Overview and Categorization of European Biogas Technologies

- Digester -

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DiBiCoo – Digital Global Biogas Cooperation
Grant Agreement N°857804

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Executive Summary of D2.2

The following document gives an overview of existing European biogas technologies.

The structure following the introduction section about Anaerobic Digestions (AD) follows the biogas processing logic: from feedstock storage on site and necessary pre-treatment to the various digester technologies. Special chapters on important elements of any biogas plant are elaborated in detail (e.g. on measurement, control and regulation technologies).

Upgrading biogas to biomethane quality as well as various application of Biogas are introduced (e.g. its GHG mitigation potential, as Combined Heat & Power (CHP) plants).

Due to the huge amount of existing information and knowledge on this topic it may occur that not everything is included or considered extensively. We propose this deliverable as a solid starting point getting to know about anaerobic digestion. This doesn´t replace special training courses and at least professional planning. In order to incorporate more relevant technologies and Biogas applications, some sections already outlined in this technology overview (e.g. on various pumps, pipes and valve types; or safety equipment) will be presented in an updated version later in October 2020.

The detailed descriptions of certain technologies are not implying any preference to a technology, service provider or device. Similarly, pictures including company names shall not be seen as a preference to any specific company or technology. It is done for visualization purposes only.

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Summary of the DiBiCoo Project

The **Digital Global Biogas Cooperation (DiBiCoo)** project is part of the EU's Horizon 2020 Societal Challenge 'Secure, clean and efficient energy', under the call 'Market Uptake Support'.

The target importing emerging and developing countries are Argentina, Ethiopia, Ghana, South Africa and Indonesia. Additionally, the project involves partners from Germany, Austria, Belgium and Latvia. The project started in October 2019 with a 33 months-timeline and a budget of 3 Million Euros. It is implemented by the consortium and coordinated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

The overall objective of the project is to prepare markets in developing and emerging countries for the import of sustainable biogas/biomethane technologies from Europe. DiBiCoo aims to mutually benefit importing and exporting countries through facilitating dialogue between European biogas industries and biogas stakeholders or developers from emerging and developing markets. The consortium works to advance knowledge transfer and experience sharing to improve local policies that allow increased market uptake by target countries. This will be facilitated through a digital matchmaking platform and classical capacity development mechanisms for improved networking, information sharing, and technical/financial competences. Furthermore, DiBiCoo will identify five demo cases up to investment stages in the 5 importing countries. Thus, the project will help mitigate GHG emissions and increase the share of global renewable energy generation. The project also contributes to the UN Sustainable Development Goals (SDG 7) for 'Affordable and clean energy", among others.

Further information can be found on the DiBiCoo website: www.dibicoo.org.

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List of Abbreviations

AD	Anaerobic Digestion
CHP	Combined Heat & Power
CSTR	Continuously Stirred Reactor
d	day
D	Deliverable
T	Task
SC	Steering Committee
UASB	Upflow anaerobic sludge blanket digestion

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1 Digester

Although pre-treatment of used substrate is a very important step for the performance of anaerobic digestion, the digester can be seen as the main technical facility in a biogas plant. Corresponding to the biological, chemical and technical requirements, biogas plants can be classified as shown in Table 1: Classification of the digestion process based on different criteria.

Table 1: Classification of the digestion process based on different criteria

Criterion	Distinguishing characteristics
Wet or dry digestion	Wet digestion Dry digestion
Substrate feed	Intermittent Continuous
Hydraulic flow	Continuously stirred digester Plug flow digester
Process phases (biologically)	Single phase Two phases
Process stages (technically)	Single Two or even multistage
Process temperature	Psychrophilic Mesophilic Thermophilic

1.1 Wet or dry fermentation

There is a difference between wet and dry fermentation. Irrespective of this differentiation however, every biological process – and thus also the process of fermentation – requires the presence of water. Hence, the real difference lies in the form of the substrate: either it is liquid, solid or even stacked.

Inside the digester there has to be always enough water for bacteria to be active, even in dry fermentation. In consequence, there is no general definition for dry fermentation. In some countries, the water content of the feedstock is used as a differentiator: if the average dry matter content of the feedstock is above 25% (or above 20%), it is defined as dry fermentation.

In other cases, it is called dry fermentation if the feedstock inside the digester is stackable, for example in cases of dry batch garage systems.

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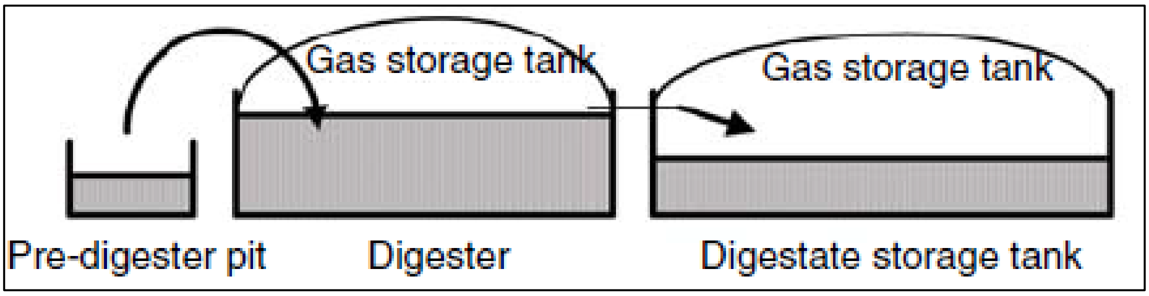
1.2 The substrate feed: Continuously vs. intermittent feeding systems

Most biogas plants are fed continuously, which means several times per day. Thereby, relatively constant conditions in the digester tank can be achieved which is beneficial for the activity of the microorganisms. However, the substrate can also be fed into the digester intermittently, only once a day. Yet, this is seldom the case as this would hinder a continuous biogas production and could additionally cause process distortions. Some special liquids are fed into the digester continuously. The same volume which is fed into the digester will be forwarded to the next fermentation step, e.g. into the post digester or storage tank. This can be done via steered pumps or through free flow. The filling level of the digester itself therefore is kept at the same level and guarantees a continuous biogas production. Even less frequently used are garage type digesters, where stackable feedstock is only fed in batches, e.g. once per month.



Picture 1: Continuous digestion process called through flow process with a followed gas-tight storage tank; © FNR,2012

1.3 The hydraulic flow: continuously stirred, plug flow digestion, or batch digester

Most wet digestion systems are continuously stirred (**CSTR: continuously stirred tank reactor**). In these systems, one or more agitators secure that the substrate within the digester is in continuous flow so no segregation into floating or sink layer occurs. Additionally, it shall guarantee that no zones occur where the temperature gets too low or where the acid concentration etc. raises too much. The stirring can be done continuously or semi-continuously. In case of the latter, stirring needs to be done at least before floating layer etc. occur.

A special form of continuously stirred digesters is the **hydraulic digester** where the stirring is done with the gas pressure of created biogas. It is usually a tank in tank digester which is connected at the bottom through concentric openings and at the top through a gas pipe with an automatic valve. Only the inner tank is directly connected to the biogas storage and to the digestate storage tank. When the valve within the connection gas pipe is closed, the produced biogas presses the substrate in the outer tank, flows through the opening at the bottom into the inner tank and raises the level of substrate there. After a difference in height between the liquid surface of inner tank to outer tank of around 4 meters, the valve is opened, and the fluid levels are immediately equalized through the concentric bottom openings. These concentric openings guarantee the stirring of the substrate.

Plug flow digesters are usually lying tanks (round or rectangular) with a horizontal agitator that mixes the substrate but also moves it forward slowly from the inlet to the outlet. There are also vertical installed plug flow digesters in operation. Both, horizontal or vertical systems can be operated in dry or wet fermentation processes. The different steps of digestion are

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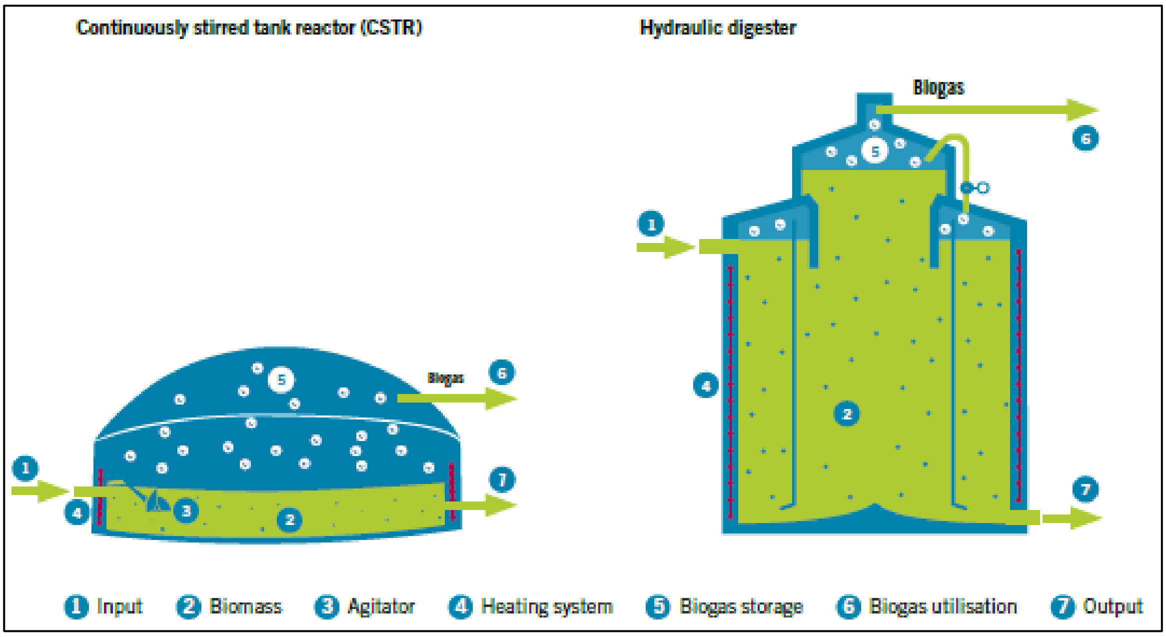
separated in this type of reactor. Which is an advantage as the different bacteria groups can all work within their own optimum pH range.

The vertical plug flow system is called UASB digestion (**UASB = up flow anaerobic sludge digester**). This is a special type of digester which is often installed to reduce chemical oxygen demand in wastewater from industries like dairies, beverage industries, sugar beet factories etc. It treats fast degradable liquid substrates with a retention time which is sometimes only around one day. As methanogenetic bacteria has a doubling time for at least 2 days, this would cause washing out of the last step of biological digestion process from the digester and therefore lead to process disturbances. Therefore, special conditioned pellets are filled into the digester where the methanogenetic bacteria can settle while the liquid substrate streams upwards and passes the bacteria. The substrate at the bottom is pumped continuously into the digester and flows slowly upwards. At the top of the digester the generated biogas is collected in special domes.



Picture 2: Types of continuously stirred digesters; left: stirred by agitator, right: hydraulically stirred; © FvB, 2017

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Picture 3: Left: Demonstration object of a continuously stirred digester, right CSTR digester.

Picture 24: Hydraulic digester with the higher inner tank and the lower outer tank.

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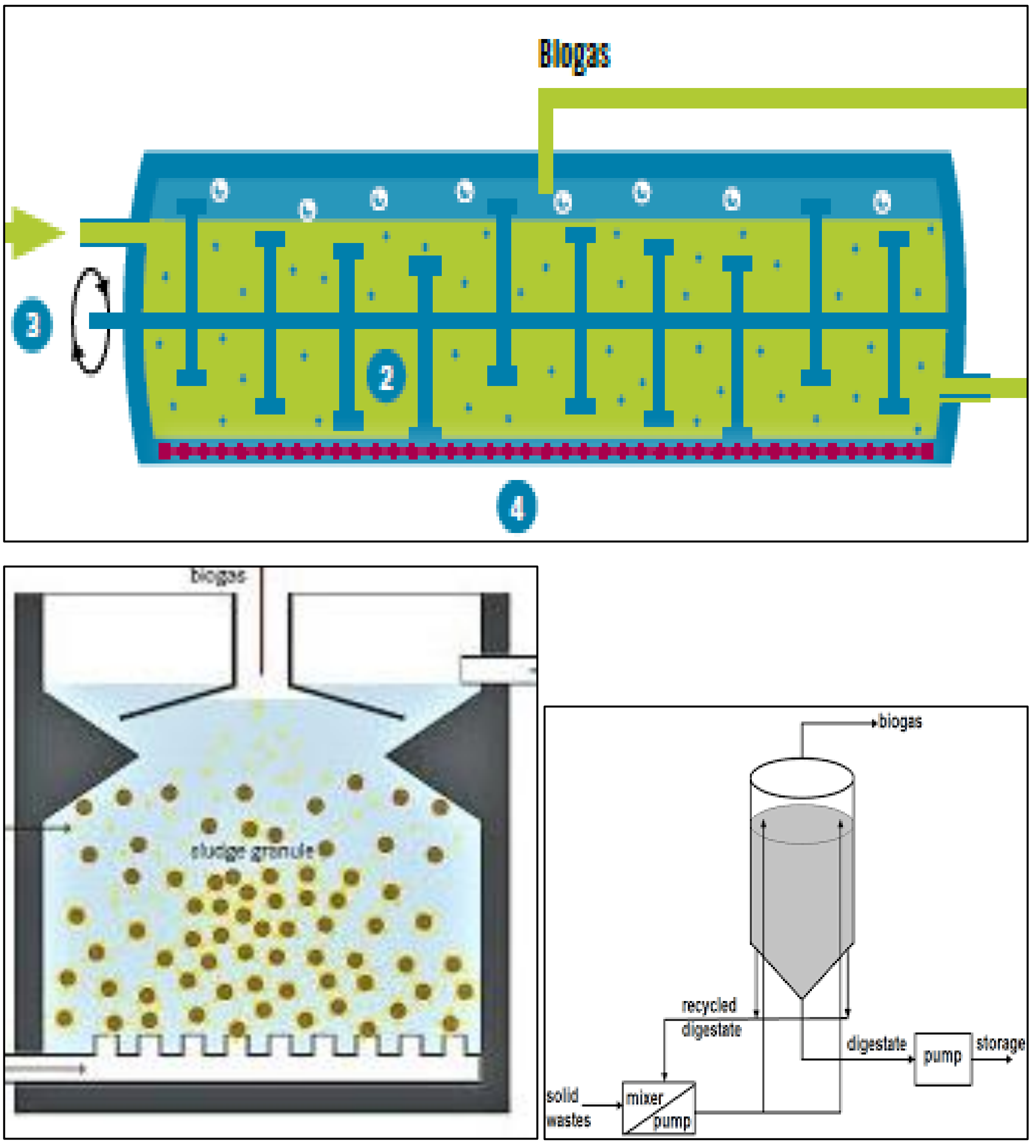

Picture 5: Schemes of horizontal and vertical plug flow digester; top: horizontal plug flow digester with horizontal agitator, bottom left: vertical downstream plug flow dry digester without mixing, bottom right: vertical upstream plug flow digester without stirring.

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Picture 6: Top: Horizontal dry digester with horizontal stirring (left round and of steel, right: square and of in situ concrete - digesters in parallel), bottom left: upstream plug flow digester without stirring, bottom right: down-stream plug flow digester without

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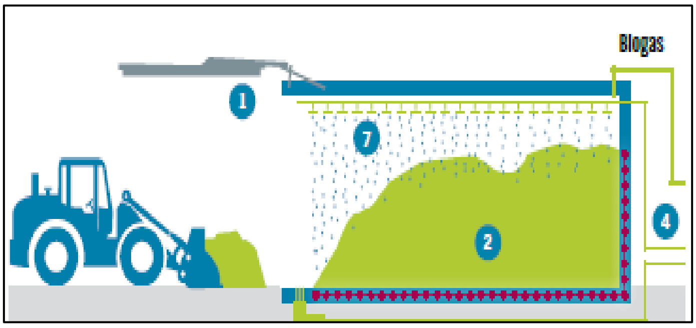
Picture 7: Upstream plug flow digester (UASB = up flow anaerobic sludge digester).

Another special form is the batch dry digester (also called **garage system**). Here the substrate is filled in a closed room (garage) which is air-tight closed after filling the feedstock. The substrate needs to be stackable and will not be mechanically mixed during the subsequent digestion process. During this digestion process percolate (intercellular water which will be set free from the feedstock during the digestion process) will be pumped and spread from the ceiling onto the substrate. The acid-rich percolate is collected at the bottom and pumped to the heated percolate tank. The biogas process usually happens within the stacked substrate and also within the percolate tank. Through the flow rate etc. it can be steered where most of the methanogenic process happens. When the substrate is degraded, the digester is aerated and afterwards emptied and filled again with new substrate. As the building of biogas is not continuous with one batch, these systems usually have several batch digesters installed in parallel.



Picture 8: Top: Scheme of a batch dry digester bottom: inside of a batch dry digester; © left Fachverband Biogas 2019

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1.4 Biological process phases: single or two phases

Usually, the different steps of the biogas production process take place simultaneously and is therefore done in one tank. Even if the process is done in more than one digester with the same pH value, this is biologically a single-phase digestion process because all steps of digestion take place simultaneously. As the involved hydrolytic and acidification forming bacteria have different requirements compared to methanogenic bacteria on pH value, this can be used to divide the digestion process into two phases:

- Hydrolysis
- Methanization

A separation of these two phases is usually done by lowering the pH value far below 6.5 in the tank where the substrate is fed. The low pH value is achieved by installing a small reactor tank that is operated with a low hydraulic reaction time of only some days and a very high loading rate. By that, the formation of organic acids in the process will lower the pH value. If a low pH value cannot be guaranteed, methane production will usually start and therefore exhaust gas should be collected and connected to the joint gas system of the biogas plant. Because even if the hydrolysis works properly, some hydrogen will be released (besides carbon dioxide) and would cause energy loss if not collected.

Picture 9 Hydrolysis tank upfront of the digester

1.5 Technical process stages: single, two or even multi-stage

Many biogas plants are designed as follows: a main digester, followed by a post digester, followed by a gas-tight storage tank. This is the case because in a continuously or semi-continuously stirred digester not fully degraded substrate leaves the digester and thus, maximum biogas yield cannot be achieved. To ensure an environmentally friendly performance, formed methane from the digestate storage tank should be collected and used. As the feeding is done into the main digester, the size and maximum loading rate of this main digester determine the total capacity of the plant. Therefore, the organic loading rate in the main digester is higher than in the post-digester. If substrate is used that might cause a process distortion, these

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arrangements can help to avoid such a process distortion. In case the process is disturbed in the main digester, due to an excessive loading rate, this can be solved with substrate from the post-digester. However, it is important that the main and post-digester have nearly the same temperature as otherwise the difference in temperature could make the situation even worse. In contrast to the biological two-stage digestion process, the whole biological degradation process occurs simultaneously in each digester.

Picture 10: Model of a biogas plant with multistage digestion process (feeder, storage tank for slurry, main digester, post digester, gas-tight storage tank.

Picture 11: Typical biogas plant with a main digester followed by a post digester.

1.6 Process temperature: psychrophile, mesophilic or thermophilic process

The biogas process can operate within different temperature ranges:

- psychrophilic (<25°C), not very relevant in practice
- mesophilic (35 - 38°C), most common temperature
- thermophilic (>50°C), fastest degradation

The higher the temperature, the faster the growth rate of the microorganisms. The most commonly applied digestion temperature is the mesophilic profile. Mesophilic operation offers high process stability and a good controllable process. The thermophilic process on the other hand, is more sensitive to process disorders (especially to a higher amount of nitrogen within the substrate) and to temperature fluctuations. In a proper operated thermophilic process, the digestion process is performed faster, and the bacteria can adapt slowly to a higher ammonia content. Faster growth and activity of microorganisms mean faster digestion. Consequently,

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required retention times are lower, the digester can be smaller and can be operated with a higher loading rate and still reaches the same biogas production. In many emerging and developing countries biogas plants are operated at ambient temperature, e.g. lagoon and little domestic biogas plants. The advantage is that no heating system must be installed. The disadvantage is a lower activity of the microorganisms and probably lower biogas yields. Additionally, high digester volumes must be built because at low activity of bacteria, high hydraulic retention times are needed.

Industrial biogas plants usually optimize their operation. To reduce needed investment, operational and possible maintenance costs, the digester volumes should be small. They have a heat recovering system with the CHP unit and therefore prefer mesophilic operation.

1.7 Material and insulation of digester

Common digester material is locally produced concrete, steel, enamel- or even stainless steel. Common steel can be used for digesters if the desulphurization via oxygen is not made in the digester itself as this would lead to corrosion. This means, that biogas from these digesters always contains H_2S which needs to be taken into consideration for all further equipment. In case that locally produced concrete is chosen, the quality of the concrete and of the used cement is very important. In order to ensure longevity of the installation, the concrete placement must be combined with the right post-treatment. For an optimal process efficiency, the digesters need to be fully isolated (floor included) so that every zone of the digester has the same temperature. A fluctuation of 1 °C within a day already causes negative effects on the performance of the bacteria.

Picture 12: Concrete digester

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Picture 13: Digester material: left: rolled stainless steel digester with floor heating pipes on the outside, right: enameled steel storage.

Picture 14: Types of wall isolation, top left: special confectioned isolation which is included in the process of casting the con-crete, top right: isolation outside of digester through nails, bottom left: sandwich panels, bottom right: isolation under the floor.

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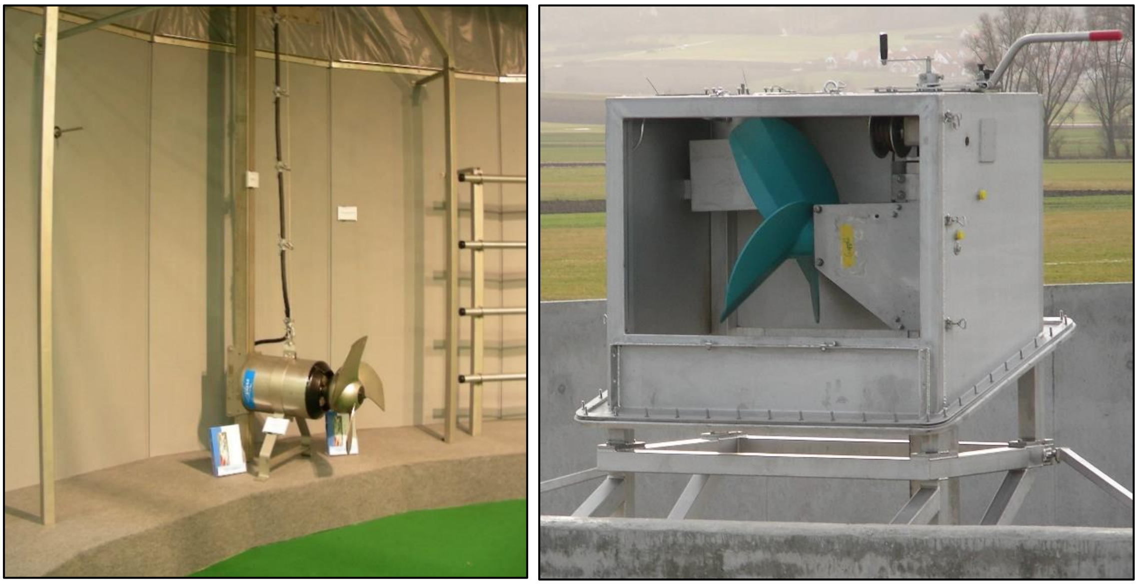
1.8 Agitation

In order to avoid segregation of the substrate in the digester, digesters – except the ones where it is not wanted or done in a different way – need to be stirred by an agitator. Vertical tanks are often stirred continuously by a central disposed agitator. Other commonly used techniques are propeller agitators (fast or slow running) or paddle agitators.

Picture 15: Vertically central positioned stirrer for a CSTR digester.



Picture 16: Different types of high-speed stirring systems.

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Picture 17: Different types of slow speed agitators.

Picture 18: Slow speed agitator in a horizontal digester

1.9 Heating

Several microorganisms are sensitive to temperature changes. Therefore, digesters need to be insulated and heated to keep a constant temperature with variations less than 1 °C per day. Heating is usually done through stainless steel pipes or plastic hoses which are directly installed at the inside of the walls and thus are directly in contact with the substrate.

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When steel digesters are used, the pipes for heating are sometimes also installed between the steel and the insulation. For concrete digesters the heating pipes can also be directly included within the concrete wall. Furthermore, also external heaters are used. Here, fresh substrate or substrate from the digester is heated in an external heat exchanger.

Picture 19: Heating system with floor heating pipes directly integrated into the concrete wall.

Picture 20: Stainless steel heat pipes directly attached to the digester wall. To avoid corrosion stainless steel pipes need to be installed galvanically isolated.

Picture 21: External heat exchanger where the substrate that will be fed gets heated and pressed into the digester.

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