Umwelt Bundesamt

ANAEROBIC DIGESTION

APPLICATION OBJECTIVE	
	- Treatment of organic wastes, sewage sludge and waste water with very high COD[1] - Reduction of the content of biodegradable organics and reactivity of the specified wastes - Energy recovery from waste

OUTLINE ON APPLICATION FRAMEWORK

PARTICULARLY APPLICABLE FOR WASTE TYPES

Glass		Light-weight packaging		Biowaste	X
Paper / paperboard		Mixed household waste	X[2]	Bulky waste	
Lamps		Textiles		Electrical and electronic waste	
Scrap metal		Waste wood		C&D waste	
Waste oil		Old paint & lacquer		Waste tyres	
Hazardous waste					
Branch specific waste	X	source separated waste such as catering waste, institutional and commercial food wastes, grease separation waste, manure, abattoir and agro-industrial by-products, slaughterhouse waste (after pressure-sterilization), yard and market waste			
Other waste material	X	sewage sludge, biological sludge generated by an earlier aerobic treatment, organic solids			

SPECIAL CHARACTERISTICS AND REQUIREMENTS OF THE APPLICATION

Pre-treatment of the input material:
The waste input should be collected separately and freed from disturbing components such as bulky parts. A comminution to obtain the required particle size may have to be performed. For specific waste (e.g. slaughterhouse waste) a pathogen elimination/hygienization might become necessary.

Options for the utilisation of the generated output:
Organic and mineral digestion residues must be drained. Where these residues originate solely from a digestion input of separately collected biodegradable waste the material can be used like compost following its hygienization or treatment in a composting process. A direct application onto farmland can be possible when certain conditions are fulfilled, in several countries this is generally permitted. Dried digestion residues are also energetically used in a number of cases.

Options for the disposal of process output and/or residues:
Other residues from digestion such as foils separated during screening have to be treated with other (e.g. thermal) processes.

Aftercare requirements:
The liquid portion of the digestion residues usually contains all dissolved substances and some particular matter concentrations which is why a further treatment is normally required, for example by way of handing the said amount over to a local waste water treatment facility.

Protective needs:
The exhaust air (especially in the receiving area and from mechanical processing) must be collected and treated, in addition technical and organizational measures for the avoidance and minimisation of emissions (odors in particular) have to be undertaken.

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[1] COD = chemical oxygen demand

[2] in particular for the organic-rich fine fraction of this waste before a landfill disposal

Potential health risks:
Especially in the receiving area and mechanical processing a higher risk of air contaminations with germs and spores must be observed. Technical and personal protection measures (wearing of mouth masks) in these places are highly recommended to avoid potential health risks.

RESTRICTIONS OR INFLUENCE OF EXTERNALITIES ON THE APPLICATION

Infrastructural conditions:
Installations should be placed in accessible locations with a connection to the electric grid and preferably close to the places where the respective wastes are generated. Some distance to the nearest residential dwelling should be kept although smaller distances as compared to most of the alternative facilities for biodegradable waste treatment are possible

Climatic conditions:
No restrictions apply but digestion reactors may have to be insulated and heated in colder climates (especially where thermophilic processes are applied), the technology is however *not recommendable* in places with extreme shortage of water

Suitable financing mechanism:
Financing can be through a fee charged in conjunction with the delivery of the waste to the treatment facility or the collection via the corresponding collection system (separate biowaste container). Alternatively the costs can be incorporated into the charges or specific fee for general waste collection services or recovered over other flat rate mechanisms for waste management financing. Proceeds from the sale of generated electricity mark a source of income except of the electricity which is used for own purposes and reduces this way the operating costs of the respective plant.

TECHNICAL DETAILS

GENERAL OVERVIEW

ABSTRACT	Anaerobic digestion involves the gradual bacterial decomposition of organic waste material in the (relative) absence of oxygen to methane, carbon dioxide and water. This is in contrast with the process of aerobic biodegradation. Principal objectives of the process is to lower the biological activity, mass and reaction potential of the waste and to produce biogas which can be used as an energy source.
BASIC REQUIREMENTS	- Balanced composition of nutrients and process feeding to maximise biogas/ methane production - High moisture content - Absence of components that would impair process and process milieu
EXPECTED RESULTS	- Biogas to be used as a biofuel or directly for energy production *In the case of a digestion of separately collected organic waste:* - semi-solid residues (50–300 kg dry substance/Mg input) which need further treatment, normally through composting, to produce a marketable end-product for use in agriculture and landscaping *In the case of a digestion of organic-rich mixed residual waste or sewage sludge:* - a considerable lower output amount as compared to the input quantity with significantly reduced biological reactivity thus making landfill disposal after an additional rottening possible *In the case of an anaerobic waste water treatment:* - small quantities of excess sludge and surplus liquor (100–600 l/Mg input), which may provide a liquid fertilizer when dewatered or can be sent to a waste water treatment plant

SPECIFIC ADVANTAGES

- in addition to dry organic waste, moist constituents like catering waste and waste from food processing and farming can also be handled.
- the biogas obtained can be used for producing electricity and heat and therefore to also generate income or to cover the treatment process' own demand on energy
- the fermented substrate to some extend can be utilized in liquid or dry condition.
- the technical installations takes up relatively little space.
- the waste quantities to be handled by incineration plants and/or sanitary landfills and the emissions/impact they consequently cause to the environment will be lowered

SPECIFIC DISADVANTAGES

- the technology is relatively complex, the costs for construction and operation consequently can differ significantly and be quite high, depending also on the employed plant model.
- an additional demand on water might arise
- the process' inability to degrade lignin and cellulose pose a principal limit to the efficiency of anaerobic digestion, especially when woody biomass is present
- the process is prone to disturbances and therefore requires tight control procedures which in turn demand the operating staff to have sufficient know-how (which is not very widely available yet) so as to be able to undertake appropriate adjustments and interventions quickly and whenever required to save the process from a collapse
- the technology is relatively new and still expensive so that despite possible revenues from the production of energy and fertilizers the cost balance is often not neutral
- Post treatment, storage and utilization of the digestion residues can be sources of significant emissions of methane, ammoniak and odors and thus a nuisance and threat to climate

APPLICATION DETAILS

TECHNICAL SCHEME

The primary variables of the process are the method of bringing the waste in contact with the microbes, the composition and moisture content of the input (e.g. liquid, slurry or solid), and the method and degree of circulation. Anaerobic digestion generally involves the following stages:

Pre-treatment:

In general, source separated organic waste makes the handling much easier than organic rich waste mixtures. However, even a source-separated input material will typically require further separation to remove unwanted impurities, such as plastics, metals and oversized components. Separation can be carried out under wet or dry conditions. Following this, a further process of size reduction is used to create a more homogenous material, which enhances fermentation and facilitates processing. For the separation and size-reduction, techniques and installations can be used which are also known from the processing of the waste input to mechanical-biological waste treatment (see also fact sheet on "Mechanical-biological waste treatment").

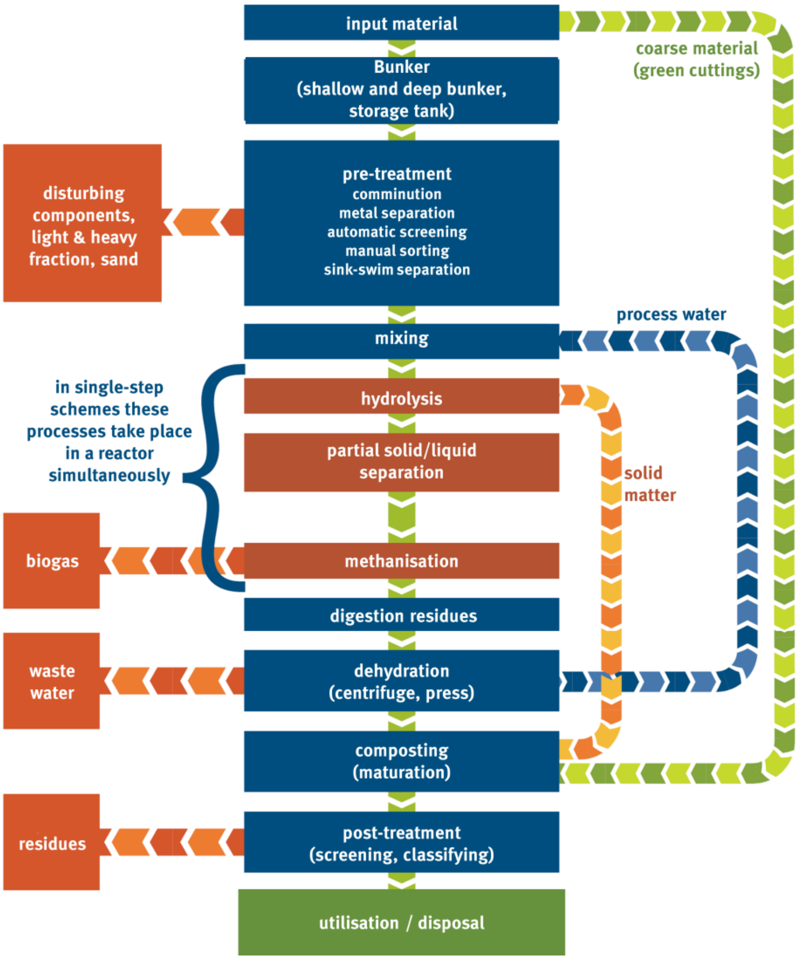
Digestion:

There are a number of different techniques used to effect digestion. They are usually distinguished on the basis of the operating temperature and the percentage of dry matter in the feedstock.

- thermophilic plants operate at around 55°C (50–65°C),
- mesophilic ones at around 35°C (20–45°C).
- dry systems work with 20–40 %, wet systems with 5-20 % dry matter content.

Generally speaking the higher the temperature, the faster the process, but thermophilic process may be harder to control and will need more biogas for heating to keep them at the required temperature. Dry systems are generally single-step systems. Single-step plants are not so prone to interferences like multi-step processes, but the production of biogas is lower.
The following Figure 1 depicts a general scheme applicable to single and double-step systems, for both dry and wet processes.

Figure 1: The process flows for single-step and multi-step waste digestion techniques



Some technical specifics of the different process configurations are listed below:

Wet single-step

Solid waste is slurried with the process water to provide a diluted feedstock (with a dry matter content at about 15 %) for feeding into a mixing tank digester. The process can be used for MSW on its own, but the wet process lends itself to co-digestion with diluted feedstock, such as animal manure and organic industrial waste. The high water content in the prepared suspension allows heavy material to settle and light material to float.

The suspended waste without heavy or light material is feed in a single step fermenter (37–40 °C; mesophilic conditions). The retention time is 15 to 20 days. Biogas is generated (65 % CH_4). The substrate is thoroughly mixed by biogas pressing. Fermented waste is discharged, sterilised at 70 °C and dewatered to 50 % dry matter. The drained water is being used as internal process water.

Wet multi-step

Solid waste is slurried and fermented by hydrolytic and fermentative bacteria to release volatile fatty acids which are then converted to biogas in a high-rate industrial waste water anaerobic digester. Basically, the hydrolysis and methanisation step take place consecutively in two different reactors. The system lends itself to the digestion of MSW and to the wet organic waste from food processors.

Multi-step plants are more prone to interferences as in comparison to single-step processes, but the production of biogas is higher.

The following picture shows a possible configuration of a wet digestion scheme.

Figure 2: Technical scheme for a multi-step wet digestion process (component arrangement according to Linde-KCA)

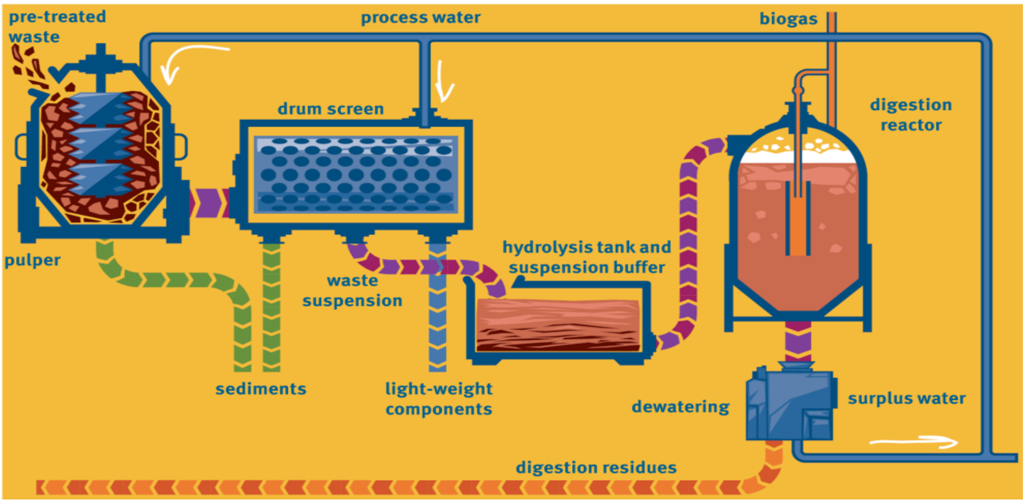


Figure 3: Real life images of key components in German plants operating a wet digestion of waste (left hand picture: Digestion reactors, Picture source: Tim Hermann; right hand picture: pre-treatment section, Picture source: INTECUS GmbH)

Dry processes

It is not always necessary but often the case that the input material is mixed with internal process water or sludge to obtain a dry matter content of 30 to 35 % before digesting. The fermentation takes place in a fermenter at 37–40°C (mesophilic conditions) or at 55–60°C (thermophilic conditions). Disturbing matter should be removed from the input before it is taken to these vessels. An additional separation of impurities from the digestion residues can be done after the anaerobic treatment. The retention time in the vessels/reactor lasts from 12 to 20 days. The remains from digestion are discharged and dewatered to 50 % dry matter. The drained water is used as internal process water. The solid matter is then taken to an additional rottening and curing under aerobic conditions for several months.

Dry continuous mode

The digestion vessel is continuously fed with a shredded and homogenized input material with a dry matter content of 20–40 %. Process water is sprayed over to inoculate the material. In both mixed and plug-flow variants, the heat balance is favourable for thermophilic digestion.

Dry batch mode

A batch is inoculated with digestate from another reactor and left to digest naturally. Leachate is re-circulated to maintain moisture content and to redistribute methane bacteria throughout the vessel.

Sequencing batch

Essentially a variant of the dry batch process, in which leachate is exchanged between established and new batches to facilitate start up, inoculation and removal of the volatile materials from the active reactor. After digestion becomes established, the digester is uncoupled from the established batch and coupled to a new batch in another vessel.

QUANTITY ASPECTS	- The anaerobic digestion process leads to a production of methane, with a theoretical methane production of 348 Nm^3/Mg of COD. Anaerobic digestion in general produces 80-140 Nm^3 biogas per Mg of organic municipal waste processed. - Biogas generation is very sensitive to the feedstock, typical is a composition in the following range: 50–75 Vol.-% methane, 25–45 Vol.-% carbon dioxide, 2–7 Vol.-% water, 20–20,000 ppm hydrogen sulphide, < 2 Vol.-% nitrogen, < 2 Vol.-% oxygen, < 2 Vol.-% hydrogen. - The overall mass flow (in German plants) can be described as follows[3]: *Input:* 100% biowaste comprising -65% water -23% dry organic matter -12% dry inorganic matter *Output:* 5% residues from pre-treatment (sand, stones, foils etc.) 11% biogas 29% waste water 55% residues after digestion/solid output
SCALE OF APPLICATION	- The majority of installations stays in a capacity range between 500 and 80,000 Mg waste input per year
INTEROPERABILITY	In practice the following technical arrangements are common: - Anaerobic digestion makes up the biological stage in a mechanical-biological treatment process (see the fact sheet on "Mechanical-biological waste treatment") - Anaerobic digestion is taking place with a subsequent composting process for the post treatment of the digestion residues. The digestion residues can be separated into a solid and a liquid fraction, whereby the liquid residue of appropriate quality might be directly utilized in form of a liquid fertilizer whilst the solid material is further processed into a compost (see the fact sheet on "Composting"). - Anaerobic digestion is coupled with a waste water treatment facility or an integrated part of the treatment system for waste water.
OPERATIONAL BENCHMARKS: RESOURCE CONSUMPTION	
ENERGY BALANCE	- The electricity and heat which is needed to heat up the digester vessels and for the other installations is usually won from the process itself in that the generated biogas is burnt in a cogeneration unit. Own demand can make up from 5% up to approx. 60% of total production depending on various factors, inter alia, the process technology employed. Figures on energy production and own consumption per Mg of input for different process configurations are shown below in

[3] Rosenwinkel, Kroiss, Dichtl, Seyfried, Weiland (editors): Anaerobtechnik – Abwasser-, Schlamm- und Restoffbehandlung, Biogasgewinnung (3rd ed.), Springer Verlag, 2015, p. 726

Table 1: Systematic comparison of electricity production and consumption figures in the main different schemes of anaerobic digestion processes in relation to the digestion input (Data source: Final report of funded research project, no. 03KB022: Steigerung der Energieeffizienz in der Verwertung biogener Reststoffe)

Process mode			Electricity production (kWh/Mg)	Electricity consumption (kWh/Mg)
Wet process	single step	mesophilic	235	71
		thermophilic	310	71
	multi step	mesophilic	274	71
		thermophilic	N/A	N/A
Dry process	continuous	mesophilic	241	48
		thermophilic	271	48
	discontinuous	mesophilic	186	23
		thermophilic	194	23

CO_2-BALANCE

- The process itself is enclosed and atmospheric emissions should therefore hardly take place except during transfer to and from the digester. Investigations have however shown that a so called methane slip occurs (losses of methane through microscopic cracks and leakage in technical components) in the range of up to 5% of total methane production.
- Important positive climatic effects of anaerobic digestion arise from the:
  - avoidance of methane emissions from landfill disposal of untreated organic waste
  - reduced emissions due to energy substitution and lower demand on fossil fuels

AIDS/ADDITIVES NEEDED

Water: 50–200 l per Mg of waste

Auxiliary materials, to which may belong

- flocculants such as iron chloride solution or such of anionic polymeric nature
- anti-foaming products
- pH-regulating agents

HUMAN RESOURCES

- Running a digestion facility requires specially qualified personnel in particular for the facility management and operations control. Depending on the kind of process and size of the plant the personnel requirement starts in the minimum with 3 skilled staff.

SPATIAL NEEDS

Table 2: Space requirements without area for the post-rottenting of the digestion residues (Data source : UBA Texte 43/2010: Aufwand und Nutzen einer optimierten Bioabfallverwertung hinsichtlich Energieeffizienz)

Plant capacity	20,000 Mg/a	40,000 Mg/a	Space per Mg/a
Wet fermentation	4,500-5,000 m²	6,000-8,000 m²	0.15-0.25 m²
Dry fermentation - continuous	4,000-5,500 m²	5,000-6,000 m²	0.125-0.275 m²
Dry fermentation - discontinuous	2,500-3,000 m²	5,000 m²	0.125-0.2 m²

AFTERCARE DEMANDS

- Aftercare for the stabilized digestion residues dumped at landfills must be an integrated part of the landfill management procedures. However, the rejects from screening and digestion can normally be incorporated into composting or the utilization in other (e.g. thermal) processes is possible.

OPERATIONAL BENCHMARKS: COST DIMENSIONS

INVESTMENT COSTS

Table 3: Investment needs for different types digestion technology
(Data source : UBA Texte 43/2010: Aufwand und Nutzen einer optimierten Bioabfallverwertung hinsichtlich Energieeffizienz)

	Dry fermentation - discontinuous	Dry fermentation - continuous	Wet fermentation	Partial-flow fermentation
Investment costs at 20,000 Mg input /a	150 – 310 EUR/Mg	250 – 480 EUR/Mg	260 – 490 EUR/Mg	40 – 100 EUR/Mg

- Reduced input amounts let the specific costs rise due to fixed cost positions (degressive cost curve). The digestion process is still relatively expensive also for larger sized plants hence there is often no neutral cost balance despite possible revenues from the production of energy and fertilizers.

OPERATING COSTS

Table 4: Operating expenses at plants with different types digestion technology
(Data source : UBA Texte 43/2010: Aufwand und Nutzen einer optimierten Bioabfallverwertung hinsichtlich Energieeffizienz)

	Dry fermentation - discontinuous	Dry fermentation - continuous	Wet fermentation	Partial-flow fermentation
Operating costs at 20,000 Mg input /a	15–30 EUR/Mg	18–38 EUR/Mg	20–50 EUR/Mg	5–15 EUR/Mg

- Reduced input amounts let the specific costs rise due to fixed cost positions (degressive cost curve).
- Repair and Maintenance: 4–6 % of the investment costs per year

POSSIBLE PROCEEDS

- The monetary energy yield is in the range from 20 to 30 EUR per Mg of waste input. With this, the overall operating costs of such plants can be covered, at least in part, by revenues from the sale of generated energy, digested sludge and/or compost. A favourable price situation can even yield a profit.

MASS SPECIFIC OVERALL COSTS

- N/A

OTHER RELEVANT ASPECTS

- The co-fermentation of bio waste substrates in the anaerobic digestion towers of waste water treatment plants is gaining momentum and is meanwhile an option that more and more plants consider and some already put into practice (see the fact sheet on “Sewage sludge management”). It is for both, economic and logistical reasons an attractive and technically feasible solution

MISCELLANEOUS

MARKET INFORMATION

REFERENCE FACILITIES

(Note: the list of sites and/or firms does not constitute a complete compilation)

Digestion techniques are used everywhere in the world. Aside from the many facilities for the sole digestion of agricultural matter in Germany there are plants for the digestion of bio waste in a larger number as well. Their number is increasing. Reference facilities in Germany are for example:

- Biogas plant of the Bioverwertungsgesellschaft Radeberg mbH www.bvr-radeberg.de
- Biogas & composting plant Bützberg of the Company for city cleansing (Stadtreinigung) Hamburg www.stadtreinigung.hamburg/kompostwerk
- Biogas plant Berlin-Ruheleben of the Company for city cleansing (Stadtreinigung) Berlin https://www.bsr.de/biogasanlage-22250.php
- Biogas & composting plants in Gütersloh and Saerbeck

RECOGNIZED PRODUCER AND PROVIDER FIRMS *(Note: the list of firms does not constitute a complete compilation of companies)*	Recognized producer firms for digestion technology and plant providers for the digestion of biowaste are for example: - Strabag Umweltanlagen GmbH, Dresden www.strabag-umweltanlagen.com - HAASE Energietechnik AG, Neumünster http://www.bmf-haase.de/ - Schmack Biogas AG, Schwandorf www.schmack-biogas.com - FARMATIC Anlagenbau GmbH, Nortorf www.farmatic.de - Biotechnische Abfallverwertung GmbH & Co KG, München www.bta-technologie.de - Eggersmann GmbH, Marienfeld www.eggersmann-recyclingtechnology.com/en/ - BEKON Energy, Unterföhring www.bekon-energy.de

ADDITIONAL REMARKS AND REFERENCE DOCUMENTS

Relevant organisations and sources for **further information** on the digestion of municipal waste fractions are:

- Fachverband Biogas e.V. www.biogas.org
- Arbeitskreis für die Nutzbarmachung von Siedlungsabfällen (ANS) e.V. www.ans-ev.de
- Arbeitsgemeinschaft Stoffspezifische Abfallbehandlung (ASA) e.V. www.asa-ev.de