Chapter 7

Used water treatment

> "Clean water is a great example of something that depends on energy. And if you solve the water problem, you solve the food problem."
>
> **Richard Smalley, American scientist, 1943–2005.**

Clean air and clean water are absolute top priorities when we talk about responsible energy development. Over the last few decades there has been an interesting development in wastewater (or used water) treatment. The traditional method of used water treatment has been centralised sewage treatment systems connected to urban water users by wide sewer networks. Now there is a remarkable development into decentralisation, and it has been recognised that centralised systems have their limitations. This becomes obvious looking at the need for water remediation in remote areas. Small-scale treatment must be both efficient and affordable. Water scarcity makes it necessary to reconsider the whole concept of sewer-based water treatment. Every drop of water is important.

Sanitation is still out of reach for too many people, as mentioned in Chapters 1–3. Furthermore, both clean water and sanitation must be achieved in order to reach the UN's Sustainable Development Goal

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doi: 10.2166/9781780409443_0083

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number 6. Having available energy is just one of the key requirements. If individual households can be empowered, many of the sanitation problems in remote areas can be solved locally without the support of governments or other institutions.

The main philosophy that should guide the wastewater treatment is that wastewater is not waste: it is a renewable and recoverable source of energy, nutrient resources and water. This should guide the development of used water treatment, considering:

- Recovery and utilisation of energy content present in the water;
- Recovery of nutrients;
- Production of water for reuse.

All three aspects can be satisfied with proven technology combined with renewable energy of realistic size. Decentralised used water treatment is described in 7.1. Various technologies are briefly explained in 7.2 and energy aspects to treat the water are summarised in 7.3.

7.1 MAIN SOURCES OF USED WATER

Decentralised treatment plants are based on self-contained modular systems that provide efficient, scalable solutions to used water treatment problems of all sorts. To find out suitable technologies for decentralised water recovery treatment it is necessary to identify the various sources of water contamination. The traditional method of used water treatment has been to treat a single waste stream from a sewer system. A decentralised system can be designed in a different way with a separate treatment facility for each category of contaminated water. In this way we may look at urine, faeces and greywater as separate sources of used water instead of being components of one type of used water. The sources should be considered useful resources rather than waste. This will also help when possibilities for financing the treatment are considered (see Chapter 12).

Depending on the source the used water can be treated differently. Here we consider three major sources from households:

- Urine,
- Greywater from washing, and
- Blackwater from toilets.

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Urine is an important source of sustainable nutrients and is usually less contaminated than water containing faeces. It is a major contributor to nitrogen, phosphorus and potassium and can be an excellent fertiliser. Urine must be separated from faeces, which can be used for biogas production. Urine can be stored in a tank until it is needed for agriculture; and if it is stored for a sufficiently long time it becomes hygienised and safer for agricultural use (WHO, 2006). Storage space may be available in remote areas but more difficult to come by in urban or peri-urban areas. A storage tank will need pumping capacity and the maintenance demand should not be underestimated (Tilley, 2013).

Greywater is often a source of many pollutants, an overview of which is presented by Friedler *et al.* (2013). High concentrations of organic substances come from the kitchen sink. Typical components are food residues, oils and fats, detergents and drain cleaners. Greywater from washing usually contains shampoos, soaps, preservatives and dyes. The water may also contain some heavy metals like zinc and copper from in-house plumbing.

Faeces and blackwater contain high concentrations of organic matter and are useful sources of bioenergy. Anaerobic treatment is a method of extracting the inherent energy and producing biogas. Particular attention should, however, be paid to hygiene; pathogens must be reduced or eliminated.

Naturally, separating the used water into different categories for separate treatment increases the complexity of the process but it is an important way to save precious water resources.

7.2 TREATMENT OF USED WATER

Today there is a wide spectrum of methods and processes available for small-scale treatment of used water. On top of conventional methods there are treatment technologies developed for specific products. However, not only do technologies have to be implemented, but financing and business models should be considered as well, as pointed out by Tilley (2013). It should be emphasised that no particular technology is necessarily better than another. The key point is the relevance of the technology for the local conditions and how its users are motivated to manage it. Here we describe major technologies that are sufficiently

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simple in design and operation and possibly affordable for low-income people. Primarily, we consider the energy aspect.

7.2.1 Septic tanks

A septic tank consists of a concrete or plastic tank. The design of the tank usually includes two chambers separated by a dividing wall with openings located about midway between the floor and roof of the tank. Used water enters the first chamber where solids will settle. These are anaerobically digested (see below), reducing the volume of solids. The liquid flows through the dividing wall into the second chamber, where further settlement takes place. The excess liquid, now in a relatively clear condition, then drains from the outlet into a septic drain field.

The remaining impurities are trapped and eliminated in the soil, with the excess water eliminated through percolation into the soil, through evaporation and by uptake through the root systems of plants and eventual transpiration, or entering the groundwater or surface water. The required size of the drain field must increase with the volume of used water. On the other hand, if the soil has a higher porosity, the drain field can be smaller compared to a field with lower porosity. The entire septic system can operate by gravity alone. A lift pump will be required for certain places.

Obviously, a septic tank has two major drawbacks: the inherent energy in the organic matter is not used and the effluent water is not reused.

The organic content of the waste is converted to biogas (mainly methane) during anaerobic digestion. The gas will escape into the air, unnecessarily contributing to the greenhouse effect in consideration of the fact that the Global Warming Potential (GWP) of methane is 30–90 times higher than that of CO_2 depending on the considered timescale.

The other drawback is that the effluent water is not reused. Naturally, a septic tank can be considered the first step in a water reuse scheme, but the loss of organic energy is still there. Furthermore, the septic tank must be emptied from the settled sludge, typically every three to five years.

7.2.2 Activated sludge systems

The traditional process for removing organic matter is biological oxidation, which involves microorganisms feeding on the carbon and

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the oxygen in the water. Around half of the organic matter is used for the growth of the microorganisms, in other words to increase their body mass. The other half is converted into carbon dioxide.

Aeration to provide oxygen to microorganisms requires electric energy for a compressor that provides compressed air. This is normally the major part of energy demand for conventional treatment. There are many different treatment schemes using aerobic biological processes. The air is dissolved in the water, supplying the organisms with the necessary amount of oxygen for their metabolism. The oxygen supply has to be sufficiently high to satisfy the microorganisms. However, an excess of aeration will not favour the biological activity; it will only waste aeration energy. So, aeration should find a balance between the biological requirement of oxygen and the need to save energy.

The energy requirement for aeration motivates to replace aerobic (using air) treatment with anaerobic treatment (requiring absence of air, see below). The key motivation to use aerobic treatment is the rate of the biological reaction. In an aerobic treatment the speed is an order of magnitude higher. As a consequence, the plant volume can be smaller, but it implies an energy cost. Therefore, when space is available there is a rationale for replacing aerobic treatment with anaerobic treatment. Even more important: in anaerobic treatment the energy in the organic matter will be converted to biogas that becomes an important energy source.

In conventional systems the influent water contains not only organic matter but also nitrogen that principally arrives at the plant as ammonium NH_4^+ (60–80%). Most nitrogen removal plants will transform the ammonium into free nitrogen that will escape via the water surface. The removal of nitrogen is a slower process than the removal of organic carbon and takes place in two principal stages, nitrification and denitrification. In nitrification ammonium is transformed into nitrate NO_3^- (an oxidation process) and in the denitrification (a reduction process, where no oxygen is allowed) nitrate is reduced to nitrogen gas N_2.

The concentration of dissolved oxygen (DO) governs carbon removal, nitrification and denitrification. In carbon removal and nitrification, the process rate will increase with the oxygen concentration. However, there is a limit to the process rate, and higher DO concentrations will not help the biology but only waste energy for the compressors that aerate the biological reactor. With too little DO microorganisms will

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suffocate and the process rate will be significantly reduced. In extreme cases the organisms will die. The opposite applies to denitrification: the higher the level of dissolved oxygen, the lower the rate.

Aeration typically represents 50% to 60% of a sewage treatment works' energy demand but energy consumption as high as 75% has been reported. This fact explains why aeration control is key to saving energy (Olsson, 2015).

Since urine accounts for most of the nitrogen in used water, urine separation eliminates the need for nitrification and denitrification, as noted in the previous section. It also lowers the energy demand for the organic matter.

Obviously, there are more energy-efficient methods to use in remote areas than the activated sludge process. Electric energy should be used for purposes other than oxidising organic matter. Instead, the inherent energy in organic carbon should be converted to useful energy via anaerobic digestion to produce biogas.

7.2.3 Anaerobic digestion

Simple home- and farm-based anaerobic digestion systems offer the potential for cheap, low-cost energy for cooking and lighting by producing biogas. The organic material that provides the feedstock for the anaerobic digestion may consist of faeces and blackwater, manure from pigs and cows, food residues and agricultural residues. The production of biogas from anaerobic treatment is a key component in resource recovery. The biogas can be converted into energy, for example to provide heat for cooking.

Anaerobic bacteria are some of the oldest forms of life on earth. The same types of anaerobic bacteria that produce natural gas in nature also produce methane in the technical processes. Anaerobic bacteria evolved before the photosynthesis of green plants released large quantities of oxygen into the atmosphere. Anaerobic bacteria break down or "digest" organic material in the absence of oxygen and produce biogas as a waste product. Anaerobic decomposition occurs naturally in swamps, waterlogged soils and rice fields, deep bodies of water and in the digestive systems of termites and large animals.

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In the anaerobic process microorganisms assist the process of organic material conversion that produces the biogas. The processes involved in fermentation are exceedingly complex and are not completely understood. There is an impressive amount of activity going on in anaerobic process research to increase knowledge of the microbiology and the internal mechanisms taking place.

A variety of factors affects the rate of digestion and biogas production. The most important is temperature. Anaerobic bacteria communities can endure temperatures from below freezing to more than 60°C and different species of bacteria thrive in different temperature ranges. At temperatures in the range 35–40°C there are mesophilic bacteria. Some of the bacteria, thermophiles, can survive at temperatures around 50–65°C. Mesophile bacteria are generally more tolerant than thermophiles of changes in environmental conditions. Therefore, mesophilic digestion systems are considered to be more stable than thermophilic ones. However, at increased temperatures the reaction rates are faster and consequently the gas yield is higher. The hydraulic retention time is also shorter. Therefore, smaller reactor volumes are required under thermophilic conditions. At lower temperatures, from 35°C to 0°C, the bacterial activity, and thus biogas production, falls off gradually. Rapid changes of the reactor temperature will upset the bacterial activity; therefore, the digester must be kept at a consistent temperature. The digesters referred to here are in subtropical or tropical regions, so they seldom need extra heating to enable their operation.

Anaerobic digestion (AD) has more advantages than the energy generation via biogas: it has a high capacity to treat slowly degradable substrates at high concentrations and it can efficiently reduce pathogens.

7.2.4 Membrane separation

Membrane separation has been described in Chapters 5.2 and 5.3. With the whole spectrum of membrane processes, it is possible to remove micron-sized particles like microorganisms and suspended solids. A partial or full disinfection can also be achieved. As mentioned in Chapter 5, the membrane technology is compact and provides consistent quality over a range of pollutant loading rates. It depends on energy supply. The main challenge is to maintain a consistent throughput

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capacity even if the product quality is unfailing. Thus, membrane fouling and cleaning are of major importance. A good overview of membrane technology in used water treatment is found in Leslie and Bradford-Hartke (2013).

7.2.5 Disinfection

Disinfection has been described in Chapter 5.4. The aim of any type of sanitation system must be to inactivate or reduce potentially pathogenic organisms. Since a decentralised system often aims at water reuse, for example when greywater is used for personal hygiene, it becomes crucial to reduce the pathogens. As mentioned in Chapter 7.1, there are international guidelines for hygiene in water (WHO, 2006). Stenström (2013) has described major issues in reducing pathogens in water. Storage of urine has been mentioned as an effective way of reducing pathogens. In faecal excreta, on the other hand, a much longer time is needed to reduce the risk of pathogens. The hygienisation depends on the storage time, pH and temperature. The storage time is usually more than a year. Thus, anaerobic treatment is advantageous, both to produce energy and to reduce the pathogens.

7.3 ENERGY ASPECTS

The main operations of used water operations that depend on electric energy are:

- Pumping;
- Aeration;
- Disinfection.

Energy for pumping has been discussed in Chapter 4. Three aspects are essential: the required flow rate, the elevation of the water and the timing of the pumping. The various types of used water may be stored in tanks and can be brought into the tanks mostly by gravity. The timing of when the tanks are to be emptied is not critical, which is helpful when electricity generation is intermittent.

For activated sludge plants the typical energy use in Sweden, Germany and Switzerland is of the order 15–45 *kWh*/person/year, where small plants have the higher specific-energy demand. Aeration

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is the dominating user or electrical energy (Lingsten *et al*., 2011; Balmér, 2010). Assuming the high-end western European energy use of 45 *kWh*, each person would need an average power of 26 W over the year, similar to low-energy light bulbs. As an example, a small activated sludge plant for one household has been in operation in Sweden over the last year (Gillblad, 2018). A power supply of 60 *W* has been more than adequate, since most of this power is used for an UV lamp for disinfection. Compared with other uses the aeration energy requirement is small. However, aeration requires a continuous supply of electric power. This must be considered for solar and wind power supplies, so energy storage is important.

Anaerobic treatment needs very little electric energy, mostly for some mixing of the sludge in the digester. This is an almost negligible energy use compared to other loads.

Membrane separation needs electric power for the compressor delivering the pressure to the membrane process. As noted in Chapter 5.3, the required pressure depends on the pore size of the membranes. For micro- and ultra-filtration, the required pressure is much less than for reverse osmosis, so the necessary electric power input is much lower than for desalination (see Chapter 5.2 and 5.3).

Disinfection using UV lamps is not an expensive energy user, as noted in Chapter 5.4.

7.4 FURTHER READING

There are hundreds of books and a huge literature on used water (or wastewater) treatment. This book does not aim to be a textbook on water reclamation, but here are a few standard references:

Grady *et al*. (2011) give a comprehensive basis for the understanding of biological wastewater treatment.

Metcalf and Eddy (2013) is a widely known standard textbook on wastewater treatment design and Asano *et al*. (2007) is devoted to various methods for water reuse.

Energy use in wastewater treatment is examined in the book Olsson (2015).

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