly, the acidic methanogenic precursors build up and the pH falls to a level which is inhibitory to most groupings. This is often referred to as “soured digestion” or as a digester being “stuck”. At this point a process may have to be taken offline; interventions at this stage are prone to odorous emissions caused by the release of intermediate volatile organic compounds.

Monitoring of these parameters requires sampling of digester feed, substrate within the digester, digestate and biogas at key points in the process. The system design should allow for this. Regular laboratory testing will be required to analyse samples and the operator should consider provision for on-site laboratory facilities at large scale AD facilities

Monitoring processes should incorporate the use of Supervisory and Control and Data Acquisition Equipment (SCADA) to monitor, record and display data for continuously monitored parameters such as temperature, pH, digester feeding and gas production rates. The results of the monitoring can then be displayed in real time to the plant operators to make manual adjustments and optimise the entire process.

Techniques being researched into improvements in AD process monitoring systems include Infrared Spectroscopy (IS) which has been used to measure VFA, COD, total organic carbon (TOC), and alkalinity. The technique has also been demonstrated to measure microbial biomass and acetate concentration.

Hazard Analysis and Critical Control Point (HACCP) is a system to ensure that production parameters are met and is useful in the running of any biogas site. The PAS 110 standard provides a documented guide and system for the control of process parameters including HACCP. HACCP analysis and monitoring is also required for compliance with Animal By-Product (ABP) Regulation where ABP material is processed. HACCP analysis is required to be conducted and the approach approved by the regulator prior to accepting and processing ABP material on site.

The general procedure of HACCP analysis requires the operator to:

- Conduct a hazard analysis
- Determine the Critical Control Points (CCPs)
- Establish critical limits
- Establish a system to monitor control of each CCP
- Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control
- Document and record all procedures, corrective actions and verification results and
- Establish procedures for verification, audit and review to confirm that HACCP is working effectively.

During design and commissioning, the operator should define the suite of indices that will be used to determine and monitor digester performance and efficiency. The relevant monitoring parameters should be reviewed and refined during operation of the facility as part of an on-going process of system optimisation.

Table 5 provides indicative parameters and values that are typically associated with successful digestion. It should be noted that if ABP material is being treated then temperature and particle size of the substrate will need to be monitored to ensure compliance with the legislation.

Process parameter	Indicative limit range
pH	7.0 – 8.5
Alkalinity	Maintained within the region of 2000mg litre-1
Temperature	Maintained within a maximum tolerance + / - 1 °C of the operational design temperature.

Process parameter	Indicative limit range
Volatile Fatty Acids:	
Total VFA	Between 500 and 3,000 mg $litre^{-1}$
Propionic Acid	Less than 1,000 mg $litre^{-1}$
Propionic: Acetic Acid Ratio	A ratio greater than 1 indicates a process imbalance
Total Ammonia Nitrogen	Not regularly exceed 1,700 with a maximum level of 14,000 mg $litre^{-1}$
FOS/TAC Ratio	0.3 but dependent on plant and therefore monitoring drift important.
Trace Elements	
Selenium	0.16 mg $litre^{-1}$ (not to exceed 1.5 mg $litre^{-1}$)
Cobalt	0.22 mg $litre^{-1}$
Molybdenum	0.30 mg $litre^{-1}$
Biogas	
CH_4 and CO_2 concentration	Maintained according to operational limits of energy recovery equipment.
O_2 concentration	Presence of elevated oxygen in biogas indicates process is not operating anaerobically.
Digestate	
Digestate sampling and testing will be required to demonstrate the digestate is fully stabilised. Currently PAS110 provides details of the standard required.	
Energy Recovery	
Availability of primary energy recovery equipment	Operators of large scale (i.e. permitted) AD facilities are required to demonstrate that a target of 90% availability has been achieved.

Table 5 ***Process Monitoring Parameters and values that are typically associated with a stable digestion process***

2.4.9. Process configuration

The typical process stages of an AD plant with the principal functions of each step are listed below:

- Feedstock acceptance and storage to:
  - Formally accept waste
  - Provide adequate capacity for the feedstock
  - Prevent fugitive emissions
  - Blend feedstocks and balance loading into the plant
- Pre-treatment of feedstock prior to digestion to:
  - Remove unwanted materials and contaminants
  - Physically and chemically prepare the feedstock for digestion
- Pasteurisation:
  - To meet the requirements of Animal By-Products (ABP) Regulations (where necessary)
- Digestion processes:
  - To stabilise the feedstock and produce the required outputs
- Biogas storage and utilisation:
  - To prepare, store and utilise the biogas output
- Digestate storage and utilisation:
  - To prepare, store and utilise the digestate output

There will also be ancillary processes, such as abatement plant for fugitive emissions, standby flares or biogas upgrading plant to allow for grid injection. These techniques are discussed in detail in Sections 6 and 8

Pre-treatment requirements for a MSW stream will differ from pre treatment for a pure manure stream due to the potential for likely contaminants. The former may require mechanical or manual separation of the packaging for example, from the waste.

Pasteurisation of materials subject to ABPR is required. As the majority of AD facilities operate at mesophilic temperatures this will need to be a separate stage of treatment.

The digestion process is discussed in Section 4, this gives the biogas and digestate outputs and requires careful management in order to operate efficiently.

Depending on the final use it may be necessary to undertake a level of gas cleaning or upgrading – for example if the gas is being injected into the grid. If the gas is to be burnt on site then monitoring of emissions may be required.

Appropriate facilities for the storage and further processing of digestate should be provided, operators need to ensure that digestate is managed appropriately in order to prevent it from causing an odour nuisance.

Waste acceptance procedures

This section covers the key issues of pre-acceptance and acceptance of wastes brought to site.

3.1. Pre-acceptance procedures to assess waste

3.1.1. Procedures for waste, waste storage, and specific activities for waste treatment.

In order to prevent the acceptance of unsuitable wastes which may lead to adverse reactions or uncontrolled emissions, systems and procedures must be in place to ensure that wastes are subject to appropriate technical appraisal. This ensures their suitability for the proposed treatment route.

Checks must be carried out before any waste is accepted. This requires a system that has, as an initial stage, a screening step or pre-acceptance procedure, involving the provision of information and representative samples of the waste. The second stage, acceptance procedures when the waste arrives at the site, should serve to confirm the characteristics of the waste, without the time pressure and potential hazard of checking a waste at the gate.

The operator must obtain the following information:

- the nature of the process producing the waste, including the variability of this process
- the composition of the waste (chemicals present and individual concentrations)

  and ensure that:

- a representative sample(s) of the waste should be taken from the production process and analysed
- for each new waste enquiry, a comprehensive characterisation of the waste and identification of a
- suitable treatment method is undertaken

This information must be recorded and referenced to the waste stream so that it is available at all times. The information must be regularly reviewed and kept up to date with any changes to the waste stream.

Waste characterisation must be completed by the operator unless all necessary information is already available from the producer or holder of the waste.

The waste producer has obligations under the Duty of Care requirements to provide information on the:

- Composition of the waste
- Its handling requirements
- Its hazards
- EWC code (See List of Waste Regulations in Statute Law Database link in Appendix D)

This information is required on transfer of the waste from the producer to a third party such as a waste disposal contractor. Experience of this system has shown that reliance cannot be placed solely upon it to provide sufficient information. The producer and operator of the receiving site must ensure that reliable and comprehensive information has been provided to determine the suitability of the waste for the AD process.

Enquiries from waste producers are commonly routed through a business section of a company, and not directly from the management of the plant producing the waste. Verification of the written information provided by the producer may be required and this may require a visit to the producer, as additional factors may become apparent when dealing with staff directly involved in the waste production.

It is not unusual for the waste producer and the operator to be separated by at least one and in some cases three or four different parties. These may be haulage contractors, brokers and waste transfer operators. Where there is a lengthy chain, information may be lost or inaccurately reproduced. It is an advantage to keep the number of waste (and Duty of Care information) transfers to a minimum. This will help avoid information loss or misrepresentation.

If not dealing directly with the waste producer, the operator should carefully verify the information received at the pre-acceptance stage, which, in addition to the minimum Duty of Care information, should include the contact details for the waste producer and a full description of the waste.

There is often reluctance amongst third parties to divulge the identity of the waste producer as this may be of commercial benefit. This however cannot override the fundamental requirement of the Operator, which is to check the information provided on a waste with the waste producer (not just the current holder), who is in the best position to verify the information.

At the pre-acceptance stage, in addition to written information regarding the waste, the operator must obtain representative sample(s) of the waste from the production process. Any deviations from this must be fully justified.

Adequate sampling and analysis must be carried out to characterise the wastes. In all cases the number of samples taken must be based on an assessment of the risks of potential problems.

As the circumstances of waste production may vary, sound professional judgement is required in ensuring the relevant questions are asked. Operators should ensure that technical appraisal is carried out by suitably qualified and experienced staff who understand the capabilities of the site, independent of sales staff responsible for obtaining the customer's business. The Environment Agency considers that a minimum qualification of a HND (or equivalent) in a relevant discipline) will be required in order to equip staff to carry this assessment out correctly.

This information is necessary to:

- Screen out unsuitable wastes
- Confirm the details relating to composition, and identify verification parameters that can be used to test waste arriving at the site
- Identify any substances within the waste (for example, by-products) that may affect the treatment process
- Identify any substances within the waste that may react with other reagents
- Accurately define the range of hazards exhibited by the waste
- Identify any substances within the waste that may be unaffected by the treatment process and transfer in an unaltered state as a residue in the effluent
- Determine the cost of the disposal option identified
- Ensure regulatory compliance with the permit.

Using the information on the waste arising, and the sample provided, the Operator should verify the information provided regarding composition and biodegradation of the waste. Once it has been established that the waste is as described, a treatment method or option for the waste should be determined.

Wastes should not be accepted at the AD facility without a clear method or defined treatment and recovery route with a full costing. Experience has shown that wastes have been accepted at a site without pre-acceptance checks, on the basis that checks would take place at another treatment facility. On examination, the wastes have not only been found to be unsuitable for the site in question, but also due to the composition and hazard have been unsuitable for anything other than incineration.

This extra cost has led to wastes being held in an attempt to find alternative disposal routes, which in turn has resulted in some long standing accumulations of wastes, with consequent problems with storage, e.g. leaking drums.

3.1.2. Records

A waste tracking system should begin at the pre-acceptance stage. With every enquiry a record should be raised (given a unique reference number) which, if the waste recovery enquiry results in waste arriving at site, should "follow" the waste during its acceptance, checking, storage, treatment or removal off-site. If the waste is a regular arising, then the document should be unique to that waste stream. Further details of the requirements of the tracking system are given in Section 3.2. All records relating to pre-acceptance should be maintained at the AD facility for cross-reference and verification at the waste acceptance stage. The length of time records should be held will be determined by whether the waste is actually delivered to the site or likely to be delivered.

3.1.3. Feedstock characterisation and sampling procedures

Characterisation of feedstock material provides valuable information to the operator that can be used to monitor and control the process in order to ensure optimal digestion. Detailed feedstock characterisation by sampling and testing should be conducted as part of establishing a supply contract. Periodic sampling as part of a documented sampling plan should be conducted to test for variation and ensure feedstock is consistent with the supply agreement.

Sampling and testing of feedstock should reflect the nature of the feedstock and how it arises, and any potential variation within the feedstock. The number of samples and period of sampling should reflect the short term and seasonal variation in key parameters in order to derive a set of data that are representative of the specific feedstock. The degree of confidence required also depends on the type of feedstock and how specific parameters lie within the operational envelope of the process. The operator needs to ensure that in accepting and processing the material they will not disturb or kill the biomass, generate emissions that cannot be controlled or abated or impact negatively on the desired quality of the outputs.

Table 6 lists the characteristics that are required to be tested as part of a detailed feedstock characterisation. Details of laboratory testing procedures for each of these characteristics can be found in the Defra report;'WR0212: Optimising Inputs and Outputs from Anaerobic Digestion Processes'

Many of these characteristics are also applicable to testing of substrate within the digester and in quality testing of digestate.

Characteristic	Description
Particle size distribution and physical contaminants	The solid sample is graded using a specified nest of sieves by mechanical vibration shaking. Physical contaminants include the recognisable fragments of glass, metal, plastic and non-combustibles (stones and ceramics).
Total solids and volatile solids	The test portion of sample is dried to constant mass in an oven at 105 ± 5°C. The difference in mass before and after the drying process is used to calculate the total solids and the water content. Then, the dried sample is heated in a muffle furnace at 550 ± 10°C. The difference in mass before and after the ignition process is used to calculate the content of volatile solids and ash.
Biochemical Methane Potential (BMP)	The biochemical methane potential (BMP) assay is a procedure to determine the maximum methane yield of an organic material during its anaerobic decomposition under optimal conditions. This test provides a simple means to monitor relative biodegradability of substrates.
Total Organic Carbon	The total organic carbon (TOC) is obtained by the difference between the results of the measurements of total carbon (TC) and total inorganic carbon (TIC). These values are determined by high temperature catalytic conversion
Nutrient analysis	Elemental analysis is used to test for Carbon, Hydrogen, Nitrogen, Sulphur and Oxygen using combustion and Gas Chromatography. Potassium can be analysed using Flame Atomic Adsorption Spectrometry
Calorific value	Calorific value can be defined as the amount of energy released on burning by each unit of combustible mass. Gross calorific value (higher heating value) is calculated using a bomb calorimeter. Net calorific value (lower heating value), assumes the latent heat of vaporisation of water in the combustion products is not recovered and is defined as the amount of heat released by combusting a specified quantity of sample and returning the temperature of the combustion products to 150°C.
Fibre content	Testing methods are based on parallel steps of chemical treatments to solubilise non-fibre components and final determination of the residue obtained.
pH and alkalinity	pH is measured potentiometrically in the undiluted liquid sample or in a sample/water slurry for semi-solid or solid sample. Alkalinity is a measure of the buffering capacity of water, and digestate with high alkalinity is able to resist increases in acidic or alkaline inputs without any change in pH.

Characteristic	Description
	.
Volatile Fatty Acids	Gas Chromatography (GC) is commonly used to provide accurate speciation of VFA concentration and the procedure is demonstrated in WRAPs Residual Biogas Potential (RBP) testing methodology (WRAP, 2010/2).
Ammonia and Kjeldahl Nitrogen	Ammonia concentrations can be analysed using titrimetric or Spectrophotometric determination. The Kjeldahl method is a means of determining the nitrogen content (in organic and ammonia form) of substances.
Heavy Metals and Potentially Toxic Elements (PTE)	Heavy Metals and PTE can be determined using Flame Atomic Absorption Spectrometry
Carbohydrate and Lipid Analysis	Carbohydrate determination is carried out by the phenol-sulphuric acid method Lipid analysis uses a Soxhlet extraction method (US EPA SW-846, 1998)

Table 6 Characterisation tests

Results of detailed characterisation should be analysed to ensure feedstock can be processed at the facility with no negative impacts on operations or the stability of the digestion process. The supply agreement should include details of procedures that will be undertaken to ensure the required feedstock quality is maintained during acceptance of feedstock at the facility. This may include periodic sampling of feedstock in addition to the defined acceptance criteria. The required sampling frequency will need to be confirmed based on assessment of the levels of variability associated with a feedstock source. A model sampling plan and template is under development with industry.

3.1.4. Indicative BAT requirements for waste pre-acceptance

Indicative BAT requirements for waste pre-acceptance
1 From the waste disposal enquiry the Operator should obtain information in writing relating to: • **the type of process producing the waste** • **the specific process from which the waste derives** • **the quantity of waste;** • **compositional analysis** • **the form the waste takes (solid, liquid, sludge etc)** • **contingency for dealing with non conforming waste and contingency planning in emergency.** **2 Wastes should not be accepted at the AD facility unless suitable for AD treatment. Biological treatment facilities should be aware that agricultural landbank may not be available and alternative recovery/disposal routes may be needed.** **3 The Operator should ensure that the sample is representative of the waste and has been obtained by a person who is technically competent to undertake the sampling process.** **4 Analysis should be carried out by a laboratory with robust quality assurance and quality control methods and record keeping.**

Indicative BAT requirements for waste pre-acceptance
5 Detailed feedstock characterisation by sampling and testing should be conducted as part of establishing a supply contract. Periodic sampling as part of a documented sampling plan should be conducted to test for variation and ensure feedstock is consistent with the supply agreement. **6 Sampling and testing of feedstock should reflect the nature of the feedstock, how it arises and any potential variation within the feedstock. The number of samples and the period of sampling should derive a set of data that are representative of the specific feedstock and take account of short term or seasonal variations in feedstock. Table 6 lists the characteristics that are required to be tested as part of a detailed feedstock characterisation.**

3.2. Acceptance procedures when waste arrives at the AD facility

The control of feedstock quality at an AD facility is a critical part of the successful operation of the facility. It is vital both in ensuring that the digestion process operates efficiently and effectively, and to maintain consistent quality of the outputs. Operators should develop procedures to deal with the identification, removal and management of any contamination. The removal of contamination is an essential requirement for the production of digestate if it is to meet the PAS110 specification.

For waste treatment or transfer, the bulk of the characterisation work should have taken place at the pre-acceptance stage. This means that acceptance procedures when the waste arrives at the site should serve to confirm the characteristics of the waste. This should minimise the time the vehicle delivering the waste is kept waiting.

Measures to deal with acceptable wastes arriving on-site, such as a pre-booking system, must be in place to ensure that capacity is available.

3.2.1. Emergency acceptance

Where facilities provide a service to the emergency services such as the removal of spillages or fly tipped wastes, there may be situations where it is inappropriate to require the pre-acceptance procedures in section 3.1 to be adhered to. As a consequence, some of the acceptance requirements outlined above would also be inappropriate. In such instances the operator should communicate the occurrence to the regulator without delay.

3.2.2. Indicative BAT requirements for acceptance procedures when waste arrives at the AD facility

Indicative BAT requirements for acceptance procedures when waste arrives at the AD facility
The issues to be addressed by the operator in relation to waste acceptance procedures for the AD facility include the following: **<u>Load arrival</u>**

Indicative BAT requirements for acceptance procedures when waste arrives at the AD facility

1 On arrival loads should:

- **be weighed, unless alternative reliable volumetric systems linked to specific gravity data are available**
- **not be accepted into site unless sufficient storage capacity exists and site is adequately manned to receive waste**
- **have all documents checked and approved, and any discrepancies resolved before the waste is accepted. Waste quarantine procedures to be in place.**
- **have any labelling that does not relate to the contents of the container removed before acceptance on site.**

Load inspection

2 Visual inspection. Where possible, confirmatory checks should be undertaken before offloading where safety is not compromised. Inspection must in any event be carried out immediately upon offloading at the AD facility.

3 Check every container to confirm quantities against accompanying paperwork. Following inspection, the waste should then be unloaded into a dedicated sampling/reception area.

4 The inspection, unloading and sampling areas should have suitably sealed drainage systems.

Sampling - checking - testing of wastes - storage

5 All wastes for on-site treatment must be sampled in accordance with the sampling plan and undergo verification and compliance testing.

6 The Operator should ensure that waste delivered to the AD facility is accompanied by a written description of the waste to comply with Duty Of Care.

7 On-site verification and compliance testing should take place to confirm suitability for the site's AD process

8 Wastes must not be deposited within a reception area without adequate space.

9 Should the inspection or analysis indicate that the wastes fail to meet the acceptance criteria (including damaged or unlabelled container), then such loads should be stored in a dedicated quarantine area and dealt with appropriately. Such storage should be for a maximum of five working days. Written procedures should be in place for dealing with wastes held in quarantine, together with a maximum storage volume.

8 If the cause of failure to meet acceptance criteria is due to unsuitability, then the wastes should be segregated to remove cross contamination.

9 Tankered wastes should be sampled prior to acceptance. There should be no storage pending sampling.

10 The driver of the vehicle carrying the waste may arrive at the AD facility with a sample that has been taken at some stage beforehand. This should be the exception and only be relied on if:

- **there are health and safety and environmental control considerations which make sampling difficult, and**
- **the following written information has been supplied - the physical and chemical composition, incompatible substances and handling precautions, information specifying the original waste producer and process, and**

Indicative BAT requirements for acceptance procedures when waste arrives at the AD facility

- **the waste has been taken directly from the production site to the waste treatment AD facility.**

11 The AD facility should have a designated sampling point or reception area.

12 The offloading, sampling point/reception and quarantine areas should have an impermeable surface with self-contained drainage, to prevent any spillage entering the storage systems or escaping off-site.

Sampling of bulk liquid wastes

13 Deliveries in bulk road tanker should be accompanied by a "wash-out" certificate or a declaration of the previous load so that contamination by this route can be checked.

14 The key requirement is to obtain a sample that is representative of the load, that is, the sample takes account of the full variation and any partitioning within a bulk load such that "separation" scenarios are accounted for.

Sampling drummed/IBC waste

15 The contents can only be identified with certainty if every container is sampled. Acceptance should involve sampling every container. However, analysis of composite samples is acceptable with such a sampling regime. A representative sample must be obtained by taking a core sample to the base of the container.

Drum/IBC labelling

16 For drummed waste, controls should ensure each drum is given a label to facilitate it's on site storage and further use.

Waste rejection procedures

17 The operator should have clear and unambiguous criteria for the rejection of wastes, together with a written procedure for tracking and reporting such non-conformance. This should include notification to the customer/waste producer and the Environment Agency. Written/computerised records should form part of the waste tracking system information. The operator should also have a clear and unambiguous policy for the subsequent storage and disposal of such rejected wastes. This policy should achieve the following:

- **identifies the hazards posed by the rejected wastes**
- **labels rejected wastes with all information necessary to allow proper storage and segregation**
- **arrangements to be put in place**
- **segregates and stores rejected wastes safely pending removal**

Records

18 The waste tracking system should hold all the information generated during pre-acceptance, acceptance, storage, treatment and/or removal off-site. Records should be made and kept up to date on an ongoing basis to reflect deliveries, on-site treatment and despatches. The tracking system should operate as a waste inventory/stock control system and include as a minimum:

- **date of arrival on-site**

Indicative BAT requirements for acceptance procedures when waste arrives at the AD facility
producers details   **all previous holders**   **a unique reference number**   **pre acceptance and acceptance analysis results**   **package type and size**   **intended treatment/disposal route**   **record accurately the nature and quantity of wastes held on site**   **where the waste is physically located in relation to a site plan**   **where the waste is in the designated recovery/disposal route**   **identification of operators staff who have taken any decisions reacceptance or rejection of**   **waste streams and decided upon recovery / disposal options**   **19 All records relating to pre-acceptance should be maintained and kept readily available at the AD facility for cross-reference and verification at the waste acceptance stage. Records should be held for a minimum of two years after the waste has been treated or removed off-site.** **20 The system adopted should be capable of reporting on all of the following:**   **total quantity of waste present on-site at any one time, in appropriate units, for example, 1 cubic meter IBC equivalents**   **breakdown of waste quantities being stored pending on-site treatment**   **breakdown of waste quantities on-site for storage only, that is, awaiting onward transfer**   **breakdown of waste quantities by hazard classification if applicable**   **indication of where the waste is located on site relative to a site plan**   **comparison of the quantity on site against total permitted**   **comparison of time the waste has been on-site against permitted limit**   **These records should be held in an designated area, as agreed with the Regulator, well removed from hazardous activities to ensure their accessibility during any emergency** **21 Back-up copies of computer records should be maintained off-site.** **<u>General</u>** **22 Wastes should not be accepted without sufficient capacity being available. These checks should be performed before the waste acceptance stage is reached** **23 The operator should ensure that the installation personnel who may be involved in the sampling, checking and analysis procedures are suitably qualified to industry standards and adequately trained, and that the training is updated on a regular basis.** **24 Analysis should be carried out by a laboratory with suitably test methods.** **25 Samples should be retained on-site for a minimum of two days after the waste has been**

Indicative BAT requirements for acceptance procedures when waste arrives at the AD facility
treated. **24 Once analysis in accordance with the sampling plan has confirmed that the waste is acceptable, the Operator should only then create a batch for AD treatment. Once a batch has been assembled for treatment, the operator should create a composite sample for analysis prior to treatment. Scope of analysis depends upon intended treatment but should be specified.**

3.3. Waste reception and storage

3.3.1. Feedstock acceptance and storage

The provision of adequate facilities for the acceptance and storage of feedstock materials is a vital part of operating a successful AD facility. Feedstock acceptance facilities should enable feedstock to be delivered in a controlled and safe manner whilst minimising potential for release of fugitive emissions. Feedstock storage can provide buffering capacity that can be utilised to compensate for fluctuations in feedstock supply and can also facilitate mixing of feedstock materials to optimise substrate degradation in the digestion process.

Feedstock material should ideally be utilised as soon as possible in order to prevent its de-composition prior to digestion to reduce avoidable fugitive emissions and prevent loss of biogas yield. Lack of control and management of materials within reception facilities may also lead to problems within the biological process as acidification of carbohydrate-rich feedstock can proceed rapidly at ambient temperatures potentially leading to sub-optimal digestion conditions.

Process requirements for PAS110 are that input materials, the process and steps used to make the whole digestate and any separated liquor and separated fibre fractions, shall be stored separately from any other materials, processes and stores on the same site. Therefore storage facilities and procedures must be designed to ensure no cross contamination occurs between inputs and outputs of the process. Each treatment and storage vessel and area shall be clearly labelled, and correspond with the production process described in the document system, including the process flow diagram. Details of feedstock storage requirements should be contained within the site management system.

If an AD facility is storing agricultural slurries prior to treatment the level of slurry must be checked regularly and arrangements made to ensure that the freeboard is maintained (see Section 3.3.10 for minimum freeboard requirements). Particular care must be taken to ensure that lagoons or stores do not overflow.

3.3.2. Feedstock reception and storage

A reception area for the solid feedstock is usually required to receive the feedstock, check the quality of feedstock, pre-treat the feedstock and process it through the plant. The reception area is typically enclosed in a building which is kept under negative air pressure; this along with door management reduces the likelihood of fugitive emissions, including noise, dust and odour. Exhaust air from the reception hall should be treated prior to discharge to atmosphere. The design must provide adequate space to allow control over waste delivery in order to minimise the amount of time that feedstock is stockpiled before being processed.

Storage of both feedstocks (prior to digestion) and digestate products is an important consideration that impacts both the operation of the facility and the capital cost. It is critical that the digesters are fed regularly to avoid depletion of the biomass as a result of starvation; so the upstream tank should be sized to have a residence time to account for weekends, public holidays and when feedstock is not available and not brought to site as scheduled.

All feedstock storage must comply with the requirements of environmental permitting and with the good agricultural practice guidelines. If feedstock contains animal by-products, then the storage and handling systems must be compliant with the requirements of the Animal By-Products Regulations.

The main objectives for the storing of material prior to processing are as follows:

- Store the waste safely and
- Provide adequate accumulation time (contingency storage space).

The key issues for storage are:

- Location of storage area
- Storage Area infrastructure
- Condition/containment of Containers
- Feedstock Control
- Building Air Handling/Air Changes
- Segregated storage of materials and
- Containment to protect the environment and workers health.

3.3.3. Weighbridge / Weighing facilities

A weighing facility for feedstock is an important requirement if feedstock is being imported from off-site. Recording of material inputs and outputs is required for the Environment Agency and HMRC purposes, as well as for processing waste transfer notes if biowaste material is being accepted. Collecting information regarding the quantities and properties of material processed at an AD facility is also important for the management and operation of the process in order to monitor and optimise gas yields.

3.3.4. Feedstock acceptance

The level of infrastructure required for feedstock acceptance will depend on the scale of the operation in terms of quantities of feedstock to be processed and also the material properties of the feedstock to be accepted. Small scale AD facilities may only require storage for materials generated on site such as agricultural manures and slurries. Larger scale commercial operations will require infrastructure and facilities to accept multiple feedstock deliveries. Depending on the configuration and type of process the feedstocks may be delivered using simple tractor and slave units for agricultural units or even pumped directly from slurry stores. Commercial AD plants may need to receive waste directly from food waste collection vehicles or via transfer on larger articulated lorries delivering up to 30 tonnes per load.

Where the AD facility forms part of an operation in which biowastes are pre-treated (typically depackaging) at an off-site facility, feedstock is often received as a slurry. In this configuration the feedstock is tankered into the AD plant and pumped directly into a storage tank.

3.3.5. Process areas

It is considered good practice that any AD site should be laid out so that there is a one way flow of material from intake of feedstock to removal of the digestate products. Where the feedstock falls under the ABPR, procedures must be in place to ensure that unprocessed feedstock cannot contaminate the digestate products either directly or via personnel or equipment. Developers should ensure that the site design and layout allows this requirement to be met effectively.

Developers should ensure that sufficient space around the digester and other equipment is considered in the layout as this will be required to allow easy access for maintenance and operation. Nearly all digesters have to be cleaned out at some time over their lifetime so this should be considered before construction.

3.3.6. Reception hall

For most commercial plants, a reception area for the solid feedstock is usually required to receive feedstock, check the quality of feedstock and perform basic pre-treatment. The reception hall should allow for the segregation of Animal By-Product (ABP) wastes where accepted to reduce the risk of cross contamination and should allow for the quarantine of waste not considered suitable for treatment. Additional controls include foot baths, dedicated equipment and sealed drainage.

For permitting purposes, the operating areas for unloading, preparing and processing feedstock must be an impermeable paved surface (i.e. to prevent the transmission of liquids beyond the pavement surface) designed to the relevant Eurocode or British Standard. Operators shall demonstrate that the surface design is suitable to accommodate all of the static and dynamic loads imposed by the vehicles, stored materials, machinery and process plant within the proposed facility. The pavement design, construction and maintenance shall take into account the movements, reversing and tipping of vehicles, the use of unloading areas for storage of waste, the use of mechanical shovels on the floor to move waste, water containing contaminants dripping from vehicles and the washing down of the floor for cleaning purposes. Feedstock unloading and preparation areas shall be finished with a proprietary finish to provide sufficient resistance to chemicals and abrasion for the stated design life. The surface shall have appropriate skid resistance and be suitable for pressure jet washing.

The reception area should be within an enclosed building maintained under negative air pressure with discharges via an emissions abatement system in order to minimise odour and dust release and to reduce noise during unloading, storage or handling operations. Areas of higher odour should be remote from main areas of access.

The air extraction system should be sufficient to ensure three air changes per hour and dead spaces are minimised. Higher extraction rates may be appropriate for certain sensitive locations. The system should be designed to allow higher numbers of air changes within the building where there is possibility of higher or more acute odour release. Any air movement should be controlled to ensure air flows are from low odour areas to high odour areas. Operators should consider the use of air lock entrances at sites with sensitive receptors. Lower extraction rates may also be appropriate for agricultural sites and may be reduced at times when site activity is reduced, such as overnight. Fast acting roller shutter doors should be provided for access and egress by delivery and other vehicles.

When designing the unloading, preparation and maturation areas adequate design features should be put in place to enhance housekeeping on site.

The reception area should be designed to facilitate cleaning including drainage to allow discharge of wash waters into gullies and to a sump for use within the process. All reception areas must have an impervious surface with self-contained drainage and bunded or high kerbing to prevent any spillage entering the storage systems or escaping off-site. The design should prevent the contamination of clean surface water. Where ABP material is processed, wheel-wash facilities should be provided for disinfecting delivery vehicles on exit from the reception hall. The provision of water and steam should be considered in order to allow for cleaning of vehicles and other transport equipment following delivery. Steam cleaning should be conducted in an enclosed area.

The reception area must be designed appropriately for the properties of the anticipated feedstock inputs to the facility. It is also essential that the reception area includes sufficient space and flexibility to manage changes in the volume and properties of feedstock and vehicles that could occur over the lifespan of the facility.

Where feedstock deliveries are required to be offloaded for inspection and acceptance sampling prior to pre-treatment the reception areas should be segregated (typically into bays) and managed to ensure waste is not stored for more than 5 days. Where a bay is utilised it should be cleaned weekly.

Should the inspection or analysis indicate that the wastes fail to meet the acceptance criteria, then such loads should be stored in a dedicated quarantine area and dealt with appropriately. Such storage should be for a maximum of five working days.

For agricultural plants treating manures and slurries the requirements for the reception area may be limited to incorporate a covered area such as a Dutch barn sited on impermeable surface to prevent unnecessary leachate formation and run off. Drainage should be designed as for larger plants with clear segregation and management of clean rainwater and dirty water on site.

At the waste reception stage the feedstock material should remain in storage for the least time possible. Operators should empty their bunkers periodically (at least once a week) to prevent a build up of older waste in the bunker. This is because a high proportion of waste is putrescible and will degrade aerobically and depending on the depth, anaerobically, generating odour and leachate. Operators should follow a First In First Out (FIFO) procedure whereby older deliveries of waste are removed before newer waste has been deposited in the bunker.

3.3.7. Building ventilation

AD facilities will include a building ventilation system and an odour abatement system (see Section 7.6 on odour). The function of the building ventilation system is to:

- Supply fresh air to occupants and
- Ensure the air in the room is changed sufficiently to ensure smells, fumes and contaminants are removed.

Operators should refer to the CIBSE Guide B - Heating, Ventilation and Refrigeration, which provides ventilation rates for industrial buildings and methods of calculation.

Extracted air from buildings with lower levels of odour can be re-circulated within buildings with higher levels of odour. For example, extracted air from the Feedstock Reception Building can be re-circulated in the Biological Treatment Buildings. In this way, the volumes of extracted air requiring treatment in the odour abatement system will be optimised.

Air extracted from AD buildings, where there is a likelihood of dust generation, should be processed through a dust filter prior to being re-circulated within other facility buildings thereby preventing dust emissions and maintaining appropriate working conditions.

3.3.8. Storage capacity and type

The dimensioning of storage facilities is determined by the quantities to be stored, delivery intervals and the daily amounts fed into the digester and the need to turnaround materials to meet the storage time limits.

The properties of the feedstock such as moisture content will also determine the type and capacity of storage required. Storage capacities typically need to be designed to ensure a continuous or semi-continuous treatment process. Commercial AD plants will require access to up to several hundred tonnes of feedstock at any time, so extensive storage facilities are likely to be needed to ensure continuity of supply over weekends (when traffic movements may be controlled) and holidays.

Sufficient storage space should be available to provide contingency. Contingency plans for feedstock acceptance are extremely important in order to ensure feedstock can be accepted, contained, and processed effectively.

Types of storage facility include bunkers and tanks for biowaste material and storage for agricultural materials including slurries and crop storage. These are discussed further below:

3.3.9. Storage bunkers and tanks

Storage bunkers are used to store feedstock brought onto site and may include movable divisions to allow flexibility to hold feedstock separately before pre-treatment and adding to the digester to assist plant management and avoid risk of contamination between feedstock.

Storage tanks are generally constructed above ground level for more cost effective construction and for ease of ongoing maintenance, but may include a reception tank that is below ground level for ease of discharge from delivery transport vehicles using gravity. However pumping will be required to extract feedstock from below ground level storage and consideration should be given to the health and safety implications of designs which introduce the need to clean and maintain areas which may be assessed as confined spaces.

Storage tanks may include a mechanism for agitation, which in the simplest form would use the transfer pumps with jetter systems to recirculate the feedstock, but mechanical propeller agitation, or forced air agitation may be selected according to the type of feedstock being stored, the planned length of time stored, and the potential for separation and settlement within the stored feedstock.

Storage tanks should be located on an impermeable surface with sealed construction joints and must be provided with appropriate secondary containment that can accommodate a volume at least 110% of the total capacity of the tank. Where tanks are within farms the secondary containment should be capable of managing at least 110% of the volume of the largest vessel or 25% of the total tankage volume, whichever is the greater. Any bunds used shall be regularly inspected to ensure that rainwater is regularly emptied and all connections and fill points should be within the bunded area with no pipework penetrating the bund wall.

Bunkers that contain odorous or potentially odorous waste should be enclosed or located inside a building and should either be gas tight with air venting, or maintained under negative pressure by air extraction via an appropriate odour abatement system. Where there is ventilation local to the storage equipment this should be managed as part of the site fugitive emissions abatement system.

3.3.10. Slurry storage

Digesters treating livestock slurries need to cater for the seasonality in the collected and available slurry.

Storage must provide at least 750mm of freeboard (earth-banked stores) or 300mm (stores constructed of materials other than earth)

Temporary slurry storage systems should be of sufficient size to store a minimum of two days' combined slurry production (including all urine, parlour washings etc) and likely rainfall. The amounts of slurry collected can be minimised by providing separate drainage for clean roof water and clean yard water. Farmers are advised to consider roofing over stores and outside soiled yard areas to keep rainfall out.

3.3.11. Crop storage (ensilement)

The most common technique for ensiling crops is to tightly stack the crop between concrete walls in "clamps" and sealed with a weighted plastic sheet. The silo may also have a roof cover. Tightly packing the crops creates anaerobic conditions that help preserve the crop via fermentation.

A bag silo may be used in place of a clamp. The capacity of a typical bag silo is about 6,000 tons. In smaller crop digestion plants, conventional big bale silos (capacity 660 kg of silage) are applied for silage preparation and storage.

Silage produces a liquid effluent when it is compressed and ensiled, which must be collected and stored safely, and this can be used as part of the AD feedstock. Silage storage on farms must meet the construction standards specified within the SSAFO regulations see Statute Law Database link in appendix D.

3.3.12. Indicative BAT requirements for Waste reception and storage (also see Emissions of substances not controlled by emission limits to surface water, sewer and groundwater)

Indicative BAT requirements for Waste reception and storage
<u>**Reception**</u> 1. **The reception area for the feedstock/waste should be appropriately sized to accommodate the expected volume and properties of feedstock, check the quality of feedstock and perform basic pre-treatment.** 2. **The reception area should allow for the segregation of Animal By Product (ABP) wastes where accepted to reduce the risk of cross contamination.** 3. **Where feedstock deliveries are required to be offloaded for inspection and acceptance sampling prior to pre-treatment the reception areas should be segregated (typically into bays) and managed to ensure waste is not stored for more than 5 days. Where a bay is utilised it should be cleaned weekly.**

Indicative BAT requirements for Waste reception and storage

4. **Should the inspection or analysis indicate that the wastes fail to meet the acceptance criteria, then such loads should be stored in a dedicated quarantine area and dealt with appropriately. Such storage should be for a maximum of five working days.**

<u>Ventilation</u>

5. **The reception area should be within an in enclosed building and will include a building ventilation system and an odour abatement system that maintains the building under negative air pressure in order to minimise odour and dust release and to reduce noise during unloading, storage or handling operations. The air extraction system should be sufficient to ensure at least 3 air changes per hour or equivalent, higher extraction rates may be appropriate for certain sensitive locations.**
6. **Operators should consider the use of air lock entrances for sites located in sensitive areas.**
7. **Fast acting roller shutter doors should be provided for access and egress by delivery and other vehicles.**

<u>Surfacing and Drainage</u>

8. **The reception area should be designed to facilitate cleaning including drainage to allow discharge of wash waters into gullies and to a sump for use within the process.**
9. **All reception areas must have an impermeable surface with self-contained drainage, to prevent any spillage entering the storage systems or escaping off-site. The design should prevent the contamination of clean surface water.**
10. **Where ABP material is processed, wheel-wash facilities should be provided for disinfecting delivery vehicles on exit from the reception hall.**
11. **The provision of water and steam should be considered in order to allow for cleaning of vehicles and other transport equipment following delivery. Steam cleaning should be conducted in an enclosed area.**

<u>Storage</u>

12. **Should the inspection or analysis indicate that the wastes fail to meet the acceptance criteria, then such loads should be stored in a dedicated quarantine area and dealt with appropriately. Such storage should be for a maximum of five working days.**
13. **Impermeable surfaces and sealed drainage systems should be provided for all areas where waste is stored and/or treated, to prevent contamination from any spillages.**
14. **Any above ground tanks used for the storage of feedstock, digestate or any other liquids whose release could be harmful to the environment must be located on an impermeable surface with sealed construction joints and must provided with appropriate secondary containment that can accommodate a volume at least 110% of the largest vessel or 25% of the total tankage volume, whichever is the greater. Any bunds used shall be regularly inspected to ensure that rainwater is regularly emptied and all connections and fill points should be within the bunded area with no pipework penetrating the bund wall.**
15. **Any below ground tanks or sumps should be constructed with secondary containment and an appropriate leak detection system.**
16. **Any tanks that contain odorous or potentially odorous waste should be**

Indicative BAT requirements for Waste reception and storage
enclosed/covered gas tight and with any venting via an appropriate odour abatement system. **17. Storage areas for drums, bags etc should be designed and managed to prevent any spillages being released into the environment.** **18. Bunkers that contain odorous or potentially odorous waste should be enclosed or located inside a building and should either be gas tight with air venting, or maintained under negative pressure by air extraction via an appropriate odour abatement system. Where there is ventilation local to the storage equipment this should be managed as part of the site fugitive emissions abatement system.** **19. Storage capacities typically need to be designed to ensure continuity of supply over weekends (when traffic movements may be controlled) and holidays.** **20. The storage of digestate that is scheduled for spreading to land needs to take into account the closed season for spreading to land and the likelihood of adverse weather conditions that may affect the ability to spread digestate. Storage capacity of digestate needs to take these factors into account.**

Treatment - general principles

4.1. Pre-treatment

The objectives of pre-treating feedstock will typically include:

- Removing packaging material from food waste (depackaging)
- Removing other non-biodegradable materials, which are not affected by digestion and take up necessary space
- Providing a uniform small particle size feedstock for efficient digestion
- Protecting the downstream plant from components that may cause physical damage
- Removing materials which may decrease the quality of the digestate

The required level of feedstock pre-treatment is dependent on the nature of the feedstock material and also the type of digestion process employed. Overall requirements for treatment are to remove non-biodegradable material and contaminants from feedstock and also to provide optimal substrate characteristics to enable an effective and efficient digestion process. Pre-treatment requirements should be decided at an early stage of the project design and be able to provide flexibility appropriate to process the types of feedstock anticipated to be accepted at the facility.

The following sections provide an overview of typical pre-treatment techniques used in an AD process. Depending on the AD facility, a combination of these techniques may be utilised in series.

4.1.1. Manual sorting

Manual separation involves a visual examination of the feedstock material by facility staff on a picking line or on the floor of a reception hall. In an AD facility treating biowastes this technique is generally limited to the removal of large contaminants and oversize materials at the reception stage. These will be removed by hand and stored on site for onward reprocessing. Operators should consider the need for manual sorting carefully and should consult the Health and Safety Executive for current best practice on manual handling.

4.1.2. Mechanical pre-treatment

Mechanical pre-treatment processes include sorting processes to remove contaminants, reduce particle size and provide mixing / homogenisation. Prior to pre-treating the waste the operator must have an understanding of the process requirements as these vary according to the type of system being used.

Table 7. Provides an overview of typical mechanical pre-treatment techniques applicable to an AD process.

Equipment Type	Description
Sieving/ screening	Used to separate large particles. Vibrating sieves, static sieves and rotary sieves are used.
Trommel screen	Rotating perforated cylinder used to separate materials by size. Can be used in series with various screen sizes to increase effectiveness of sorting. The screen sizes selected depend on the feedstock delivered and the characteristic required for the AD process.
Bag Splitter	Comprises a shredder that generally rotates at a low speed and high torque to split up bags containing feedstock. This action exposes the waste to the remainder of the process whilst leaving it intact. Rather than send the entire waste stream through the bag splitter the bagged materials are often pulled from the processing line in the pre-sort area and sent through the bag splitter. These materials will then rejoin the processing line
Sedimentation	Sedimentation is used to separate particles of solid material in suspension within a fluid. The sedimentation process uses gravity to remove sands, silt and other contamination present in the waste stream. The sedimentation process concentrates the organic solids, which are periodically removed. In a de-gritter (grit channel) the velocity of the incoming waste is adjusted to allow the settlement of grit. Grit is best removed to avoid damage to pumps and other equipment.
Hammer Mill	Method of size reduction consisting of a horizontal or vertical shaft, with mounted steel hammers, enclosed within a casing incorporating a screen. The hammers can be fixed or pivoted where they attach to the shaft. As the shaft rotates, the hammers break-up the material until it can pass through the screen. The number of hammers and size of screen assist in determining the

Equipment Type	Description
	extent of size reduction
Wet Rotating Drum with knives	Feedstock is made wet to form heavy lumps of material. This material is then broken up with knives during the rotation of the drum
Pulverisers	Method of shredding. Twin 'breaker' shafts comprising multi-blade breaker knives which contra-rotate, pulverising and mixing the waste the
Hydro pulper	Non-biodegradable materials are taken out of suspension due to their different densities. The light fraction floats on the surface of the suspension while the heavy fraction is removed by a lock system at the bottom of the pulper.
Homogenisers	Standard equipment for crushing / pulverising of hard solids in a liquid, dispersing fine particles evenly.
Cyclone	Cyclones use centrifugal forces to separate materials by density. This may be used to reduce the liquid content of a feedstock.

Table 7 Mechanical pre-treatment techniques

4.1.3. Food waste de-packaging equipment

Food waste de-packaging equipment is designed to remove non-biodegradable packaging material from delivered food waste prior to digestion.

De-packaging equipment may include elements of the mechanical pre-treatment technology described above and typically includes a bag splitter, a feeding conveyor or hopper and a unit with blades, screws, breaker bars or crushers for shredding and breaking apart the packing material. This is followed by a screening stage comprising various screens depending upon the technology, product size and consistency. De-packaging systems may operate by using cylinders or screws that apply pressure and separate liquids/paste from packaging material. The residual packaging may subsequently be rinsed with water to wash any remaining organic feedstock from the packaging material.

Table below provides a summary of de-packaging equipment types and performance as listed on the WRAP food waste de-packaging webpage. Further details and supplier contact details are provided on the WRAP website (see links in Appendix D). The separation efficiencies listed in are the quoted values from equipment suppliers. Practical experience suggests that these are rarely achieved and this needs to be taken into consideration when designing a plant as it has implications on many technical and economic aspects of design and operation.

Equipment Type	Suitable Material	Details	Capacity / Performance
Turbo Separator	Beverages, biscuits, baby foods, cereals, coleslaw, coffee, custard, food tins,	Flanged inlet, variable speed, beater blades and breaker bars. Various screens depending upon	1-20tph Separation efficiency up to 99%

Equipment Type	Suitable Material	Details	Capacity / Performance
	gravy granules, household products, pasta, pet foods.	product size and consistency.	
Belt / Drum separator	Partly damaged goods, shelf life expired articles, packages made of cardboard, paper, plastics, aluminium foil composite film with pasty to liquid contents.	Flexible squeezing belt and rotating perforated drum.	Various capacities Separation efficiency ~ up to 97%
Separator	All types of mixed food waste including those packaged in: plastic, tins, glass bottles.	Screw elevator feed. Batch process rotary action, substrate passed through sieves and the plastic fraction is washed before passing through an eject hatch aided by a pulsating compressed air blast. Washed packaging material contains <1% organic fraction.	7.5 to 10 tonnes per hour Separation efficiency up to 95% for mixed packaged waste
Shredder and pulper	Pre-packaged food waste, out-of-date food waste, packaging waste.	Slow-running shredders Dissolution of the organic materials in a pulper and separation of contaminants.	Throughput capacity: (15,000 tpa) Separation efficiency (%): 90-95% in conjunction with Hydro-pulper
Shredder and screen	Plastic packaging, tins, glass.	Feed hopper, 2 screw conveyors, 2 shredders and a separating screen Material sprayed with water. Liquidised food waste runs back down into a hopper, solid waste is discharged at the top into a container	Throughput capacity (t/h): 4-8 Separation efficiency up to 99%
Screw Press	Mixed supermarket waste, liquid and pasty foodstuffs in cans, tetra-Pack	Material fed to screw press via filter chute. Conical outlet remains closed until the internal	Throughput capacity (t/h): 1-3t/h, or 8-12t/h

Equipment Type	Suitable Material	Details	Capacity / Performance
	products, beverages in PET bottles, tinned packaging. Dairy and ice cream products.	pressure exceeds the working pressure. Internal pressure drives free liquids/ pastes through perforated screen discharging separated foodstuff into a hopper. Packaging retained and discharged.	Separation efficiency 70 – 95%, depending on material
Screw Press	Filled drinks cans, creamy spray cans, preserving cans/ tins, soft packaging, PET packaging.	Packaging presses operate electro-hydraulically. Material fed manually into supply funnel or fully automated via conveyors. Separated liquid collected in large-volume collection trough and discharged by a separate level-controlled pump.	Throughput capacity (m^3/h): 2.4 – 17,8 Separation efficiency (%): 99
Pulveriser	All liquid filled containers, dairy products, biscuits, cereals Granules (e.g. coffee, sugar, salt and gravy), Pasta Tinned Foods Cosmetic Items Pharmaceuticals Plasterboard, industrial cake or filter cake	Materials fed into pulveriser via an infeed hopper. Twin 'breaker' shafts comprising multi-blade breaker knives which contra-rotate, pulverising the packaging and releasing the contents against an interchangeable breaker bar grille.	Up to 25 tonnes per hour (dependent upon mix) Separation efficiency up to 99%.
Accelerator	Mixed food waste Packed food waste Unpacked food waste Slaughter house waste Food waste and green waste mixed Energy crops	Material accelerated within a chamber results in one material hitting another, releasing contents from the packing. Process involves no cutting just acceleration resulting in low operating costs. Packaging and contraries are then removed. Organic fraction is	4 – 20 tonnes per hour Separation efficiency up to 99% dependant upon down removal

Equipment Type	Suitable Material	Details	Capacity / Performance
		completely broken down with maximum surface area.	
Belt Press	Removes food from packaging. Handles both cans and plastic packs.	Two stages. Packaging opened and pressed flat in a continuous operation then cleaned in the second stage. Solids in rinsing water circuit removed, packages ejected at the end of the sieve drum. Can be combined with a feeding and discharging facility	Throughput capacity (t/h): 1-7 (tins) Separation efficiency (%): 90-98 depending on feedstock

Table 8 Examples of Food Waste De-packaging Equipment (source: WRAP)

4.1.4. Chemical pre-treatment

Chemical pre-treatment includes oxidative treatments and the addition of acids or alkalis. It is typically used to improve the digestibility of feedstocks containing complex polymeric substances such as cellulose and hemicellulose. This will include some energy crops with hard stem material such as cereal straw, and secondary sewage sludge. Strong acids or alkaline chemicals can be used to mediate chemical hydrolysis of complex woody polymers and to break open cell walls. This facilitates further hydrolysis and digestion within the digestion process. Alkali pre-treatment in particular can be particularly advantageous when using plant material in an AD process.

4.1.5. Thermal and thermo-chemical pre-treatment

Thermal and thermo-chemical pre-treatment refers to the use of thermal or a combination of thermal and chemical methods to enhance the digestibility of polymeric substances and cellulose and hemicellulose rich feedstocks. The addition of heat increases the rate of the chemical pre-treatment which will reduce the capacity of the pre-treatment vessel or reduce processing time. Reaction conditions may be made more aggressive through the application of pressure.

During thermal treatment the substrate is subjected to low temperatures (<100 °C) or high temperatures (>100 °C) at elevated pressure to prevent evaporation.

High temperature heating is often performed by steam injection and in the specific case of ‘‘steam explosion’’, the pressure is quickly released in a flash tank. When the temperature increases above 150-180°C and when there is a fast decrease in pressure, microbial cells are disrupted and polymeric substances, hemicelluloses and even lignin can become soluble, thus decreasing the time required for hydrolysis. Thermal pre-treatment is currently under full-scale operation at some AD Waste Water Treatment Plants (WWTP) and several food waste plants in European countries. Laboratory and bench scale testing has been applied to all categories of feedstock material including food waste, energy crops and manures.

Freeze/thaw relies on freezing the material from between -10 and -80 °C with subsequent thawing and it has been applied mostly to Waste Water Treatment Plant (WWTP) residues and to a much lesser extent than other thermal pre-treatments

Research is currently being conducted into the use of novel chemical pre-treatment techniques including Microwave Irradiation (MW), which has been applied to all categories of substrates, and Pulsed Electric Fields (PEF), that has been investigated for WWTP residues and manure. Wet Oxidation (WO) is a thermal pre-treatment conducted under high pressure with the addition of oxygen. This technique has traditionally been used for the pre-treatment of lignocellulosic biomass prior to bioethanol fermentation. These techniques correspond to new innovative attempts of rendering pre-treatment for AD more efficient and are at an early stage of development.

4.1.6. Ultrasonic pre-treatment

This technique is commonly used to break down complex polymers in the treatment of sewage sludges. Mechanical shear forces from ultrasonic cavitation alter the sludge characteristics prior to digestion and have been shown to increase methane yields.

4.1.7. Biological pre-treatment

Biological hydrolysis is a method of speeding up the hydrolysis stage of the AD process. The feedstock is fed into a vessel in which the environmental conditions (temperature and pH) are optimised for the microorganisms that facilitate hydrolysis to thrive. Where the biological pre-treatment process is operated anaerobically, this may be viewed as the first stage in a multi-stage digestion process. The configuration of processes as single or multiple stages depends on the technology provider, the feedstock as well as other technical and commercial considerations. Multi-stage digestion systems are discussed in more detail in Section 4.3.3.

Enzyme addition is a means of accelerating the process of breaking down the cellular structure of the feedstock material. Enzymes can either be dosed into a separate pre-treatment stage or directly into the digester feed. Biological enzymes include the use of cell lysate to speed up hydrolysis of a feed material.

4.1.8. Nutrient addition

The addition of nutrients to a feedstock may be required where the intrinsic nutrient content in the feedstock is known to be low or where biogas yield is lower than expected. This may require the addition of nitrogen or phosphorous via alternative feedstocks such as agricultural slurries or supplementing the feed with trace elements. Commercially produced trace nutrient supplements are available for this purpose and may be considered by an operator to improve digestion performance and biogas yields. However, studies have shown that the addition of micro-nutrients is not an effective strategy for the recovery of a severely VFA-laden digester. Where the feedstock is rich in nitrogen, a carbon rich feedstock such as glycerol may be added with caution to prevent excessive ammonia formation. A full investigation of all the possible causes of poor biogas yield should be carried out first before considering nutrient addition. The operator should understand that there are risks associated with any change to the substrate mix and it is a balanced and steady composition that is essential.

4.1.9. Third party / off-site pre-treatment

Pre-treatment of feedstock material can be conducted off-site from the AD treatment facility at a third party facility. In an example, source separated food waste collected from households is accepted at a centralised processing facility where pre-treatment may include de-packaging, homogenisation, blending and possibly pasteurisation prior to transportation by tanker to one or more AD plants for treatment. This has been referred to as the Hub and PoD (Point of Digestion) concept. The objectives and requirements for pre-treatment at a third party facility are equivalent to an on-site facility. The pre-treatment facility will require a separate site permit and biowaste material must be transported to and from sites in accordance with Duty of Care legislation.

4.1.10. Pasteurisation

A pasteurisation stage is required if an AD operator is treating ABP material and is also a requirement for PAS110 certification with few exceptions. Pasteurisation temperatures must be continually monitored to ensure compliance with the regulations.

If the feedstock includes Animal By-products then temperatures must be maintained at required levels set out in the Animal By-Products Regulations to ensure sanitisation has been achieved. Refer to Table 9 for required ABP pasteurisation temperatures. Further information regarding the ABPR approval process can be found on the animal health website (see links in Appendix D).

To qualify for PAS110 certification, digested materials must be produced by an AD process that includes a pasteurisation stage (with few exceptions) as specified by the ABP regulations even if not digesting any ABP material. Operators should refer to the PAS110 specification for full details.

There are EU and National standards for minimum temperature and time and maximum particle size that AD plants processing Category 3 ABP or Category 3 ABP including catering wastes can apply. These requirements are summarised in Table 9. below:

Minimum Temperature	Minimum Time	Maximum Particle Size
EU Standard		
70°C	1 hour	12 mm
National Standard (option for catering waste only)		
57°C	5 hour	50 mm
70°C	1 hour	60 mm

Table 9 Animal By-Products Pasteurisation Requirements

For low solids feedstocks pasteurisation can be achieved in a number of ways both pre and post digestion. A commonly used system involves pumping substrate through a heat exchanger to slightly above the desired temperature before leaving it to reside in a highly insulated tank for the required time. Most plants operate on the 70°C:1 hour pasteurisation conditions. The heat for the exchanger is provided by hot water taken from the jacket and exhaust of associated engine generators on the CHP unit or from a boiler output.

Thermometers and stirrers in the tank ensure that the required temperature is met in all of the material. Multiple pasteurisation tanks (typically three or more) may be used in order to process feedstock on a batch basis with one tank filling, one discharging and the third being held at the required temperature. This helps to provide a regular supply of feedstock to the digester. The heat from pasteurised material may be recovered via heat exchangers to reduce feedstock to the required digestion temperature.

For high solids feedstocks, pasteurisation can be achieved by augering material into a highly insulated tank and applying heat via heating elements or steam lances. The elements will be situated in the centre of the vessel, whilst temperature probes will be situated in the vessel walls to ensure that the material has reached the required temperature throughout. After a period of 1 hour, the material can be augered out of the bottom of the tank into a sealed storage tank.

Capturing heat from the dry material for re-use is very difficult due to the insulating properties of the dry material. The pasteurisation process can pre-heat feedstock prior to digestion at mesophilic or thermophilic temperatures, which is often a requirement in high solids systems due to operational difficulties in achieving the required temperature within the digester.

4.2. Loading techniques

The biodegradable feedstock is introduced to an anaerobic process either as a batch or continuously. This loading of the process is also referred to as feeding the digester.

4.2.1. Continuous flow systems

In continuous systems feedstock is continually fed into the digester and the digestate outputs are similarly continuously discharged. Where the feedstock is consistent (either as it arises or as a result of storage and pre-treatment) this enables a more stable rate of digestion and biogas production, allowing downstream gas processing systems to be optimised. Some systems may be operated in a semi-continuous process whereby an amount of feedstock is added to the digester and digested material is removed in batches representing a proportion of the total digester content. Biogas is generated continuously in both options although the semi-continuous feeding yields some natural diurnal variation in gas production rates.

4.2.2. Batch fed systems

In batch fed systems, digesters are filled entirely with fresh feedstock and the digested contents are removed following the required retention time leaving only a small fraction to inoculate the next batch. Batch fed AD systems are designed to be less complex and are typically more suited to smaller scale applications. Batch processes are considered relatively robust, however, a lack of mixing in the digester may lead to substrate stratification, a reduced area of active digestion resulting in less efficient digestion. Therefore batch fed systems usually require a large digester volume, longer retention times, and lower organic loading rates. Processing a new batch of feedstock requires re-starting the system, purging, re-seeding, and re-heating the digester. This can result in a lag phase in the digestion process before digestion stabilises and biogas is produced. Biogas production in the digester will also decline over time (typically following a plateau after approximately 10 to 14 days). To compensate for the unsteady levels of biogas production in a single digester, multiple batch fed digesters may be operated in parallel but with staggered start and end times (sequential batch processing). This will maintain biogas production levels and allow gas processing to be optimised.

A generalised comparison between continuous flow and batch fed AD systems is provided in Table 10.below:

Digester Feeding	Advantages	Disadvantages
Continuous (semi-continuous)	- Biomass retained within the digester providing stable digestion conditions - Steady gas output - Higher digestion efficiency and biogas yield - Shorter retention times	- Generally higher capital and operational costs - Requires additional infrastructure for pre-treatment to provide a substrate composition suitable for continuous feeding (higher moisture content) -Critical with separation of sand/soil and floating material in the digester for wet systems.
Batch Fed	- Lower technical complexity and capital costs - Lower maintenance required	- Larger space required for digester - Generally lower digestion efficiency and biogas yield - Generally Longer retention times - Variation in biogas production (unless multiple digesters are used)

Table 10 Comparison between Continuous and Batch Fed Systems

4.3. Digestion

4.3.1. Start-up of a digester

There is no standard procedure for the start-up of an AD system and procedures should be specified by the technology supplier and detailed as part of the design and commissioning process. It is recommended a full HAZOP is carried out (see accidents and abnormal operation later) to cover every aspect of the plant. An overview of considerations during the start-up process is provided below.

The commissioning process will require testing of all equipment and pipework prior to loading the digester.

Seeding of the digester is conducted to provide active biomass prior to loading the digester with feedstock material.

Approaches to loading a digester on start-up may require a stepped increase in loading based on the rate of conversion of feedstock, starting with the reactor only 50% full for example. Purging with nitrogen or other inert gas is an essential safety precaution to ensure a non-exploioisve atmosphere is maintained within the vessels.

Other procedures may flood the digester as this provides a better examination of the pipework and is, in effect a wet commissioning of all the mechanical and electrical components. Integrity of the digester-gas system must be confirmed prior to introducing feedstock The key elements of a start-up procedure are consistent in both approaches and include;

- The preparation of a viable biomass from a suitable source

- The acclimatisation of the biomass to the feedstock and
- The gradual loading of the biomass up to the design conditions under close monitoring.

The biomass (inoculum) used in seeding the digester during start-up should ideally be sourced to match the type of feedstock to be processed at the facility. For example, if the main feedstock to be processed is food waste then digested material from a successfully operating food waste AD plant could be used.

This will provide microorganisms responsible for biogas production that are already adapted to the substrate. Alternatively, cattle manure may be used as inoculum as it generally has a relatively high buffer capacity, which is an advantage when starting up a digester with quickly acidifying materials such as food waste.

Sewage sludge is also used as an inoculum. Although not specific to a particular feedstock, it has the benefit of being readily available but will require screening to remove fibre and concentrate active biomass.

Digested materials should be used in preference to fresh manures because less time will be required for acclimatisation of the microbial population. The presence of methane producing bacteria is vital for start-up, and biomass originating from non-methanogenic processes, such as compost, is not suitable as an inoculum.

Gradual loading of the digester may be required in order to ensure that optimal conditions for the growth of anaerobic micro-organisms are maintained. The basic approach is that the feeding of the reactor is increased step-wise, with the increase in feeding rate determined by the VFA concentration and pH in the digester.

Regardless of the procedure employed, monitoring VFA concentration and pH is important for assessing the performance of digester during start-up. Where gradual loading is used, the empty air space in the digester should be flushed with nitrogen gas in order to prevent the creation of explosive atmospheres and prevent loss of viable methanogenic biomass.

4.3.2. Design temperature

The operating temperature of an AD system influences the rate at which the digestion occurs, with higher temperatures generally corresponding to a faster rate of digestion and therefore reduced retention times. The operating design temperature for a digester also has impacts on capital and operational costs, and size requirements.

The digestion process in the mesophilic range is well understood and requires less energy to sustain the operation than a thermophilic process. Bacteria operating in the mesophilic range are more robust and can tolerate greater changes in environmental parameters such as minor changes in feed or feedstock solids content. The stability of the mesophilic process makes it more popular in current AD facilities in comparison to thermophilic digestion, but at the expense of longer retention times and lower biogas yields. In cases where feedstock varies, mesophilic digesters are more suitable.

Thermophilic digesters generally operate at a faster rate, achieve higher solids destruction and higher methane production and more effective pathogen reduction. This may mean that the required plant footprint is lower than for an equivalent mesophilic system. A thermophilic digestion system may be designed so that a separate pasteurisation stage is not required, reducing capital costs of providing additional tanks, pumps and other ancillary equipment. The effectiveness of plant pathogen destruction has been demonstrated in thermophilic digestion systems and is one of the key reasons why AD facilities processing plant materials tend to be operated at thermophilic temperatures. These systems are typically operated in a plug flow configuration with the material passing through as a discreet unit. Disadvantages of thermophilic digestion include higher energy requirements to provide heating of the contents of the digester..

A further categorisation of digester design temperature is psychrophilic digestion. Psychrophilic digestion occurs at ambient temperatures in the range 5-15°C. Operating at such temperatures has a substantial impact on the energy balance. Due to the corresponding lower rates of degradation, this may imply a larger digester and this will have an impact on capital costs and landtake.

Psychrophilic digester designs are typically lagoons which may be covered with a basic system to collect biogas. The ultimate gas yield of psychrophilic digestion is lower than at mesophilic temperatures. Due to large land area requirements and low biogas yields, digestion systems operating at psychrophilic temperatures are regarded as low grade technology and unsuitable for use in England and Wales. **For this reason Psychrophilic Digestion is not classed as Anaerobic Digestion for the purposes of the EPR regulations 2010.**

An overview of the operating characteristics for mesophilic, thermophilic and psychrophilic digester designs is provided in Table 11:

Digester design	Advantages	Disadvantages
Mesophilic	- Typically stable digestion and more robust to changes in feeding regime - Lower energy requirements than thermophilic digestion - Lower capital costs	- Additional infrastructure required for pasteurisation of ABP material
Thermophilic	- Higher biogas production rates - Shorter retention times - May not require a separate pasteurisation stage - Smaller plant footprint (reduced visual impact)	- Typically less stable microbial population and more sensitive to changes in feedstock properties - Higher energy demand required to maintain process temperature
Psychrophilic	- Generally lower capital and maintenance costs	- Uncontrolled digestion process efficiency - Low and unstable biogas production rates - Large space requirements

Table 11 Comparison between Mesophilic, Thermophilic and Psychrophilic Systems

4.3.3. Single stage vs multi-stage systems

As discussed in Section 2, the microbial stages of anaerobic digestion occur at different rates and the bacteria responsible for each step may be more sensitive to factors such as temperature and pH. For example rapidly degradable wastes such as fruit and vegetables, the slower metabolism of methanogens relative to acidogens could lead to a build up of VFA, potentially inhibiting the digestion process in a single stage system. This is because In single stage digestion systems all of these processes occur within the same vessel. The aim of multi-stage AD systems is to provide optimal conditions for different stages of the digestion process in order to maximise degradation and biogas production. Typically multi-stage digestion involves separating out the faster hydrolysis and acetogenesis stages from the slower methanogenesis stage.

The increased technical complexity of a two stage digestion process compared to one stage does not always lead to higher digestion rates and biogas yields. The main advantage is the greater biological stability for plants with fluctuating type of feedstocks and fluctuating organic loading rates. In effect the initial stage provides greater balancing capacity within the process and allows for more regular loading of the digester. The hydrolysis tank is typically used as a balance tank for feeding during weekends.

A two stage process with a separate hydrolysis stage may be used to increase the rate of hydrolysis by supplying a small amount of oxygen in an anaerobic zone, creating microaerophilic conditions. Such systems can either by anaerobic or aerobic, however aerobic systems will convert some organic material to carbon dioxide and water reducing biogas potential.

In some instances the storage of digestate with biogas recovery may also be referred to as two-stage digestion by some technology providers and operators. This is fundamentally different to the 2-stage process described above and is discussed in Section 0 on digestate treatment and storage. More recently processes have been developed using a thermophilic operated main digester followed by a mesophilic (unheated) secondary digester.

Some two stage reactor designs include ring tank, or ring in ring digesters that have a tank within a tank, one each for either methanogenesis or hydrolysis.

A comparison between single and multiple digester designs is provided in Table 12:

	Advantages	Disadvantages
Single Stage	- Lower capital and maintenance costs - Lower technical complexity	- Less control of the digestion process in comparison to multi-stage systems -Higher demand on feedstock management when treating different types of feedstock
Multi-stage	- Allows greater control of the digestion process and biological stability - Suitable for fluctuating feedstock types and rapidly degradable feedstock material	- Additional capital and maintenance costs - Greater technical complexity

Table 12 Comparison between Single and Multi-Stage Systems

4.3.4. Low solids (wet) or high solids (dry) processes

The main difference between a high solids (dry) digestion and a low solids (wet) digestion system is the operating level of solids in the digesters and the corresponding means of mixing. A further categorisation of liquid effluent digestion refers to treatment of feedstock of less than 0.1% dry solids, but these systems are usually associated with wastewater treatment and industrial effluent applications. Most current systems operating in the UK for the treatment of biowastes are low solids systems.

Low solids waste systems are particularly suited to treating feedstocks containing 5 to 15% dry solids. The feed to the digester may comprise much higher solids content, but fed at a rate that dilutes the solids concentration down to the operating condition of the digester. Typically these digesters also include re-circulation of a proportion of the digested material to assist the mixing system. Low solids digesters are suitable for all types of organic waste including liquid wastes, with the exception of woody green waste.

In high-solids systems, the digester contents are kept at a solids content of 15 - 50 % Total Solids. Generally speaking high solids digesters require some recycling of liquid digestate and/or whole digestate from the end of the process. It should be noted that although referred to as “dry”, a high solids digestion process still operates with up to 85% moisture content of the substrate. Plastics and other low density materials can lead to problems with floating layers in low solids AD systems; this is less of an issue in high solids systems. High solids systems do not usually have internal mixing, and depend on external mixing of the feed for homogeneity and the dispersion of the inoculum. High solids digesters are most suitable for feedstocks containing elements of green waste (garden waste etc) as they are capable of handling large particle sizes.

A comparison between low and *high solids* AD systems is provided in Table 13:

	Advantages	**Disadvantages**
Low Solids	- Systems are usually fully mixed allowing greater stability and control of digestion conditions	- More sensitive to feedstock contamination - Generally not suitable for processing feedstock containing woody green waste
High Solids	- Less sensitive to feedstock contamination - Capable of handling feedstock containing green waste - Typically produces less waste water	- Generally larger plant footprint required - External digester mixing may be required.

Table 13 Comparison between Low and High solids Systems

4.4. Digester designs

The following sections provide an overview of the most commonly used AD digester designs.

4.4.1. Low solids processes

4.4.1.1. *Continuously and semi-continuously fed low solid digesters*

The most widely used low solids AD system is a Continuously Stirred Tank Reactor (CSTR) which typically refers to a steel or concrete tank that is mixed either by impeller / gas injection, pump recirculation or a combination of these approaches. In a single stage CSTR reactor all chemical and biological reactions happen within the same tank and can be operated at mesophilic or thermophilic temperatures. The mixing process in a CSTR is required to be designed to prevent short-circuiting of digestion, preventing passage of a fraction of the feedstock with a shorter than intended retention time. Short-circuiting reduces biogas yield and (more importantly) impairs proper feedstock stabilisation and hygienisation. CSTR type digesters can be fed on a continuous basis whereby substrate is added and digestate removed continually, or loaded semi-continuously.

The design of CSTR digesters should allow for sludge draw-off and grit removal. This can be provided by either having a conical bottom with a central desludging pipe or a "waffle" shaped bottom.

A typical layout for a CSTR digester is shown in ***Figure 5*** below.

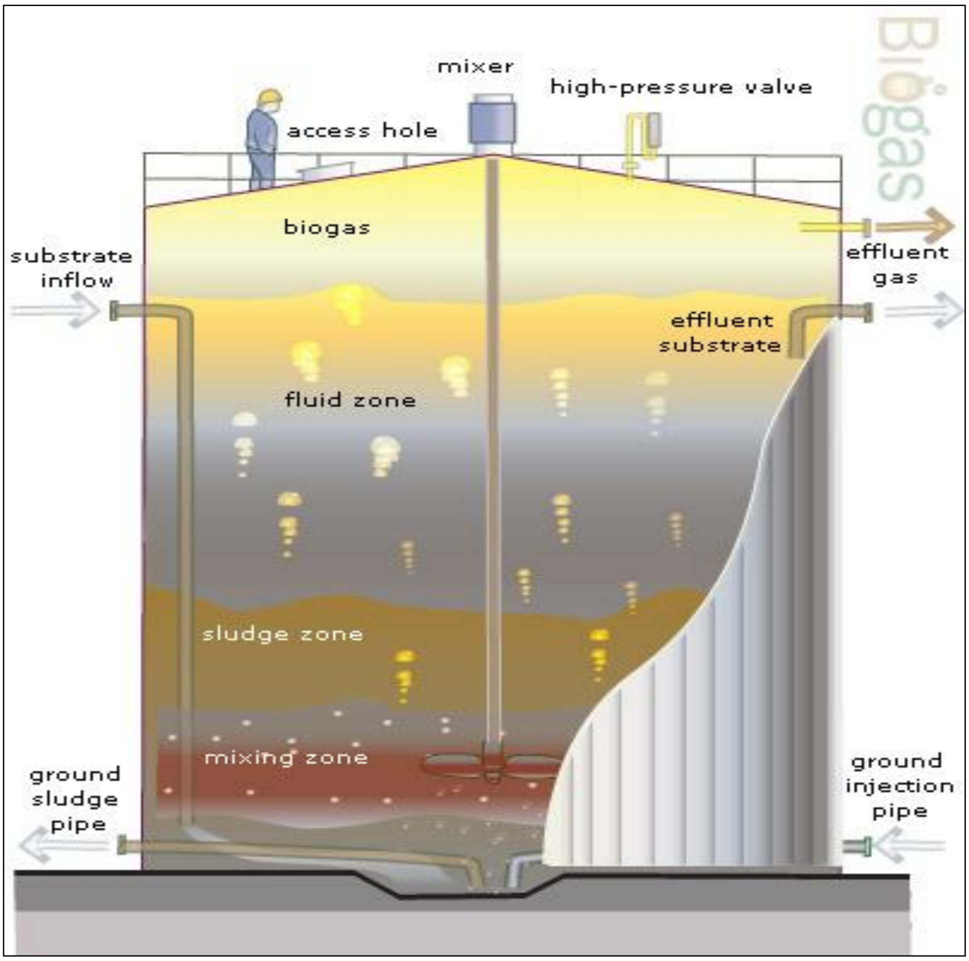


Figure 5: Typical CSTR Digester Layout (Source: REA Biogas)

4.4.2. Anaerobic Lagoons

Anaerobic lagoons can be described as covered ponds. However, it is important to distinguish between storage of slurries in ponds in which the principal purpose is storage and where generated gas may be collected, and engineered lagoons designed to actively manage biowaste material to generate biogas. The management of slurry stores falls within the SSAFO regulations.

In a typical anaerobic lagoon design, organic material enters at one end and the digested material is removed at the other. The lagoons generally operate at ambient (generally using organisms that are *Psychrophiles* or *Cryophiles (bacteria or archaea) that can survive at* -15 to +10 degrees Celsius) temperatures and for AD are classed as psychrophilic. Consequently, the reaction rate is affected by seasonal variations in temperature. Some designs may incorporate a heating system to maintain operational temperatures.

Psychrophilic Digestion is not classed as Anaerobic Digestion for the purposes of the EPR Regulations 2010.

Where anaerobic lagoons are operated at psychrophilic temperatures, the rate of conversion of solids to gas is low. In addition, solids tend to settle to the bottom where decomposition occurs in a sludge bed. The lack of mixing or agitation means that there is little contact between bacteria and the bulk of the liquid. The biomass growth is slow and the overall concentration of biomass is low, resulting in very low organic solids conversion to gas. Actual gas production rates are low and erratic.

Solids may be screened and removed prior to entering the lagoon, but a considerable amount of energy potential is lost with the removal of these solids. The sole advantage of anaerobic lagoons is low capital cost. The low cost is offset by the lower energy production and poor effluent quality. Periodically the covered lagoons must be cleaned to remove accumulated solids at considerable cost and this may also generate considerable odour.

Designs of anaerobic lagoons include an impermeable UV resistant liner placed over the top of the lagoon to capture and trap the biogas resulting from the natural breakdown of the slurry in the lagoon. The liner is held down on the surface of the lagoon by weighted uPVC pipes filled with water forming a boom or dug in to the lagoon bank with a key trench. Gas is collected and pumped to a boiler or engine for energy generation. No additional heat or control measures are used, with limited or no stirring. Lagoons need to be deep, 4m ideally with steep sides.

Variations to the design of anaerobic lagoons include flexible anaerobic lagoon tanks which utilises a series of smaller flexible digestion tanks with separate gas collection systems. An Accumulation Continuous Flow (ACF) system is similar to a lagoon tank and acts as a slurry store but includes an overflow holding tank in times such as winter when demand for digestate is low.

Figure 6 below, shows a typical layout for a covered anaerobic lagoon.

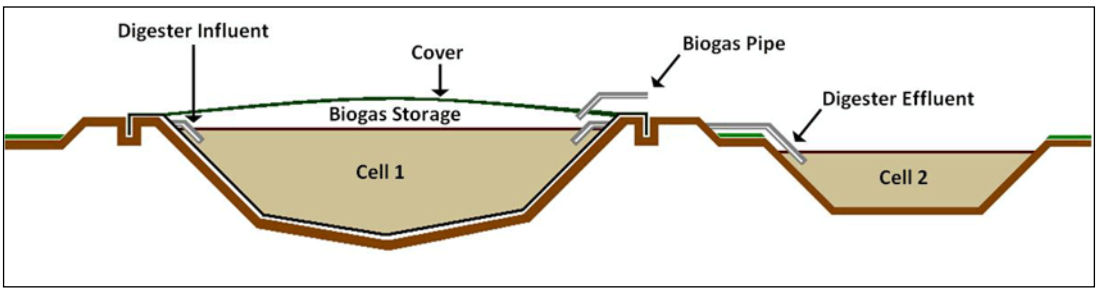


Figure 6: Covered Anaerobic Lagoon.

4.5. High solids processes

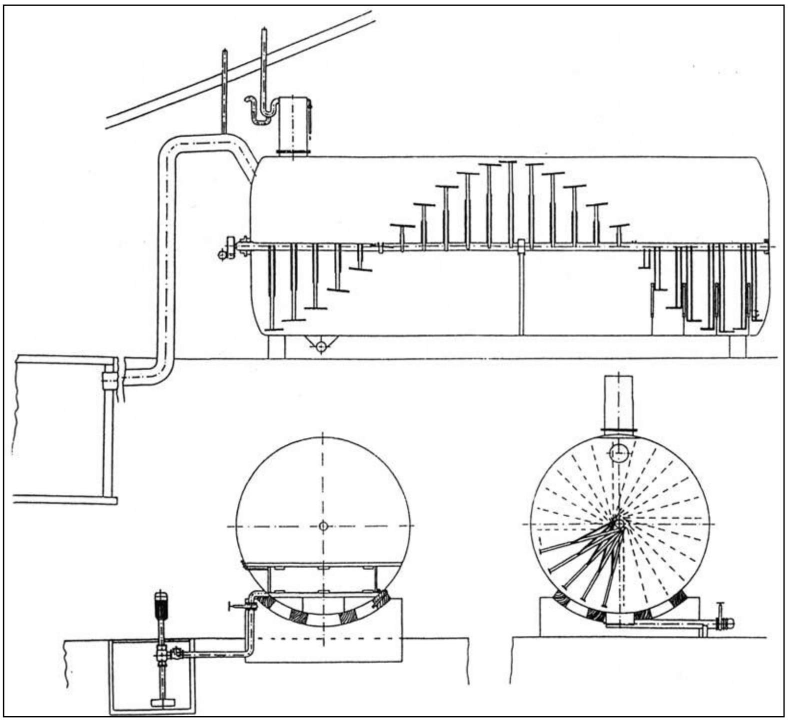
4.5.1. Continuously fed high solids digesters (plug flow)

In a plug flow reactor, a plug of feed passes through the reactor as a discrete slug. Plug flow digesters are not always mixed, and when mixing is done it is only in the vertical direction. As a result the digester contains material in different stages of the digestion process.

Plug flow digesters are loaded mechanically using an auger type delivery mechanism and are suited to high solid materials. Feedstock is loaded into one end of the digester, and the digested material is unloaded from the opposite end. Paddles on the axle are placed in a spiral formation so that the digesting material is slowly 'corkscrewed' through the digester. The heating is from hot water which is circulated through the mixing paddles nearest to the feeding point. Plug flow digesters can be operated at mesophilic or thermophilic temperatures. Due to limited mixing within the digester, feedstock must be inoculated by mixing with digestate prior to digestion. Plug flow digesters can be vertically or horizontally mounted.

The size of plug flow digesters are usually limited by mechanical torque constraints of the mixing axle, motor and gearbox and multiple digesters maybe used to provide more capacity. Like most tanks plug flow digesters can be subject to stratification, where sands and silts settle to the bottom of the digester and organic fibres migrate to the surface. The stratification can be partially inhibited by maintaining a relatively high solids concentration in the digester. Some designs of plug flow digester include gas mixing systems to reduce stratification. However, solids will periodically need to be cleared from the digester requiring a shut down.

A typical design for a plug flow digester is provided in **Figure 7** below



In the top part of the picture, substrate is added from the left. Inside the digester is a horizontal steering mechanisms, which transports the substrate from left to right

Figure 7: Horizontal Plug Flow Digester (source: Raven & Gregersen, 2005).

4.5.2. Batch fed high solids digesters

These systems take a batch of relatively dry material which is loaded into a vessel and processed for a set period of time for the digestion to take place. The process is suitable for processing stackable organic matter with typically 50% dry matter content.

Vessels are normally a concrete constructed tunnel, with a removable and sealed door on one end and of a large enough dimension to allow loading of feedstock and removal of digested solids using a wheeled loader vehicle. The vessel has gas collection from the top of the vessel, and liquid percolate is circulated around the vessel, irrigated to the surface, and collected in a perforated drainage floor. The percolate can be retained in a separate sealed tank that services the batch vessels with liquid innoculant.

Due to their appearance they are often termed garage systems. As the system is a batch process the number of individual vessels in a system is typically four or more, operated on a sequential batch basis in order to provide a more continuous biogas production.

Operating multiple high solids batch digesters rather than a single large digester enables flexibility in the processing of feedstock and avoids the requirement for substantial feedstock and digestate storage capacity and potentially long storage times.

No mixing of substrate occurs within the digester, therefore feedstock is required to be mixed sufficiently prior to digestion in order to ensure homogeneity. The porosity of the substrate may be increased by the addition of structural biowaste such as straw. This facilitates the limited mixing achieved within the digester by introducing leachate recovered from the base of the process to the top of the substrate and allowing it to percolate through the mass.

4.6. Retention time and digester capacity

For all anaerobic systems, digester capacity is directly related to the design retention time, the operating temperature and the quantity of material processed. Longer retention times within the reactor releases more biogas and cuts down post digestion methane release. However, excessive retention times are not economic. Typical retention times range from 20 - 40 days, with energy crop and crop residue feedstock requiring the longest retention times. Therefore, installed capacity becomes an economic balance between the capacity cost and the biogas production and is dependent on the feedstock to be processed.

4.7. Digester design and construction

In general, anaerobic digestion plants are provided as prefabricated, modular turnkey packages. At both large and small scale AD facilities, prefabricated section tanks are increasingly the norm. Small scale plug-flow systems are usually of concrete construction but concrete CSTRs are now rarely used in larger Centralised Anaerobic Digestion (CAD) facilities and small scale plants due to their technical limitations within larger designs and more expensive construction costs.

Anaerobic digestion tanks can be either cylindrical, rectangular or egg-shaped. The most common design is a low, vertical cylinder. Cylindrical digesters have no ‘dead’ corners, where biomass can accumulate, provided an appropriate mixing system is installed.

In continuously fed, low solids systems, the use of two (or more) digesters, as opposed to a single vessel, can provide operational flexibility (non-feeding of one reactor in times of low load or when there is a risk of inhibitory substances in the feed). It is also easier to start-up one vessel during commissioning and then seed additional reactors using digested solids from the first as the biomass will have developed to reflect the characteristics of the feedstock. Major shutdowns can be staggered to maintain 50% or more availability.

Vessels used for treatment should be equipped appropriately e.g. high-level, pH, temperature and pressure monitors. These should be automatic and continuous and linked to a clear display in the control room or laboratory together with an audible alarm. Depending on the operational model, location, and manning levels, process monitoring may be interlocked so that, for example, reactor feeding stops when an alarm condition is evident. The detailed requirements for process monitoring, alarms and interlocking should be informed by risk assessment.

4.8. Digester mixing and heating techniques

4.8.1. Digester Mixing

Efficient mixing in a low solids digester is important in order to:

- Ensure complete digestion; to prevent short circuiting (whereby feedstock is diverted out of the digester before being fully treated); and
- Ensure uniform heat transfer and to prevent sedimentation of silt and stratification in the reactor.

In order to monitor mixing efficiency and to check potential solids settlement, a series of sampling ports at different heights along the walls of the digester can be incorporated. This will allow detection of any uneven solids content within the digester tank, indicating the need for maintenance of the mixing equipment. Since efficient mixing is essential for successful operation of low solids systems, a lithium tracer test should be carried out during the commissioning phase and periodically afterwards, in order to test the adequacy of the mixing system installed. Build up of floating contamination is a real concern, regardless of how good the mixing is and removal methods should be considered early in the design. When deciding to take in a wider range of feedstocks than originally intended at design, further investment in pretreatment may be necessary to limit problems that mixing alone can not resolve.

Studies have shown that excessive mixing can disrupt the digestion process and reduce biogas yields potentially due to the disturbance of the structure units of the biomass which form flocs or granules. The microenvironments within these microbial structures are thought to offer some protection to changes within the environmental conditions within the digester and this may be lost where there is excessive mixing.

There are typically three types of techniques which are used to mix feedstock within the digester vessels, these are:

- Mechanical Mixing
- Gas Mixing and
- Hydraulic Stirring.

They may be used in isolation or in combination. Each of these techniques is discussed below, and includes suitability of application and advantages and disadvantages:

4.8.1.1. *Mechanical stirring*

Mechanical mixing systems include an agitator or impeller mixing. The mixing may be enhanced through internal baffles to create turbulence and avoid dead zones (areas with low mixing and consequently ineffective digestion within the reactor).

Impeller mixing systems consist of an impeller, a drive shaft, a gearbox or variable speed drive and a motor. Submerged small blade impellers are most commonly used in agricultural digesters.

Damage or failure of the impeller itself may require some form of shutdown to affect a repair or to retrieve the impeller. Although some designs allow extraction without requiring shutdown of the digester. A mechanism for maintaining the stirring system without the need to drain down the digester is very important for safety and to reduce maintenance costs.

If mechanical mixing is used, slow speed mixers are the favoured option as they use less energy and the external motor and gearbox are accessible for maintenance. Single large mixing blades, or top and bottom paddle designs are less susceptible to fouling by fibrous materials.

Impellers may be top or side mounted designs both of which are described below.

4.8.1.2. *Top mounted (large blade) impellers*

These systems consist of a single large impeller with a roof mounted motor and gearbox with a suspended shaft. The blade will be mounted near the base of the digester and rotate at low RPM, creating a large downward flow that will set up a recirculation current within the digester. A second smaller impeller will often be installed just below top water level to ensure an even top to bottom flow pattern.

When considering roof mounted impellers it is important to assess additional costs for the digester roof to support and access the motor, shaft and gearbox. Due to the low speed of the unit the absorbed power is typically very low, typically 3.5kW for a 2000m^3 digester.

4.8.1.3. *Side mounted impellers*

Very common in energy crop digesters these mixing systems usually incorporate an external motor and gear box mounted on the digester wall with a long angled shaft and smaller (than the large blade above) impeller. Due to the smaller diameter of the impeller these systems tend to run at higher RPM than large blade impellers and can achieve a vigorous mixing within the digester. Consideration must be given to the avoidance of long fibres in the substrate that may catch on the blades.

4.8.1.4. *Gas mixing*

Gas or pneumatic mixing systems recirculate biogas through the tank to induce mixing, with most configurations discharging gas at or near the bottom of the tank. All gas mixing systems include a compressor to increase the gas pressure to allow injection into the digester tank. Gas mixing is typically not suited to AD facilities with dry solids content exceeding 15 percent in the digester. Mechanical or hydraulic mixing are more commonly used for higher solids applications.

Different types of gas mixing system can be employed including unconfined and confined systems, and venturi systems. These are outlined in ***Table 14*** below.

	Description
Unconfined Gas Mixing	- Draw biogas from the digester headspace which is compressed and reintroduced into the base of the digester via a series of nozzles. The nozzles may be designed to operate simultaneously or sequentially. Sequential mixing is more effective in substrates with higher solids contents. - Gas introduces a re-circulation current promoting mixing in the digester - No moving parts requiring maintenance
Confined Gas Mixing	- Similar to unconfined mixing except gas is re-circulated via a mixing tube producing a gas lift effect to promote mixing (often referred to as 'blurping') - May incorporate heat exchangers to maintain digester temperature - Less common in new systems
Gas Injection Venturi	- Hybrid of hydraulic and gas mixing systems, digester material is pumped through a venturi device that draws gas from the digester headspace and mixes it with the slurry - Produces a liquid jet mixed with gas bubbles which rise a plume and a recirculation current within the digester

Table 14 Gas Mixing Systems

4.8.1.5. *Hydraulic stirring*

If stirred hydraulically, the substrate in the digester is mixed by pumps and horizontal or additional vertical pivoted vents in the digester. The suction and discharging of the substrate must be designed in such a way that the digester content is stirred as thoroughly as possible.

Hydraulically stirred systems have the advantage that the mechanical parts of the systems are located outside of the digester, subject to lower wear and can be easily maintained. Hydraulic mixing is only occasionally appropriate for destruction of floating layers and, like the pneumatic stirring, only used for low solids liquid feedstock, with a low tendency of forming floating layers.

Pumped mixing systems consist of pumps, piping and nozzles. The pumps are typically "chopper" pumps or incorporate in-line grinders to prevent fibrous materials from causing plugging problems. The pumps are installed outside the tanks to allow easy access for maintenance. High-velocity nozzles are mounted inside the tanks.

	Description
Pump Recirculation	- entire contents of the digester are pumped typically from the bottom to the top over a period of 2 to 10 hours to fully mix the tank - More common for large digesters

Jet Mixing	- Digested slurry is pumped through a series of smaller (50 – 100 mm) nozzles creating high velocity jets - Promotes mixing through bulk movement and entrainment in the jet stream - Require higher input energy to mix a given volume - Maybe paired with chopper pumps to prevent pipe blockages - Jets can be positioned to scour the base of digesters and entrain floating crust material

Table 15 Hydraulic Mixing Systems

4.8.2. Digester heating techniques

In order to achieve and maintain a constant process temperature and to compensate for eventual heat losses, digesters must be insulated. The contents are or need to be heated by external heating sources. The most frequently used source is heat from the Combined Heat and Power (CHP) unit of the biogas plant. Insulation options are to spray the tank with foam insulation or to use rigid board insulation attached to the tank and then covered with metal cladding.

The heat requirements of digesters consist of the amount needed to raise the feedstock to digester temperatures, and to make up for losses from the digester and process pipework. The heat source is usually from the CHP unit although a biogas boiler or even oil or electrical heaters may be used. There will generally need to be an alternative source of heat to the CHP to provide heating for the digester at start up or when the CHP is not operating.

Heating the feedstock can be done either during the loading process (pre-heating) through heat exchangers or from the direct injection of hot steam, or it can be done inside the digester by heating elements. Pre-heating the feedstock during feeding, has the advantage of avoiding temperature fluctuations inside the digester. External pre-heating typically uses plate heat exchangers or ‘shell and tube’ heat exchanger designs. In AD systems with a pre-digestion pasteurisation stage, pasteurised feedstock may need to be cooled to the required digestion temperature via heat exchangers prior to introduction into the digester.

A sufficient heat transfer area should be provided to minimise high temperature differences and prevent local high hot water temperatures leading to fouling of exchange surfaces and more frequent maintenance.

Heat recovery from digestate also reduces the overall demand for heat but is likely to increase maintenance demands due to the fouling of heat exchangers.

Deposition of struvite (magnesium ammonium phosphate) in heat exchangers is an issue in some waste water treatment AD plants, in particular in processes where effluent (centrate or filtrate) is recycled through the process. The mechanism of struvite formation is poorly understood but can lead to reduced efficiency and additional maintenance requirements for heat exchangers.

Steam heating (the injection of steam directly into the incoming feed line) is used in some digesters eliminating the requirement for digester heat exchangers.

In digesters with internal heating systems, cold feedstock is pumped directly into the digester tank and the temperature is regulated by either wall-embedded or wall mounted piping. Internal heating has the disadvantage of being harder to maintain.

4.8.3. Indicative BAT requirements for Treatment - general principles

Indicative BAT requirements for Treatment - general principles
Digester startup **1. When loading, the empty air space in the digester should be flushed with nitrogen (or other inert gas) gas in order to prevent the creation of explosive atmospheres.** **Management and pre treatment of wastes** **2. The pre-treatment of wastes is to remove non-biodegradable material and contaminants from feedstock and also to provide optimal substrate characteristics to enable an effective and efficient digestion process.** **The objectives of pre-treating feedstock will typically include;** • **Removing packaging material from food waste (depackaging)** • **Removing other non-biodegradable materials e.g. grit & metals which are not affected by digestion and take up necessary space by sedimentation. Removing plastics that can cause long term operational problems by the formation of floating layers.** • **Providing a uniform small particle size feedstock for efficient digestion** • **Protecting the downstream plant from components that may cause physical damage** • **Removing materials which may decrease the quality of the digestate** **3. Where ABP and non ABP material are processed the facility should allow for both materials to be segregated preventing cross contamination.** **4. Where ABP material is processed, wheel wash facilities should be provided for the disinfection of delivery vehicles on exit from the reception hall. All other cleansing of ABP delivery vehicles should be carried out in an enclosed area.** **5. Where ABP material is processed, pre-treatment must meet minimum particle size requirements as specified by the ABP regulations during pasteurisation.** **6. AD facilities accepting ABP materials should be capable of raising the temperature of the feedstock in accordance with Table 9.** **7. A discrete quarantine area should be provided for the segregation of unacceptable wastes.** **Digester vessels and pipework** **8. Vessels used for treatment should be equipped appropriately e.g. high-level, temperature and gas pressure monitors.** **9. These should be automatic and continuous and linked to a clear display in the control room or laboratory together with an audible alarm.**

10. Depending on the operational model, location, and manning levels, process monitoring may be interlocked so that, for example, reactor feeding stops when an alarm condition is evident. The detailed requirements for process monitoring, alarms and interlocking should be informed by risk assessment such as HAZOP.

11. Vessels should be fitted with an appropriate mixing/stirring mechanism for the type of vessel and waste to be processed to:

- **ensure efficient mixing.**
- **ensure complete digestion; to prevent short circuiting (whereby feedstock is diverted out of the digester before being fully treated); and**
- **to ensure uniform heat transfer and to prevent sedimentation of silt and stratification in the reactor.**

12. AD operators should demonstrate that all process equipment including vessels, ancillary pipework, valves and other mechanical and electrical items and controls are made of materials suitable for each unit operation and to achieve the stated availability and design life of the plant.

Process Monitoring Controls

13. A suitable monitoring system, both manual and instrumental, is essential to ensure stable reactor operation and to minimise operational difficulties, such as foaming, which may lead to odour and aesthetic problems It should also provide sufficient warning of system failures which may lead to loss of containment and potentially explosions.

- **The key factors to be monitored during the digestion process itself include:**
- **Alkalinity and pH**
- **Temperature and temperature distribution**
- **Hydraulic Loading Rate**
- **Organic Loading Rate including Total solids and Volatile Solids Fractions**
- **Concentration of VFA**
- **Ammonia**
- **C:N ratio and other nutrient and key feedstock data**
- **Gas production and composition**
- **Gas pressure**
- **Gas H2S concentrations**

14. Monitoring of these parameters requires sampling of digester feed, substrate within the digester, digestate and biogas at key points in the process. Periodic digester capacity testing should also be undertaken. The system design should allow for this. Regular laboratory testing will be required to analyse samples and the operator should consider provision for on-site laboratory facilities at large scale AD facilities

15. For large scale AD facilities, monitoring processes should incorporate the use of Supervisory and Control and Data Acquisition Equipment (SCADA) to monitor, record and display data for continuously monitored parameters such as temperature, digester feeding and gas production rates

16. The operator should establish and make available to all relevant staff an operational manual which includes all procedures for the safe and efficient operation of the facility.

17. **The operator must establish and follow appropriate process monitoring arrangements to facilitate process optimisation and maintain stable digestion. As a minimum the following parameters should be regularly monitored and recorded:**

- **pH – the digester should be maintained between ph 6.5 and 8.0 by ensuring a stable FOS/TAC ratio.**
- **Alkalinity – the alkalinity within the digester should be maintained between 2000-4000 mg litre-1 (as $CaCO_3$)**
- **Temperature.- The optimum operating temperature should be defined depending on the ecology (mesophillic or thermophilic) deployed . The digester should be held within +/- 2 degrees Celsius of the optimum temperature.**
- **The organic loading rate and hydraulic residence time should be managed to deliver a stable and sanitised digestate. Maximised removal (stabilisation) efficiencies for volatile solids reduction or COD reduction in the substrate should be clearly demonstrated.**
- **Monitor and control process parameters in order to ensure a stable digestion process**

18. **The operator should carry out adequate inspection and maintenance (including planned preventative maintenance) to maintain the availability of the process and minimise unscheduled shut downs or any other event where equipment or process failure could lead to impact on the environment.**

Biogas treatment and storage

The exact composition of biogas generated from an AD process will vary depending on feedstock and process type but is primarily composed of methane (CH_4) and carbon dioxide (CO_2), with smaller amounts of hydrogen sulphide (H_2S) and ammonia (NH_3). Trace concentrations of hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO) and oxygen (O_2) are occasionally present in the biogas. Biogas is usually saturated with water and may contain dust particles.

The following table provides a typical composition and properties of biogas values prior to adding aeration air for desulphurisation.

Compounds	Typical Concentration
Methane	60 - 70 (vol - %)
Carbon Dioxide	30 - 40 (vol - %)
Nitrogen	~2 (vol - %)
Hydrogen Sulphide	0 - 4,000 ppm
Ammonia	~100 ppm
Lower Heating Value	6.5 (kWh Nm^{-3})

Higher Wobbe index	27 MJ Nm^{-3}
Density	1.2 kg Nm^{-3}

Table 16 Typical Biogas Composition and characteristics (Source: IEA Bioenergy, 2009 + IEA Bioenergy, 2006)

Requirements for biogas treatment depend on the gas quality requirements for the intended end use of the biogas. The Wobbe index is used to compare the energy output of combustible gasses i.e. two gases with the same Wobbe value at the same temp and pressure will give the same output. Potential biogas utilisation options are set out in the following diagram which also indicates the typical level of gas treatment required

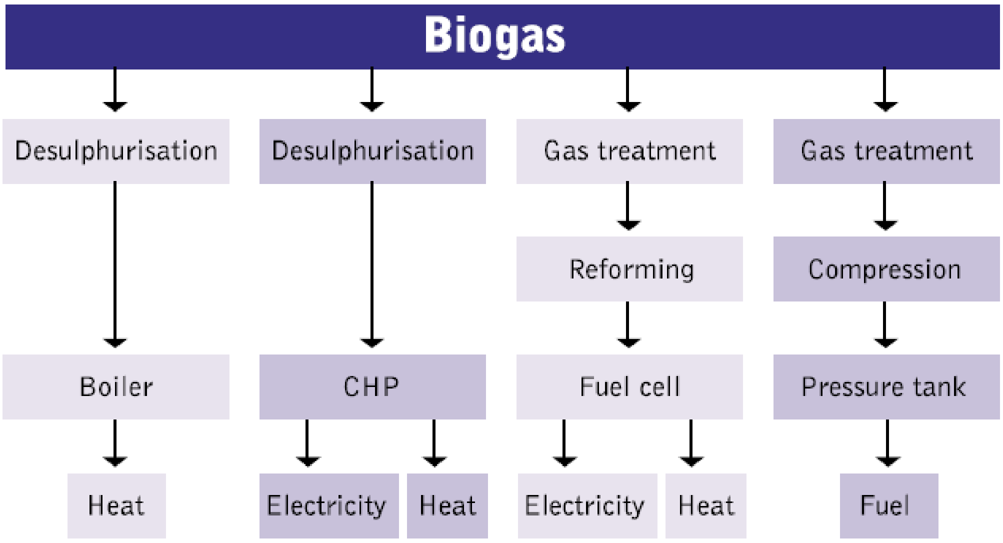


Figure 8: Options for Biogas Utilisation (Source IEA Bioenergy, 2006)

End uses for biogas include burning in a simple boiler to generate heat, or use in an engine with generator to produce power. The most common biogas use is combined heat and power (CHP) generation to produce both heat and power. Heat is most effectively used on-site or locally whereas power can be used on-site or connected to the main electricity grid.

Alternatively biogas can be upgraded, which requires removal of carbon dioxide and other contaminant gases, in order to generate biomethane. The addition of propane to biomethane may also be required in order to achieve the required gas Calorific Value (CV). Biomethane can be injected into the natural gas distribution network, for conversion to heat or power at the point of off-take, or used as a transport fuel in a similar way to LPG or CNG. Whilst biogas upgrading may be more efficient in terms of energy utilisation, it is also significantly more costly and biogas upgrading options aren't generally viewed as viable for a small scale AD application.

The following table provides an indicative overview of the requirements for biogas treatment in relation to the intended use.

Application	**H_2S**	**CO_2 removal**	**H_2O removal**
Gas heater (boiler)	<1000 ppm	no	no

Kitchen stove	yes	no	no
Stationary engine (CHP)	< 500 ppm	no	moisture removal
Vehicle fuel	yes	yes	yes
Natural gas grid	yes	yes	yes

Table 17 Requirements to remove gaseous components for biogas utilisation options (Source: IEA Bioenergy, 2006)

5.1. Biogas treatment techniques

Biogas Treatment primarily consists of:

- Dewatering
- Removal of H_2S (potentially corrosive to engines)
- Removal of oxygen and nitrogen (where present)
- Removal of ammonia
- Removal of siloxanes (if treating Sewage Sludge)
- Removal of particulates and
- Removal of CO_2 (for upgrading to biomethane).

The techniques used in biogas treatment to remove these different elements are outlined below.

5.1.1. De-watering

Biogas is saturated with water when leaving the digester, and this water may condense in gas pipelines. The condensate will be contaminated with acid and may cause corrosion. It is important that wet gas transmission pipes and storage vessels can be drained to prevent them from becoming flooded with condensate.

Water removal techniques include:

- Cooling / Condensation
- Compression
- Adsorption and
- Absorption

For small scale AD-plants water removal techniques such as moisture traps or water taps at low point in the gas line are commonly used and are sufficient for using biogas in gas-engines. Due to high capital and operational costs, water removal based on drying methods are rarely considered economical unless the biogas is intended to be upgraded to biomethane.

Table 18 provides an overview of biogas de-watering techniques.

Technique	Description
Cooling / Condensation:	
Gas pipeline condensation; Moisture Traps Water Taps	Cooling of biogas can occur within gas pipelines and removal of condensed water can be achieved by the following methods: Moisture traps - in which condensation of water by expansion of the biogas takes place; Water taps in the gas pipeline to remove condensed water.
Refrigeration	Biogas is chilled with a heat exchanger and the condensed water is separated. In order to reach higher dew points the gas can be compressed before it is cooled.
Demisters	Involves cooling of the gas and leading it through a demister with micro pores (cool dryer). Dew points of 20 to 2 °C can be reached. Condensed water is entrapped in a demister.
Cyclone separators	Water droplets are separated using centrifugal forces equal to several hundred times the force of gravity (g).
Drying;	
Adsorption	Adsorption of water on the surface of a drying agent Common method used to reach the very low dew points needed in vehicle fuel applications. Drying agent can be silica gel, aluminium oxide, activated carbon or other types of molecular sieve and is usually regenerated by heating and/or a decrease in pressure. System usually consists of two vessels one in operation and one in regeneration mode to ensure continuous operation Can be conducted at elevated or atmospheric pressure. Regeneration at atmospheric pressure requires the addition of air to the biogas.
Absorption	Involves absorption of water in glycol or hygroscopic salts. New salt needs to be added in order to replace the saturated or even dissolved salt. The drying medium can be recovered by drying at elevated temperatures. Dew points of -5 to -15 °C can be reached using glycol. Used glycol is pumped into a regeneration unit, where regeneration takes place at 200 °C.

Table 18 Biogas De-watering Techniques

5.1.2. Removal of Hydrogen Sulphide

The main sulphur compound in biogas is hydrogen sulphide (H_2S). H_2S is formed during microbial reduction of sulphur containing compounds (sulphates, peptides, amino acids). It is reactive with most metals and the reactivity is enhanced by concentration and pressure, the presence of water and elevated temperatures.

H_2S can cause corrosion problems in gas engines. Hydrogen sulphide has an energy value and burns readily. When combusted, it forms SO_2 leading to acidic conditions in the presence of moisture formed when methane is burned. The presence of H_2S in the gas may also result in more frequent oil changes being required. Gas engine manufacturers set limits on H_2S tolerances (typically below 500 ppm).

H_2S concentrations in the biogas can be decreased by precipitation in the digester or by treating the gas either as a stand alone treatment or as part of carbon dioxide removal. The following techniques are described;

Technique	Description
Precipitation	Addition of Fe^{2+} or Fe^{3+} ions in compounds of $FeCl_2$, $FeCl_3$, or $FeSO_4$ to the digester precipitates iron sulphide that can be removed with the digestate. Typically used in digesters with a high sulphur concentration as a first measure.
Chemical Absorption	
Sodium Hydroxide (NaOH) Washing	Based on neutralising H_2S to form an insoluble salt which can then be removed. Due to a high technical requirement to process caustic solution, this application is rarely used except where very large gas volumes are treated or high concentrations of H_2S are present. Regeneration of NaOH is not possible.
Iron Oxide adsorption	Biogas is passed through $Fe(OH)_3$ or Fe_2O_3 coated support material (pressed minerals, sometimes wood chips). Regeneration is possible for a limited number of times, after which the material has to be renewed. Process typically operates with two columns, operated with one absorbing, the other re-oxidising. Technologies include a catalyst that adsorbs siloxanes and removes H_2S from raw gas, achieving up to 2,000 ppm of H_2S removal.
Adsorption on activated carbon	H_2S is adsorbed on inner surfaces of engineered activated carbon with defined pore sizes. The addition of oxygen (in the presence of water) oxidises H_2S to elemental sulphur that binds to the surface. Activated carbon is either impregnated or doped with permanganate or potassium iodide (KI), potassium carbonate, or zinc oxide (ZnO) as catalysers. Due to limits on oxygen levels in biomethane, oxidisation of sulphur is not a suitable technique where the gas is intended for grid injection or use as vehicle fuel. Use of KI-doped carbon or permanganate impregnated carbon is used to effect oxidation without the need for oxygen. ZnO impregnated carbon is expensive but extremely efficient. H_2S concentrations of less than 1 ppm can be achieved.
Biological treatment (Both methods are applied widely but are not suitable for biogas upgrading due to traces of oxygen remaining in the gas)	
Injection of air into the top level of the digester	Involves the injection of air bubbles (or pure oxygen if levels of nitrogen required to be minimised) into the top layer of digested slurry in the digester, which oxidises the H_2S into

Technique	Description
	elemental sulphur and is retained in the digestate. With this method the H_2S level can be reduced by up to 95 % to levels lower than 50 ppm in the biogas. There are of course several factors that affect the reduction rate including temperature, reactor design and the rate of air addition. When adding air into the biogas safety measures need to be taken into consideration to avoid overdosing of air in case of a pump failure. Pure methane is explosive in the range of 5–15 % in air.
Biological trickling filter	The procedure involves addition of 5 - 10% air to the gas as it enters a separate purification vessel. The filter vessel is filled with plastic carriers and a liquid made up from the gas condensate and the liquid fraction of digestate separation is continuously recirculated over the filter. The temperature is maintained at 35°C. H_2S is biologically converted to sulphur or sulphate which is retained in the liquid in the filter and replaced when the pH drops below a certain level. Surplus liquid is returned to the digestate storage tanks, resulting in the return of the sulphur or sulphate to the digestate. This technique may achieve a reduction in H_2S levels from 3000–5000 ppm to 50–100 ppm. Ammonia is oxidised at the same time by a different set of aerobic micro organisms.

Table 19 Biogas Hydrogen Sulphide Removal Techniques

5.1.3. Removal of Oxygen and Nitrogen

Oxygen is not normally present in biogas as it will be consumed by facultative aerobic microorganisms in the digester. If air is present in the digester then nitrogen will also be present in biogas. Oxygen and nitrogen can be removed with activated carbon, molecular sieves or membranes.

These gases will be removed to some extent in a desulphurisation process or in some upgrading techniques. Both gases are difficult (expensive) to remove, and their presence should be avoided if the gas is to be upgraded. The presence of oxygen and nitrogen is less of a concern if the gas is used for CHP or boilers as air is added to the gas during the combustion process.

5.1.4. Removal of Ammonia

Levels of ammonia present in biogas depend on the digester substrate composition and pH within the digester. High concentrations of ammonia are a problem for gas engines, and are often limited by manufacturers (typically up to 100 mg Nm^{-3}). The combustion of ammonia leads to the formation of nitrous oxide (NOx) in the exhaust. Ammonia is usually separated when the biogas is dried by cooling, as its solubility in water is high, and most upgrading technologies are also selective for the removal of ammonia, therefore a separate removal step is not normally required.

5.1.5. Removal of Siloxanes

Siloxanes are volatile silicone compounds used in products such as deodorants and shampoos. They are found in sewage treatment plants and landfill gas but are not usually found in biogas generated from slurry or pure food waste. Most manufacturers of gas engines set maximum limits for siloxanes in biogas.

Siloxanes form a highly abrasive white powder of silicon oxide when burned, which can create problems in gas engines. Silicaceous deposits on valves, cylinder walls and liners are the cause of extensive damage by erosion or blockage. Silicon compounds may also reach the lubrication oil requiring more frequent oil changes.

Siloxanes can be removed by gas cooling, and adsorption on activated carbon. This method is very effective but can be expensive since spent carbon can't be regenerated and needs to be replaced. Another method for removing the compounds is absorption in a liquid mixture of hydrocarbons, activated aluminium or silica gel, or by absorption in liquid mixtures of hydrocarbons. Siloxanes may also be removed during a hydrogen sulphide removal process.

5.1.6. Removal of particulates

Particulates may be present in biogas and can cause mechanical wear in gas engines and turbines. All biogas plants must be equipped with some kind of filter and/or cyclone for reduction of the amounts of particles in the biogas. Filters not only remove particulates but also remove droplets of water or oil. Filters with a 2 – 5 micron mesh size are normally regarded as appropriate for most downstream applications.

5.1.7. Removal of Carbon Dioxide (upgrading)

Several upgrading technologies are commercially available and others are at a pilot or demonstration plant level. Currently utilised techniques for biogas upgrading are set out below. The upgrading technology that is most cost effective is likely to depend on biogas flow rates.

Technique	Description
Pressure Swing Adsorption (PSA)	Carbon dioxide is removed from biogas by adsorption on a material such as activated carbon or zeolites under elevated pressure. The adsorbing material is regenerated by a sequential decrease in pressure before the column is reloaded. Typically uses 4, 6 or 9 vessels (most often four) working in parallel (sequentially absorbing or regenerating). Gas that is released during regeneration may be returned to the inlet as it will contain some methane together with the carbon dioxide. Desorbed gas is released to atmosphere if almost entirely free of methane. H_2S and water must be removed prior to PSA. Water vapour is usually condensed in a cooler prior to the PSA system. H_2S is typically removed via an additional tank containing activated carbon.
Water scrubbing	Biogas is compressed and fed into the bottom of a column where it meets a counter flow of water and CO_2 is absorbed. Water leaving the column is transferred to a flash tank where the saturated liquid stream undergoes a reduction in pressure by passing through a throttling valve or device. Dissolved gas is released and passed back through the scrubber. Water is cooled to maximise the difference between CO_2 and CH_4 solubility before it is recycled to the absorption column. The process may be enhanced by air stripping or by vacuum. Air stripping brings oxygen into the system which is a problem when the gas is used as fuel or when it is fed into the grid. H_2S, if present, is released to the air creating an emission problem and can cause

	problems with fouling and plugging of pipework. It is therefore recommended that hydrogen sulphide is separated beforehand. Plugging in the absorption column due to organic growth can be an issue therefore it is recommended to install automatic washing equipment for the column.
Organic physical scrubbing	Similar to water scrubbing except CO_2 is absorbed in an organic solvent such as polyethylene glycol. CO_2 is more soluble in polyethylene glycol than in water, therefore requires lower flow of liquid and the plant can be smaller. H_2S, water, oxygen and nitrogen may be removed as well as CO_2.
Chemical scrubbing	Chemical scrubbing typically uses amine solutions. CO_2 dissolves and reacts reversibly with the amine. The reaction is strongly selective and methane loss can be as low as <0.1%. Amine solution is regenerated by heating with steam although part of the liquid is lost due to evaporation and has to be replaced. Two types of compound are used: mono ethanol amine (MEA) and di-methyl ethanol amine (DMEA). H_2S will be absorbed if present requiring higher temperatures for regeneration, and it is advisable to remove H_2S prior to the amine scrubber. The process is very efficient but has a relatively high energy demand.
Membrane Separation	Membrane separation processes include gas phase separation across a membrane (dry membranes) or gas-liquid absorption Gas-liquid absorption uses a liquid such as an amine to absorb CO_2 diffusing through the membrane. The system is high selectivity compared to dry membrane systems. Gas phase membranes work at high pressure > 20 bar or at low pressures 8-10 bar. Membranes are made of materials usually in the form of hollow fibres that are permeable to CO_2, water and ammonia. Nitrogen and methane have limited permeability. The process often has two stages with the first removing water, oil droplets and aerosols which would otherwise negatively affect membrane performance. H_2S is usually removed using activated carbon prior to passing the prepared gas to the membrane.

Table 20 Biogas Upgrading (carbon dioxide removal) Techniques

A comparison between the performance and operational requirements for the most common biogas upgrading techniques is provided in Table 20 below. The values stated in Table 20 have been sourced from a review of biogas upgrading technologies by IEA Bioenergy in 2009 and represent data obtained from equipment manufacturers and AD plant operators in Europe.

Parameter	**PSA**	**Water Scrubbing**	**Organic physical scrubbing**	**Chemical Scrubbing**
Pre-cleaning needed[a]	Yes	No	No	Yes
Working pressure (bar)	4–7	4–7	4–7	No pressure
Methane loss[b]	< 3 % / 6 – 10%[f]	< 1 % / < 2%[g]	2– 4%	< 0.1%
Methane content in upgraded gas[c]	> 96%	> 97%	> 96 %	> 99%
Electricity consumption[d] ($kWh\ Nm^{-3}$)	0.25	< 0.25	0.24–0.33	< 0.15
Heat requirement (°C)	No	No	55–80	160

Controllability compared to nominal load	+/- 10–15%	50 –100%	10 –100%	50 –100%
References[e]	> 20	> 20	2	3

a Refers to raw biogas with less than 500 mg m^{-3} of H_2S. For higher concentrations, pre-cleaning is recommended also for the other techniques.

b The methane loss is dependent on operating conditions. The figures given here refer to figures guaranteed by the manufacturer or provided by operators.

c The quality of biomethane is a function of operational parameters. Figures given refer to figures guaranteed by the manufacturer or provided by operators, based on air-free biogas.

d Given in kWh Nm^{-3} of raw biogas, compressed to 7 bar(g).

e The number of references reviewed. Some are pilot plants.

f Different values reported from two technology suppliers.

g Different values reported from two technology suppliers.

Table 20 Comparison between Biogas Upgrading Technologies (Source: IEA Bioenergy, 2009)

5.1.8. New developments for biogas treatment

Research and development in biogas treatment and upgrading technology is ongoing in order to maximise efficiency and reduce operational costs. Cryogenic upgrading is a development that separates CO_2 from biogas as a liquid by cooling the gas at elevated pressure, and technologies are under development that produce liquid methane as an end product. Other potential developments include in-situ methane enrichment that circulates digester material through a CO_2 desorption column before returning it to the digester and the use of the natural enzyme carboanhydrase to dissolve CO_2 from biogas.

5.2. Biogas storage

Gas storage is required to maintain a relatively constant reaction volume and pressure within the digester and to allow adequate reserves of biogas to be held in order to maintain the target availability of energy recovery plant. Correct selection and dimensioning of a biogas storage facility brings a substantial contribution to the efficiency, reliability and safety of the biogas plant while ensuring a constant supply of biogas to energy recovery plant and minimising fugitive biogas losses and unnecessary flaring.

All biogas storage facilities must be gas tight and pressure-resistant, and where storage facilities are not protected by buildings, they must be UV, temperature, and weather proof.

Storage vessels that are sealed for biogas collection should be fitted with over and under pressure relief valves. Isolating valves should be incorporated to enable inspection and maintenance. Gas storage tanks must be checked for gas tightness prior to start up of the digester.

The correct system operating pressure should be maintained by venting the gas through a valve on the line to the gas holder.

Pressure sensors should be provided on top of the digestion tanks and the gas storage tank. In a situation of excessive pressure build up in these tanks, due to pipe damage or blockage, an alarm signal should be triggered with immediate venting systems instigated.

The design of the gas collection system should ensure that excessive negative pressures cannot be imposed on the digester vessel or the gas collection vessel.

Various types of biogas storage facilities are available. The simplest solution is biogas storage established on top of digesters, using a gas tight membrane, which also functions as a digester cover. For larger biogas plants, separate biogas storage facilities are established, either as a stand-alone facility or included in storage buildings. The biogas storage facilities can be operated at low pressure for on-site usage, or medium and high pressure storage before and/or after transportation to off-site distribution points or systems (typically for biogas upgraded to biomethane).

Table 21 below lists options for biogas storage for different applications.

Purpose of Storage	Pressure psi (mbar)	Storage Device	Material	Size
Short and intermediate term storage for on-site use	< 0.1 (6.9 mbar)	Floating cover	Reinforced and non-reinforced plastics, rubbers	Variable volume, sized according to biogas production rate
		Fixed roof	Plastic, reinforced plastic	Variable volume, sized according to biogas production rate
	< 2 (138 mbar)	Gas bag	Reinforced and non-reinforced plastics, rubbers	150 – 11,000 ft^3 (5 – *310* m^3)
		Weighted gas bag	Reinforced and non-reinforced plastics, rubbers	880 – 28,000 ft^3 (*25 – 795* m^3)
	2 – 6 (138 – 414 mbar)	Water sealed gas holder	Steel	
Storage for longer term on-site or off-site use (typically for biogas upgraded to biomethane)	10 – 2,900 (6.89 – 200 bar)	Propane or butane tanks	Steel	2,000 ft^3 (60 m^3)
	> 2,900 (200 bar)	Commercial gas cylinders	Alloy steel	350 ft^3 (*10* m^3)

Table 21 Gas storage devices (Source: Adapted from Sustainable Conservation, 2005)

5.2.1. Low pressure storage

Low pressure gas storage is the least expensive and easiest to use system for on-site applications. Low pressure gas storage may be provided by floating or fixed digester covers or separate low pressure tanks.

If the digester or digestate storage is used for storing biogas, both must be covered with gas tight membrane domes (double membrane reservoirs), fixed on the upper edge of the digester. A supporting frame can be installed in the digester to hold the membrane when it is empty. The membrane expands according to the volume of gas contained. An engineered net can be mounted over the cover in order to limit membrane expansion.

Digester covers typically operate at pressures up to 10-inch water gauge (less than 30 mbar) and can be made of steel, fibreglass, or a flexible fabric. Flexible synthetic material is often used because it does not react with H_2S in the biogas. Flexible materials commonly used include high-density polyethylene (HDPE), low-density polyethylene (LDPE), linear low density polyethylene (LLDPE), and chlorosulfonated polyethylene covered polyester. Thicknesses for cover materials typically vary from 0.5 to 2.5 millimetres. Digester covers may be floating or fixed:

Floating covers fit on the surface of the digester contents and allow the volume of the digester to change without allowing air to enter the digester (if gas and air are mixed, an explosive mixture can result).

Fixed covers provide a free space between the roof of the digester and the liquid surface.

In addition gas bags of varying sizes are available and can be added to the system. These bags are manufactured from the same materials mentioned above and may be protected from puncture damage by installing them as liners for steel or concrete tanks.

A separate tank may be used in addition to a floating gas holder for the storage of the digestate and also storage of the raw biogas prior to treatment.

5.2.2. Medium and high pressure biogas storage

The energy, safety, and gas treatment requirements of medium- and high-pressure storage systems make them costly and high-maintenance options for on-site use. The additional cost can be best justified when upgrading biogas to biomethane, which has a higher heat content and is therefore a more valuable fuel than biogas.

Medium pressure storage is between 2 and 200 psi, and this is rarely used for on-site use of biogas. To prevent corrosion of the tank components and to ensure safe operation, biogas must first be cleaned by removing H_2S. The cleaned biogas must be slightly compressed prior to storage in tanks. Typical commercially available gas tanks are rated to 250 psi (17.2 bar).

Biogas upgraded to biomethane can be stored as ompressed BioMethane (CBM) to save space for transportation. The gas is stored in steel cylinders such as those typically used for storage of other commercial gases. Medium and high pressure storage facilities must be adequately fitted with safety devices such as rupture disks and pressure relief valves. Biomethane is typically compressed to high pressures of between 2,000 and 5,000 psi. The compressor should be specified to handle the output flow rate from the biogas upgrading equipment.

Since Compressed Natural Gas (CNG) refuelling stations normally provide CNG at 3,000 to 3,600 psi, CBM would be transported at similar or higher pressures to minimize the need for additional compression at the refuelling station.

Biomethane can also be liquefied producing Liquefied Biomethane (LBM). Two of the main advantages of LBM are that it can be transported relatively easily and it can be dispensed to either LNG vehicles or CNG vehicles. Typical LNG storage tanks are double-walled, thermally insulated vessels with storage capacities of around 50,000 litres for stationary, above ground applications.

5.3. Biogas monitoring, composition, quality and pressure

Monitoring of biogas production in an AD system is imperative both as a means of ensuring the digestion process is stable and to achieve minimum availability of energy recovery equipment.

As a minimum requirement in small scale AD facilities gas production rates should be continuously monitored and composition of the principal biogas components, methane and carbon dioxide, should be monitored or periodically tested using portable gas monitoring equipment.

Large scale AD facilities must be equipped with Continuous Monitoring Systems (CMS) including output information and alarms.

All biogas monitoring systems should provide continuous biogas pressure monitoring with an alarm mechanism.

Safety features such as relief valves, monitoring equipment and alarms can become compromised as a result of fouling. If unchecked this may result in pressure build up and catastrophic failure.

The biogas collection, storage and management pipework, vessels and ancillary equipment should be maintained (including cleaning) inspected and tested to ensure layers of safety built into the design are maintained in operation.

Two options for gas monitoring including portable monitoring equipment and fixed continuous monitoring systems (CMS). Fixed monitoring systems vary in levels of automation and may include output information and alarms. H_2S cannot be monitored continuously as it damages the monitoring equipment.

All equipment should be ATEX certified (previously referred to as being “intrinsically safe”) as it will be operating in an explosive environment. ATEX refers to an EC directive by which all electrical equipment to be used in potentially explosive environments (as defined in the UK by the Dangerous Substance and Explosive Atmosphere Regulations (DSEAR)) must be certified by the supplier as safe to use according to specific risk categories.

Biogas methane levels are required to be measured both as an indicator of output from the process but also to protect downstream energy generation equipment such as gas engines or CHP units. Engines are sensitive to sudden changes in methane levels and also require a minimum methane concentration on restart.

Hydrogen sulphide levels in the biogas should also be monitored both before and after gas cleaning equipment in order to monitor the efficiency of the removal process.

Carbon dioxide (CO_2) and oxygen (O_2) levels are also useful indicators to monitor. The CH_4 / CO_2 balance can help confirm the effectiveness of the AD process and oxygen levels demonstrate that anaerobic conditions are being maintained. When acidification processes occur in the digester, initially, the biogas production may continue, but the composition changes to lower amounts of CH_4 and higher amounts of CO_2.

The measurement of hydrogen partial pressure of biogas is a technology being researched as a potential indicator of digester health. In studies an increased partial pressure of 6.5 – 7 Pa indicated early stages of digester overload. The technique currently requires laboratory analysis of biogas using Gas Chromatography (GC) and is therefore not currently used to provide continuous monitoring of digester health. However, developments on monitoring equipment may make this a viable technique in the future.

A Quality Protocol for Biomethane is currently under development and will include requirements for biogas quality monitoring purposes in order to meet end of waste criteria. Operators considering certification to the Biomethane Quality Protocol should refer to the Environment Agency's Waste Protocols Project website (link provided in Appendix D)

5.4. Gas flaring

The use of an auxiliary flare must be restricted to only short periods of breakdown or maintenance of energy recovery equipment. Flares should not be used routinely. Gas storage facilities and combustion equipment should be sized in order to deal with all the biogas generated from AD.

Auxiliary flares are required on all AD and must be available for use at all times.

Gas flares must be of an enclosed (ground) design and capable of achieving a minimum of 1,000°C and 0.3 seconds retention time at this temperature.

Open (elevated) flares will only be allowed at small scale (not IED scale) AD facilities, subject to site specific justification and should only be used in emergency situations or for very short durations when the gas engines/CHP are temporarily unavailable.

5.4.1. Enclosed (ground) flares

Enclosed flares contain a single or several burners, enclosed within a cylindrical enclosure and lined with refractory material. The enclosure prevents quenching and, as a result, the combustion is much more uniform and the emissions are low. Continuous monitoring of temperature, hydrocarbons and carbon monoxide maybe incorporated, as means of process control through the regulation of air into the biogas intake. A typical layout of an enclosed flare is indicated in Figure 9 below:

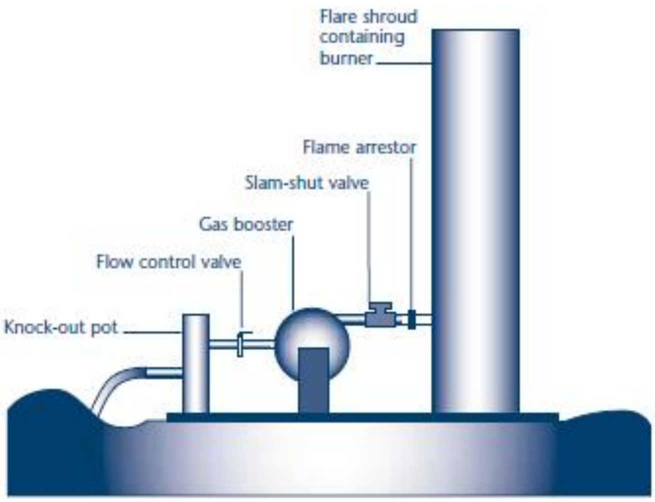


Figure 9: Enclosed Flare Schematic (source: EA, 2004)

As a flare is exposed to all weather conditions, it is important that the finish on the exterior of the flare is weatherproof as well as heat-resistant. The structure of the flare must be designed to withstand wind stresses. Ancillary items such as control and instrumentation equipment, including cabling, must be protected. Provision of housing makes maintenance tasks easier, but explosion hazards must be considered.

The basic elements of an enclosed flare are:

- gas cleaning/conditioning before the flare to remove moisture and possibly impurities, such as particulates, from the gas;
- a blower or booster developing the head of pressure needed to feed gas to the flare;
- one or more flame arrestors in the gas feed line to prevent flash-back of the flame down the pipe;
- equipment to control the flow rate of gas to the burner, and in some designs the supply of combustion air;
- a burner designed such that it maintains turbulent mixing of air and fuel and that the velocity of the gas is high enough to reduce the risk of flash-back of the flame down the feed pipe without blowing off the flame;
- an ignition system to light the gas mixture on start-up; and
- a flame detector and alarm system to check that ignition has been successful and combustion is taking place, including a slam-shut valve to prevent gas flow to the burner in the event that the flame is blown out.

Burnout, or complete combustion, may not be achieved in flares operating outside their design conditions, and partially burned fuel may show up as carbon (smoke, soot, particulates) and/or intermediate reaction products such as CO.

Further information regarding flare design and use is contained within the Environment Agency's Landfill Gas Use of Flares guidance document (link provided in Appendix D).

5.5. Indicative BAT requirements for biogas treatment

Indicative BAT requirements for biogas treatment
1. Requirements for biogas treatment depend on the gas quality requirements for the intended end use of the biogas. When treating raw biogas the following factors need to be taken into account: • **Dewatering** • **Removal of H_2S (potentially corrosive to engines)** • **Removal of oxygen and nitrogen (where present)** • **Removal of ammonia** • **Removal of siloxanes (if treating Sewage Sludge)** • **Removal of particulates and** • **Removal of CO_2 (for upgrading to biomethane).** **Taking these treatment factors into account will protect the plant infrastructure including the engines, reduce downtime and maintenance, improve the operating life of the engines and reduce emissions to the environment.** **<u>Dewatering</u>** **2. The removal of water from the biogas must be undertaken in order to protect the collection system, energy recovery plant and auxiliary flare. This can be achieved by water removal techniques such as moisture traps, condensate pots or water taps at low point in the gas line.** **Additional water removal techniques include;** • **Cooling / Condensation** • **Compression** • **Adsorption and** • **Absorption** **<u>Biogas monitoring</u>** **3. As a minimum requirement in small scale AD facilities gas flow to the consumer unit, and flow rates to gas holders should be continuously monitored and composition of the principal biogas components, methane and carbon dioxide, should be monitored or periodically tested.** **4. Large scale AD facilities should be equipped with Continuous Monitoring Systems (CMS) including output information and alarms.** **5. All biogas monitoring systems should provide continuous biogas pressure monitoring with an alarm mechanism. Any application should specify the maximum pressure above which there should be no feed to the AD reactor which should be interlocked.** **6. Biogas methane levels are required to be measured both as an indicator of output from the process but also to protect downstream energy generation equipment such as gas engines or CHP units.** **7. All equipment in contact with biogasshould be ATEX certified.** **8. Hydrogen sulphide levels in the biogas should also be monitored both before and**

Indicative BAT requirements for biogas treatment

after gas cleaning equipment in order to monitor the efficiency of the removal process.

Biogas Storage

9. **Biogas should be collected from all digesters and all other vessels where methane is generated.**
10. **Where vessels are sealed for biogas collection they should be fitted with over pressure and vacuum relief valves. Isolating valves should be incorporated to enable inspection and maintenance**
11. **Biogas upgrading or energy recovery plant should form part of the design and operation of the facility. Any plant that combusts biogas (boilers, CHP, Flare) must incorporate appropriate flame arrestors to prevent flash back and automatic isolation valves..**
12. **Biogas storage facilities must be equipped with safety valves (vacuum and over-pressure). Explosion protection must also be built in and an emergency flare provided.**
13. **The use of pressure relief valves must be restricted to emergency situations only and be carefully controlled and monitored in order to minimise the release of fugitive gas emissions.**
14. **Biogas and air must not be allowed to mix as explosions may result. Where air is used for H2S removal, oxygen must be monitored automatically and a high level alarm set to automatically stop air addition before the lower explosive limit is reached.**
15. **Pressure sensors should be provided on top of the digestion tanks and the gas storage tank. In a situation of excessive pressure build up in these tanks, due to pipe damage or blockage, an alarm signal should be triggered with immediate venting systems instigated.**
16. **The design of the gas collection system should ensure that excessive negative pressures cannot be imposed on the digester vessel or the gas collection vessel.**
17. **The correct system operating pressure should be maintained by the gas storage device..**
18. **To protect critical infrastructure safety relief valves set to operate at a slightly higher than designed operational gas pressure but at a safe level to protect the digesters and gas holders should be provided.**
19. **The gas actuated pressure relief valves should be protected against environmental and climatic conditions.**
20. **An enclosed biogas flare with a minimum residence time of 0.3 seconds at 1000ºC should be provided to burn collected biogas where the biogas upgrading or energy recovery plant becomes unavailable.**

Energy recovery

One of the key benefits provided by the treatment of biowastes in an AD facility is the recovery of energy from the digestion process in the form of biogas. In order to ensure that this benefit is being realised at AD facilities, we require operators to monitor and demonstrate that the biogas generated from the process is being effectively utilised. This will also provide evidence that the uncontrolled release of biogas to atmosphere is minimised.

The operator is required to meet a minimum availability target for energy recovery at an AD facility. Monitoring of availability will depend on how the biogas is utilised and the type of energy recovery equipment employed.

For large scale AD facilities a minimum availability of 90% must be achieved. Where power generation such as CHP is utilised this should be monitored based on the availability of the primary generating equipment.

As outlined in Figure 8, biogas produced from an AD process may be utilised for electricity and heat generation on site or may be upgraded to biomethane for export. Currently available options for energy recovery from biogas are discussed in the following sections.

6.1. Electricity generation and use

6.1.1. CHP engines

Biogas can be used in a combined heat and power (CHP) plant to produce electricity and heat. CHP currently provides the most efficient conversion of the biogas to electrical energy. However, there is quite a wide range of overall energy efficiency with different makes of CHP. CHP can be configured to produce more electricity and less heat or vice versa depending on the heat demand local to the AD plant. In general the higher the heat recovery the higher the overall energy efficiency.

The amount and cost of maintenance and operation, and life of the CHP, can vary very significantly with different makes. Some CHP units will include gas cleaning systems to protect the engine, others won’t. Some have integral flares for excess gas, some CHP units can be operated on diesel or biogas and so can be used for back up heating as well. There will generally need to be an alternative source of heat to the CHP to provide heating for the digester at start up or when the CHP is not operating.

6.1.2. Internal combustion engines

The most common technology for power generation within CHP is internal combustion. Engines are available in sizes from a few kilowatts up to several megawatts. Gas engines can either be SI-engines (spark ignition) or dual fuel engines.

Dual fuel engines with injection of diesel (10% and up) or sometimes plant oil are very popular in smaller scales because they have good electric efficiencies, which can be up to 43%. On the other hand they have higher emissions unless they use a (selective non catalytic reduction) SNCR catalyst. Another advantage is the easy start-up of the AD plant because heat and electricity can be produced immediately by using diesel as a support fuel to start the CHP.

SI-engines are equipped with normal ignition systems and a gas/air mixing system that provides a combustible mixture to the engine. SI-engines can either be stoichiometric or lean-burn engines. The stoichiometric engines operate without air excess and can thereby also use a three-way catalyst that is common in light duty vehicles. Lean burn engines are more common in larger sizes and generally have a higher efficiency.

The performance and typical capacities of different engine types is indicated in Table 22 below.

6.1.3. Gas turbines

Gas turbines are an established technology in sizes above 800 kW. In recent years also small scale engines, so called micro-turbines in the range of 25 to 100kW have been successfully introduced in biogas applications. They have relatively low electrical efficiencies comparable to small SI-engines with low emissions and allow recovery of low pressure steam which may potentially be utilised in industrial applications. Maintenance costs are typically low.

Feature	Petrol Engine Spark Ignition	Diesel Engine Compression Ignition	Diesel Engine Spark Ignition	Micro Turbine
Electrical Efficiency [%]	24–29	30–38	35–42	26–29
Maintenance cost	High	High	Medium	Low
Investment cost	Low	Medium (high)	Medium	High
Power [kW]	5–30	30–200	>200	<100
Lifespan	Low	Medium	High	High

Table 22 Comparison between Electricity Generation Technologies (Source: IEA Bioenergy, 2006)

6.1.4. Fuel cells

Fuel cell technology is not yet in widespread commercial use. Fuel cells have the potential to reach very high efficiencies (>60%) and low emissions but they require a high grade biomethane. Special interest for stationary biogas application is focussed on hot fuel cells operating at temperatures above 800°C particularly because CO_2 does not inhibit the electrochemical process, but rather serves as an electron carrier. Two types of fuel cells are in an advanced stage of development: the solid oxide fuel cell (SOFC) for small applications of a few kW and the molten carbonate fuel cells (MCFC) operating in the range of 250kW and above.

6.1.5. Connection to the National Gas Grid

Following cleaning and upgrading of the biogas generated through AD, the process for biomethane injection typically involves the injection of propane in order to increase the calorific value and therefore the Wobbe Number of the biomethane. Following this, a small amount of odorant or stenching agent is added in order to give the gas its characteristic smell. This allows escapes to be recognised. Subsequently, the gas needs to be monitored and metered.

Gas quality requirements for injection into the gas grid are defined within the Gas Safety Management (GS(M)R) regulations implemented by the Health and Safety Executive (HSE). Biomethane for injection into the gas network must satisfy the requirements of the GS(M)R at the entry point, or be granted an exemption under GS(M)R Regulation 11. Gas quality requirements for the injection of biomethane produced from biogas are currently under review. Further information can be obtained from the UK Department for Energy and Climate Change (DECC). A link is provided in Appendix X.

The following table sets out the current gas quality requirements for injection into the gas grid;

Content or characteristic	Value
Hydrogen Sulphide (H_2S)	Less than or equal to 5 mg/m^3;
Total Sulphur (including H_2S)	Less than or equal to 50 mg/m^3;
Hydrogen (H_2)	Less than or equal to 0.1% (molar);
Oxygen (O_2)	Less than or equal to 0.2% (molar);
Impurities and water and hydrocarbon dewpoints	The gas shall not contain solids or liquids that may interfere with the integrity or operation of the network or appliances
Wobbe Number (WN) (Calorific Value divided by the square root of the relative density)	Between 47.20 and 51.41 MJ/m^3
Odour	Gas below 7 bar will have a stenching agent added

Table 23 Partial summary of the key gas quality requirements from Schedule 3 of the GS(M)R (Source: DECC, 2009)

The level of equipment required for injection of biomethane is largely dependent on the supply agreement provided by the Grid Distribution Network (GDN). DECC produced guidance for biomethane injection into the gas grid that is available from the DCC website. Table 24 below summarises the type of equipment that is likely to be required.

Equipment	Description
Enrichment equipment	Required to increase the energy content (Calorific Value) of the gas to a level similar to that of the gas already in the network to ensure consumers are billed fairly for the volume of gas they use. Biomethane can be enriched by blending it with a gas with higher energy

Equipment	Description
	content than natural gas (e.g. propane).
Gas Quality Monitoring Equipment	Required to measure the energy content of the gas, and demonstrate to the Gas Transporters and HSE that the biomethane is compliant with the gas quality requirements. On sites designated as “directed” by Ofgem, the equipment to measure the energy content of the gas has to be approved by Ofgem.
Metering Equipment	Needed to measure the volume of gas injected into the gas network. On sites designated as “directed” by Ofgem it is likely that Ofgem would require fiscal standard metering. This means that metering must be accurate to within ±1 % on volume measurement, and ±1.1 % on energy measurement.
Odorisation Equipment	Odorisation is required for public safety, to give a characteristic smell, which can be widely recognised in the event of an escape. Odorant (80% tertiarybutyl mercaptan, 20% dimethyl sulphide). Dosing rate is usually 6 mg/m^3, ±2 mg/m^3, depending on GDN’s requirements.
Pressure control equipment	It is likely that biomethane pressure will need either to be increased, using compressor equipment, or reduced, using a pressure reduction valve (regulator) depending on pressure at injection point. In some parts of the network there may be significant swings in gas pressure during the day.
Automatic Valve	An automatic valve or slam shut is required to stop the injection of biomethane if it is not of appropriate quality, and also to prevent the over-pressurisation of the gas network. GDN may require a remote operation capability, to maintain the safe operation of the network.
Telecommunications Equipment	Required to send data from the injection facility, for billing and operational reasons.

Table 24 Biomethane Injection Equipment

6.2. Biomethane use as vehicle fuel

The use of biomethane as a vehicle fuel is not currently widespread in the UK mainly due to a lack of distribution infrastructure and vehicles capable of running on natural gas or biomethane.

Gas quality demands for use of vehicle fuel are strict. Quality requirements for biomethane use as a vehicle fuel are being defined as part of the Biomethane Quality Protocol currently under development. Once published the Biomethane Quality Protocol it will be available at the Quality Protocols section of our website (link provided in Appendix X).

Biogas produced from an AD plant has to be upgraded and pressurised prior to storage and distribution.

Gas vehicles are fuelled with either Compressed Natural Gas (CNG) (stored at 200/250 bar) or Liquefied Natural Gas (LNG) (stored at -162°C). Biomethane can be provided in equivalent forms to CNG and LNG. The supply of CNG or LNG requires gas refuelling stations with infrastructure to supply either types of gas as a vehicle fuel.

6.3. Heat generation and use

AD plants utilising a CHP unit for power generation will produce heat in addition to the electrical output. Some of this heat is likely to be recovered and utilised in heat exchangers to meet the heating needs of the facility. Typically this will represent between 10 -20% of the heat produced but the level will depend on the design and operating conditions of the AD facility. At small scale AD facilities a biogas boiler may be used to produce heat that is utilised on site for digester heating, office and house heating etc. Larger scale facilities may utilise biogas boilers as a back-up in case of shutdown or maintenance of the primary energy recovery equipment.

Maximising utilisation of the heat produced in an AD process will bring improvements in the overall efficiency of the process and operators should seek to identify potential markets for heat as part of the design of an AD facility.

The following sections discuss the use of biogas boilers for generating heat and also the potential for utilising heat in a small scale District Heating Network (DHN).

6.3.1. Biogas boilers

Biogas (without upgrading) can be utilised directly from the digester in a gas boiler to provide heating and/or hot water or in a kitchen range cooker to provide heating, hot water and cooking. The equipment used needs to be corrosion resistant, and is usually cast iron or stainless steel. Standard natural gas equipment can be used, but usually the jet size in the burner is increased to allow more gas through, as biogas has only about two thirds of the calorific value of natural gas. Condensation boilers are not really suitable for biogas, because they take too much heat from the exhaust. The exhaust should be vented fairly hot with biogas because it is a wet gas that contains some level of sulphur; this combination is more likely to cause corrosion once it cools. Burning biogas in a boiler is an established and reliable technology. Low demands are set on the biogas quality for this application. A gas boiler without a gas booster will require at least 25mbarg most use boosters to around 50mbarg but this depends on the gas train size.It is recommended to reduce the level of hydrogen sulphide to below 1,000 ppm.

6.3.2. District heating networks

Surplus heat generated from an AD facility may potentially be utilised in local small scale District Heating Networks (DHN). This may be to provide process heat or space heating to local businesses or housing. In order to be economically feasible, the use of a DHN requires recipients to be in close proximity to the AD facility and for the necessary infrastructure to be installed from the source to the recipient

6.4. Energy and BAT

Energy efficiency measures are required for AD subject to regulation as an installation. A number of these measures will also be relevant to AD regulated as a waste operation. Operators should take proportional steps to ensure that the AD facility is designed and operated in such a way as to optimise energy efficiency.

The operator should meet the basic energy requirements in Section 6.5 and Section 6.6 as a minimum.

Where electricity is generated, operators should also look to utilise the waste heat as well. A combined heat and power plant will result in a significant increase in energy efficiency.

6.5. Basic energy requirements (1)

The BAT requirements of this section are basic low-cost energy standards that apply in all cases.

6.5.1. Indicative BAT requirements for basic energy requirements

Indicative BAT requirements for Basic Energy Requirements Provide a breakdown of the energy consumption and generation by source and the associated environmental emissions.
1. The operator should provide the energy consumption information in terms of delivered energy and also, in the case of electricity, converted to primary energy consumption. For the public electricity supply, a conversion factor of 2.6 should be used to derive overall efficiency figures. Where applicable, the use of factors derived from on-site heat and/or power generation, or from direct (non-grid) suppliers should be used. In the latter cases, the Operator should provide details of such factors. Where energy is exported from the AD facility, the Operator should also provide this information. All this information should be submitted in the application (in England and Wales the H1 software tool should be used to produce this information). The Operator should also provide energy flow information (such as "Sankey" diagrams or energy balances) showing how the energy is used throughout the process. **2. The operator should provide the following Specific Energy Consumption (SEC) information. Define and calculate the SEC of the activity (or activities) based on primary energy consumption for the products or raw material inputs that most closely match the main purpose or production capacity of the AD facility. Provide a comparison of SEC against any relevant benchmarks available for the sector. (See Energy Efficiency Guidance).** **3. The operator should provide associated environmental emissions. This is dealt with in the operator's response to the emissions inventory using the H1 software tool.**

Our Energy Efficiency Horizontal Guidance Note IPPC H2 provides an appraisal methodology. If Operators use other appraisal methodologies they should state the method in the Application, and provide evidence that appropriate discount rates, asset life and expenditure (£/t) criteria have been employed.

The energy efficiency plan is required to ensure that the operator has considered all relevant techniques. However, where a Climate Change Agrement (CCA) or Development Permit Area (DPA) is in place the Regulator will only enforce implementation of those measures in categories 1-3 above.

6.6. Basic energy requirements (2)

The BAT requirements of this section are basic low-cost energy standards that apply in all cases.

6.6.1. Indicative BAT requirements for Basic energy requirements (2)

Indicative BAT requirements for Basic Energy Requirements (2). Describe the proposed measures for improvement of energy efficiency.
1. **Operating, maintenance and housekeeping measures should be in place in the following areas, where relevant (Indicative checklists of appropriate measures are provided in Appendix 2 of the guidance note H2 Energy efficiency for IPPC):** • **air conditioning, process refrigeration and cooling systems (leaks, seals, temperature control, evaporator/condenser maintenance)** • **operation of motors and drives** • **compressed gas systems (leaks, procedures for use)** • **steam distribution systems (leaks, traps, insulation)** • **space heating and hot-water systems** • **lubrication to avoid high-friction losses** • **boiler operation and maintenance, e.g. optimising excess air** • **other maintenance relevant to the activities within the AD facility** 2. **Basic low-cost physical techniques should be in place to avoid gross inefficiencies. These should include insulation, containment methods, (such as seals and self-closing doors), and avoidance of unnecessary discharge of heated water or air (e.g. by fitting simple control systems such as timers and sensors).** 3. **Energy-efficient building services should be in place to deliver the requirements of the Building Services section of the guidance note H2 Energy efficiency for IPPC. For energy intensive industries these issues may be of minor impact and should not distract effort from the major energy issues, but they should nonetheless find a place in the programme, particularly where they constitute more than 5 percent of the total energy consumption.** 4. **Energy management techniques should be in place, in particular, the need for monitoring of energy flows and targeting of areas for reductions.** 5. **An energy efficiency plan should be provided that:** • **identifies all techniques relevant to the AD facility, including those identified in section 6.7 that are applicable to the AD facility** • **estimates the CO_2 savings that would be achieved by each measure over its lifetime**

The Energy Efficiency Guidance Note provides an appraisal methodology. If Operators use other appraisal methodologies they should state the method in the Application, and provide evidence that appropriate discount rates, asset life and expenditure (£/t) criteria have been employed. The energy efficiency plan is required to ensure that the Operator has considered all relevant techniques. However, where a CCA or DPA is in place the Regulator will only enforce implementation of those measures in categories 1-3 above.

6.7. Further energy efficiency requirements

The Operator should demonstrate the degree to which the further energy-efficiency measures identified in the implementation plan, including those below, have been taken into consideration for this sector and justify where they have not.

6.7.1. Indicative BAT requirements for Further energy efficiency requirements

Indicative BAT requirements for further energy efficiency. Climate Change Agreement or Trading Agreement.
1. The following techniques should be implemented where they are judged to be BAT based on a cost/benefit appraisal according to the methodology provided in Appendix 4 of the Guidance Note H2 Energy efficiency for IPPC. **Energy supply techniques** 2. The following techniques should be considered: • use of Combined Heat and Power (CHP) • generation of energy from waste • use of less polluting support fuels 3. The Operator should provide justification that the proposed or current situation represents BAT, irrespective , where there are other BAT considerations involved, e.g.: • the choice of support fuel impacts upon emissions other than carbon dioxide, eg. sulphur dioxide • the potential for practical energy recovery from waste conflicts with energy efficiency requirements.

Digestate treatment and storage

7.1. Introduction

Ready access to chemical fertilisers over the last 50 years has increased agricultural production yields. However, the manufacture and use of inorganic fertiliser is recognised to give rise to particular issues, arising both from fossil fuel use and from nitrous oxide emissions. The use of digestate from AD can help to displace chemical fertilisers by providing a significant amount of nitrogen as well as phosphorus, sulphur and potassium in an organic form. Digestate has a range of potential beneficial uses on land, including use as a fertiliser or soil improver.

Digestate is the residual material from the digestion process once biological decomposition and stabilisation of the waste has taken place. The digestion process should provide a stable sanitised material that can be applied to land for the benefit of agriculture or to improve the soil structure or nutrients in land.

Digestate is made up from a liquid digestate and a residual solid or fibrous fraction suspended in the liquid digestate.

7.2. Digestate treatment

The stability of the digestate depends on the type of feedstock, the pre-treatment and digestion process and how this is managed in terms of organic load and residence time. Shortening residence time will increase the organic load and reduce the degree to which organic matter within the digester is converted to gas. Where this happens the digestate will be more active and capable of further anaerobic or aerobic biodegradation.

Some of the organic matter may remain in the liquor as VFA and this presents the potential for continued activity once outside the digester. This could also present challenges in the ongoing management of the digestate as a result of biogas generation, the release of VFA (many of which are highly odorous) and trace components within the biogas (including hydrogen sulphide).

As a minimum requirement, treated digestate should be tested in order to confirm that the process is achieving the required level of treatment indicated by the stability of the treated digestate. Digestate sampling and testing will be required to demonstrate the digestate is fully stabilised. Currently PAS110 provides details of the standard required. The level of testing of digestion composition and quality will depend on the intended market for the digestate and specifically whether the digestate is intended to meet ADQP requirements and PAS110 which are voluntary.

Individual contractual arrangements with market outlets may specify material requirements (e.g. moisture content, and CV where the digestate is intended for use as a fuel, or nutrient concentrations and impurities less than 0.5% by mass where it is to be marketed for as a soil improver).

For PAS 110 purposes any sampling of digestate must be representative of the portion of production sampled. Indicative sampling rates are provided in PAS110.

Digestate produced from wastes that do not meet the QP and PAS110 protocols will still be a waste and its use will therefore be subject to further regulation by the Regulator. The use on land of any such digestate will require an Environmental Permit and Deployment authorisations or exemption where applicable. Such wastes should consist of a stable sanitised material that can be applied to land for the benefit of agriculture or to improve the soil structure or nutrients in land

The digestate from an AD process can be applied to land 'whole' or it can be separated into a 'fibre' and 'liquor'. Separating the digestate using mechanical, biological or thermal separating equipment can have a number of benefits that can justify the cost of the separation.

A variety of fibre separator systems that are used for digestate separation, including:

- Rotary screens
- Flat belt separators

- Roller presses
- Vibrating screens
- Centrifuges and
- Screw or ram presses.

A brief description of typical digestate processing techniques is provided in Table 25:

Technique	Description
Bio-drying	Uses the activity of aerobic bacteria which occurs at the beginning of composting in order to heat and remove the water content of digestate.
Screw Press	Digestate is compressed into a gradually decreasing screw channel between a screw shaft and a fluid permeable mantle.
Belt Press	Digestate is sandwiched between two tensioned belts, or a single belt between two rollers, which are passed through decreasing diameter rolls to squeeze out water.
Brushed screens	A concave perforated screen swept by rotary brushes beaters, inclined or parabolic wedge wire screen.
Centrifuges	Use high speed rotation to separate the fibre and the liquor.
Liquor treatment	Additional processing using ultra filtration or reverse osmosis can be used to purify the liquor so it can be discharged into water bodies.

Table 25 Digestate Processing Techniques

Separation performance depends on the characteristics of the feedstocks being processed and the separator type and screen size. The design of a separator should be matched to the properties of whole digestate being separated and to the qualities of the separated products that are required. For example a belt press usually has a slow throughput, but can separate almost any kind of digestate, a drum press has a high throughput, but will have difficulty with fine solids or greasy digestate, whereas a screw press requires a digestate that contains fibrous material, but will then produce a drier fibre than other types of separator.

The following table provides a comparison of typical efficiencies for digestate separation techniques.

Separator	**Separator efficiency (%)**				
Type	**Dry Matter**	**Nitrogen**	**Phosphorus**	**Potassium**	**Volume Reduction (%)**
Belt press	56	32	29	27	29
Sieve drum	20 – 62	10 – 25	10 – 26	17	10 – 25
Screw press	20 – 65	5 – 28	7 – 33	5 – 18	5 – 25
Sieve centrifuge	13 – 52	6 – 30	6 – 24	6 – 36	7 – 26

Decanter centrifuge	54 – 68	20 – 40	52 – 78	5 – 20	13 – 29

Table 26 Separator efficiency common mechanical separators (Source IEA Bioenergy, 2010)

The fibres produced by many AD processes differ from aerobic compost in three ways:

- The content of ammonium nitrogen is high
- The degree of structural stability is low and
- Only a few species of micro-organisms are present.

The fibres are best suited for agricultural usage, while a post-treatment composting stage may be needed for general marketing in other sectors.

Where the solid/fibre proportion of digestate is separated the process should take place within an enclosed building which is kept under negative air pressure. Fast acting roller shutter doors should be provided for access and egress.

Abatement prior to discharge will be required for exhaust air from areas processing/separating and storing solid digestate prior to discharge to atmosphere.

The separation/processing of digestate should be carried out on an impermeable surface with a sealed drainage system.

Where separated fractions do not meet the PAS 110 QP, these fractions must continue to be treated as wastes and the guidelines for the storage of wastes will apply.

7.2.1. Nutrient stripping

The stripping of nutrients from whole digestate or the separated liquor fraction may be beneficial to an AD operation, in particular where a proportion of the digestate or liquor is recycled through the process or where the residual liquor is disposed to the sewerage system following treatment. The process may also result in the production of materials such as ammonium salts including struvite which have an economic value. Typical processes for ammonia stripping include gas stripping, utilising biogas and heat produced from the process, and is used in conjunction with an acid scrubbing process.

7.3. Use of digestate as a solid fuel

There is the potential development in the use of the dried fibre fraction of digestate as a biomass fuel. The process typically involves drying the separated digestate fibre to form pellets. The drying process can utilise excess heat from the CHP unit. The digestate pellets typically contain a dry matter content of 80 – 85% and have a CV of around 15 $MJkg^{-1}$.

In order to be used as biomass fuel the operator must demonstrate to the satisfaction of the Regulator, that the digestate meets end of waste for use as a fuel. Currently, where digestate is burnt, it is done so in an energy from waste (EfW) combustion facility, compliant with the Waste Incineration Directive. Issues may arise from higher concentrations of nitrogen, sulphur, chlorine or heavy metals than that found in non-waste derived fuels.

7.4. Storage of digestate

Storage of digestate represents a potential source of emissions from both gaseous and liquid run-off.

On-site digestate storage must be designed to prevent liquid emissions and minimise gas emissions. Digestate must be stored in a manner that will minimise odour and not give rise to pollution.

Operators must ensure that sufficient provision has been made for digestate storage prior to distribution.

Storage provision should take into account situations where the land-bank may be unavailable for prolonged periods, for example, where the land is waterlogged or frozen.

The length of storage period required will depend on the seasonal market of digestate.

Where digestate is stored pending application on agricultural land in a Nitrate Vulnerable Zone (NVZ), sufficient storage capacity must be available to span the winter 'no spread' periods.

In accordance with NVZ regulations storage requires at least:

- 6 months (1 October to 1 April inclusive) storage capacity for pig slurry and poultry manure; and
- 5 months (1 October to 1 March inclusive) storage capacity for other livestock slurry e.g. cattle slurry.

Losses of methane and nutrients from storing and handling of digestate are possible. In order to prevent gaseous emissions, storage equipment should always be covered with a gastight cover. Roof structures, or roof membranes can be fitted to concrete or steel structure stores, and flexible covers can be fitted to lagoons. All such storage areas (including those for the storage of solid fractions) should be provided with appropriate emissions control and abatement systems.

In order to maximise recovery of biogas, operators should consider including a system to collect additional biogas produced from the storage of digestate. Digested material must be stored upon an impermeable surface supplied with a sealed drainage system.

Digestate must be stored within covered tanks or covered lagoons and should be of a design and capacity fit for purpose. Lagoons should have a free board of minimum 750 mm.

Where digestate is dewatered, the fibre must be covered either in a Dutch barn or sheeted and stored on an impermeable surface with a sealed drainage system.

7.4.1. Indicative BAT requirements for digestate treatment and storage

Indicative BAT requirements for digestate treatment and storage
<u>**Separation**</u> **The separation (solids/fibres from liquid) of digestate must:** **1. Take place within an enclosed building which is kept under negative air pressure.** **2. The building should have fast acting roller shutter doors provided for access and egress.**

3. **Exhaust air from processing/separating and storage areas will require abatement prior to discharge to atmosphere.**
4. **The separation/processing digestate should be carried out on an impermeable surface with a sealed drainage system.**
5. **Where separated fractions do not meet the PAS 110 QP, these fractions must continue to be treated as wastes and the guidelines for the storage of wastes will apply.**

Storage of digestate

6. **Digestate must be stored within covered tanks or covered lagoons and should be of a design and capacity fit for purpose. Lagoons should have a free board of minimum 750 mm.**
7. **All such storage areas (including those for the storage of solid fractions) should be provided with appropriate emissions control and abatement systems.**
8. **In order to maximise recovery of biogas, operators should consider including a system to collect additional biogas produced from the storage of digestate.**
9. **Digested material must be stored upon an impermeable surface supplied with a sealed drainage system.**
10. **Operators must ensure that sufficient provision has been made for digestate storage prior to distribution.**
11. **Digestate must be stored in a manner that will minimise odour and not give risk to pollution. Storage provision should take into account situations where the land-bank may be unavailable for prolonged periods, for example, where the land is waterlogged or frozen.**
12. **Where digestate is stored pending application on agricultural land in a Nitrate Vulnerable Zone, sufficient storage capacity must be available to span the winter no spread periods.**
13. **Where the digestate does not meet the PAS 110 QP, the digestate must continue to be treated as wastes and the guidelines for the storage of wastes will apply.**

Emissions control and abatement

7.5. Emissions to air

7.5.1. Point Source Emissions to Air

Combustion Exhaust Emissions

The energy within biogas should be recovered efficiently. This may be carried out on site or biogas may be exported for energy recovery offsite. Most biogas utilisation schemes produce electricity and/or heat although wider applications are possible where the biogas is upgraded to biomethane and exported.

Most AD plants utilise the biogas on-site, either as a fuel for use in boilers to provide hot water and heating (small scale AD plants) or by combustion within CHP gas engines to provide electricity and heat.

Maintaining the availability of the on-site energy recovery plant is a priority and this requires alignment of the reactor design to the energy recovery plant to avoid any biogas surplus and operating and maintaining the energy recovery plant to minimise unnecessary downtime.

Stand-by flares are used to burn excess biogas, when the energy recovery plant is unavailable due to maintenance or breakdown and the on-site biogas storage has exceeded its capacity. Biogas should not be routinely flared.

Monitoring of the exhaust emissions of the combustion plant is required in order to ensure that the combustion characteristics have been optimised and drift in engine performance is minimised.

The emissions and monitoring standards that apply to biogas fuelled engines are the same as those we apply to engines fuelled by landfill gas, with limits being set for oxides of nitrogen (NOx), carbon monoxide (CO) and VOCs. A limit for sulphur dioxide may also be included, depending upon the likely presence of sulphur-containing compounds within the biogas. Current limits for engines and boilers are provided in Table 27 below, although operators should always seek to maximise the performance of the engines and achieve emissions well below those limits in the permit.

Emission Point and Source	Parameter	Limit (including units)
Stacks on engines	Oxides of Nitrogen Carbon monoxide Total volatile organic compounds including methane Minimum stack exit velocity	500 mg/m^3 1400 mg/m^3 1000 mg/m^3 15 m/s to ensure effective plume breakaway

Table 27 – Typical Emission Limits for New Biogas Engines

Operators should refer to our guidance document LFTGN08 – Guidance for Monitoring Landfill Gas Engine Emissions for details of how gas engine monitoring is to be undertaken and for details of the current limits which apply, the link is provided in Appendix D. Reporting against a compliance limit should take into account the uncertainty of the result.

Where CHP plants involving biogas engines are used, routine servicing of the engine is also required to maintain combustion efficiency as these plants fall out of tune within relatively short periods. As well as the annual monitoring usually required, additional monitoring of NOx and CO should also be undertaken periodically and the engine(s) re-tuned to ensure the energy recovery plant remains within the permitted emission limits. Further details regarding the methodology for such monitoring can be found in Appendix C of guidance document LFTGN08.

Records should be kept by the operator of all monitoring undertaken and the monitoring results, maintenance undertaken, periods of operation of the auxiliary flare and releases of biogas from pressure release valves.

7.5.2. Indicative BAT requirements for point source emissions to air

Indicative BAT requirements for point source emissions to air
1. Operators should refer to our guidance document LFTGN08 – Guidance for Monitoring Landfill Gas Engine Emissions for details of how gas engine monitoring is to be undertaken and for details of the current limits which apply, this is available in the landfill gas guidance section of our website in appendix D. **2. Where CHP plants involving biogas engines are used, routine servicing of the engine is also required to maintain combustion efficiency. As well as the annual monitoring required, additional monitoring of NOx and CO should also be undertaken periodically and the engine(s) re-tuned to ensure the energy recovery plant remains within the permitted emission limits. Further details regarding the methodology for such monitoring can be found in Appendix C to LFTGN08.** **3. Records should be kept by the operator of all monitoring undertaken and the monitoring results, maintenance undertaken, periods of operation of the auxiliary flare and releases of biogas from pressure release valves.** **4. Biogas storage and combustion should be appropriately sized to deal with the quantity of biogas generated from the AD process operating as designed. Biogas should not be routinely flared to atmosphere.** **5. The main chemical constituents of the emissions should be identified. This will allow the appropriate abatement technology to be selected to clean incidental emissions.** **6. Emphasis should be placed on the prevention of the production and displacement of pollutants. Abatement can be readily overloaded and become ineffective. Abatement techniques should not be used as an inline process tool as part of the treatment process.** **7. Correctly operate and maintain the abatement equipment, including the handling and disposal of spent scrubber medium or spent carbon.** **8. Vent and chimney heights should be assessed for dispersion capability and an assessment made of the fate of the substances emitted to the environment.** **9. The Operator should justify whether or not abatement is required, assessing the impact of the emissions.** **10. Sampling facilities should be provided in line with Environment Agency M1 guidance for point source emissions.**

7.5.3. Fugitive emissions to air

The majority of fugitive emissions occur during the acceptance of wastes and from the transfer of wastes to the bio-reactor and removing digestate from the bioreactor. Suitable operational procedures should be developed and followed to minimise fugitive emissions during these processes – these include transferring the wastes to the bioreactor via sealed pipeline from a suitably enclosed waste acceptance and treatment building and appropriate sealed transfer and storage of digestate.

There are other potential sources of fugitive biogas emissions, including those related to emergency vent valves and from poorly sealed water traps, flanges and other unions within/between pipework and the reactor headspace and within the gas collection pipework. Efficient design, construction, operation and maintenance of the AD plant will prevent or minimise fugitive emissions from these sources.

The main methods of preventing such emissions are regular scheduled checks and maintenance, including leak detection tests and other plant monitoring where appropriate. Any hazards related to such emissions need to be managed since they pose fire and/or explosion risks, as well as toxicity from gases such as H_2S and the potential for nuisance from the release of highly odorous compounds such as mercaptans.

Fugitive emissions (including particulates, odour and/or bioaerosols) may occur from waste pre-treatment areas, depending on the type of pre-treatment process used (particularly mechanical pre-treatment). Unless it can be justified otherwise, waste treatment should take place in an enclosed building with an appropriate air management system that maintains a negative pressure within the building and discharges via an emissions abatement system.

Examples of common sources of fugitive emissions are:

- Open vessels (for example, digestate storage tanks)
- Sampling activities
- Storage areas (for example, bays, stockpiles, lagoons, etc.)
- The loading and unloading of containers
- Transferring/bulking up of material from one vessel to another
- Conveyor systems
- Pipework and ductwork systems (for example, pumps, valves, flanges, catchpots, drains, inspection hatches, etc.)
- Poor building containment and extraction
- Potential for by-pass of abatement equipment (to air or water)
- Spillages
- Accidental loss of containment from failed plant and equipment
- Tanker and vessels manhole openings and other access points
- Displaced vapour from receiving tanks
- Cleaning or replacing of filters
- Condensate storage and handling

- Wastewater storage
- Drum storage
- Tank cleaning
- Tanker washing

As part of the application the operator should identify and, where possible quantify, significant fugitive emissions to air from all the specific relevant sources listed above, estimating the proportion of total emissions that are attributable to fugitive releases for each substance. Where there are opportunities for reductions, the permit may require the updated inventory of fugitive emissions to be submitted.

This section should be read in conjunction with section 7.6 Odour.

7.5.4. Indicative BAT requirements for fugitive emissions to air

Indicative BAT requirements for fugitive emissions to air
1. The AD facility must be designed, constructed, operated and maintained to a high standard so as to prevent or minimise any potentially polluting point source and/or fugitive emissions. **2. Fugitive biogas emissions must be prevented as they pose fire and/or explosion risks, as well as toxicity from gases such as H2S and the potential for nuisance from the release of highly odorous compounds. A programme of regular scheduled checks and maintenance, including leak detection tests and other plant monitoring, must be developed and followed.** **3. Effective monitoring of all processes and emissions must be undertaken.** **4. Emissions abatement systems must be specifically selected and designed to minimise the release of odour, bioaerosols and microorganisms, taking into account all relevant process parameters for the area of operations they are to control and they should be installed, monitored and maintained so as to ensure their continued effective operation.** **5. Where odour generating activities take place in the open, (or potentially odorous materials are stored outside), a high level of management control and use of best practice to prevent odours will be expected.** **6. The following general techniques should be employed where appropriate:** • **Covering of skips and vessels** • **Avoidance of outdoor or uncovered stockpiles (where possible)** • **Where dust creation is unavoidable, use of sprays, binders, stockpile management techniques, windbreaks and so on** • **Regular wheel and road cleaning (avoiding transfer of pollution to water and wind blow)** • **Closed conveyors, pneumatic or screw conveying (noting the higher energy needs), minimising drops. Filters on the conveyors to clean the transport air prior to release** • **Regular housekeeping**

Indicative BAT requirements for fugitive emissions to air
For further information on odour, see Section 7.6 **7. In addition:** • **When cleaning filters, filter pot lids should be replaced as soon as possible.** • **Contaminated waters have potential for odours and should be stored in covered tanks.** • **Maintenance schedules should ensure regular cleaning/ desludging of tanks to avoid large scale decontamination activities. All odorous materials being transferred directly to sealed containers.** • **Tanker washing should be conducted under a permit to work scheme. If the load is likely to give rise to odour, then the first wash should be with water/aqueous waste and discharged direct to abated storage systems before opening the tanker manways. Open tanker barrel for the minimum amount of time. All washings to be directed to abated storage systems.**

7.6. Odour

AD sites may produce odours as a result of normal operations and odours can become significant if there are local sensitive receptors.

The operator should have an odour management plan containing the following:

- Information relating to sensitive receptors, in particular the type of receptor, location relative to the odour sources and an assessment of the impact of odorous emissions on those receptors (This should normally be available before a Permit is issued, but where very detailed information has to be obtained the Operator may be able to secure an agreement to supply it as part of a preoperational requirement).
- An overview of any complaints received, what they relate to (source/operation) and remedial action taken.
- The types and source of odorous substances used or generated, intentional and fugitive (unintentional) release points and monitoring undertaken.
- A description of the actions taken to prevent and/or minimise odour annoyance for each odour source.
- A demonstration that the indicative BAT requirements are being complied with.
- Identification of any circumstances or conditions which might compromise the ability to prevent or minimise odour annoyance, and a description of the actions that will be taken to minimise the impact.

There may be a requirement placed upon the Operator to provide some or all of this information in the form of an odour management statement. The use of appropriate sections of H4 Horizontal Guidance for Odour - Part 1 (Regulation and Permitting) and Part 2 (Assessment and Control) is advised.

The definition of pollution includes “emissions which may be harmful to human health or the quality of the environment, cause offence to human senses or impair or interfere with amenities and other legitimate uses of the environment”. Odour emissions can constitute “offence to human senses” and are associated with point sources as well as fugitive sources.

The information presented in this section should be read in conjunction with the Environment Agency H4 Odour Management Horizontal Guidance available on our website (see link in Appendix D).

The guidance provides further details and requirements regarding odour management that the developer will need to take into account when preparing an Odour Management Plan (OMP).

AD has the potential to generate odour emissions from the anaerobic stabilisation process. In addition exhaust and combustion gases can also contain odorous compounds.

The most likely compounds to cause odour issues are ammonia, hydrogen sulphide, volatile fatty acids, mercaptans, alkyl sulphides and terpenes. These compounds are present in many feedstocks or are formed during the process.

Bio waste materials have the potential to generate odour as they biodegrade. Poor management of unprocessed waste/substrate storage can lead to the generation of offensive odours, which can become a persistent nuisance to local residents and may result in enforcement action being taken by us against the site operator.

Odours can also create negative perception of AD facilities by local residents and communities, which may impact on the long term viability of facilities. The potential for odour therefore needs to be assessed and managed carefully with each new facility.

7.6.1. Odour management

Appropriate measures must be taken in the design and operation of the AD to prevent potential odour pollution or minimise it when prevention is not practicable. The measures that are appropriate will depend on the process and site-specific circumstances whilst taking cost and benefits into account.

Operational handling and management of wastes has a part to play in the management of odour but it is accepted that the nature of the feedstocks and process may make some fugitive emissions unavoidable. Good housekeeping, vehicle management, the rotation of feed to prevent unnecessary ageing and degradation within storage areas and routine maintenance and cleaning will all help reduce the generation and release of fugitive emissions. Nevertheless the challenge of controlling odour from wastes that are intrinsically odorous when received remains. This leads in most cases to the need for engineered containment of storage and process areas where waste and solid outputs are exposed.

The reception and pre-treatment of odorous or potentially odorous wastes should take place within an enclosed building with an appropriate air management system that maintains a negative pressure within the building and discharges via an emissions abatement system. Vehicle and other access points to the building should avoid wash out of odour through ventilation design, the use of high speed roller shutter doors and designing the containment to segregate areas of low and high odour. Areas of higher odour should be remote from main areas of access. The extraction system should be capable of providing a minimum rate of 3 air changes per hour to the operational area to prevent the build up of odours and gasses. The system should also be designed to allow higher numbers of air changes within the building where there is possibility of higher or more acute odour release. Any air movement should be controlled to ensure air flows are from low odour areas to high odour areas.

Ultimately developers and operators risk the closure of their facility if they cannot adequately mitigate odours, it is therefore important to fully understand the mechanisms and events which cause odours to arise.

7.6.2. Odour monitoring

Monitoring odour should be part of measuring the effectiveness of operational practices, as it may identify an imbalance of the anaerobic degradation process or reveal the need to improve housekeeping and maintenance.

When a digester is first filled and becomes air tight, not only will it take several days to fill and reach the correct temperature, but the anaerobic conversion process could take several weeks before the correct bacterial cultures develop and start generating methane. Therefore a great deal of care and attention are required, especially during the commissioning stage of an AD plant, when the plant is in its start up phase. Reaching a stable operational stage could take up to six months, during which time there will be a great deal of intervention from the technology suppliers, commissioning engineers and operators. This is likely to increase the amount of fugitive biogas release which could carry high levels of VOCs and cause odour. The Operator should ensure that any such releases are controlled and minimised. Should any significant releases of biogas be necessary then these should be collected and appropriately managed, e.g. by flaring where possible.

Once the plant is operational there are various parameters that will require checking or monitoring daily to ensure that digestion is balanced. This will help reduce the potential for fugitive emissions by improving the degree of stabilisation and reducing more odorous VFA within the digestate.

There are a number of methods for measuring odours and the right method should be chosen based on particular conditions, the degree of accuracy required and affordability.

Monitoring can take several different forms depending on site, scale and type, location and location of sensitive receptors. These should be considered as part of the OMP. Monitoring includes:

- Sniff testing (to check ambient air on or off site)
- Meteorological monitoring
- Complaints
- Odour diaries
- Process parameters
- Field dilution olfactometers
- Grab sampling and analysis
- Chemical monitoring techniques.

7.6.3. Odour abatement

As previously detailed, the reception and pre-treatment of odorous or potentially odorous wastes should take place within an enclosed building with an appropriate air management system that maintains a negative pressure within the building and discharges via an emissions abatement system. The abatement system must be specifically designed to minimise the release of odour, bioaerosols and microorganisms and maintained for the process undertaken and be fit for purpose. There are a number of suitable abatement techniques:

- Biofiltration
- Wet Chemical Scrubbing
- Activated Carbon
- Ozone Treatment.

The techniques may be used in isolation or in combination depending on the species to be abated and other site specific factors such as the proximity of receptors and available space. The operator should deploy the technique or techniques which most effectively prevent or minimise the emission of odours.

7.6.3.1. *Biofiltration*

Biofilters operate by directing the exhaust air from the air management system through a substrate that supports a population of aerobic microbes (microorganisms including both bacteria and fungi). Odorous air is directed into the biofilter and the odorous substances transfer into a biofilm on the surface of the substrate and the microbial community degrades the chemicals/substances to carbon dioxide and water.

Biofilters, in a wide range of configurations, are by far the most popular and common method of scrubbing odours from enclosed waste operations utilising biowastes, due to their potential for high removal efficiencies and low cost. However, biofilters are not particularly effective with highly variable odour streams (unlikely to be an issue with most AD plants), require a relatively large area and need to be actively maintained by competent personnel.

Biofilters are designed to operate based on the nominal volume of process air that they are required to filter per unit time and will require active management. Accordingly, if a biofilter is accustomed to coping with moderate loadings a drop in removal efficiency will be evident where this loading is increased suddenly.

Biofilter design

The basic design consists of biologically active media bed supported over an enclosed chamber that allows odorous gas to be fed into the filter media (fixed bed biofilter). Biofilters vary from relatively simple open designs to highly engineered closed systems, all of which work on the same principle. There are two basic designs:

- Closed biofilters; the filtration medium is housed within a structure that typically has an inlet port for the dirty air and an exhaust port for the treated air that has been through the filter.
- Open biofilters; the medium is exposed to atmosphere, sometimes at the sides as well as the top. They have an inlet port but filtered emissions will exhaust freely from all exposed surfaces.

It is also possible to enhance the basic biofilter design to include biotrickling filters and bioscrubbers.

A biotrickling filter is a modification to the trickling filter design used in waste water treatment. The process gas and liquid (commonly sewage sludge) flow through a fixed bed either counter currently or co-currently. The fixed bed material provides a surface for an aqueous biofilm to form in which biodegradation can occur. The packed bed is generally made of an inert material such as structured plastics, resins, ceramics, celite, polyurethane foam, or lava rocks.

A bioscrubber is an enhancement to the biotrickling filter. The bioscrubber attempts to improve the absorption of pollutants into the liquid phase, and lengthen the time the microbes have to consume the pollutants. These are accomplished in two ways: the tower packing is flooded with a liquid phase and the discharge effluent from the bioscrubber is collected in a storage tank (sump) before being recycled back to the bioscrubber.

The relative advantages and disadvantages of each these biofilter treatment methods are set out in the table below.

Design	Advantages	Disadvantages
Fixed Bed Biofilter	Low operation, capital and maintenance costs. Easy operation and start-up. High gas/liquid surface area.	Large land requirement for traditional design. No continuous internal liquid flow in which to adjust bed pH or to add nutrients. In an open design it is difficult to obtain samples to prove effectiveness. Natural bed media must be replaced every 2 to 5 years.
Biotrickling Filter	Good for high flow rates.	Media require regular replacement.
Bioscrubber	Humidification of process gas is not required. Smaller size than traditional biofilters. pH and nutrient feed can be automated.	Considerably more expensive to install and operate than other biofilter designs. Overfeeding can lead to plugging.

Table 28 – Biofilter Design Advantages and Disadvantages (Sources: US EPA 2003, Cabrera et al., 2011)

Biofilter operational requirements

The key factors influencing biofilter performance are the choice of biofilter media, residence time of the odorous air within the biofilter, sizing of the biofilter bed, temperature, moisture content of the filter material, pH and the availability of nutrients. Maintaining optimal operational conditions is vital to ensure that a biofilter remains effective in treating fugitive odorous emissions.

Biofilter Media

The filter media to be used in a biofilter is an important consideration and must be selected to provide; adequate residence times, sufficient surface area (sorption capacity) for contaminants and microbial attachment, living space and reserve nutrients for micro-organisms, water content, structural support to maintain internal structure.

Materials that can be used as filter media can include organic materials and wastes from a variety of sources and inert materials for structural support and often a mixture of compost and wood chips is used to aid adsorption capacity. Additives may be used to maintain optimum conditions such as limestone or crushed shells for pH maintenance.

Recommended operational conditions for biofilters are provided inTable 29***.***

Characteristic	Description
Filter media	Biologically active, but reasonably stable
	Organic matter content >60 %
	Porous and friable with 75 – 90 % void volume
	Resistant to water logging and compaction
	Relatively low fines content to reduce gas headloss
	Relatively free of residual odour
	Specifically designed mixtures of materials may be desirable to achieve the above characteristics
Moisture content	50 – 80 % by weight
	Provisions must be made to add water and remove bed drainage
Nutrients	Must be adequate to avoid limitations
	Usually not a problem with aerobic digestion gases because of the high NH_3 content
pH	7 to 8.5
Temperature	Near ambient, 15 – 35 or 40 °C
Gas pre-treatment	Humidification could prove to be useful in order to achieve near 100 % inlet gas humidity
	Dust and aerosols may be removed to avoid media plugging, but for most biofilters this is not a problem (unless they have a tissue layer in the bottom)
Gas residence time	Min 30 - 60 seconds, preferably nearer 60 seconds
Media depth	>1m, <2 m
Elimination capacity	Depends on media and compound (typically in the range 10 – 160 g.m-3.h-1)
Gas distribution	The manifold must be properly designed to present a uniform gas flow to the media

Table 29 – Recommended Operational Conditions for Biofilters

7.6.3.2. *Wet chemical scrubbers*

As indicated above, biofilters efficacy can be limited with highly variable odour streams, and will require a relatively large area compared to chemical scrubbers and need to be actively maintained by competent facility staff. Therefore, there may be circumstances where wet chemical scrubbing is a suitable supplement or replacement for biofiltration in the removal of odours, for example when large air volumes need regular replacing or for removal of high levels of ammonia.

Wet chemical scrubbers provide intimate and prolonged contact between the treated air stream and an aqueous absorbing solution. A wide range of variations are possible including:

- Re-circulating and single-pass scrubbing solutions
- Acidic or alkaline scrubbing solutions
- Oxidising scrubbing solutions
- Packed column, plate or spray towers.

Common chemicals used in wet scrubbing include oxidizing agents (sodium hypochlorite, hydrogen peroxide), bases (lime, hydrated lime, caustic), acids (sulphuric, hydrochloric), reducing agents and absorption enhancing agents.

Due to the complex nature of gases within AD emissions that include ammonia, organic sulphur compounds, and other organic compounds such as VFA and terpines, different absorption conditions are necessary to remove all these compounds. Therefore single stage scrubbing will not be particularly effective and a multi-stage process is usually required. Examples of multi-stage scrubbing systems include misting towers and packed bed scrubbers.

Capital costs for these systems can be relatively high, particularly when equipped with systems to re-circulate and chemically dose the scrubbing solutions. However, their compact size, high potential removal efficiency and ability to handle highly variable air streams and loading rates can make them cost effective in some cases, particularly where high volumes of air require treatment (e.g. building ventilation) such as on a large scale in-vessel composting or AD facility.

7.6.3.3. *Ozone treatment*

Ozone gas can be used to treat malodorous air at biowaste facilities. Ozone oxidizes volatile organic compounds within an emission stream to yield compounds which are less odorous. Ozone itself is reduced to form oxygen. It may be used in isolation or in combination with other techniques for abatement. There is limited information on its application within AD although it is used widely in other areas including wastewater treatment.

7.6.3.4. *Activated Carbon*

Activated carbon is used in an adsorption process for odour removal from gas, and is effective in humid gas streams. Systems may use carbon adsorption following a water scrubbing process as activated carbon can be prone to plugging from dust and fine particulates. Activated carbon is also not effective at ammonia removal and therefore scrubbing to remove ammonia is typically required in addition to carbon adsorption in applications with high nitrogen containing substrates. Activated carbon must be either replaced or regenerated prior to saturation to prevent reduced performance.

7.6.4. Bioaerosols

There is the potential for bioaerosols to arise within the waste acceptance and pre-treatment building or from the operation of a biofilter. The abatement system chosen to manage the emissions from such sources must be specifically designed to minimise the release of odours, bioaerosols and microorganisms.

The regulator may therefore require the monitoring of bioaerosol emissions, particularly if the facility is located near to any sensitive receptors.

7.6.5. Indicative BAT requirements for odour control

Indicative BAT requirements for odour control
1. **Where odour can be contained, for example within buildings, the Operator should maintain the containment and manage the operations to prevent its release at all times by ensuring a negative pressure. There should be a minimum of 3 air changes per hour and the air vented to an odour abatement system before release (also see point source discharge to air).** 2. **Emissions abatement systems must be specifically selected and designed to minimise the release of odour, taking into account all relevant process parameters for the area of operations they are to control and they should be installed, monitored and maintained so as to ensure their continued effective operation as agreed with the regulator. Where odour releases are expected to be acknowledged in the Permit, (i.e. contained and treated prior to discharge or discharged for atmospheric dispersion) the regulator expects that:** • **For existing AD facilities, the releases should be modelled to demonstrate the odour impact at sensitive receptors. The target should be to minimise the frequency of**

exposure to ground level concentrations that are likely to cause pollution.

- **For new AD facilities, or for significant changes, the releases should be modelled and it is expected that the Operator will achieve the highest level of protection that is achievable with BAT from the outset.**
- **Where there is no history of odour problems then modelling may not be required although it should be remembered that there can still be an underlying level of pollution without complaints being made.**

3. **Where odour generating activities take place in the open, (or potentially odorous materials are stored outside) a high level of management control and use of best practice will be expected.**
4. **Where an AD facility releases odours but has a low environmental impact by virtue of its remoteness from sensitive receptors, it is expected that the Operator will work towards achieving the standards described in this Note, but the timescales allowed to achieve this might be adjusted according to the perceived risk.**
5. **Assessment of odour impact should cover a range of reasonably foreseeable odour generation and receptor exposure scenarios, including emergency events and the effect of different mitigation options.**
6. **Emphasis should be placed on pre-acceptance screening and the rejection of specific wastes, for example, highly odorous materials that are only suitable for acceptance under special handling requirements. These may include dedicated sealed handling areas with extraction to abatement.**
7. **Emphasis should be placed on the prevention of the production, containment and displacement of pollutants. Abatement can be readily overloaded and become ineffective. Abatement techniques should not be used as an inline process tool as part of the treatment process. Scrubbers should be monitored to ensure optimum performance, i.e. operating at correct pH, ensuring adequate chemical wash replenishment and replacement and pressure drop monitoring. Scrubbers should be alarmed to alert operators to conditions where performance may be adversely affected.**
8. **Correctly operate and maintain the abatement equipment, including the handling and disposal of spent scrubber medium or spent carbon.**

7.7. Point source emissions to surface water and sewer

7.7.1. Nature of effluent

The majority of point sources from AD treatment plants are in the form of treated digestate. The outlet for the liquid output from the AD is in the digestate that is spread to land for agricultural or ecological benefit. Depending on the availability of the landbank or the type of waste feed, the liquid may be separated from the solid fraction of the digestate and discharged to foul sewer with the permission of the sewerage undertaker. Emissions to watercourses and groundwater (under consent) are rare and secondary treatment methods are required such as reverse osmosis followed by tertiary reed bed treatment in order to meet environmental quality standards.

Consideration could be given to membrane processes, for example, micro-, ultra- and nano filtration. These are being utilised by some water utilities on discharges from WWTW, primarily to control pathogens. There would appear to be scope for the application of these filtration techniques (including sand filters) to remove particulate in effluents from AD plants, reducing suspended solids.

It is important to note that, whereas a trade effluent consent for a discharge to sewer allows the release of a stated level of pollution, this does not necessarily mean that this is BAT for the treatment process. BAT requires that pollution should be prevented or reduced, within the cost and benefit framework of BAT.

The primary consideration should be to prevent releases of harmful substances to the aquatic environment, whether releases are direct or via a sewage treatment works.

7.7.2. Indicative BAT requirements for point source emissions to surface water and sewer

Indicative BAT requirements for point source emissions to surface water, sewer
1. **The following general principles should be applied in sequence to control emissions to water:** • **water use should be minimised and wastewater reused or recycled** • **contamination risk of process or surface water should be minimised** 2. **Consideration should be given to the use of filtration/osmosis or other techniques which allow the effluent water to be cleaned if discharge is to be to controlled waters.** 3. **Where effluent is treated off-site at a sewage treatment works the above factors still apply. In particular, it should be demonstrated that:** • **action plans are appropriate to prevent direct discharge of the waste-waters in the event of sewer bypass, (via storm/emergency overflows or at intermediate sewage pumping stations) for example, knowing when bypass is occurring, rescheduling activities such as cleaning or even shutting down when bypass is occurring.** • **a suitable monitoring programme is in place for emissions to sewer.** 4. **The operator should conduct daily visual checks on the effluent management system and maintain a log.** 5. **The operator should have in place procedures to ensure that the effluent specification is suitable for the on-site effluent treatment system or discharge criteria** 6. **Measures should be in place to isolate effluent where samples indicate a breach of specification. Incidents of this nature should be recorded in the effluent log.**

7.8. Point source emissions to groundwater

In general, there should be no permitted releases to groundwater of either a direct or indirect nature.

On 6 April 2010 the controls to protect groundwater quality formerly dealt with under the transitory Groundwater regulations 2009 (which superseded the Groundwater regulations 1998) came within phase 2 of environmental permitting regime via the Environmental Permitting (England and Wales

Regulations 2010. EPR 2010 implements the requirements for controls on discharges to groundwater imposed by the Water Framework Directive.

EPR also replaces the offences under previous regulations and the Water Resources Act 1991 for the discharge of pollutants without a permit. Anything defined as a groundwater activity now requires either an environmental permit or must be an exempt groundwater activity. It is an offence to operate a regulated facility or to cause or knowingly allow a groundwater activity to take place without an environmental permit or an exemption.

The Water Framework Directive (2000/60/EC) introduced the concept of 'hazardous substances' and 'non-hazardous pollutants', which replaced the previous definitions of List I and List II substances in the now revoked Groundwater Regulations. Hazardous substances are defined as 'substances or groups of substances that are toxic, persistent and liable to bio-accumulate, and other substances or groups of substances that give rise to an equivalent level of concern.' All substances previously confirmed to be on List I are automatically considered to be hazardous substances subject to any re-classification. The UK is required under the Groundwater Daughter Directive (2006/60/EC) to publish a list of substances it considers hazardous. This list is determined by the Joint Agencies Groundwater Directive Advisory Group (JAGDAG). Non-hazardous pollutants include any substance capable of causing pollution. Note that the range of non-hazardous pollutants is now much wider than those contained on the previous List II.

In England and Wales, the inputs of hazardous substances and non-hazardous pollutants to groundwater are controlled via EPR (2010). An input is any entry of a substance into groundwater from an activity or discharge, whether accidental or deliberate, point source or a diffuse source, that causes a release of a pollutant into groundwater. Inputs can be direct or non-direct:

- A direct input is defined as 'the introduction of a pollutant to groundwater without percolation through soil or subsoil.'
- An indirect input is characterised by the discharge into groundwater after percolation through the soil or subsoil.

Inputs of hazardous substances must be effectively prevented from entering groundwater; inputs of non-hazardous pollutants into groundwater must be limited. The direct input of hazardous substances to groundwater is not permitted by regulation unless it satisfies certain specific criteria.

To 'prevent' an input into groundwater means taking all measures deemed necessary and reasonable to avoid the entry of hazardous substances into groundwater. While it is technically difficult to demonstrate that no hazardous substances will enter groundwater, the practical interpretation is that hazardous substances should not be discernible above the natural background groundwater quality. Any deliberate discharge of non-hazardous pollutants need to be controlled via an environmental permit and must not cause pollution.

For more information, interpretation and key definitions (for England and Wales) see Groundwater Protection: Principles and Practice (GP3) Environment Agency, 2012.

EPR Horizontal Guidance note H5 'Site Condition Report – Guidance and Templates' provides guidance for operators of new and existing operations where there may be a significant risk to land or groundwater. A Site Condition Report (SCR) describes and records the condition of the land and groundwater at a site. It enables operators to demonstrate that they have protected groundwater during the lifetime of the site and it is in a satisfactory state when they come to surrender their permit.

7.8.1. Indicative BAT requirements for point source emissions to groundwater

Indicative BAT requirements for point source emissions to groundwater
1. In general, there should be no permitted releases to groundwater of either a direct or indirect nature. **2. If there are releases to groundwater and they are to continue, the requirements of the Regulations, as summarised above, must be complied with.**

7.9. Emissions of substances not controlled by emission limits to surface water, sewer and groundwater

There should be no fugitive releases to surface or groundwater other than clean runoff. Appropriate steps should be taken to ensure runoff remains uncontaminated. Some common examples of sources of fugitive releases to waters and their preventive measures are given in the BAT box below.

7.9.1. Indicative BAT requirements for emissions of substances not controlled by emission limits to surface water, sewer and groundwater

Indicative BAT requirements for emissions of substances not controlled by emission limits to surface water, sewer and groundwater
1. For subsurface structures: **• establish and record the routing of all AD facility drains and subsurface pipework** **• engineer systems to minimise leakages from pipes and ensure swift detection if they do occur, particularly where polluting substances are involved** **• provide secondary containment and/or leakage detection for sub-surface pipework, sumps, treatment and storage vessels** **• establish an inspection and maintenance programme for all subsurface structures, eg. Pressure tests, leak tests, material thickness checks or CCTV.** **2. All sumps should:** **• be impermeable and resistant to stored materials** **• be subject to regular visual inspection and any contents pumped out or otherwise removed after checking for contamination** **• where not frequently inspected, be fitted with a high level probe and alarm, as appropriate** **• be subject to programmed engineering inspection (normally visual, but extending to water testing where structural integrity is in doubt).** **3. For surfacing:** **• design appropriate surfacing and containment or drainage facilities for all operational areas, taking into consideration collection capacities, surface**

Indicative BAT requirements for emissions of substances not controlled by emission limits to surface water, sewer and groundwater
thicknesses, strength/reinforcement; falls, materials of construction, permeability, resistance to chemical attack, and inspection and maintenance procedures • **have an inspection and maintenance programme for impervious surfaces and containment facilities** • **unless the risk is negligible, have improvement plans in place where operational areas have not been equipped with:** – **an impermeable surface** – **spill containment kerbs** – **sealed construction joints** – **connection to a sealed drainage system** **4. All above-ground tanks containing liquids should be bunded. Bunds should:** • **be impermeable and resistant to the stored materials** • **have no outlet (that is, no drains or taps) and drain to a blind collection point** • **have pipework routed within bunded areas with no penetration of contained surfaces** • **be designed to catch leaks from tanks or fittings** • **have a capacity greater than 110 percent of the largest tank or 25 percent of the total tankage, whichever is the larger** • **be subject to regular visual inspection and any contents pumped out or otherwise removed under manual control after checking for contamination** • **where not frequently inspected, be fitted with a high-level probe and an alarm, as appropriate** • **where possible, locate tanker connection points within the bund, otherwise provide adequate containment** • **be subject to programmed engineering inspection (normally visual, but extending to water testing where structural integrity is in doubt)** • **be designed, constructed and maintained to meet with the specifications outlined in the Construction Industry Research and Information Association guidance document titled CIRIA 164.**

7.10. Dust

The main sources of dust will include the handling of waste and the movement of vehicles on site.

A number of control measures should be implemented by operators to suppress particulate creation and dispersion including:

- Using enclosed systems for reception
- Implementing stringent loading bay door management

- Use of negative aeration and air treatment within enclosed reception and processing areas
- Initiating dust suppression techniques including water mists and sprays and windbreaks
- Wetting and washing techniques – i.e. Washing wheels of vehicles and roadways
- Barrier techniques – Sheeting, netting, covered transfers, windbreaks
- Direct Clean up – rotary brush vacuum wagons, shaker bars
- Maintaining and cleaning of plant and machinery to avoid dust generation
- Sealing of roads particularly if traffic volumes or meteorological conditions that would encourage dust formation are likely to be high
- Reducing on-site vehicle speeds.

7.11. Vermin

As the digester and biogas handling unit operations are enclosed they limit the potential to attract vermin and birds. However it is possible for flies to enter the building during waste delivery and accumulate in hot weather. Rats and other similar vermin may also gain access to the waste reception and pre-treatment building.

These sources of vermin, if not managed can affect operations and create a negative perception of a waste facility. They pose an environmental and health hazard as a potential vector for pathogens and can result in cross contamination between clean and dirty areas of a site.

The presence of vermin and other vectors should be mitigated through effective housekeeping and on site management of storage and tipping areas. In addition the waste heat from the process can be passed through the fresh input waste to such a temperature that fly larvae cannot survive. Specialist pest control services should be appointed for the control of rats and similar vermin.

Feedstock reception areas should be closed, except for when receiving deliveries as this can limit the entry of vermin.

Operators need to have written procedures for the inspection and control of vermin. Inspections should be carried out weekly by a nominated person and the results recorded. All operatives should report any sightings to the nominated person immediately.

If vermin are detected then immediate action needs to be taken to control the situation. This may be by instigating better housekeeping, clearing spillages etc. Where an infestation is likely, or occurs, it is recommended that professional pest control contractors are brought in to eradicate the problem immediately. Appropriate control measures need to be implemented to prevent a reoccurrence. All action taken must be recorded.

7.12. Noise

The term “noise” should be taken to refer to “noise and/or vibration” as appropriate, detectable beyond the site boundary. Where noise issues are likely to be relevant, the Operator will be required, to provide information on the following:

- the main sources of noise and vibration that will fall within the AD facility and also on Infrequent sources of noise and vibration
- the nearest noise-sensitive sites

- conditions/limits imposed under other regimes
- the local noise environment
- any environmental noise measurement surveys, modelling or any other noise measurements
- any specific local issues and proposals for improvements.

The level of detail supplied should be in keeping with the risk of causing noise-related annoyance at sensitive receptors. Where an AD facility poses no risk of noise-related environmental impact because the activities undertaken are inherently quiet, this should be justified and no further information relating to noise need normally be supplied. It should, however, be remembered that there can still be an underlying level of annoyance without complaints being made.

In the case of noise, "offence to any human senses" can normally be judged by the likelihood of complaints, but in some cases it may be possible to reduce noise emissions still further at reasonable costs, and this may exceptionally therefore be BAT for noise emissions.

For advice on how noise and/or vibration related limits and conditions will be determined please refer to horizontal guidance on noise pollution (H3 Noise Assessment and Control).

Anaerobic Digestion operations present potential emissions from noise in respect of mechanical handling equipment such as shredders, mobile plant such as shovels and extraction fans. Where the flare is operational this may also be a point source for noise emissions. In the case of increased capacity or new facilities there may also be additional noise from traffic and construction activities.

Planning applications for industrial facilities address noise using a British Standards BS 4142 noise assessment[1]. Findings of any such rating assessment can be used as part of an Environmental permit application.

Horizontal guidance on noise pollution (H3 Noise Assessment and Control). This guidance describes the principles of noise measurement and prediction, the control of noise by design and by operational and management techniques, abatement technologies and noise monitoring. The guidance assists in determining if proposals are BAT for a given AD facility and can be found in the Environmental Permitting Guidance section of our website (link provided in Appendix D).

Design considerations and best management practice for minimising the emission of noise include:

- Incorporation of noise screening and cladding around particularly noisy site equipment
- Attenuation provided by trees and hedges around boundary
- Undertaking certain processing operations during normal working hours
- Using mobile noise screens
- Consideration of noise rating as part of equipment selection policy.

7.12.1. Indicative BAT requirements for noise and vibration

Indicative BAT requirements for noise and vibration

Describe the main sources of noise and vibration (including infrequent sources); the nearest noise sensitive locations and relevant environmental surveys which have been undertaken; and the proposed techniques and measures for the control of noise.

[1] BS 4142:1997 - Method for rating industrial noise affecting mixed residential and industrial areas

1. **The Operator should employ basic good practice measures for the control of noise, including adequate maintenance of any parts of plant or equipment whose deterioration may give rise to increases in noise (for example, bearings, air handling plant, the building fabric, and specific noise attenuation kit associated with plant or machinery).**
2. **The Operator should employ such other noise control techniques necessary to ensure that any noise from the AD facility does not give rise to reasonable cause for annoyance, in the view of the Regulator. In particular, the Operator should justify where Rating Levels (LAeq,T) from the AD facility exceed the numerical value of the Background Sound Level (LA90,T).**
3. **Further justification will be required should the resulting field rating level (LAR,TR) exceed 50 dB by day and a facade rating level exceed 45 dB by night, with day being defined as 07:00 to 23:00 and night 23:00 to 07:00. 4 In some circumstances "creeping background" (i.e. creeping ambient) may be an issue. Where this has been identified in pre-application discussions or in previous discussions with the local authority, the Operator should employ such noise control techniques as are considered appropriate to minimise problems to an acceptable level within the BAT criteria.**
4. **Noise surveys, measurements, investigations (e.g. on sound power levels of individual items of plant) or modelling may be necessary for either new or for existing AD facilities, depending upon the potential for noise problems. Where appropriate, the operator should have a noise management plan as part of its management system.**

7.13. Litter

Litter can cause a significant impact on the health of local wildlife and loss of amenity for nearby residents. Loose packaging from certain types of food wastes may give rise to litter if not carefully managed. Waste deliveries should arrive in enclosed or suitably sheeted vehicles and should not be discharged except within the waste acceptance and pre-treatment building.

The following measures for the prevention of litter should be considered:

- Use of mobile screens to intercept incidental litter
- Programme of litter picking on and around site throughout and at the end of each working day
- Robust management of site to ensure prompt disposal of any residual wastes and
- Management procedures should be in place to ensure rejected material is promptly redirected to an appropriate facility.

7.14. Light

Light pollution is defined as excessive or obtrusive light. There has been an increase in complaints about light to local authorities in recent years and lighting schemes may be included within the planning consent for a facility.

If lighting is required then only the right amount of light for the task should be installed. Lighting will then only become a problem if it is poorly designed or incorrectly installed.

If lighting is necessary, a number of measures can be taken to avoid causing a nuisance:

- Make sure that lights are correctly adjusted so that they only illuminate the surface intended and do not throw light onto neighbouring property
- Security lights should be correctly adjusted so that they only pick up the movement of persons in the area intended and not beyond
- To reduce the effects of glare, main beam angles of all lights should be below 70 degrees
- If uplighting has to be used then install shields or baffles above the lamp to reduce the amount of wasted upward light and
- Do not install equipment which spreads light above the horizontal.

Management

8.1. Management Systems

The regulator requires implementation of an effective management system for ensuring that all appropriate pollution prevention and control techniques are delivered reliably and on an integrated basis.

Further information is provided in Horizontal Guidance Note H6 – Environmental Management Systems (link provided in Appendix D).

The regulator supports the operation of formal environmental management systems (EMS) but equally will accept non-certified systems. The level of information and control should be proportional to the risk each activity may have to the environment or on process control. An Operator with such a system will not only find it easier to meet the BAT requirements for management of the AD but also many of the technical/regulatory requirements listed in other Sections of this Guidance.

The regulator recommends either certification to the ISO 14001 standard or registration under EMAS (EC Eco Management and Audit Scheme) (OJ L114, 24/04/01). Both certification and registration provide independent verification that the EMS conforms to an auditable standard. EMAS now incorporates ISO 14001 as the specification for the EMS element, and the regulator considers that overall EMAS has a number of other benefits over ISO14001 - including a greater focus on environmental performance, a greater emphasis on legal compliance, and a public environmental statement. For further details about ISO 14001 and EMAS contact British Standards Institute (BSI) or the Institute of Environmental Management and Assessment (IEMA), respectively.

Whilst an effective EMS will help the operator to maintain compliance with specific regulatory requirements and manage all significant environmental impacts, this section of the Guidance identifies only those EMS requirements that are not specifically covered elsewhere in the document. This section should not, therefore, be taken to describe all of the elements of an effective environmental management system. The requirements below are considered to be BAT, but they are the same techniques required by a formal EMS and so should be capable of delivering wide environmental benefits.

The European Commission has also set out its views on BAT and Environmental Management Systems in the form of standard text which will be included in all new and updated BREFs.

Your management system must include information about the condition of the land before you start operations, and how you have protected it during the life of the permit and site closure. When you come to apply to surrender your permit, you will need to be able to show you have taken the necessary measures to avoid any pollution risk resulting from your activities and the site has been returned to a satisfactory state.

Further information is provided in our Horizontal Guidance Note H5 – Site Condition Report Guidance (link provided in Appendix D).

8.2. Technical competence

The regulator requires operators holding environmental permits to be competent to deal with the environmental risks associated with their activities throughout the life of the permit.

Operators should ensure that staff are suitably trained and qualified for the management and operation of an AD facility. Any facility undertaking a specified waste management activity under an environmental permit must be operated by suitable technically competent management in accordance with an approved competence scheme. This is a mandatory requirement.

Further details on the requirements for technical competence can be found in our Regulatory Guidance Note No.5: Operator Competence,(link provided in Appendix D).

8.2.1. Indicative BAT requirements for Management Systems

Indicative BAT requirements for Management Systems
<u>Operations and maintenance</u> **1 Effective operational and maintenance systems should be employed on all aspects of the process whose failure could impact on the environment, in particular there should be:** • **documented procedures to control operations that may have an adverse impact on the environment** • **a defined procedure for identifying, reviewing and prioritising items of plant for which a preventative maintenance regime is appropriate** • **a preventative maintenance programme covering all plant, whose failure could lead to impact on the environment, including regular inspection of major ‘non productive’ items such as tanks, pipework, retaining walls, bunds, ducts and filters** • **documented procedures for monitoring emissions or impacts.** **2 The maintenance system should include auditing of performance against requirements arising from the above and reporting the result of audits to top management.** **<u>Competence and training</u>** **3 Training systems, covering the following items, should be in place for all relevant staff which cover** • **awareness of the regulatory implications of the Permit for the activity and their work activities** • **awareness of all potential environmental effects from operation under normal and abnormal circumstances**

Indicative BAT requirements for Management Systems

- **awareness of the need to report deviation from the Permit**
- **prevention of accidental emissions and action to be taken when accidental emissions occur.**

4 The skills and competencies necessary for key posts should be documented and records of training needs and training received for these post maintained.

5 The key posts should include contractors and those purchasing equipment and materials.

6 The potential environmental risks posed by the work of contractors should be assessed and instructions provided to contractors about protecting the environment while working on site.

7 Where industry standards or codes of practice for training exist (e.g. WAMITAB) they should be complied with.

<u>Accidents/incidents/non-conformance</u>

8 There should be an accident plan founded on a risk assessment which:

- **identifies the likelihood and consequence of accidents**
- **identifies actions to prevent accidents and mitigate any consequences**
- **The accident management plan should consider risk and impact of flooding and fires.**

9 There should be written procedures for handling, investigating, communicating and reporting actual or potential non-compliance with operating procedures or emission limits.

10 There should be written procedures for handling, investigating, communicating and reporting environmental complaints and implementation of appropriate actions.

11 There should be written procedures for investigating incidents, (and near misses) including identifying suitable corrective action and following up

<u>Organisation The following are indicators of good performance</u>

12 The company should adopt an environmental policy and programme which:

- **includes a commitment to continual improvement and prevention of pollution**
- **includes a commitment to comply with relevant legislation and other requirements to which the organisation subscribes and**
- **identifies, sets, monitors and reviews environmental objectives and key performance indicators independently of the Permit.**

13 The company should have demonstrable procedures (eg. written instructions) which incorporate environmental considerations into the following areas:

- **the control of process and engineering change on the AD facility;**
- **design, construction and review of new facilities and other capital projects (including provision for their decommissioning)**
- **capital approval and**
- **purchasing policy.**

14 The company should conduct audits, at least annually, to check that all activities are being carried out in conformity with the above requirements. Preferably, these should be

independent.

15 The company should report annually on environmental performance, objectives and targets, and future planned improvements. Preferably, these should be published environmental statements.

16 The company should operate a formal Environmental Management System. Preferably, this should be a registered or certified EMAS/ISO 14001 system (issued and audited by an accredited certification body).

17 The company should have a clear and logical system for keeping records of, amongst others:

- **policies**
- **roles and responsibilities**
- **targets**
- **procedures**
- **results of audits**
- **results of reviews.**

Closure

18 Your management system must include information about the condition of the land before you start operations, and how you have protected it during the life of the permit and site closure.

Operations during the EPR Permit

19 Operations during the life of the Permit should not lead to any deterioration of the site. Should any instances arise which have, or might have, impacted on the state of the site, the operator should record them along with any further investigation or ameliorating work carried out. This will ensure that there is a coherent record of the state of the site throughout the life of the Permit. This is as important for the protection of the Operator as it is for the protection of the environment.

Steps to be taken at the design-and-build stage of the activities

20 Care should be taken at the design stage to minimise risks during decommissioning. . Designs should ensure that:

- **underground tanks and pipework are avoided where possible (unless protected by secondary containment or a suitable monitoring programme)**
- **there is provision for the draining and clean-out of vessels and pipework prior to dismantling**
- **lagoons are designed with a view to their eventual clean-up or surrender**
- **insulation is provided that is readily dismantled without dust or hazard**
- **materials used are recyclable (having regard for operational or other environmental objectives)**
- **either the removal or the flushing out of pipelines and vessels where appropriate and their complete emptying of any potentially harmful contents**
- **as installed plans of all underground pipes and vessels are provided to the permit**

Indicative BAT requirements for Management Systems
holder • **the design allows for the safe clearing of lagoons**

8.3. Raw materials selection

The process of selecting raw materials can present an opportunity to control emissions at source so the range of possible raw material options should be carefully examined.

An application for a permit should contain a list of the materials in use which have potential for significant environmental impact, together with the following associated information:

- the chemical composition of the materials, where relevant
- the quantities used
- the fate of the material in the AD facility (i.e. approximate percentages to each environmental medium and to the products)
- the environmental impact potential, where known (e.g. degradability, bioaccumulation potential, toxicity to relevant species)
- any reasonably practicable alternative raw materials that may have a lower environmental impact (including, but not limited to, any alternatives described in the BAT requirements below) on the substitution principle
- and justification for the continued use of any substance for which there is a less hazardous alternative (e.g. on the basis of impact on product quality) to show that the proposed raw materials are therefore BAT.

A list of typical raw materials used for AD facilities are included below;

- Process Water
- Ferric chloride
- Hydrochloric Acid
- Sulphuric Acid
- Caustic agents e.g. sodium hydroxide
- Masking Agents.

There might be other reagents depending on the nature of the AD Process and these should be identified by the operator.Other legislation may apply to raw material storage for example COMAH.

This section is concerned with material used in addition to waste (raw) materials which are themselves feedstocks to the process. Operators should ensure the specification of the materials are adequately defined to allow the process to operate as designed to help ensure plant performance, availability and the quantity and quality of outputs. This is covered in detail under Section 3, Waste Acceptance.

8.3.1. Indicative BAT requirements for raw materials selection

Indicative BAT requirements for raw materials selection
1. **The Operator should maintain a list of raw materials and their properties as noted above.** 2. **The Operator should have procedures for the regular review of new developments in raw materials and for the implementation of any suitable ones with reduced environmental impact.** 3. **The Operator should have quality-assurance procedures for controlling the impurity content of raw materials.** 4. **The Operator should complete any longer-term studies needed into the less polluting options and should make any material substitutions identified.**

8.4. Waste minimisation audit (minimising the use of raw materials)

Waste minimisation can be defined simply as: "a systematic approach to the reduction of waste at source, by understanding and changing processes and activities to prevent and reduce waste". A variety of techniques can be classified under the term waste minimisation, from basic housekeeping through statistical measurement, to application of clean technologies.

In the context of waste minimisation and this Guidance, waste relates to the inefficient use of raw materials and other substances at an AD facility. A consequence of waste minimisation will be the reduction of gaseous, liquid and solid emissions. Key operational features of waste minimisation will be:

- The ongoing identification and implementation of waste prevention opportunities
- The active participation and commitment of staff at all levels including, for example staff suggestion schemes
- Monitoring of materials' usage and reporting against key performance measures

For the primary inputs to activities which are themselves waste activities, e.g. Anaerobic Digestion, the requirements of this section may have been met "upstream" of the AD facility. However, there may still be arisings that are relevant.

8.4.1. Indicative BAT requirements for Waste Minimisation (minimising the use of raw materials)

Indicative BAT requirements for Waste Minimisation (minimising the use of raw materials)
In the context of waste minimisation and this Guidance, waste relates to the efficient use of raw materials and other substances at an AD facility. A consequence of waste minimisation will be the reduction of gaseous, liquid and solid emissions. Key operational features of waste minimisation will be:

- The ongoing identification and implementation of waste prevention opportunities
- The active participation and commitment of staff at all levels including, for example staff suggestion schemes
- Monitoring of materials' usage and reporting against key performance measures

8.5. Water use

Water used for cleaning should be minimised. Grey water should be utilised where possible to reduce the use of potable mains water.

The benefits to be gained from reducing water input include cost savings where water is purchased from another party.

The use of a simple mass balance for water use should help to reveal where reductions can be made.

8.5.1. Indicative BAT requirements for water use

Indicative BAT requirements for water use
1 The operator should carry out a regular review of water use (water efficiency audit) at least every 4 years. If an audit has not been carried out in the 2 years prior to submission of the application and the details made known at the time of the application, then the first audit should take place within 2 years of the issue of the Permit. • **Flow diagrams and water mass balances for the activities should be produced.** • **Water-efficiency objectives should be established, with constraints on reducing water use beyond a certain level being identified (which will be usually AD facility specific).** • **Water efficiency techniques should be used for maximising reuse.** **2 Within 2 months of completion of the audit, the methodology used should be submitted to the regulator, together with proposals for a time-tabled plan for implementing water reduction improvements for approval by the regulator.** **3 The following general principles should be applied in sequence to reduce emissions to water:** • **Water-efficient techniques should be used at source where possible** • **Water should be recycled within the process from which it issues** • **In particular, if uncontaminated roof and surface water cannot be used in the process, it should be kept separate from other discharge streams, at least until after the contaminated streams have been treated in an effluent treatment system and been subject to final monitoring.** **4 The water-quality requirements associated with each use should be established, and the scope for substituting water from recycled sources identified and input into the improvement plan.**

Indicative BAT requirements for water use
5 Water usage for cleaning and washing down should be minimised by: • **vacuuming, scraping or mopping in preference to hosing down** • **reusing wash water (or recycled water) where practicable, and** • **using trigger controls on all hoses, hand lances and washing equipment.** **6 Fresh water consumption should be directly measured and recorded regularly at every significant usage point - ideally on a daily basis.**

8.6. Waste recovery or disposal

The Waste (England and Wales) Regulations 2011 require the Regulator, through update to the Environmental Permitting Regulations (England and Wales) 2010 to set permit conditions to ensure that the waste hierarchy as set out in the Waste Framework Directive (2008/98/EC) is applied to wastes generated by a waste operation, i.e. AD facilities, is treated in accordance with the waste hierarchy as set out in Article 4 to the Directive, namely that the following steps shall apply as a priority order in waste prevention and management legislation and policy:

(a) prevention

(b) preparing for re-use

(c) recycling

(d) other recovery, e.g. energy recovery; and

(e) disposal.

The objectives of the National Waste Strategies should also be considered.

8.6.1. Indicative BAT requirements for waste recovery or disposal

Indicative BAT requirements for waste recovery or disposal Describe how each waste stream is proposed to be recovered or disposed of. If you propose any disposal, explain why recovery is technically and economically impossible and describe the measures planned to avoid or reduce any impact on the environment.
1. Waste production should be avoided wherever possible. Any waste that is produced should be recovered, unless it is technically or economically impractical to do so. **2. Where waste must be disposed of, the Operator should provide a detailed assessment identifying the best environmental options for waste disposal - unless the Regulator agrees that this is unnecessary. For existing disposal activities, this assessment may be carried out as an improvement condition to a timescale to be approved by the Regulator.** **3. Most containers are designed, manufactured and marked to enable reconditioning / refurbishment. As such 205 litre drums, 800 and 1000 litre IBCs should be cleaned and reconditioned to enable re-use where technically and economically possible.** **4. Containers that cannot be re-used where there is no reconditioning market and**

which have been cleaned can be released into the secondary materials market.

8.7. Accidents

This section covers accidents and their consequences. It is not limited to major accidents but includes spills and abnormal operation. Some AD facilities will also be subject to the Control of Major Accident Hazards Regulations 1999 (COMAH), IPPC and COMAH can sometimes overlap, and some systems and information may be usable for either regime.

The main risks to the environment are:

- loss of containment of waste liquors or digestate. This has a very high biological oxygen demand which can render water bodies anoxic and damage ecosystems. Pathogens associated with the waste inputs may also be released to the environment.
- Uncontrolled release of biogas which may result in complaints about odour and more importantly, risk of explosion and/or asphyxiation.

For accident management, there are three particular components:

- identification of the hazards posed by the AD facility/activity
- assessment of the risks (hazard x probability) of accidents and their possible consequences
- implementation of measures to reduce the risks of accidents, and contingency plans for any accidents that do occur.

8.7.1. Indicative BAT requirements for accidents and abnormal operation

Indicative BAT requirements for accidents and abnormal operation

Describe your documented system that you proposed (to be used) to identify, assess and minimise the environmental risks and hazards of accidents and their consequences.

1 A formal structured accident management plan should be in place which covers the following aspects:

2 Identification of the hazards to the environment using a methodology akin to a HAZOP study. Areas to consider should include, but should not be limited to, the following:

- **Biogas storage**
- **Biogas transfer operations**
- **arrangements for the receipt, and checking of incoming wastes, including rejection and quarantine**
- **arrangements for the storage, segregation and separation of differing waste types**
- **procedures for the internal transfer, including "bulking-up", of waste materials**
- **transfer of substances (eg. filling or emptying of vessels)**
- **overfilling of vessels**
- **emissions from plant or equipment (eg. leakage from joints, over-pressurisation of vessels, blocked drains)**

Indicative BAT requirements for accidents and abnormal operation

Describe your documented system that you proposed (to be used) to identify, assess and minimise the environmental risks and hazards of accidents and their consequences.

- **failure of containment (eg. physical failure or overfilling of bunds or drainage sumps)**
- **failure to contain firewaters**
- **wrong connections made in drains or other systems**
- **incompatible substances allowed to come into contact**
- **unexpected reactions or runaway reactions**
- **release of an effluent before adequate checking of its composition**
- **failure of main services (e.g. power, steam, cooling water)**
- **operator error**
- **vandalism**
- **Air/ventilation management**
- **Abatement sytems.**

3 Assessment of the risks. The hazards having been identified, the process of assessing the risks should address six basic questions:

- **how likely is the particular event to occur (source frequency)?**
- **what substances are released and how much of each (risk evaluation of the event)?**
- **where do the released substances end up (emission prediction - what are the pathways and receptors)?**
- **what are the consequences (consequence assessment – what are the effects on the receptors)?**
- **what are the overall risks (determination of overall risk and its significance to the environment)?**
- **what can prevent or reduce the risk (risk management – measures to prevent accidents and/ or reduce their environmental consequences)?**

4 The depth and type of assessment will depend on the capacity of the AD facility and waste types handled and its location. The main factors to take into account are:

- **the scale and nature of the accident hazard presented by the AD facility**
- **the risks to areas of population and the environment (receptors)**

5 Identification of the techniques necessary to reduce the risks. The following techniques are relevant to most AD facilities:

- **there should be an up-to-date inventory of substances, present or likely to be present, which could have environmental consequences if they escape.**
- **where the AD facility is situated in a floodplain, consideration should be given to techniques which will minimise the risk of the flooding causing a pollution incident or making one worse.**

Indicative BAT requirements for accidents and abnormal operation

Describe your documented system that you proposed (to be used) to identify, assess and minimise the environmental risks and hazards of accidents and their consequences.

- **security systems to prevent unauthorised access should be provided where appropriate.**
- **there should be formal systems for the logging and recording of all incidents, near misses, abnormal events, changes to procedures and significant findings of maintenance inspections.**
- **there should be procedures for responding to and learning from incidents, near-misses, etc.**
- **the roles and responsibilities of personnel involved in incident management should be formally specified.**
- **clear guidance should be available on how each accident scenario might best be managed (e.g. containment or dispersion, to extinguish fires or to let them burn).**
- **procedures should be in place to avoid incidents occurring as a result of poor communications between staff at shift change or during maintenance or other engineering work.**
- **safe shutdown procedures should be in place.**
- **communication channels with emergency services and other relevant authorities should be established, and available for use in the event of an incident. Procedures should include the assessment of harm following an incident and the steps needed to redress this**
- **appropriate control techniques should be in place to limit the consequences of an accident, such as; fire walls, firebreaks isolation of drains, provision of oil spillage equipment, alerting of relevant authorities and evacuation procedures.**
- **personnel training requirements should be identified and training provided.**
- **the systems for the prevention of fugitive emissions are generally relevant and in addition, for drainage systems:**
  - **procedures should be in place to ensure that the composition of the contents of a bund sump, or sump connected to a drainage system, are checked before treatment or disposal;**
  - **drainage sumps should be equipped with a high-level alarm or with a sensor and automatic pump to storage (not to discharge);**
  - **there should be a system in place to ensure that sump levels are kept to a minimum at all times;**
  - **high-level alarms and similar back-up instruments should not be used as the primary method of level control.**
- **duplicate or standby plant should be provided where necessary, with maintenance and testing to the same standards as the main plant.**
- **spill contingency procedures should be in place to minimise accidental release of raw materials, products and waste materials and then to prevent their entry into water.**
- **process waters, potentially contaminated site drainage waters, emergency firewater,**

Indicative BAT requirements for accidents and abnormal operation

Describe your documented system that you proposed (to be used) to identify, assess and minimise the environmental risks and hazards of accidents and their consequences.

chemically- contaminated waters and spillages of chemicals should be contained and, where necessary, routed to the effluent system and treated before emission to controlled waters or sewer. Sufficient storage should be provided to ensure that this can be achieved. Any emergency firewater collection system should take account of the additional firewater flows and fire-fighting foams, and emergency storage lagoons may be needed to prevent contaminated firewater reaching controlled waters (see the Releases to water references).

- **Consideration should be given to the possibility of containment or abatement of accidental emissions from vents and safety relief valves/bursting discs. Where this may be inadvisable on safety grounds, attention should be focused on reducing the probability of the emission.**
- **Spillage prevention controls must be in place during the transfer of substances (for example, transfer of bulk liquid waste from tanker to storage vessels)**
  - **The weakest link and subsequently the main source of spillage during transfer from the vehicle to storage arises from the transfer hoses. This is due to either:**
  - **“tanker drive-off” - a vehicle pulling away whilst still coupled (systems should be in place to prevent this)**
  - **or because the hose couplings have become damaged or are incompatible. Although the spillages tend to be relatively small, measures should be taken to ensure that the couplings are the correct fit and system. This will prevent the coupling loosening or becoming detached, and in turn will also be helped by the AD facility providing and maintaining its own hoses**
  - **A more serious event would occur if the coupling were unable to withstand the maximum shut valve pressure of the transfer pump**
  - **Spillages of this nature may also be a source of odour) and represent poor “housekeeping” practice, requiring constant attention and cleaning**
  - **Protection of the transfer hose may not be necessary where a gravity feed system is in place. It will however still be important to maintain a sound coupling at each end of the transfer hose**
  - **A more acute accident situation may arise due to the failure of plant or equipment. This may include the failure of a pump seal or the blockage of a filter pot commonly used at transfer points. The prevention of these situations should be addressed by the provision of routine maintenance.**

Accumulations of liquids in bunds, sumps, etc., should be dealt with promptly

Monitoring

This section describes monitoring and reporting requirements for emissions to all environmental media. Guidance is provided for selecting the appropriate monitoring methodologies, frequency of monitoring, compliance-assessment criteria and environmental monitoring.

Process monitoring is dealt with elsewhere.

9.1. Emissions monitoring

9.1.1. Indicative BAT requirements for emissions monitoring

Indicative BAT requirements for emissions monitoring
1 Monitoring should generally be undertaken during all phases of operation (i.e. commissioning, start-up, normal operation and shutting-down) unless the regulator agrees that it is not necessary. **2 Continuous monitoring and recording (or at least sampling in the case of water) are likely to be required under the following circumstances:** • **Where the potential environmental impact is significant or the concentration of substance varies widely.** • **Where a substance is abated, monitoring of the substance is required to show the performance of the abatement plant. For example continuous monitoring of dust is needed after a fabric filter to show the effectiveness of the filter and indicate when maintenance is needed, or sampling BOD from an effluent treatment plant.** **3 Where effective surrogates are available, they may be used with the agreement of the regulator (and without prejudice to legal requirements) to minimise monitoring costs.** **4 Where monitoring shows that substances are not emitted in significant quantities, it may be reasonable to reduce the monitoring frequency.** **Monitoring and reporting of emissions to air:** **5 Where appropriate, periodic visual and olfactory assessment of releases should be undertaken** **6 Any substances found to be of concern, or any other individual substances to which the local environment may be susceptible and upon which the operations may impact, should also be monitored more regularly.**

9.2. Environmental monitoring (beyond AD facility)

9.2.1. Indicative BAT requirements for environmental monitoring (beyond the AD facility)

Indicative BAT requirements for environmental monitoring (beyond AD the facility) Describe the proposed measures for monitoring emissions, including any environmental monitoring, and the frequency, measurement methodology and evaluation procedure proposed.
1. **The Operator should consider the need for environmental monitoring to assess the effects of emissions to controlled water, groundwater, air or land, or emissions of noise or odour.** 2. **Environmental monitoring may be required, for example, when:** • **there are vulnerable receptors** • **the emissions are a significant contributor to an Environmental Quality Standard (EQS) that may be at risk** • **the Operator is looking for departures from standards based on lack of effect on the environment** • **to validate modelling work.** 3. **The need should be considered for:** • **groundwater, where it should be designed to characterise both quality and flow and take into account short- and long-term variations in both. Monitoring will need to take place both up-gradient and down-gradient of the site** • **surface water, where consideration will be needed for sampling, analysis and reporting for upstream and downstream quality of the controlled water** • **air, including odour and bioaerosols** • **land contamination, soils, including vegetation, and agricultural products** • **assessment of health impacts** • **noise** 4. **Where environmental monitoring is needed, the following should be considered in drawing up proposals:** • **determinants to be monitored, standard reference methods, sampling protocols** • **monitoring strategy, selection of monitoring points, optimisation of monitoring approach** • **determination of background levels contributed by other sources** • **uncertainty for the employed methodologies and the resultant overall uncertainty of measurement** • **quality assurance (QA) and quality control (QC) protocols, equipment calibration and maintenance, sample storage and chain of custody/audit trail** • **reporting procedures, data storage, interpretation and review of results, reporting**

Indicative BAT requirements for environmental monitoring (beyond AD the facility)

Describe the proposed measures for monitoring emissions, including any environmental monitoring, and the frequency, measurement methodology and evaluation procedure proposed.

format for the provision of information for the Regulation

Monitoring of emissions to air:

5. **There should be in place daily olfactory odour monitoring programmes.**

Monitoring of emissions to land:

6. **There should be no emissions to land and consequently there are no monitoring requirements.**

Monitoring of emissions to groundwater:

7. **Groundwater monitoring should take place where:**

- **there are any subsurface structures carrying or holding waste or other harmful substances**
- **there is uncertainty about surfaces on operational areas and drainage systems, especially on older sites.**

9.3. The Environment Agency's Monitoring Certification Scheme (MCERTS) - Background.

The Environment Agency has established its Monitoring Certification Scheme (MCERTS) to deliver quality environmental measurements. MCERTS provides for the product certification of monitoring systems (for example, instruments, analysers and equipment), the competency certification of personnel and the accreditation of laboratories under the requirements of European and International standards. MCERTS has been developed to reflect the growing requirements for regulatory monitoring to meet European and International standards. It brings together relevant standards into a scheme that can be easily accessed by key stakeholders, such as manufacturers, operators, regulators and test houses.

MCERTS will be extended to include all regulatory monitoring activities. Technical Guidance Notes M1 and M2 are key reference documents underpinning MCERTS for stack-emission monitoring. The Agency has published MCERTS performance standards for continuous emissions monitoring systems (CEMs), ambient air quality monitoring systems (CAMs), the chemical testing of soils, water monitoring instrumentation and manual stack emissions monitoring. Other MCERTS standards are under development to cover portable emissions monitoring equipment, data acquisition and operators' own arrangements, such as AD facility, calibration and maintenance of monitoring equipment. Organisations undertaking manual stack emission monitoring (and any subsequent analysis of samples) must be accredited by UKAS to ISO/IEC 17025.

Further information about MCERTS is provided on our website. A link is provided in Appendix D.

Impact

10.1. Impact assessment

You will need to assess the risks to the environment and human health when applying for a bespoke permit under the Environmental Permitting Regulations 2010. The H1 Environmental Risk Assessment framework consists of an overview guide and a set of supporting technical annexes for specific risks. This is available on our website (link provided in Appendix X).

10.2. Habitats

The EU Habitats Directive aims to protect the wild plants, animals and habitats that make up our diverse natural environment.

The directive created a network of protected areas around the European Union of national and international importance. They are called Natura 2000 sites. These sites include:

- Special Areas of Conservation (SACs) - these support rare, endangered or vulnerable natural habitats, plants and animals (other than birds).

- Special Protection Areas (SPAs) - these support significant numbers of wild birds and their habitats.

In the UK, the Habitats Directive is implemented by the Conservation of Habitats and Species Regulations 2010, more commonly known as the Habitats Regulations.

If you apply for any bespoke environmental permit, we must consider its potential impact on these important protected sites.

The regulator strongly advises the operator to have a pre-application discussion with them before preparing and submitting an application so that the regulator can let you know if any protected sites might be affected.

Defra have published guidance on the Habitats Directive on their website. A link is provided in Appendix D.

Appendix A: Trouble Shooting Guide

Condition or Situation	Potential Problem	Indicators	Recommendations
Operational Issues			
Significant rise of volatile fatty acids in the digesting medium (i.e. >>1500 mg/l)	Over loading/feeding the digester with biodegradable materials Feedstock with high biodegradability	Low pH Odours from digesting medium or digestate Low or reducing concentration of CH4 in biogas (due to inhibition of methanogens) Sour smell from digestate (or coming out of the digester and with biogas)	Slow or stop the feeding temporarily; thereby increasing residence time of feedstock in the digester Monitor the VFA level at regular intervals and increase alkalinity or buffering capacity of medium (e.g. by introducing carbonate or bicarbonate) until the levels are reduced and stabilised Add alkali (lime or use high pH feeds), if necessary, to neutralise acids Consider insufficient micro nutrients inhibiting methane formation
Poor temperature control (low)	Poor calibration or failure of temperature control	Reduced gas production, fouling (at greatly reduced temperature	Check digester temperature manually, calibrate temperature control, investigate heat exchangers
Poor temperature control (high)	Poor calibration or failure of temperature control	Digestate, increase VFA, increased temperature	Check digester temperature manually, calibrate temperature control, and consider mixing efficiency.
Excessive foaming – often in low solids AD process	Excessive gas circulation Over loading/feeding the digester with biodegradable materials	Low pH Excessive foam carry over in the outlets – biogas and digestate Visual observations of foam (e.g. through glass window on process or side arm)	Monitor volatile solids loading rate Reduce the feed rate; thereby increasing residence time of feedstock in the digester Monitor the VFA levels at regular intervals and control pH around 7.0
Pumping – erratic behaviour	Grit or debris in line (carried with incoming waste)	Pressure swings in pump suction and discharge Pump knocking	Address debris intake and control Recycle or flush the lines with warmer liquors

Condition or Situation	Potential Problem	Indicators	Recommendations
(suction and discharge pressure fluctuations)	Scum build up and carried to pumps	Scum build up in specific areas prior to pump	Check and address foaming or scum build up (see above)
Poor quality biogas	Imbalance in microbial biological activities due to various factors considered above	Higher levels of Carbon dioxide Boiler or off-gas burner not firing or yellowing of flame	This is primarily due to imbalance of biological activity (see above)
Biogas – fluctuating pressures	Lower pressure due to insufficient production, leakage, low temperatures / insufficient heating Higher pressure due to blockages in biogas line	Low biogas pressure High biogas pressure	Low pressure - Check and address for any leakage High pressure – check integrity and function of any pressure relief valves
Odour Issues			
Site-related odours (Material not odorous)	Raw materials	Odour is characteristic of the raw material	Reject raw materials if appropriate. Work with suppliers to eliminate any decay of feedstock prior to delivery
			Handle raw materials promptly with minimal storage
			Enclosed stockpiling of feedstock with air management system
	Nutrient rich puddles because of poor drainage	Standing puddles of water	Divert runoff away; maintain hard surfaces and pavements, Check leachate management system, drains and CCTV.
	Holding pond or lagoon overloaded with nutrients or sediment	Heavy algae and weed growth; gas bubbles on pond surface	Install sediment traps; enlarge pond surface area; use runoff and pond water in the process
Excessive odour from AD process (Hydrogen sulphide,	Imbalance of anaerobic biological reactions (with reduced activity of methanogens) Over loading/feeding the	Low pH Low or reducing concentration of CH4 in biogas (due to inhibition of methanogens) Rotten eggs or putrid odours or penetrating	Recycle biosolids (to increase residence time for methanogens to flourish) Reduce feed rate Consider changing waste mixes in feedstock

Condition or Situation	Potential Problem	Indicators	Recommendations
VFAs or Ammonia)	digester with biodegradable materials	Ammonia odour from biogas and digestate (especially during exit out of the digester)	Reducing the feedstock high in sulphur if odour persists, consider abatement systems (such as scrubber or biofilter)
Persistently high Ammonia levels in digesting medium** (Gradually inhibitory up to ~10,000mg/l measured in digesting media)	Persistent over loading/feeding the digester with biodegradable materials High N content in feed (e.g. food waste) with low C:N ratio (i.e. <<20:1) Reduced methanogenic activity	Odour (which spreads and lingers throughout plant area) Hydrogenotrophic methanogens continue to generate biogas (though overall yield would be affected); Acetoclastic methanogens are inhibited, particularly at around 7000 mg/l ammonia.	Change feedstock mix Consider adding trace elements such as Selenium and Cobalt (among others) to increase activity of Acetoclastic methanogens** Control fugitive emissions and channel them through biofilter or for use as combustion air
Persistently high levels of Hydrogen sulphide in biogas	High Sulphur compounds in feed	Odour from biogas handling area	Consider changing waste mixes in feedstock, by reducing the feedstock high in sulphur If odour persists, consider abatement systems (such as scrubber or biofilter)
Persistent odour issues	Odour mot mitigated by process optimisation and feedstock amendment		Add on-site abatement plant such as a biofilter
<u>Pests</u>			
Insect problems	Flies breeding in material	Fresh manure or food material at material surface; flies hover around feedstock	Mix material every four to seven days to turn eggs and maggots into hot interior; Cover vessel with membrane to contain heat Use of different breeds of flies to eradicate certain types Use of electronic fly control (ultraviolet lure light with electrical grid)
	Flies breeding in raw materials	Wet raw materials stored on site for more than four days	Handle raw materials promptly. Reduce surface area of storage. Use contained storage bins. Apply insecticide spray
	Mosquitoes breeding in	Standing puddles of water; nutrient-rich pond or	Grade site properly; maintain pad surface; maintain

Condition or Situation	Potential Problem	Indicators	Recommendations
	stagnant water	lagoon	holding pond or lagoon in aerobic condition
Animal infestation - rodents, birds	Potential contravention of the Animal By-Products Regulations and Environmental Protection Act 1990.	Food scraps exposed, animal access evident e.g. rodent droppings, bird droppings. Damage to building fabric indicating pest entry, burrows in banks and compost stockpiles	Process as soon as possible
			Improve housekeeping, clean up spills Secure food waste storage. Sealed bins are better than open floor storage.
			Eliminate potential areas of harbourage. Turn over the feedstock frequently.
			Enclose spaces with netting to prevent birds gaining access.
			Call exterminators/ pest control
<u>Composting of digestate</u>			
Problems related to composting of digestate	See Composting Technical Guidance	See Composting Technical Guidance	Consult the "Composting Technical Guidance Note–", 2013
<u>Process Emissions</u>			
Dust	Presence of dust can cause health problems for staff and potential for explosive dust	Staff health monitoring Incidents of dust exploding/Fires	Dust extracted using ducting and ventilation Increase surface cleaning frequency Apply spray water onto external roads LEV positioned over equipment likely to generate excessive dust PPE for staff – dust masks Enclose specific operations
<u>Post Processing – Storage of Materials</u>			
Degradation of material stored uncovered	Material degrades due to weathering Increase in litter both on and off-site	Material quality lowered – material gets wet	Store on a concrete surface to minimise contact with dirt/mud Cover materials to protect against degradation from moisture or light Limit materials to have a quick turnaround time

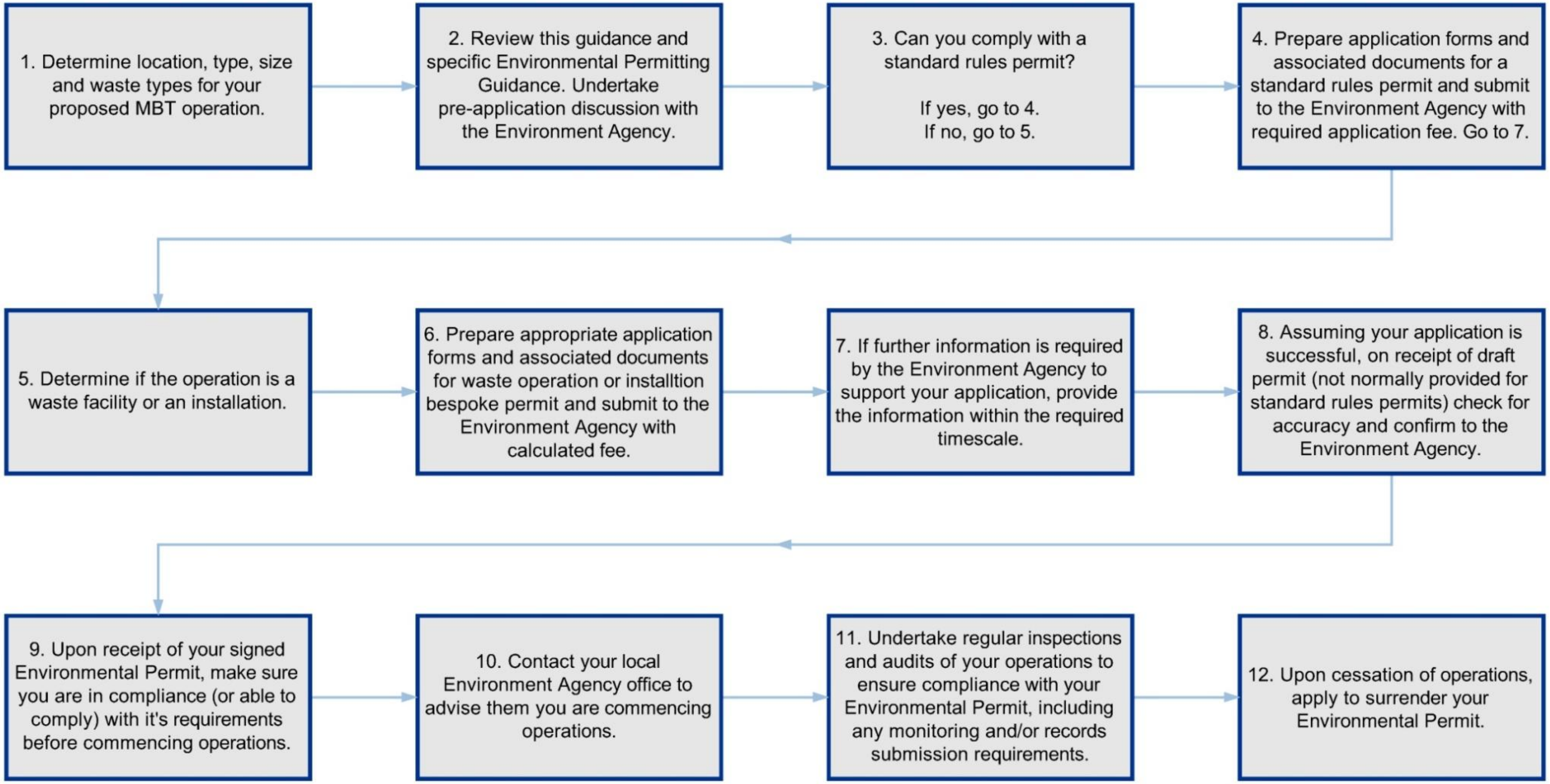
Appendix B: Summary of AD exemptions and permits

Activity	Type of authorisation needed
Exempt Waste Facilities	
Anaerobic digestion and burning of resultant biogas at premises used for agriculture Main criteria • operator can treat and store up to 1,250 cubic meters of waste at any one time • wastes types include manures, slurries and plant tissue only • combustion appliance must have a net rated thermal input of less than 0.4 MW • waste must be retained in the digester for a minimum of 28 days	T24 Exemption – Anaerobic digestion at premises used for agriculture and burning of resultant biogas
Anaerobic digestion and burning of resultant biogas at premises not used for agriculture Main criteria • operator can treat and store up to 50 cubic meters of waste at any one time • wastes types include manures, slurries, plant tissue/vegetation and catering wastes only • combustion appliance must have a net rated thermal input of less than 0.4 MW • waste must be retained in the digester for a minimum of 28 days	T25 Exemption – Anaerobic digestion at premises not used for agriculture and burning of resultant biogas
Standard Rules – Waste Recovery Operation	
Anaerobic digestion and burning of resultant biogas at premises used for agriculture Main criteria • treatment capacity of waste must be less than 100 tonnes on any one day • wastes arising from on-farm activities only • combustion appliance must have a net rated thermal input of less than 5 MW. • maximum throughput of animal waste must be less than 10 tonnes per day.	Standard rules SR2012 No 10 – waste recovery operation
Anaerobic digestion and burning of resultant biogas at premises not used for agriculture Main criteria	Standard rules SR2012 No 12 – waste recovery operation

• wastes arising from on-farm activities only • treatment capacity of waste must be less than 100 tonnes on any one day • combustion appliance must have a net rated thermal input of less than 5 MW. • maximum throughput of animal waste must be less than 10 tonnes per day.	
Standard Rules – Part A Installation	
Anaerobic digestion and burning of resultant biogas at premises used for agriculture Main criteria • treatment capacity of waste exceeding 100 tonnes on any one day • wastes arising from agriculture and dairy activities – 02 01 and 02 05) only • combustion appliance must have a net rated thermal input of less than 5 MW. • maximum quantity of waste accepted at the facility must be less than 100,000 tonnes a year	Standard rules SR2012 No 9 – Part A installation
Anaerobic digestion and burning of resultant biogas at premises not used for agriculture Main criteria • treatment capacity of waste exceeding 100 tonnes on any one day • combustion appliance must have a net rated thermal input of less than 5 MW. • maximum quantity of waste accepted at the facility must be less than 100,000 tonnes a year	Standard rules SR2012 No 11 – Part A installation
Bespoke Waste Operation	
Anaerobic digestion of waste for the purpose of disposal in a facility with a capacity less than 50 tonnes per day (*or 100 tonnes per day if the only waste treatment activity is anaerobic digestion*)[1]	Environmental permit for a waste operation (disposal only)
IED Part A Installations	

Anaerobic digestion of waste for the purpose of disposal in a facility with a capacity exceeding 50 tonnes per day (*or 100 tonnes per day if the only waste treatment activity is anaerobic digestion*) by biological treatment[2]	Environmental permit for an IED Installation – Section 5.4 A(1)(a)(i)
Anaerobic digestion of waste for the purpose of recovery in a facility with a capacity exceeding 75 tonnes per day (*or 100 tonnes per day if the only waste treatment activity is anaerobic digestion*) by biological treatment	Environmental permit for an IED Installation – Section 5.4 A(1)(b)(i)
Anaerobic digestion of animal waste for the purpose of recovery or disposal above 10 tonnes per day	Environmental permit for an IED Installation – Section 6.8 A(1)(c)
Combustion of biogas	
Waste exemptions	
Combustion of resultant biogas from waste in any appliance with a rated thermal input of less than 0.4 MW	T24 or T25 Exemption
Standard Rules (waste operation and Part A Installations)	
Combustion of resultant biogas from waste in any appliance with a rated thermal input of less than 5 MW	Standard rules SR2012 No 9; Standard rules SR2012 No 10; Standard rules SR2012 No 11; Standard rules SR2012 No 12; Directly associated activity to an IED Installation or a bespoke waste operation (disposal only)
IED Part A Installations	
Combustion of resultant biogas from waste in any appliance with a rated thermal input exceeding 5 MW[3]	Directly associated activity to an IED Installation or a bespoke waste operation (disposal only)
Note 1 – The waste operation specified in the table refers to where AD where the treated material is subject to further disposal operation such as incineration (D10) or Landfill (D1) or D(5) or discharge to water bodies, seas or oceans (D6 or D7) (RGN2 April 2013). For example this may occur as part of a site's effluent treatment plant. Note 2 – as per note 1 Note 3- There may be change to the regulatory framework applied to the combustion of waste biogas. It is strongly advised to contact your local Environment Agency office for the latest information.	

Appendix C: Environmental Permit Application Process


1. Determine location, type, size and waste types for your proposed MBT operation.
2. Review this guidance and specific Environmental Permitting Guidance. Undertake pre-application discussion with the Environment Agency.
3. Can you comply with a standard rules permit?
If yes, go to 4.
If no, go to 5.
4. Prepare application forms and associated documents for a standard rules permit and submit to the Environment Agency with required application fee. Go to 7.
5. Determine if the operation is a waste facility or an installation.
6. Prepare appropriate application forms and associated documents for waste operation or installtion bespoke permit and submit to the Environment Agency with calculated fee.
7. If further information is required by the Environment Agency to support your application, provide the information within the required timescale.
8. Assuming your application is successful, on receipt of draft permit (not normally provided for standard rules permits) check for accuracy and confirm to the Environment Agency.
9. Upon receipt of your signed Environmental Permit, make sure you are in compliance (or able to comply) with it's requirements before commencing operations.
10. Contact your local Environment Agency office to advise them you are commencing operations.
11. Undertake regular inspections and audits of your operations to ensure compliance with your Environmental Permit, including any monitoring and/or records submission requirements.
12. Upon cessation of operations, apply to surrender your Environmental Permit.

Appendix D: Web Links List

Please note at the time of writing this guide the Environment Agency web page is undergoing a move to www.gov.uk/

Environmental Permitting Guidance "The Waste Framework Directive". chapter 3, : http://www.defra.gov.uk/publications/files/pb13569-wfd-guidance-091001.pdf

Statute Law database http://www.legislation.gov.uk/.

EA Environmental Permitting section, including "How to Comply with your Environmental Permit"

http://www.environment-agency.gov.uk/business/topics/permitting/default.aspx

EA Sector Guidance Notes (SGN) and BAT Reference Standards (BREF). The SGN for the recovery and disposal of hazardous waste is SGN5.06

http://www.environment-agency.gov.uk/business/sectors/39737.aspx.

EA Waste Exemptions page :

http://www.environment-agency.gov.uk/business/topics/permitting/32322.aspx

EA Standard permits page:

http://www.environment-agency.gov.uk/business/topics/permitting/32334.aspx

EA horizontal guidance documents:

http://www.environment-agency.gov.uk/business/topics/permitting/36414.aspx

EA requirements for a bespoke Environmental Permit application::

http://www.environment-agency.gov.uk/business/topics/permitting/117626.aspx

Animal health website: http://animalhealth.defra.gov.uk/

Defra (2011): Government Review of Waste Policy in England 2011, Department for Environment, Food and Rural Affairs, London, Crown Copyright 2011

WRAP - food waste de-packaging information:

http://www.wrap.org.uk/content/food-waste-depackaging-equipment

Environment Agency's Waste Protocols Project website:

http://www.environment-agency.gov.uk/business/topics/waste/32154.aspx

EA's Landfill Gas Use of Flares guidance document:

http://www.environment-agency.gov.uk/business/sectors/108918.aspx

UK Department for Energy and Climate Change (DECC): http://www.decc.gov.uk/

EA Biomethane Quality Protocol:

http://www.environment-agency.gov.uk/business/sectors/142481.aspx

EA LFTGN08 – Guidance for Monitoring Landfill Gas Engine Emissions http://www.environment-agency.gov.uk/business/sectors/108918.aspx

EA H4 Odour Management Horizontal Guidance:

http://publications.environment-agency.gov.uk/PDF/GEHO0411BTQM-E-E.pdf

EA Horizontal guidance on noise pollution (H3 Noise Assessment and Control).: http://www.environment-agency.gov.uk/business/topics/permitting/36414.aspx

EA Horizontal Guidance Note H6 – Environmental Management Systems http://www.environment-agency.gov.uk/business/topics/permitting/36414.aspx

EA Horizontal Guidance Note H5 – Site Condition Report Guidance http://www.environment-agency.gov.uk/business/topics/permitting/36414.aspx

EA Regulatory Guidance Note No.5: Operator Competence,

http://www.environment-agency.gov.uk/static/documents/Business/RGN_5_Operator_Competence.pdf

EA MCERTS Guidance: http://www.environment-agency.gov.uk/business/regulation/31829.aspx

EA H1 Environmental Risk Assessment framework:

http://www.environment-agency.gov.uk/business/topics/permitting/36414.aspx

Habitats directive guidance http://www.defra.gov.uk/habitats-review/implementation/process-guidance/guidance/

HSE - Guidance for COSHH

http://www.hse.gov.uk/coshh/industry/engineering.htm

HSE - Guidance for COMAH

http://www.hse.gov.uk/comah/

Appendix E: Glossary

Term	Definition
ABPR	Animal By-Product Regulations
Actinomycetes	A specific group of bacteria that is capable of forming very small spores. The most common organism in this group is responsible for causing a variety of infections
AD	Anaerobic Digestion
Aerobic	In the presence of air or oxygen
Aerosol	A suspension in gaseous medium of solid or liquid particles having a negligible falling velocity.
Agricultural plant wastes	Waste material from agricultural food production such as green vegetable discards and sugar beet tops can be utilised as feedstock for AD. Plant materials such as crop wastes generally have a high carbon content and can be more difficult to digest than other organic waste material. To improve digestion, agricultural wastes are often mixed with other organic waste from C&I sources or livestock slurries. They may also be used to optimise nutrient loading in a digester when processing feedstock material with a high nitrogen content.
Anaerobic	Absence of oxygen
Animal By-Products	These include animal carcasses, parts of animal carcasses (including blood) or products of animal origin not intended for human consumption, with the exception of animal excreta and catering waste.
Aspergillus fumigatus	Species of fungus with spores that can cause allergic reactions in some people.
ATEX	The ATEX directive consists of two EU directives describing what equipment and work is allowed in an environment with an explosive atmosphere. .
Bacteria	A group of micro-organisms with a primitive cellular structure, in which the genetic material is not retained within an internal membrane (nucleus)
Bioaerosols	Micro-organisms suspended in air as an aerosol.
Bio-fertiliser	Digestate derived from source segregated organic material and which and can be added to soil/ applied to land to improve the nutrient value.
Biofilter	Organic, microbially active substrates (the medium) that filter odorous air through the action of micro-organisms that grows on the medium.
Biomethane	Naturally occurring gas produced by the anaerobic digestion of organic matter.
Biowaste	Organic waste material
BMP	Biochemical Methane Potential
BMW	Biodegradable Municipal Waste
Bulking agent	Material added to improve the structure of a feedstock material e.g.

Term	Definition
	woodchips.
Carbon to nitrogen ratio (C:N)	The ratio of total organic carbon to total nitrogen.
COGAP	Code of Good Agricultural Practice
CH_4	Methane
CHNSO	Carbon Hydrogen Nitrogen Sulphur Oxygen
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand
CODs	Chemical oxygen demand in the soluble phase
Co-digestion	Co-digestion can provide benefits in terms of optimising feedstock characteristics such as an improved nutrient profile or to optimise the solid matter content of digester feed.
Commercial and Industrial organic waste	Commercial and industrial (C&I) sources of organic waste material include semi-solid biowastes from catering and food processing industries as well as organic effluent streams from a wide range of industries. The processing of C&I organic wastes using AD can provide a range of benefits including energy generation and reduced costs through recycling and recovery in comparison to landfill or direct disposal into the sewage system.
COSHH	Control of Substances and Hazardous to Health (1994
CSTR	Completely Stirred Tank Reactor
CV	Calorific Value
DHN	District Heating Network
Digestate	Fully treated stabilised, sanitised product from Aneorobic Digestion
DNO	Distribution Network Operator
EA	Environment Agency
EDPM	Ethylene Propylene Diene Minomer
EP	Environmental Permitting
EP	Electroporation (pre treatment method with short electric pulses)
FIT	Feed in Tariff
fit for purpose	In this guide this also refers to a relevant standard where applicable i.e. CEN, BS, ISO or Eurocode. The Construction Industry Research and Information Association (CIRIA) has also produced guides which should be used i.e. CIRIA 126 & 164 where relevant.
FW	Food Waste
FYM	Farmyard Manure
GC	Gas Chromatograph
GGCS	Green Gas Certification Scheme
GHG	Green House Gas
Green waste	Organic garden waste such as grass clippings, tree prunings, leaves etc, which can be used as composting feedstock. Synonymous with 'garden wastes', 'yard trimmings', 'botanical wastes', or 'garden trimmings'. They can arise from domestic gardens, public areas, private parks or gardens, or landscaping activities.
GWP	Global Warming Potential
HAc	Acetic acid
HAZOP	A hazard and operability study - a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent

Term	Definition
	risks to personnel or equipment, or prevent efficient operation.
HDPE	High Density Poly Ethylene
HPr	Propionic acid
HRT	Hydraulic retention time
HSE	Health and Safety Executive
Impermeable paving	a surface or pavement constructed and maintained to a standard sufficient to prevent the transmission of liquids beyond the pavement surface.
ISR	Inoculum to substrate ratio
kW	kilowatt (1 kW = 103 W)
kWe	Kilowatt electrical (refers to electric power produced)
kWh	Kilowatt hour
kWt	Kilowatt thermal (refers to thermal power produced)
Leachate	Liquid run-off from stored feedstocks or outputs that contains dissolved substances or suspended solids from that material.
Livestock farming wastes	AD represents a good treatment solution for a wide range of organic wastes and materials generated from livestock farming. Wastes that can be treated include pig and cattle manures and slurries, poultry manure and farmyard manure. The energy generated from an AD plant can be used to provide energy to local farm infrastructure as well as offering a potential revenue stream from selling electricity to the grid. The use of digestate from an AD process on agricultural land as opposed to raw slurries can also provide benefits in terms of increased nutrient availability and reduced odour generation.
LPA	Local Planning Authority
LPG	Liquefied Petroleum Gas
LU	Livestock Unit(s)
MBT	Mechanical Biological Treatment
Mesophilic	Group of microorganisms that operate around 35^{o}C
Micro-organisms	Microscopic organisms that are capable of living on their own. Often simply called ‘microbes’.
Moisture content	The mass of water in a sample, usually expressed as a percentage on a mass for mass basis (m/m).
MSW	Municipal Solid Waste
MW	Megawatt (1 MW = 103 kW)
MWe	Megawatt electrical (refers to electric power produced)
MWh	Megawatt hour
MWt	Megawatt thermal (refers to thermal power produced)
NPK	Nitrogen, Phosphorous and Potassium
NVZ	Nitrate Vulnerable Zone
Odour	A chemical or mixture which stimulates a human olfactory system so that an odour is perceived. In the context of this guide, odours are generally presumed to be unwanted, unpleasant or malodorous, unless otherwise indicated.
OFGEM	The Office of Gas and Electricity Markets
OFMSW	Organic fraction of municipal solid waste
OLR	Organic loading rate
Organic matter	A collection of complex humic substances and other organic

Term	Definition
	compounds, generally of animal or vegetable origin.
Organic fraction of MSW	Most local authorities in the UK now implement collection schemes for segregated household organic waste including food and garden waste. AD is considered to deliver the best overall environmental outcome for the treatment of source segregated food waste. The application of AD is better suited to processing separately collected food waste than co-mingled food and garden waste. The presence of woody material in garden waste makes it unsuitable for digestion, although some AD plants can handle softer elements such as grass and soft plant clippings. Processing garden waste in a dedicated AD plant is generally considered uneconomic due to the generally lower capital costs of composting as an alternative.
Organic waste	A general, loosely defined term used to describe materials derived from long living organisms that can be composted.
Pathogen	A micro-organism with the potential to cause disease through infection.
Pathogen kill	
PEF	Pulsed electric fields (pre treatment method with short electric pulses)
pH (potential Hydrogen)	The measure of acidity/alkalinity (as in soils, composts, solutions, etc.) It is a logarithmic scale. pH 7 is neutral. Not to be confused with total acidity or alkalinity.
pKa	A measure of the acid dissociation.
Psychrophilic	Group of microorganisms that operate at ambient temperatures between $5^{o}C$ and $15^{o}C$
PTE	Potentially toxic element
Purpose Grown Crops (PGCs)	Purpose Grown Crops (PGCs), often referred to as ‘energy crops’ can be utilised as feedstock for AD plants. These typically include whole crop cereals including maize silage, grass and wheat silage as well as a range of other crop types are also considered suitable. The digestion of PGCs can generate high biogas yields in comparison to other feedstock types. PGCs may be considered for co-digestion with other agricultural feedstock material in order to achieve an economic scale for the facility.
RDF	Refuse Derived Fuel
ROC	Renewable Obligation Certificate
RTFC	Renewable Transport Fuel Certificate(s)
RTFO	Renewable Transport Fuel Obligation
Sanitisation	The destruction of pathogenic micro-organisms, weed seeds and weed propagules by exposure to high temperatures (above 55oC) over an extended period of time.
SBP	Specific Biogas Production
SCADA	Supervisory and Control Data Acquisition system
Self-heating	The rise in temperature during composting, caused by the metabolic activity of microbes.
Sewage and wastewater sludge	Biosolids (often referred to as sewage sludge) arising from sewage treatment was the first type of feed stock used within AD process in the UK and is now widely implemented on large sewage treatment works. The benefits of applying AD to the treatment of sewage sludge include odour reduction, reduction in pathogens and stabilisation of solid wastes from the wastewater treatment process and energy recovery in the form of biogas. The energy generated from AD is

Term	Definition
	typically used to meet the energy demand of large waste water treatment facilities.
SMP	Specific Methane Production
Soil conditioner	A soil additive that improves its structural and textural qualities reducing its susceptibility to degradation
SRB	Sulphate Reducing Bacteria
SRF	Solid Recovered Fuel
SRT	Solids retention time
Stoichiometry	Quantitative relationship of chemical substances.
STP	Standard Temperature and Pressure
Structural material	Material able to resist settling and compaction
Struvite	Is a phosphate material with formula: $NH_4MgPO_4{\cdot}6H_2O$
TAN	Total Ammonia Nitrogen
Thermophilic	Group of microorganisms that operate around 55^{o}C
TK	Total Potassium
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TS	Total solids (% of wet weight)
TS	Total Solids
VBP	Volumetric Biogas Production
VFA	Volatile Fatty Acid
VMP	Volumetric Methane Production
VS	Volatile solids (% of total solids or % of wet weight)
VSD	Volatile solids destruction
VSS	Volatile suspended solids
WAS	Waste activated sludge
WWTP	Wastewater treatment plant

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