Applied processes and techniques – AD

Purpose

Anaerobic digestion (AD) is used to transform organic matter into biogas and digestate. Biogas is a renewable energy source which can be used for the production of electricity, heat, natural gas and fuel. Digestate is a biofertiliser rich in humus forming materials and nutrients which can be directly applied on land or be further upgraded (e.g. composting, drying, stripping, filtering, evaporating, percipitation).

Principle of operation

AD is the microbiological decomposition of biomass (biogenic organic materials) with the absence of free oxygen which can be observed in nature for instance in moors, marshes, inundated rice fields, badly aerated soils, eutrophic waters sediments, digestive tracts of animals (in particular cow's rumen) or expired food in closed vessels. The deposition of organic waste at landfills under oxygen starvation leads to the uncontrolled decomposition processes.

The biogas technology makes use of these processes in which organic compounds are degraded by different groups of micro-organisms under exclusion of air (as source of oxygen) resulting in biogas and digestate. Biogas can be combusted in boilers to produce heat or in combined heat and power units (CHP) to generate electricity also in combination with heat. Biogas can also be upgraded to biomethane by removal of the carbon dioxide content to be injected into the natural gas grid or used as a fuel for vehicles. Dry biogas has a typical composition of 55 – 70 % methane, 30 – 45 % carbon dioxide and 50 – 4000 ppm hydrogen sulphide alongside other traces of volatile elements. The biogas yield and the proportion of methane to carbon dioxide will vary with the feedstock and the temperature of the system. The content of nutrients in the feedstock needs to meet all nutrient demands from the microbes in order to operate an efficient process.

Feed and output streams

A great variety of organic materials are suitable as feedstock, for instance agricultural wastes, separately collected household biowaste, organic fraction of mixed waste, garden and park waste, fat separator contents, food leftovers from kitchen, hotels and restaurants, expired food from retail markets, agricultural by-products like manure and other animal by-products, industrial slurries and sewage sludge from municipal waste water treatment. One of the main limits of AD is its inability to degrade lignin (a major component of wood). This is in contrast with the process of aerobic biodegradation (composting). Most types of biowastes are legally required to be hygienisated to eradicate pathogens or reduce them to acceptably low, sanitary levels. This can be done by a pasteurisation (>70°C, 1h), thermophilic digestion (> 50°C), a post composting step or other validated methods.

The characteristics of the feedstock have very important effects on the AD process and the biogas yield. A clean biodegradable feedstock will increase the quality of the digestate, which – if complying with national and European legislation and voluntary product specifications- can be used as an organic fertilizer or soil improver in agriculture, either in a liquid form (about 5-15 % dry matter) like manure, in a semi-solid form (10–30 %) like peat or being further upgraded e.g. by composting, drying and/or pelletising in landscaping and horticulture as well as in private gardens. In Germany, Belgium, Netherlands and other MS, digestate are commonly post-composted if the feedstock is mainly based on household biowaste. In UK and Sweden source separated biowaste from households is mainly digested in liquid systems, even when separation into a liquid and a solid fraction occurs, the solid fraction is usually not post-composted. Liquid or separated solid digestate produced from industrial and agricultural biowaste are commonly not composted but used directly as fertiliser. The nutrients that were contained in the feedstock remain in the digestate. Only carbon, hydrogen, oxygen (as part of CO_2) and in marginal quantities nitrogen and sulphur can leave the process within the gas phase. Therefore, the used feedstocks determine directly the composition of the generated digestate. The nutrient content is predominantly described by nitrogen, phosphorus, potassium and the organic carbon content. If the digestate cannot be used as fertiliser due to high contents of impurities and other contaminants like heavy metals, the energetic recovery of the digestate is a possible alternative.

Process description

In order to maintain a long term healthy and continuous digestion process, materials, such as plastics, metals and oversized components are removed from the waste to be treated or later on in the process. 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. The size reduction could be brought about by screw-cutting, milling, drumming, pulping or shredding machines.

The conversion of biomass to biogas and digestate is a complex biochemical process. Four phases can be distinguished as follows:

1. In the first step, the **hydrolysis**, polymers components of the feedstock (e.g. carbon hydrates, proteins, fat) are disassembled into lower molecular organic compounds (inter alia amino acids, sugar and fatty acids). The hydrolytic micro-organisms involved release hydrolytic enzymes, which decompose the material biochemically outside the microbial cells. During hydrolysis some hydrogen is formed which can be directly used for methane formation.

2. The produced intermediates are degraded during **acidogenesis** by acidogenic bacteria to lower fatty acids (acetic acids, propionic and butyric acid) as well as to carbon dioxide and hydrogen. Also lactic acid and alcohols are produced in small quantities.

3. The intermediates subsequently are transformed during **acetogenesis** by acetogene bacteria to acetic acid, hydrogen and carbon dioxide.

4. In the last phase, the **methanogenesis**, methane and carbon dioxide are formed, by archaea.

There are a number of different techniques used to effect digestion. They are usually distinguished on the basis of the operating temperature (thermophilic plants operate at around 55 °C and mesophilic ones at around 40 °C and the percentage of dry matter in the substrate (e.g. dry systems or high solid with 15 – 40 % dry matter and wet systems below 15 % dry matter). Generally speaking, the higher the temperature, the faster the process, but the thermophilic process may be harder to control and will need more energy for heating due to higher heat losses from the tanks. The most common technologies are listed in the following table. Moisture content and degradability of feedstock are very important for the choice of the technology. Therefore, kitchen waste and other putrescible wastes, which may be too wet and lacking in structure for composting, can provide an excellent feedstock for AD. In pre-treatment, liquids are added to control the dry matter content. For digestion, liquids are added to control ammonia in particular and sometimes salt concentrations. Viscosity control is managed by recycling of liquid digestate.

Technique	Description	Input
Wet digestion	Solid biowaste is slurried with process water or liquid waste to provide a diluted feedstock for feeding into the digester. Liquid biowaste can be used directly.	The technique can be used for household, industrial, commercial and agricultural biowaste as well as animal manure and energy crops.
Dry continuous digestion	The digestor is continuously fed with a material with 15 – 40 % dry matter through semi continuous feeding. In both mixed and plug flow variants, the heat balance is favourable for thermophilic digestion. There are vertical and horizontal digesters.	The technique can be used for household, industrial, commercial and agricultural biowaste and the organic fraction of mixed household waste of overall limited degradation.

Dry batch digestion	A batch is inoculated with digestate from another reactor and left to digest without further mixing. Leachate is recirculated to improve the contact between locally formed organic acids and methane forming bacteria.	The technique is commonly used for comingled kitchen and garden waste with a considerable content from structural material. Other applications are solid manure and energy crops.

Table: Anaerobic digestion (AD) technologies

Users

AD is a common treatment for a wide range of biodegradable wastes described as feedstock in all European member states, although the feedstock and applied techniques can vary widely among them due to different legal requirements and local situations. AD of biodegradable wastes produce a biogas which can be used to generate electricity and heat or upgraded to replace natural gas or vehicle fuel. The digestate can be applied to soils as a fertiliser or soil conditioner. The recovery of energy and fertiliser from biowaste and other biodegradable material like sewage sludge and the organic fraction of mixed household waste become very attractive due to European legislation (Waste Framework Directive 2008/98/EC, Landfill Directive 1999/31/EC, Renewable Energy Directive 2009/28/EC, Animal BY-Product Regulation 1069/2009/EC etc.)