CTB3365x – Introduction to Water Treatment

W6b – Digestion

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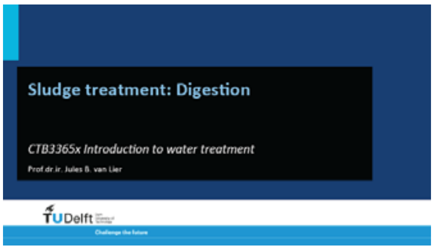
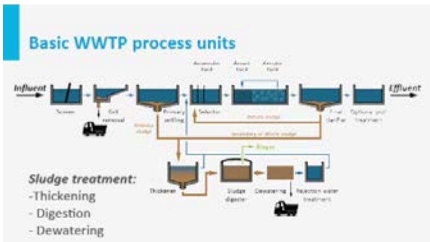
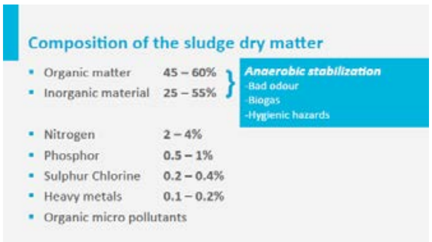


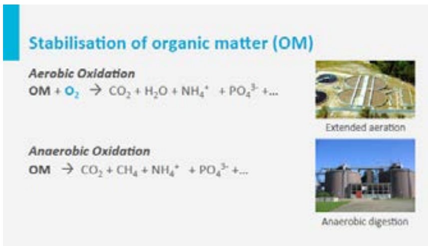
Thickened sludge is rich in organic matter, which hampers the dewatering process. Can we degrade the organic matter? Does it require additional energy? Or can we recover the energy enclosed in the organic matter?



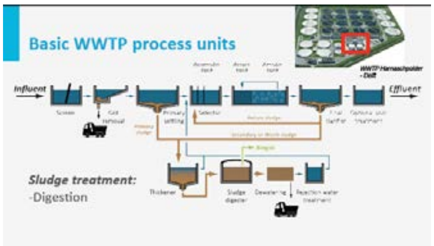
After sludge thickening, the concentrated flow needs to be stabilized. Stabilization in this sense means controlled putrefaction: conversion of organic matter in mineralized end products. Anaerobic digestion is considered the most cost-effective technology for stabilizing the excess sewage sludge. The basic principles of anaerobic digestion will be discussed in this lecture.



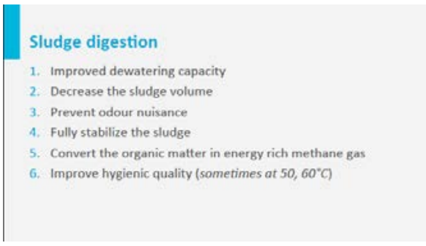
The thickened excess sludge, which generally consists of a mixture of primary and secondary sludge, is rich in organic matter. Between 45 to 60% of the sludge is organic matter and between 25 to 55% of the material is inorganic. The nitrogen content of the sludge mass is about 2 to 4%, and phosphorous amounts up to 0.5 to 1%. In addition to these macro pollutants, the sludge mass contains much more contaminants, such as heavy metals, salts, sulphates, micro--pollutants and of course, pathogenic bacteria. The excess sludge or bio-solids is a waste stream that requires further treatment prior to discharge. To minimize transport costs of excess sludge, organic matter destruction and a high degree of dewatering is pursued. The organic matter in the mixed excess sludge easily decays and starts to rapidly acidify, producing unbearable odorous compounds when it is not directly processed. Therefore stabilization of organic matter is needed, which is achieved by mineralizing the biodegradable organic matter to its end product.



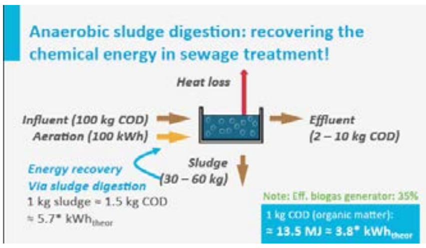
Remember that in the presence of oxygen as electron acceptor, all carbon is further oxidized to the end product carbon dioxide. This for instance occurs in extended aeration processes. In the absence of oxygen, carbon is both the electron donor as well as electron acceptor. This means that under anaerobic conditions a gas will appear consisting of a mixture of the most oxidized form of carbon, CO2 and the most reduced form, CH4 or methane. This gas mixture is called biogas and is produced in anaerobic digesters.



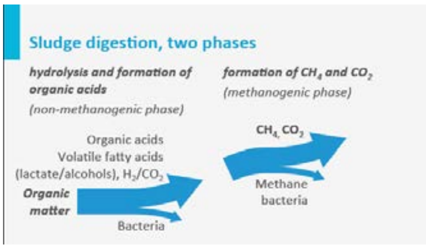
In most large activated sludge treatment plants, stabilization of the thickened sludge is immediately performed in an anaerobic digester in which, under oxygen free conditions, microorganism further breakdown the sludge particles to its mineral components, producing biogas.



From the process point of view, sludge digestion is implemented: 1) to improve the dewatering capacity of the excess sludge, since fresh sludge adsorbs more water than digested sludge; 2) to reduce the organic fraction of the sludge and thus to decrease the sludge volume; 3) To prevent that odorous components are produced from the sludge; 4) to fully stabilize the sludge, so that no further putrefaction and odor occurs during the further handling of the sludge; 5) to convert the organic matter in energy-rich biogas; and to 6) to improve the hygienic quality of the sludge. When hygienic quality improvement is important, then sludge digestion can be performed at temperatures between 50 and 60°C. At these temperatures most infectious germs are died off during treatment.

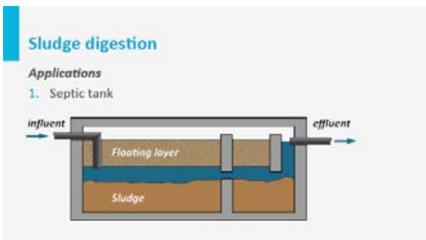


Anaerobic digestion is a reductive mineralization process, with energy-rich biogas as the end product. This means that by applying anaerobic sludge digestion, part of the energy consumed during the sewage treatment process can be recovered. How does this work? When we start feeding the aeration tank with COD we need about 1 kWh per kg COD that is fed to the aerobic reactor. Or, for 100 kg COD we need 100 kWh, as depicted in the scheme. This, of course, depends on the type of aeration system and treatment process, so, less energy may be required. In the aeration tank all biodegradable organic carbon is oxidized to CO2 resulting in low effluent COD values, meanwhile a high amount of sludge mass is produced. From the incoming COD, about 50% will end up in the biomass produced. The rest of the energy that is liberated in the process will leave the system as heat. 1 kg of produced sludge mass equals about 1.5 kg COD. The chemical energy enclosed in 1 kg COD is about 13.5 MJ, which theoretically equals about 3.8 kWh. If we assume that 50% of the COD which enters the sewage treatment plant would end up in the sludge, then the chemically bound energy in the sludge would be sufficient to cover the energy requirement for sewage treatment. However, with anaerobic digestion, only a fraction of the sludge COD can be converted to biogas, and only about 35% of the biogas energy can be converted into useful electricity, using a biogas generator. Therefore, using the standardized technologies, only part of the required energy can be derived from sludge digestion. At present, research is focused on maximizing the energy recovery, trying to develop an energy neutral or even energy producing sewage treatment plant. In principle this must be possible!! In such set-up, the anaerobic digester plays a crucial role in energy recovery.

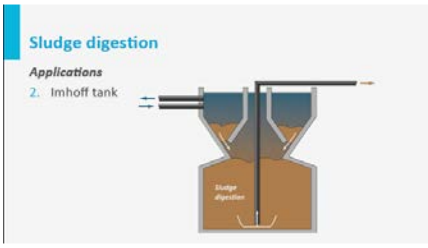


Anaerobic digestion can be roughly divided in 2 sub-processes or 2 phases: an acid forming phase and a methane production phase. During the acid-forming phase, large molecules such as cellulose, proteins and fats are hydrolyzed to carbohydrates, amino acids, glycerol-esters, and subsequently acidified to volatile fatty acids, alcohols, lactate, hydrogen and carbon dioxide. The acidification reaction is a very fast process and lowers the pH of the medium resulting in odorous sludge. For this reason the SRT in the sludge-thickening tank should be limited to about 1 day. In the methanogenic phase all these intermediate acidified products are further mineralized, and ultimately converted to methane and carbon dioxide. During this process the pH of the medium will increase. In a mixed digester process, in which both sub-processes are well balanced, the reactor pH stays neutral and methane is instantaneously being produced from the incoming waste. Overloading, sudden temperature drops, or the presence of toxic compounds may impact the methanogenic biomass, resulting in an imbalance in the digestion process.

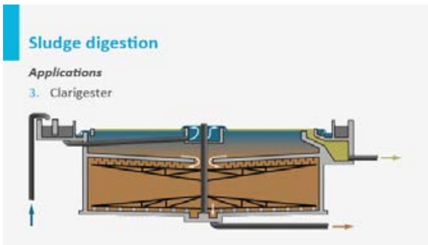
Sludge digesters are characterized by typical forms such as the egg shaped reactors in the picture. Although the digestion process is a rather complex microbiological system, it is a very common process, which occurs in may natural ecosystems such as in swamps, marshes, rice fields, being part of the natural carbon cycle. The anaerobic process is presently also used for high-rate wastewater treatment, a technology that is extensively discussed in our master lectures.



One of the oldest applications of anaerobic digestion is the so-called septic tank system, which is often used as an on-site sanitation system. A septic tank is a lateral flow treatment system in which solids are entrapped and partly digested. Light solids will form a floating or scum layer, whereas the more heavy solids will settle to the bottom. The partly stabilized effluent is subsequently infiltrated in the soil, or conveyed for further treatment.



The Imhoff tank can be considered an improved septic tank for larger flows. The Imhoff tank is a continuous flow system in which the sewage enters the tank at one side and leaves the tank at the other side. During the lateral flow, the solids will settle to the digestion compartment and will be anaerobically stabilized. A baffle system prevents that the bubbling biogas will disturb the solids settling process. The upper compartment can be regarded as a primary clarification zone.

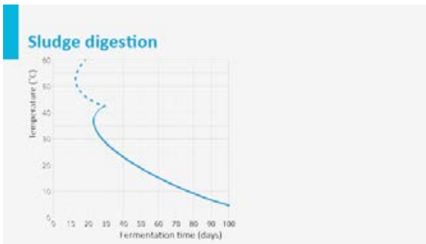


A clarigester is in fact a combination of a clarifier and a digester and was developed in South Africa. In this reactor the sludge flow is introduced from top to bottom where it is distributed. The liquid flow is upward, causing adequate mixing of the incoming flow with the active methanogenic biomass in the reactor. The clarification zone separates the treated sludge water on top from the sludge mass in the lower compartment.

At present, for the digestion of excess sewage sludge, a stirred tank reactor is most commonly applied. These reactors are generally heated until 30-35 °C, which is considered an optimum temperature for digestion. Initially the feeding is performed discontinuously, allowing the sludge to settle after which the sludge water is withdrawn.

At present, sludge digesters are operated as continuously fed stirred tank reactors, in which the mixing is performed with mechanical stirrers, impellers, or via biogas recycling. Sometimes high temperatures of 55 °C are applied to enhance the solids degradation such as this example in Echten, The Netherlands.

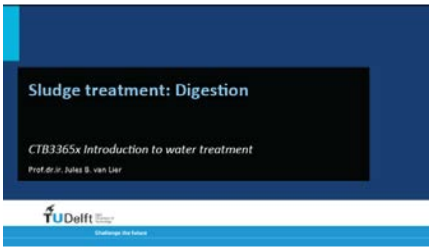
Since reactors are intensively mixed, sludge water separation needs to be performed outside the digester. Sludge separation can be performed by using a post digestion thickener, or by more advanced sludge separation techniques, such as centrifuges or belt presses.



The applied process conditions should allow for most optimal digestion, which means, proper mixing, neutral pH, and temperature control to the set values. At the most common digestion temperature of 30-35 °C the generally detention time is about 20-25 days. Shorter detention times reaching 15 days or sometimes even lower can be achieved by applying thermophilic digestion at temperatures of 50-60 °C. At these temperatures, also solids hygienisation is achieved. The latter is of particular importance when the use of the treated biosolids for agricultural purposes is considered.

Many different designs are used for sludge digesters. Most commonly, height / diameter ratios are between 1:1 and 1:1.5, whereas volumes are between 1000-10.000 m3. The feeding is generally semi-continuously, equally distributed over the day, having a constant sludge level in the digester. For heating the digester to 30-35°C the energy requirement in winter is about 120 MJ/m^3 feed sludge, and in summer about 85 MJ/m^3, depending on reactor type and insulation.

The biogas production depends on the sludge composition but is on average about 1000 L/kg destructed organic material, with a composition of 60-65% methane and 35-40% carbon dioxide. The produced biogas has a caloric value of about 24 MJ/m3. Since only part of the chemically bound energy can be recovered by digestion, and the efficiency of the biogas generator does not exceed 35-40%, the total energy coverage is about 50-60%, sometimes reaching 70%. The reduction of organic matter during digestion of mixed sludge is about 50%, in which primary sludge is much better degraded than the secondary sludge from the aeration tanks. Finally, digested sludge after gravity thickening may reach a concentration of about only 4-6%. Therefore, after digestion a dewatering step is required to minimize transport costs of the excess sludge.



Sludge digestion reduces the sludge organic fraction, by converting it into energy-rich biogas. Consequently, the sludge de-waterability is improved, which is imported for the next step: mechanical sludge dewatering. Let’s have a look to this in the next lecture.