Decentralised Sanitation and Wastewater Treatment

BGR

BGR
Bundesanstalt für
Geowissenschaften
und Rohstoffe

Federal Institute for Geosciences and Natural Resources
Stilleweg 2, 30655 Hannover, Germany
Coordination Groundwater:
Dr. Wilhelm Struckmeier, E-mail: w.struckmeier@bgr.de
Phone: +49 (0)511 643-2366, Fax: +49 (0)511 643-2304
Author: Torsten Krekeler, E-mail: t.krekeler@bgr.de
Phone: +49 (0)511 643-2759, Fax: +49 (0)511 643-2304
Figures: Ulrich Gersdorf, E-mail: u.gersdorf@bgr.de

Internet: www.bgr.bund.de

Foreword

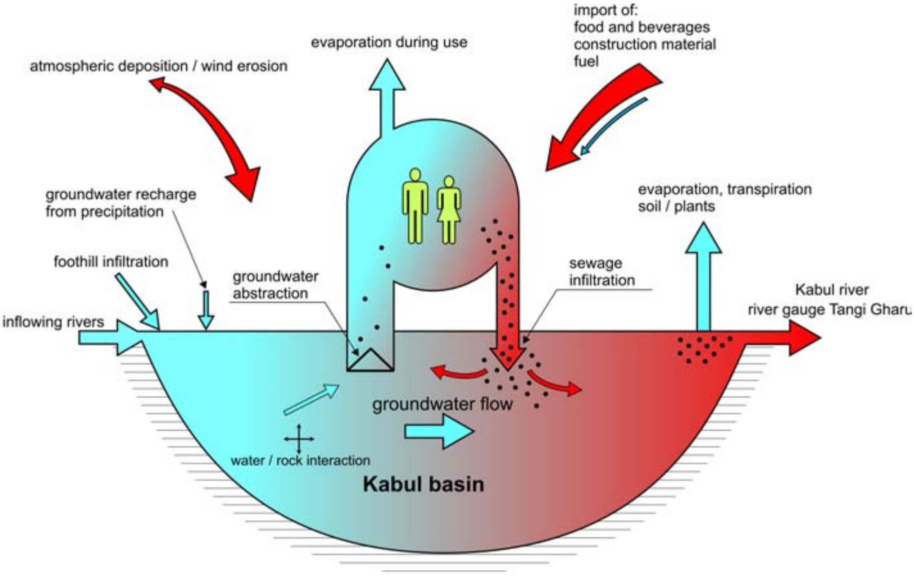
The Federal Institute for Geosciences and Natural Resources (BGR) looks back on a long tradition of geoscientific work in Afghanistan. After a long period of wars ended with the defeat of the Taliban, BGR resumed its work in Afghanistan in 2003.

The new project was carried out on behalf of the Federal Foreign Office of Germany. It included a joint hydrogeological field data campaign. BGR's local partner organisations included:

- Afghan Ministry of Mines and Industries
- Afghan Ministry of Energy and Water
- Kabul University, Faculty of Geosciences
- Kabul Polytechnic University

Groundwater represents the main source for drinking water in the Kabul basin. Only 20% of the population have access to piped water. The rest depends on shallow wells equipped with hand pumps. Several thousands of these wells can therefore be found all over the city. The quality of these wells was tested within the aforementioned field campaign.

The shallow groundwater in the city has received tremendous amounts of pollutants due to a lack of proper wastewater disposal. Most households have a simple cesspit without any further wastewater treatment. Hence, elevated concentrations of faecal bacteria and nutrients can be found in the shallow groundwater. This leads to a serious deterioration of the groundwater resources of the almost closed Kabul aquifer, as outlined in the schematic figure below.



As the infiltration of untreated wastewater has been identified as the main source of pollution for the Kabul groundwater resources, the implementation of adequate sewage treatment systems is considered as the most effective tool for the improvement of human health in Kabul.

The construction of a centralised wastewater treatment system will require several decades and huge amounts of funding. In addition, the operation of such a system requires highly skilled personnel, as well as high investments and a secure power supply. Even if the construction of a sewer network will start within the next years, decentralised solutions will still be necessary at some locations to improve the living standards of the Kabul citizens. Therefore, medium term, decentralised solutions are necessary.

The present brochure provides a collection of common decentralised wastewater treatment systems and their main technical characteristics. The goal of the brochure is to give an overview about these low cost facilities and help to select the most appropriate solution for the immediate improvement of the groundwater quality in the Kabul Basin.

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1 Introduction

Presently, 1.1 billion people lack access to improved water supply and 2.4 billion to improved sanitation. In the vicious poverty/ill-health cycle, inadequate water supply and sanitation are both underlying cause and outcome: invariably, those who lack adequate and affordable water supplies are the poorest in society. [Cit. UNESCO World Water Development Report, 2003]

In 2000, the estimated mortality rate due to water sanitation hygiene-associated diarrhoeas and some other water/sanitation-associated diseases was 2,213,000. The majority of those affected by water-related mortality and morbidity are children under five. The tragedy is that this disease burden is largely preventable. [Cit. UNESCO World Water Development Report, 2003]

The key to protecting drinking water resources and preventing illness are safe and properly adapted sanitary practices.

Complex and highly technical wastewater treatment methods of the kind used in industrial countries are usually not suitable for developing countries. However, a great deal can often be achieved by using less complex measures appropriately adapted to the circumstances.

This brochure provides an overview of the standard wastewater treatment methods using small scale sewage treatment units, as well as sanitary technologies which use no water. The various installations are presented following a description of the constituents of sewage and each of the process steps required to breaking down these undesirable constituents.

The methods presented range from highly technical to close-to-nature and simple sanitation technology options. Obviously, not all of the methods can be adapted for use under all circumstances. The high technical standards of some of the methods are completely out of tune with the conditions prevailing in many developing countries.

2 Dry sanitation

There is a great deal of discussion in many parts of the world about the use of non-flushing toilets. The main advantage is that drinking water is not contaminated by using it as a transport medium for human waste.

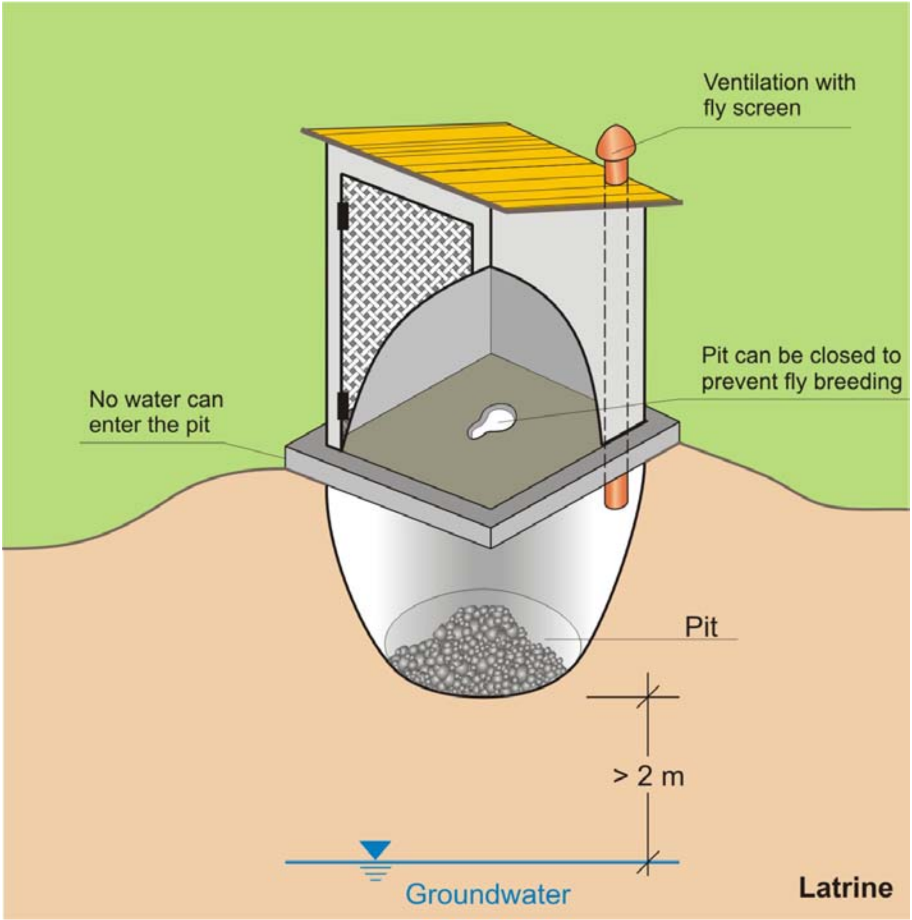
The simplest form of dry toilet is the pit latrine. Other concepts are usually based on the use of dried or composted excrement and of untreated urine in agriculture. Urine contains the highest proportion of nutrients directly absorbable by plants. Faeces contain a large amount of organic carbon and because of their hygienic significance, should always be treated.

The objective of dry sanitation is processing the materials to render them hygienically safe but not to destroy the nutrients.

2.1 Dry toilets: modus operandi

Dry toilets can be divided into three basic types. They all share the same problems of having to remove odours and prevent flies from entering the collecting tanks. It is very important that flies are prevented from coming into contact with faeces and food because this is a common route for the spreading of diseases!

2.1.1 Pit latrine



A pit latrine is a means of directly disposing of faeces within a hole in the ground. When the pit is full, the toilet is moved to a new hole and the old hole is covered up. The faeces in the old hole are broken down by bacteria and soil organisms. In some cases the faeces are removed from the pit.

Unlike the more highly developed methods used in drying and composting toilets, the faeces in latrines are not stored in a closed system. This means that there is a risk that latrines can contaminate groundwater.

Pathogenic germs can be transported by groundwater. Percolating water moves particularly slow in the unsaturated zone. The germs die off in the unsaturated zone during long retention times. The unsaturated zone therefore effectively protects underlying aquifers.

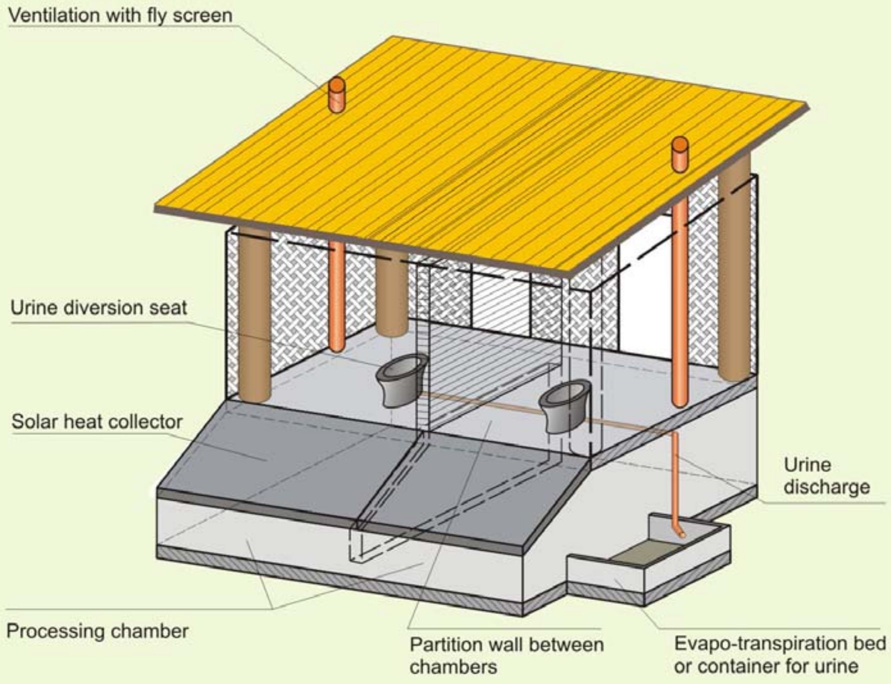
It is very important that no water from external sources be allowed to enter the pit. Less liquid in the pit means less risk of groundwater contamination.

The larger the vertical distance between the base of the pit and the groundwater table the better the protection of the groundwater. For most soil types a minimum distance of 2 m is recommended. (Ch.5, Location Selection)

The horizontal distance between the latrine and a water point should be larger than 15 m. (Ch.5, Location Selection)

In areas with high groundwater levels or areas that are periodically flooded pit latrines are not suitable.

2.1.2 Dehydrating toilets



2-chamber dehydrating toilet

Dehydrating toilets can be installed in yards/gardens just like an old-fashioned latrine. They can also be installed in houses.

Dehydration usually takes place at high temperatures. Good ventilation is required to remove the condensation. Urine and faeces are usually separated. To ensure the separation, toilet seats have built-in urine separators as shown in the figure.

Source: Öko-Energie

The processing chamber can be fitted with a flap which opens when someone sits on the toilet seat.

The processing chamber and the way the urine is collected separately have any number of shapes and designs. They are dependent on various factors such as the type of soil and regional differences.

Unlike composting toilets which are usually purchased as ready-made plastic toilets, dehydrating toilets usually come in the form of brick-built or wooden structures constructed by the owners on site.

Generally it makes sense for the processing chambers to be so large that they enable complete drying that the contents can be directly spread on fields as fertilisers without any additional intermediate storage.

The *Gopuri* toilet developed in India is based on this concept as well as the *EcoSan* (Ecological Sanitation) concept which originated in Ethiopia. It involves a two-chamber system for drying, storage and sterilisation. The chambers are used alternately following an annual cycle.

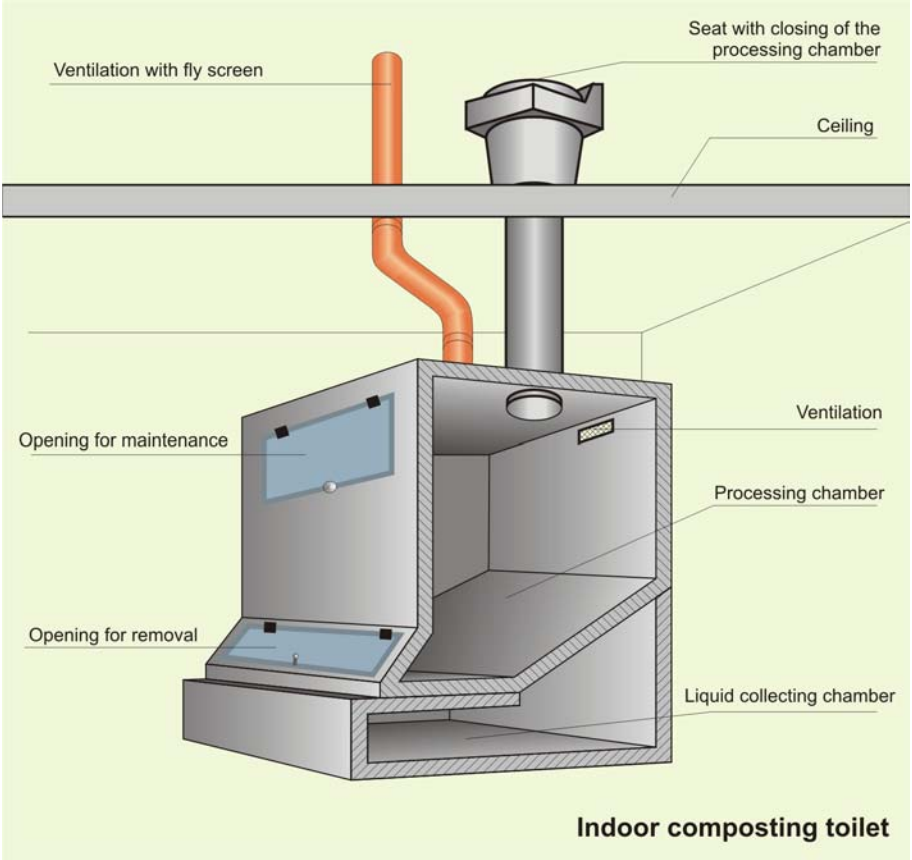
The name *EcoSan* is now used by many of the players involved in development work as the general term for dry sanitation methods.

The system depends on maintaining dry conditions in the collecting tank and therefore requires complete separation of all liquids.

The flap to extract the dried faeces faces the sunny side and is painted black to enhance drying.

Structural improvers and drying agents such as wood shavings or ash are regularly added to the processing chamber. Combustion is also possible in addition to using the dried faeces for fertiliser.

2.1.3 Composting toilets



Composting is the aerobic decomposition of organic matter by microorganisms and worms. The end products are carbon dioxide, water, heat and humus.

Composting can be divided up into three phases:

- Mesophile phase: lasts a few days, temperature 20 – 40°C
- Thermophile phase: lasts days to months, temperature 40 – 70°C
- Cooling down over several months

[Kunst, 2002]

The temperature in compost containers should always be more than 15°C. Many microorganisms are killed by temperatures exceeding 65°C. This slows down the decomposition process which means that cooling may be necessary to prevent this temperature being reached. The moisture content should ideally be 50 – 60 %. [Kunst, 2002]

Urine is only rarely separated out prior to composting.

Compost toilets can either be built on site or purchased in pre-fabricated form. Many products are also suitable for installing inside houses. The Swedish-built *Clivius Multirum* toilet is widely used in North European holiday cottages. This toilet contains a single compost container for faeces, urine and organic kitchen waste.

A general recommendation is to add structural material such as vegetable left-overs, straw or wood shavings. The compost container requires a suitable sealing system.

Composting in a new compost container can be speeded up by adding humus and possibly also earthworms. Compost containers should never be completely emptied because this means that the useful composting organisms are also removed.

2.2 Construction of standard dry toilets

There are countless different dry toilet systems which are sometimes also based on a combination of drying and composting. The many different systems available open up a whole range of applications, end products and properties.

The following table summarises the most common models and their most important properties. This list only includes a selection of available common products. Dry toilets can be constructed in any number of different designs to comply with the particular specifications in each case.

Dehydrating toilets	**Properties**
Dry Ecological Toilet (Mexico)	2 chambers Seat with urine separation Pre-fabricated seat, the rest built on site Approx. € 150/unit Successfully used in various climatic zones
Vietnamese Dry Toilet	2 chambers No seat: 2 holes in the floor for squatting Urine separation: urine in container or percolating 2-3 steps high Addition of ash, soil or lime to improve drying Separate disposal of toilet paper Wooden lid above collecting tank When full, covered with earth and sealed with mud Needs to be emptied after 2 months
DAFF (Guatemala)	2 chambers Seat with urine separation: urine in a tank Pre-fabricated seat, the rest built on site Addition of ash, soil or lime to improve drying The lid of the drying chamber is outside Retention time: 10 – 12 months € 40 – 100/unit Good results in the slums of El Salvador
Urine Diversion Dry Toilet (South Africa)	1 chamber with 2 containers Seat with urine separation: urine percolates into the ground When first container is full, seal and use second Add ash for drying, No aeration or ventilation
EcoSan (Ethiopia)	2 chambers Urine separation with collecting container Built completely on site Add ash, soil, leaves, grass or saw dust Alternating use of both chambers Retention time: approx. 1 year, Approx. € 100/unit

Single Chamber Dehydrating Toilet (Yemen)	In-house toilet Urine separation: 2 downpipes: urine pipe outside, faeces pipe inside the house walls (several floors) Urine and grey water evaporate in the pipe, the rest percolates into the ground Dry faeces collected and used as fuel Hot dry climate speeds up drying
Tecpan Solar Heated Toilet (El Salvador)	1 chamber Solar heating Many pre-fabricated components, or as a complete system Added ash, soil or lime Mix up layers after 1-2 weeks Remove odourless dried faeces after 2-3 months
Two Chamber Solar Heated Composting Toilet (Ecuador)	2 chambers No urine separation. Fast evaporation at high altitude Addition of saw dust or ash Ventilation in each chamber Seat, lid and ventilation pre-fabricated, remainder built on site
Ecological Sanitary Unit (Mexico)	2 chambers Urine separation and percolation into the ground Completely fabricated in HDPE Separate toilet paper disposal Add ash, soil and lime in equal proportions to 0.5 kg/(Capita · day) Higher pH by adding lime: good at killing germs bad for crops

Composting toilets	**Properties**
Clivius Multirum (Sweden)	1 chamber for toilet and kitchen waste No urine separation, Pipe for ventilation Completely pre-fabricated Suitable for cellar installation Add peat and humus before using for the first time Approx. 10 – 30 l compost produced per capita per year Emptied once per year
Sirdo Seco (Mexico)	2 chambers No urine separation, with solar heating Combination of drying and composting unit Moisture 40 – 60 % Temperature up to 70°C Completely pre-fabricated Composting takes approx. 6 months Emptying once per year
Carousel Toilet (Pacific Islands)	4 chambers consisting of fibre glass tanks Rotates around an axle (carousel) so that when one chamber is full, the next empty one can be rotated into place Electrical ventilation for drying Gravel drainage Tanks full after two years, contents can be used as fertiliser Aerobic operation requires addition of organic material, e.g. leaves or coconut fibres System requires very hot conditions

[Esrey, 1998 / Winblad, 2004 / Peasey, 2000]

2.3 Destruction of pathogenic germs

The following factors have an effect on the survival of pathogenic germs:

Temperature	Rapid destruction at high temperatures (> 40°C) Strong multiplication at warm to moderate temperatures Inhibited multiplication but lengthy survival at low temperatures (< 5°C)
pH	High pHs deactivate microorganisms Very rapid sterilisation at pH > 12 Sterilisation takes approx. 6 months at pH > 9
NH_3	Ammonia leads to the deactivation of microorganisms
Dryness	Moisture supports the survival of pathogens; most germs die off when dry.
Sunlight	The survival times of microorganisms is reduced when exposed to sunlight because they are sensitive to UV radiation.
Other micro-organisms	Different types of microorganisms compete and displace one another. Higher microorganisms eat lower microorganisms
Nutrient deficiency	Intestinal bacteria are adapted to cope with the nutrient excess, shortages of nutrients reduce their reproduction rates and considerably lower their chances of survival
Oxygen	Many pathogenic germs are anaerobic and are therefore displaced by other organisms in an aerobic environment.

[Esrey, 1998 / Winblad, 2004]

2.3.1 Dehydrating

Dehydration kills off most of the germs but some more resistant germs can survive for long periods of time. Disinfection is primarily dependent on the pH and the drying time. Higher pH enhances disinfection by killing off bacteria. It is therefore beneficial to add lime or ash. [Peasey, 2000]

2.3.2 Composting

All of the pathogenic germs are killed off at 50 – 60°C within a few days during composting. This process only takes a few hours at 70°C. However, high temperatures also kill off the composting worms and bacteria. [Kunst, 2004]

Composting toilets are more vulnerable to fly breeding than dehydrating toilets.

[Esrey et al. 1998] describes in detail the different designs and conditions required for a waterless sanitary installation. A summary of various studies looking into hygiene and dry toilets is available in [Peasey, 2000].

3 Wastewater

Water which has been used and discharged is called wastewater or sewage. This brochure describes domestic sewage and its treatment/purification in small-scale decentralised treatment plants. In many developing countries, domestic sewage still accounts for most of the wastewater generated, particularly in small to medium-sized towns.

Domestic wastewater consists of the following:

	Grey water bath/kitchen	**Urine**	**Faeces**
Volume [l/(cap. · a)]	25,000 – 100,000	500	50
Nitrogen	3 %	87 %	10 %
Phosphorous	10 %	50 %	40 %
Potassium	34 %	54 %	12 %
COD	40 %	10 %	50 %

Source: Geigy, Scientific tables Basel, volume 2. Fitschen and Hahn 1998

Industrial and commercial effluent has a different composition and therefore in some cases needs completely different treatment to domestic wastewater.

3.1 Constituents

3.1.1 Organic load / nutrients

3.1.1.1 Carbon C

Entry: Organically bound in vegetable and animal matter, measured as TOC (Total Organic Carbon), DOC (Dissolved Organic Carbon), inorganic in the form of CO_2, HCO_3^-

Carbon concentrations are generally reported indirectly via the amount of oxygen required for oxidation (cf. COD). The German wastewater ordinance now includes a correlation factor to give a measure of the total amount of organic carbon: TOC / COD = 4.

3.1.1.2 Nitrogen N

Entry: Particularly from urea and protein

Nitrogen is usually quoted as Total-N or as Kjeldahl-N the latter represents the sum of organically bound nitrogen and ammonium-nitrogen.

Conversion products: NH_3, NO_2^-, NO_3^-

Concentration (Kjeldahl-N): One inhabitant generates maximum 12 g nitrogen per day. Assuming a water consumption of 150 l/d, this gives a concentration of 80 mg/l in untreated sewage. This figure often reaches up to 200 mg/l in rural areas. [Veenstra, et al. 1997]

3.1.1.3 Phosphorous P

Entry: From detergents and excrement, as PO_4^{3-}

Concentration: max. 2.5 g phosphorous per capita per day. With an average water consumption of 150 l/d this corresponds to a concentration of 17 mg/l, the concentrations in rural areas reaches up to 50 mg/l. [Veenstra, et al. 1997]

Sewage also contains nutrient salts in the form of K^+, Ca^{2+}, Fe^{2+}, Fe^{3+}..., and trace elements.

3.1.2 Toxic substances

Toxins have a negative effect on microorganisms and are toxic to living things in water. They should not be present in domestic sewage. Intermediate products (metabolites) can be formed at certain stages of breakdown during the biochemical treatment of wastewater constituents. These metabolites can be more toxic than the original substances.

Metabolites are formed from many new pesticides and are suspected of being carcinogenic. [University Bremen, 2000]

3.1.3 Disruptive materials

Disruptive materials include sand, oil and corrosive substances which disrupt the breakdown processes.

3.1.4 Hygienic parameters

Bacteria, viruses, protozoa and worms can spread diseases and cause epidemics. Indicator: Coli bacteria.

3.2 Wastewater evaluation parameters

3.2.1 Biochemical oxygen demand $BOD_{5(20)}$

BOD is the summation parameter for the concentration of organic substances which are biologically degradable.

$BOD_{5(20)}$ describes the oxygen required over 5 days at a temperature of 20°C to oxidise the organic constituents of sewage. It consists of four sub-reactions: [Hosang/Bischof, 1998]

- Substrate respiration of the bacteria during the physiological utilisation of the dissolved organic substance
- Endogenic internal respiration of the bacteria at the end of substrate respiration
- Respiration by higher microorganisms (bacteriophages)
- Respiration by nitrifiers

Amount: A BOD of up to 60 g is generated every day by each inhabitant. This means that the concentration in untreated sewage corresponding to a water consumption of approx. 150 l/d is approx. 400 mg/l. In rural areas where water is scarce, BOD can be up to 1000 mg/l. [Veenstra, et al. 1997]

3.2.2 Chemical oxygen demand COD

The chemical oxygen demand is the amount of oxygen required to oxidise all of the oxidisable constituents including those which are not biologically degradable. This figure is therefore always higher than the BOD.

Amount: The maximum COD per capita is 120 g per day. The concentration in untreated sewage corresponding to a daily water consumption of 150 l is therefore approx. 800 mg/l. In rural areas where water is scarce, the figure can rise to approx. 2500 mg/l. [Veenstra, et al. 1997]

3.2.3 Total suspended solids TSS

TSS is the summation parameter for dispersed solids in the sewage. High amounts of suspended solids cause problems in open water bodies by increasing the turbidity, reducing the available light for light depending organisms.

Concentration: The specific production per capita amounts to 40 - 80 g/d. [Veenstra et al. 1997] Assuming a daily water consumption of 150 l, the concentration in untreated wastewater is 250 - 550 mg/l.

3.2.4 Ammonium NH_4^+-N

The conversion of ammonium to nitrate is the first step in the nitrogen elimination chain. A high ammonium concentration in the sewage plant discharge indicates that nitrification is not functioning properly. This may be attributable to high levels of organic load in the plant (only organic carbon is oxidised) and also the faulty aeration and bad mixing and thus poor oxygen availability.

The non-toxic ammonium NH_4^+ and the toxic ammonia NH_3 are in equilibrium with one another.

$$pH7: \frac{NH_4^+}{NH_3} = \frac{99}{1} \qquad pH9: \frac{NH_4^+}{NH_3} = \frac{70}{30}$$

3.2.5 Nitrate NO_3^--N

Water discharged from a sewage treatment works usually contains more nitrate than the inflowing water because untreated sewage contains very little nitrate. High nitrate concentrations in the discharge primarily indicate a high level of oxygen availability in the system and properly functioning nitrification. In addition, high nitrate concentrations in the discharge indicate that little denitrification is taking place.

The parameters NH_4^+-N and NO_3^--N must always be considered in relation to one another. If for instance there are very small amounts of NO_3^- in the discharge from a treatment plant, this could either mean properly functioning denitrification or very poorly functioning nitrification.

4 Wastewater treatment

4.1 The objective of wastewater treatment

When wastewater engineering was first implemented, it was limited to transporting contaminated water out of cities. This simple but inadequate solution had the goal of protecting the urban inhabitants from the epidemics which proliferated in European cities in the previous centuries and claimed many lives.

The focus of wastewater treatment in most industrial countries today is the elimination of nutrients. The objective is to protect surface water and groundwater.

If sewage is to be used for irrigation, the main aim of wastewater treatment is to eliminate pathogenic germs. The nutrients are welcomed in the sewage in this case and used to fertilise the crops.

4.2 Quality of treated wastewater

The quality of the treated sewage is often related to its expected use. Typical treated effluent standards applied in many countries are given in the following table.

Typical discharge standards in many countries

Parameter	**Discharge in surface water**		**Discharge in sensitive water**	**Use in irrigation or aquaculture**
	High quality	Low quality		
BOD [mg/l]	20	50	10	100
TSS [mg/l]	20	50	10	<50
Kjeldahl-N [mg/l]	10	-	5	-
Total N [mg/l]	-	-	10	-
Total P [mg/l]	1	-	0.1	-
Faecal coliforms [No./100ml]	-	-	-	<1000
Nematode eggs/l	-	-	-	<1
Total dissolved solids (salts) [mg/l]	-	-	-	<500

[Veenstra et al. 1997]

In Germany, the decomposition capacities of treatment plants have to comply with its dimension, measured as connected inhabitants. The larger the plant, the higher the decomposition capacity must be.

Maximum load of effluent from treatment plants in Germany [mg/l]

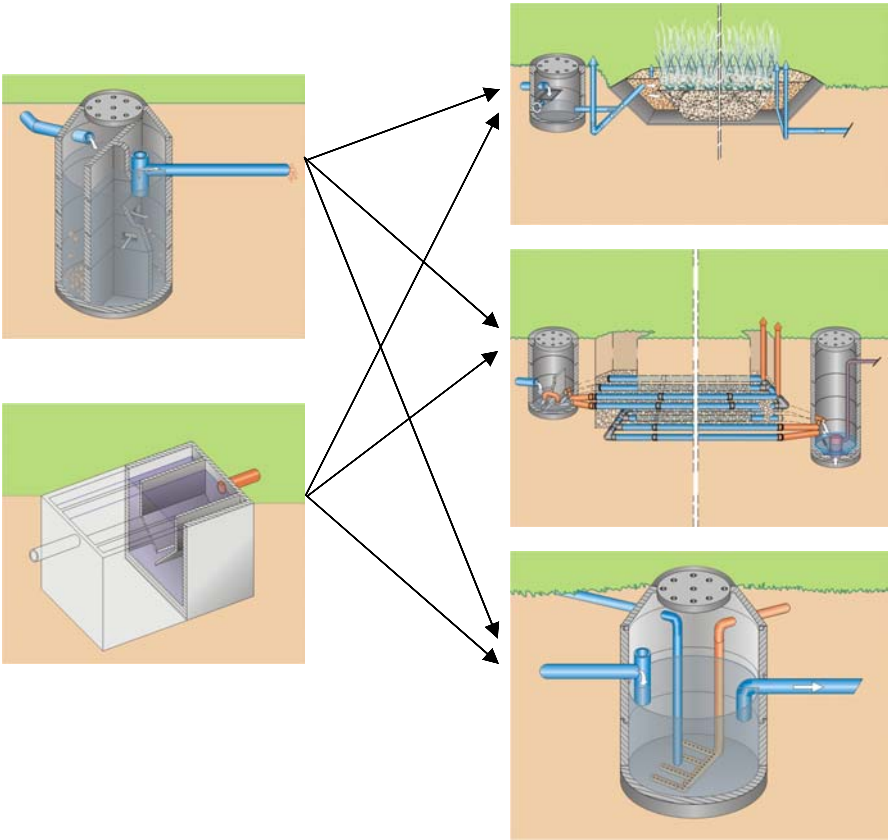
Inhabitants	**BOD_5**	**COD**	**NH_4-N**	**Total N**	**Total P**
< 1,000	40	150	-	-	-
1,000 - 5,000	25	110	-	-	-
5,000 - 10,000	20	90	10	-	-
10,000 - 100,000	20	90	10	18	2
> 100,000	15	75	10	18	1
Input	*400*	*800*	*80*	*80*	*17*

[BGBI. Abwasserverordnung, 2002]

4.3 General wastewater treatment concept

Various processes take place in special reactors, chambers or stages:

1. Separating out solids and suspended substances
   → Primary (mechanical) wastewater treatment
2. Breakdown of dissolved organic sewage constituents by microorganisms
   → Secondary (biological) wastewater treatment



1. Primary treatment

2. Secondary treatment

As shown in a few typical installations in the figure, different types of reactors can be combined with one another. All of the arrangements follow a common principle: the first step in the treatment of the sewage is to slow down its movement to enable the mechanical separation of coarse constituents before the sewage pre-treated in this way is fed into a reactor for secondary treatment.

If microorganisms are artificially kept in suspension (e.g. by an aeration system) a final settling chamber is necessary to enable them to settle out.

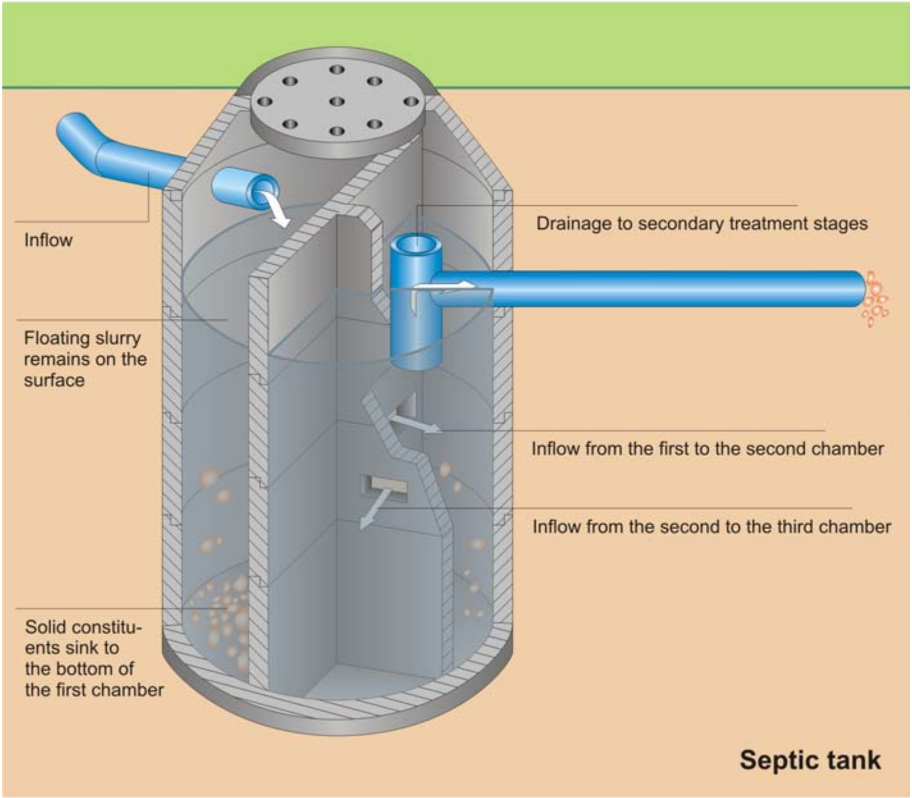
The treatment process must be considered as the sum of the mechanical and biological processes taking place in each reactor.

The installations are used for a wide range of sewage volumes: very small sewage treatment plants can be used to treat the wastewater from single buildings, while much larger treatment plants can accommodate the effluent from whole city districts.

4.4 Primary wastewater treatment (mechanical)

Primary wastewater treatment is the first step in the treatment process. The aim of this stage is to separate out from the sewage the heavy constituents (suspended solids) and the particularly light constituents (floating solids). Movement of the sewage is reduced to a minimum to enable the solids to settle out. This is conducted in small-scale treatment plants via septic tanks or digestion tanks, Imhoff tanks, or settling ponds.

4.4.1 Septic tank



[Münster, 2002]

Septic tanks (or multi-chamber settling tanks) involve a varying number of chambers. In two-chamber tanks, the first tank must hold 2/3 of the total working volume. In three-chamber and four-chamber tanks, the first tank must hold 1/2 of the total working volume. [Finke, 2001]

The working volume of septic tanks is calculated on the basis of ≥ 300 l/capita, the minimum total working volume is 3 m^3. [DIN 4261]

A BOD reduction of 30 – 35 % can be achieved by settling the slurry in a septic tank. [University Bremen, 2000]

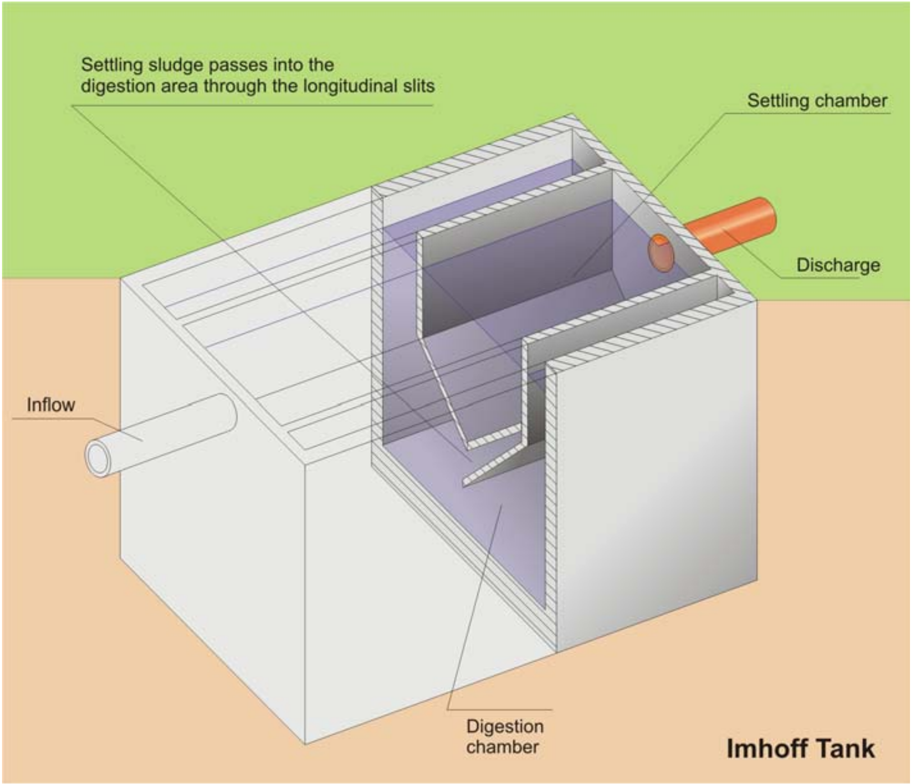
Larger tanks can also be constructed as multi-chamber digestion tanks. The latter serve two purposes: removing suspended solids and floating solids, and the partial decomposition of organic constituents.

The working volume is calculated at ≥ 1500 l/capita, and the minimum total working volume is 6 m^3. [DIN 4261]

A BOD reduction of 30 – 50 % can be achieved merely by settling and biological decomposition in a multi-chamber digestion tank. [University Bremen, 2000]

The primary sludge from a septic tank must be disposed of as required, around once a year.

4.4.2 Imhoff tank



The Imhoff tank is a special form of multi-chamber tank. This method was patented as long ago as 1906. Because Imhoff tanks are not modern technology, no standard design method can be quoted. However, because of its major international significance, this method is briefly described here.

The volume of the settling chamber should correspond to at least 50 l/capita. The volume of the sludge digestion chamber should be at least 120 l/capita. [Sasse, 1998]

Wastewater flows through the settling chamber horizontally. This is underlain by a digestion chamber. The floor of the settling chamber is conical (45°) and has slits at the base. These slits are the boundary between the settling chamber and the digestion chamber. Sludge that settles out passes through these longitudinal slits in the roof of the digestion chamber where it becomes compacted and digested. The digestion time is approx. 3 months. The BOD breakdown rate is 25 – 50 %. [Sasse, 1998]

The displaced sludge water in this design is filtered by the newly settled sludge at the base of the settling chamber. This filters out the floating sludge flakes. The simple construction of the Imhoff tank and the low operating costs very quickly made it popular around the world. [University of Bremen, 2000]

The large height of the tank is a significant disadvantage of the system.

4.4.3 Settling pond

Settling ponds are used to separate out the suspended constituents in wastewater which can settle out. The sludge which settles out is then digested. The dimensions are calculated using the formula ≥ 500 l/capita. The depth of the settling and sludge zone should be ≥ 1.5 m.

The BOD reduction in settling ponds amounts to 20 – 50 %, or less at lower temperatures. [University of Bremen, 2000]

The base of settling ponds should be sealed if the soil has a permeability of $k \geq 10^{-8}$ m/s. Settling ponds create an odour nuisance and need to be securely fenced in. [Finke, 2001]

The inflows and outflows need to be cleaned every year and the depth of the sludge needs to be measured. When the height of the sludge reaches ¼ of the original water depth, it needs to be removed.

The following general rules apply to primary sludge (sludge from a mechanical stage): **The sludge stinks, is unhygienic and contains high levels of organic material**. The sludge must always be treated. Sludge basins can be used for digestion of the organic matter. The digested sludge can usually be spread on fields as fertiliser.

4.5 Secondary wastewater treatment (biological)

Wastewater contains microorganisms which feed on the nutrients in the sewage and thus reduce its nutrient level.

The living conditions of the microorganisms are maintained at the optimum level in biological wastewater treatment plants to maximise the microorganism population and boost the decomposition capacity.

Organic carbon directly depletes the amount of oxygen in water (main proportion of BOD). Other nutrients such as phosphorous and nitrogen promote plant growth (eutrophication) and thus give rise to secondary oxygen depletion.

The primary biological process which takes place is the elimination of organic carbon by bacteria.

Advanced effluent treatment involve the oxidation of ammonium to form nitrate (nitrification) and its subsequent reduction to molecular nitrogen (denitrification) – which leaves the treatment plant in the form of gas.

Simple, decentralised systems are usually not designed for the removal of ammonium and nitrate.

4.5.1 The process steps

4.5.1.1 Carbon elimination

The breakdown of carbon is extremely complex. Carbon exists in numerous organic compounds which can be removed from wastewater by aerobic, anoxic and anaerobic processes.

As an example, the following shows the breakdown of glucose in extremely simplified form which takes place under the following conditions:

- Aerobic respiration: $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
- Anoxic respiration: $C_6H_{12}O_6 + 4\ NO_3 \rightarrow 6\ CO_2 + 6\ H_2O + 2\ N_2$
- Anaerobic fermentation: $C_6H_{12}O_6 \rightarrow 3\ CH_4 + 3\ CO_2$

Organic substances are most extensively broken down during aerobic respiration. This process is also the one that takes place fastest. [Sasse, 1998] Anoxic respiration plays the crucial role in nitrate reduction (denitrification). Anaerobic processes are generally associated with major odour nuisances. However, anaerobic decomposition processes also generate methane which can be used as an energy source.

4.5.1.2 Nitrification

Nitrification is the conversion of ammonium to nitrate. It is carried out in surface water and during biological wastewater treatment by nitrifying bacteria.

Nitrification: NH_4^+ (nitrosomonas + free O_2) NO_2^- (nitrobacter + free O_2) NO_3^-

aerobic

The ammonium oxidisers (nitrosomonas) convert ammonium into nitrite by bacterial oxidation. The nitrite oxidisers (nitrobacter) oxidise the nitrite formed in this way to convert it to nitrate. Ammonium and nitrate are electron donors.

Additional oxygen must be added to support the nitrification process.

Nitrification is dependent on various aspects including:

Temperature	Optimum between 28 – 36°C, nitrification is slowed down at temperatures below 12°C and stops at temperatures below 8°C
Dissolved oxygen	≥ 2 mg/l is necessary for nitrification
pH	Optimal pH between 7.5 and 8.3
Organic load	Treatment plants with high organic loads only oxidise carbon
Relevant substrate concentration	Higher concentrations of ammonium and nitrite lead to higher degradation rates
Potential inhibitors	Can impede nitrification
Contact time	The longer the contact time between nitrifying biomass and wastewater is the higher is the decomposition

[University of Bremen, 2000]

4.5.1.3 Denitrification

Denitrification means the ability of microorganisms to reduce nitrate to molecular nitrogen. This process only takes place if there is no free oxygen available in the water (anoxic).

Denitrification:

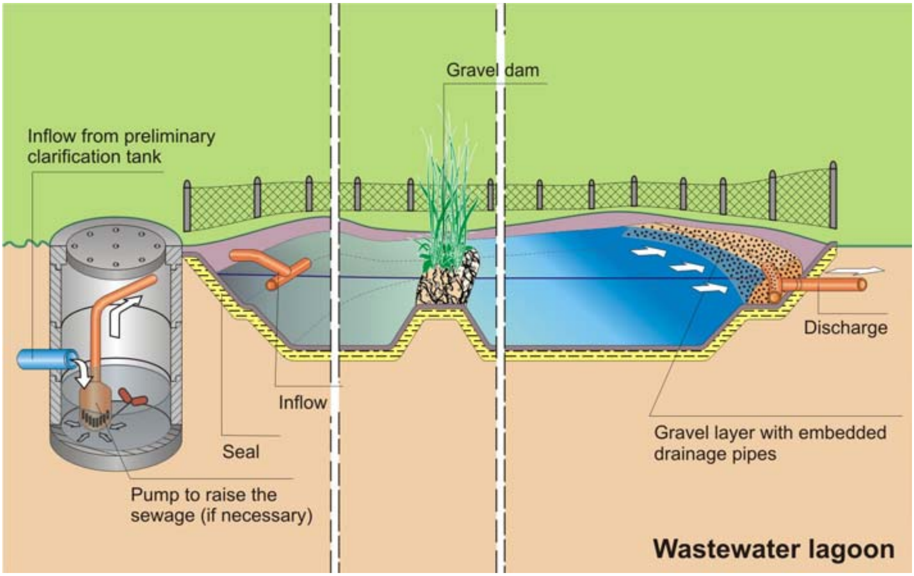
NO_3^- (no free O_2, only from NO_3^-) NO_2^- (no free O_2, only from NO_3) N_2

anoxic

Denitrifiers can only break down nitrate to molecular nitrogen in the presence of organically-bound carbon which acts as an electron donor. This relationship is expressed in the ratio of BOD_5 to nitrate concentration which should be around 4:1 for nitrification. If there is an inadequate amount of dissolved organic carbon in the wastewater, i.e. low BOD_5 levels, decomposition can stop early at an intermediate stage. This can cause the accumulation of nitrate or nitrous oxide. This is undesirable. It is therefore important that the denitrifiers always have an adequate supply of carbon. [University of Bremen, 2000]

4.5.2 Methods without artificial aeration

4.5.2.1 Wastewater lagoon / stabilisation pond



[Münster, 2002]

The sewage must be pre-treated in a settling pond or a septic tank.

Different kinds of wastewater lagoons are common:

- facultative ponds
- aerated ponds
- anaerobic ponds

In facultative ponds oxygen is taken up at the surface. Near the ground anaerobic conditions prevail. Aerated ponds have technical equipment to artificially aerate the wastewater. Anaerobic ponds are deeper (2- 6 m) than the aerated and facultative ponds.

A wastewater lagoon usually consists of different zones: a small preliminary pond and one or more larger main ponds. These zones can be separated from one another by gravel dams. The preliminary pond holds back suspended solids.

The ground in which the wastewater lagoons are constructed, should have a permeability (k-value) of $\leq 10^{-8}$ m/s. Ground with higher permeabilities needs to be sealed off with impermeable sheeting which is then covered with sand.

Typical inflow and outflow values for wastewater lagoons [Kunst, 2002]

	COD [mg/l]	**NH_4^+-N [mg/l]**	**NO_3^--N [mg/l]**
Inflow	400	70	0
Outflow	80	15	5

Unaerated wastewater lagoons are essentially simple and fairly natural treatment methods. On sites with inadequate natural gradients, a pump is required to lift the wastewater from the pre-clarification unit. Operating and maintenance costs are generally low. Wastewater lagoons are very important in developing countries. This is due to their simplicity and low energy and capital investment costs, as well as their high degree of suitability even under the climatic conditions existing in hot countries.

The biological processes taking place in wastewater lagoons are temperature-dependent. Because of its large surface area, the external temperature has a significant effect on the ponds. Wastewater lagoons are therefore unsuitable for locations exposed to large temperature fluctuations. A drawback of this method in urban areas is the large amount of space required and the non-optimal hygienic conditions – insects multiply in wastewater lagoons and can therefore spread diseases and cause epidemics.

The size of unaerated wastewater lagoons is calculated on the basis of 10 – 20 m^2/capita. The water depth is approx. 1 m and the retention time at least 20 days.

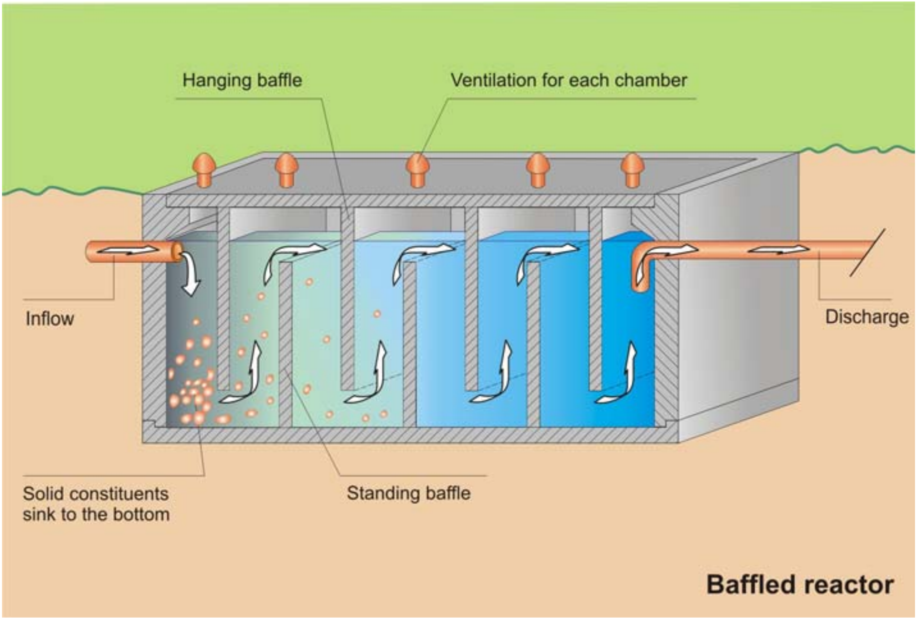
Particularly for wastewater to be reused for irrigation, stabilisation ponds are the most common technology. Retention times of 20 - 30 days are necessary to provide satisfactory pathogen removal. [Veenstra et al. 1997]

Past experience shows that the sludge only needs to be removed once every ten years. [Finke, 2001]

An often successful practised variation of wastewater lagoons is duckweed based sewage treatment. A description of some alternative systems can be found in [UNEP, 2004]

A detailed description of wastewater lagoons of all types, as well as size calculations and instructions for computer-supported dimensioning can be found in [Sasse, 1998].

4.5.2.2 Anaerobic Baffled reactor



A baffled reactor combines mechanical separation and biological degradation in one tank. No additional pre-treatment tank is necessary.

Anaerobic baffled reactors (ABR) consist of several chambers acting as settling and digestion tanks. The inflow is forced through the sludge which settles at the base of the tank to come into contact with the biologically active bacteria. Baffled reactors usually have at least four chambers. The treatment capacity increases with the number of chambers.

Baffled reactors are simple to construct and operate. Another advantage is their relatively small size. This system also requires no electricity. The wastewater constituents are broken down anaerobically.

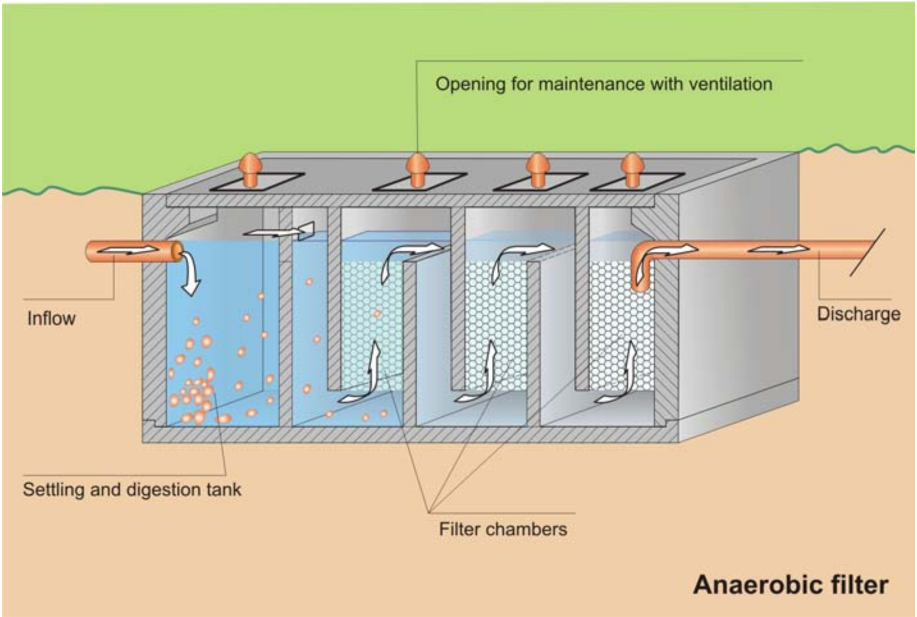
The treatment capacity lies between 70 to 90 % BOD decomposition according to [Sasse, 1998].

The space required for a baffled reactor for 8 persons is < 5 m^2. Calculating the size of the reactor is based on the maximum up-flow velocity of approx. 1.4 m/h [Sasse, 1998] and the retention time of the wastewater in the reactor of 40 h [Foxon, 2005].

Clearing out the sludge which collects in the reactor is only required at very long intervals. The retention time can be 5 to 10 years as long as no paper or other poorly digestible material enters the plant. [Foxon, 2005]

A detailed description of baffled reactors including size calculation formulae and instructions on computer-supported dimensioning are found in [Sasse, 1998].

4.5.2.3 Anaerobic filter



An anaerobic filter plant requires an appropriately large digestion chamber to treat the wastewater before entering the anaerobic filter to prevent the pore spaces from being blocked.

Anaerobic filters basically have a similar construction to the fixed-bed reactors described earlier. The difference is that this system is operated anaerobically and therefore requires no aeration equipment.

The anaerobic filters are designed to also be capable of breaking down dissolved and permanently suspended materials. The microorganisms are encouraged to colonise the filter medium and form a biological film.

Anaerobic filters are designed for downflow or for upflow operation. The filter material consists of gravel, coarse gravel or slag with diameters of 5 - 15 cm. This lies above a perforated concrete slab. A 50 – 60 cm gap is required between the concrete slab and the floor of the tank for the sludge to settle.

The treatment capacity lies between 70 to 90 % BOD decomposition. [Sasse, 1998]

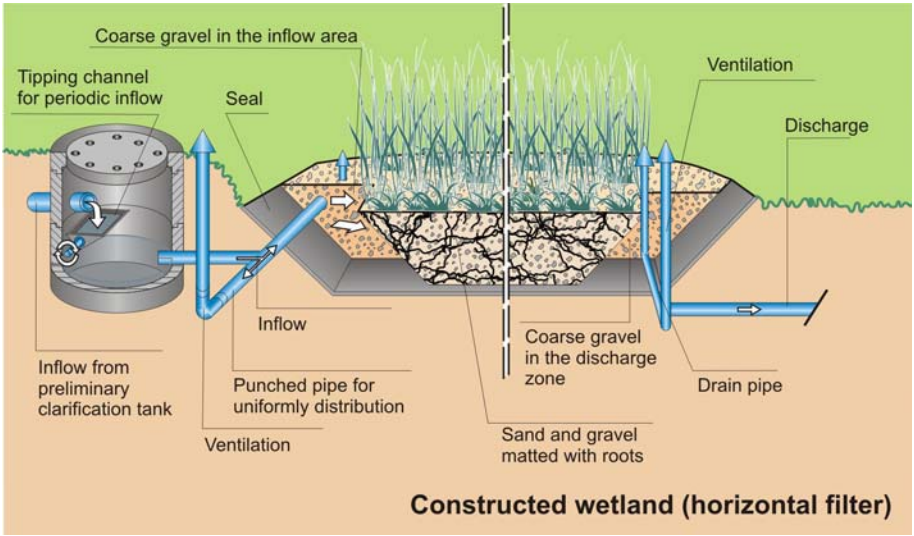
The size of anaerobic filters is calculated based on approx. 0.5 m^3/capita which means that a plant treating the wastewater from 8 people takes up < 10 m^2.

Anaerobic filter systems are simple to operate. However, construction of the perforated concrete slabs can be relatively expensive.

The sludge only needs to be removed once a year at most. The filters also need to be flushed clean if required.

A detailed description of anaerobic filters including details on how to calculate the size of the plant and instructions on computer-supported dimensioning are found in [Sasse, 1998].

4.5.2.4 Constructed wetland



[Münster, 2002]

Mechanical pre-treatment of the wastewater is required (settling tank adequate, digestion tank recommended).

Aeration is improved by the pulsed inflow of wastewater. Long periods with high water levels should be avoided. There are two different types of plants with different sewage flow directions: horizontal filters and vertical filters. The figure above shows a horizontal filter plant.

The space required for a horizontal filter plant is calculated on the basis of ≥ 5 m^2/capita. The total area must be at least 20 m^2. Vertical filter plants only require ≥ 2.5 m^2/capita. The total area of the plant must be at least 10 m^2. [Finke, 2001]

A horizontal filter plant for the sewage of 8 persons occupies around 40 m². [Pabst/Flasche]

The filter medium should have the following soil parameters [Finke, 2001]

k-value:	$10^{-4} - 10^{-3}$ m/s
U: d_{60}/d_{10}	≤ 5
d_{10}	$\geq$ 0.2 mm
$\leq$ 0.063 mm	≤ 5

If the permeability of the soil is higher than $k = 10^{-8}$ m/s, it must be sealed off with waterproof sheeting.

Typical inflow and outflow values for constructed wetlands [Kunst, 2002]

	COD [mg/l]	**NH_4-N [mg/l]**	**NO_3-N [mg/l]**
Inflow	400	70	0
Outflow: vertical filter	70	10	40
Outflow: horizontal filter	90	30	5

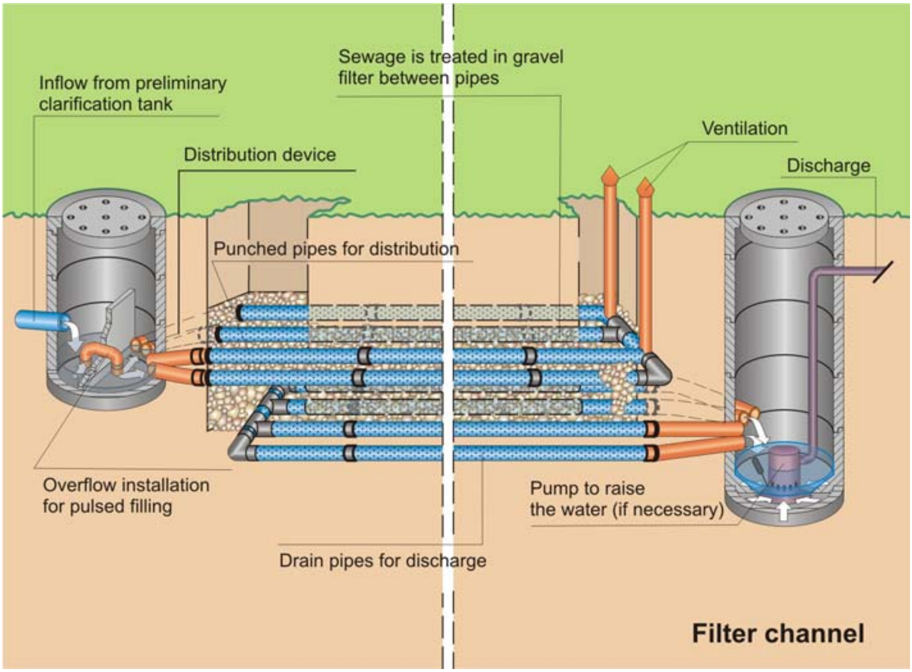
The differences in the nitrification and denitrification capacities of these two systems primarily reflect the availability of O_2. The smaller vertical filter provides better aeration. Horizontal filters have the advantage that they are simpler to construct and require no operational pumps.

Constructed wetlands are basically simple and low-maintenance systems. The disadvantages are the poor clarification capacity at low temperatures and the relatively large amount of space required.

The filter medium is completely blocked with sludge after 10 to 20 years and needs to be replaced.

Detailed descriptions of the various soil filter systems with size calculation details and instructions on computer-supported dimensioning are found in [Sasse, 1998].

4.5.2.5 Filter channel



[Münster, 2002]

The sewage needs to be pre-treated in a multi-chamber digestion tank from where it flows via a shallow drainage pipe, then passes through a filter layer and then enters the underlying discharge drainage pipe. The upper pipe terminates in an aeration unit. The lower pipe is 60 cm deeper and terminates in a collection shaft.

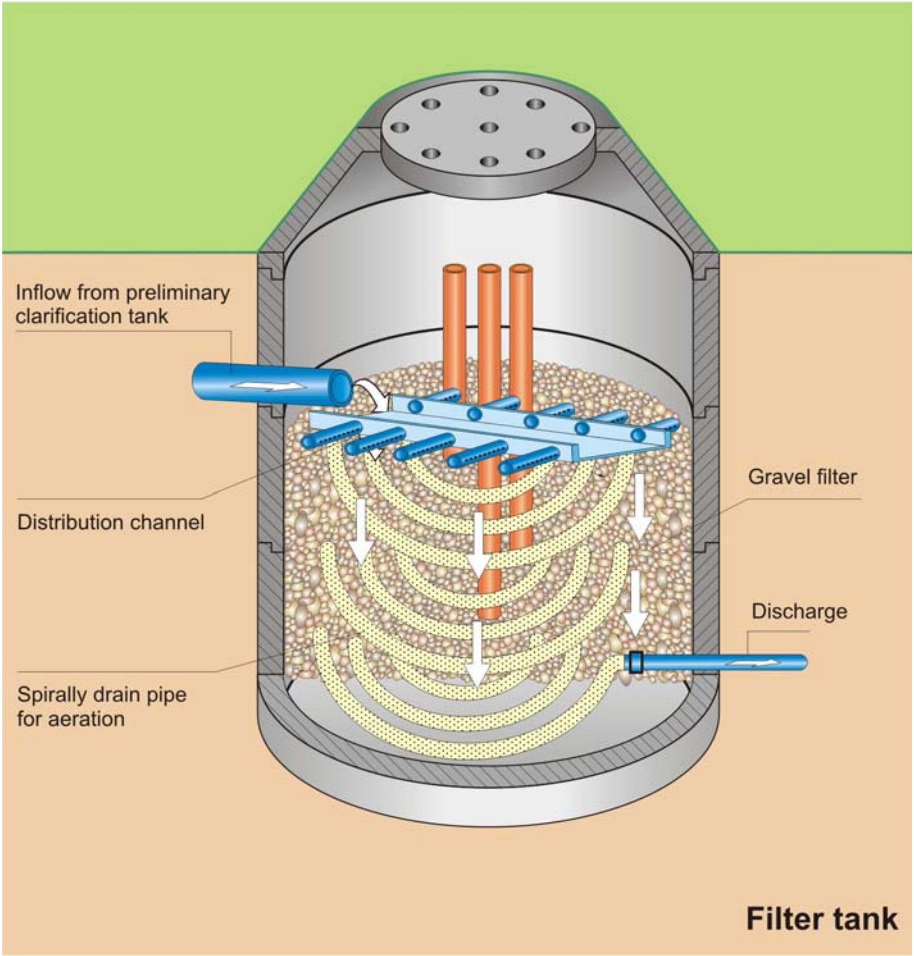
This is a simple system, although electricity is required in some cases to pump the clarified wastewater from the collection shaft up to the specified discharge height. Filter channels are probably not as sensitive to temperature as wastewater lagoons or constructed wetlands. A relatively large amount of space is required.

Pulsed inflow is very important for proper operation.

Filter channels need to be at least 6 m long per capita or need to have a minimum surface area of 3 m^2/capita. The minimum total area is 12 m^2. The ground needs to have very low permeability of $K \leq 10^{-8}$ m/s. [DIN 4261] Fine gravel is used as the filter medium.

The filter medium has to be replaced after 8 – 10 years.

4.5.2.6 Filter tank



The sewage needs to be pre-treated in a multi-chamber digestion tank.

The filter tank principle is basically a filter channel constructed in a shaft. The amount of space required by a filter tank is less than a filter channel.

Filter height	≥ 1.50 m
Filter volume	≥ 1.50 m^3/capita
Filter surface	≥ 1 m^2/capita

[Finke, 2001]

Filter tanks can have various distribution systems designed to allow wastewater to inflow periodically (pulsed inflow) and to ensure uniform distribution of the wastewater throughout the filter tank.

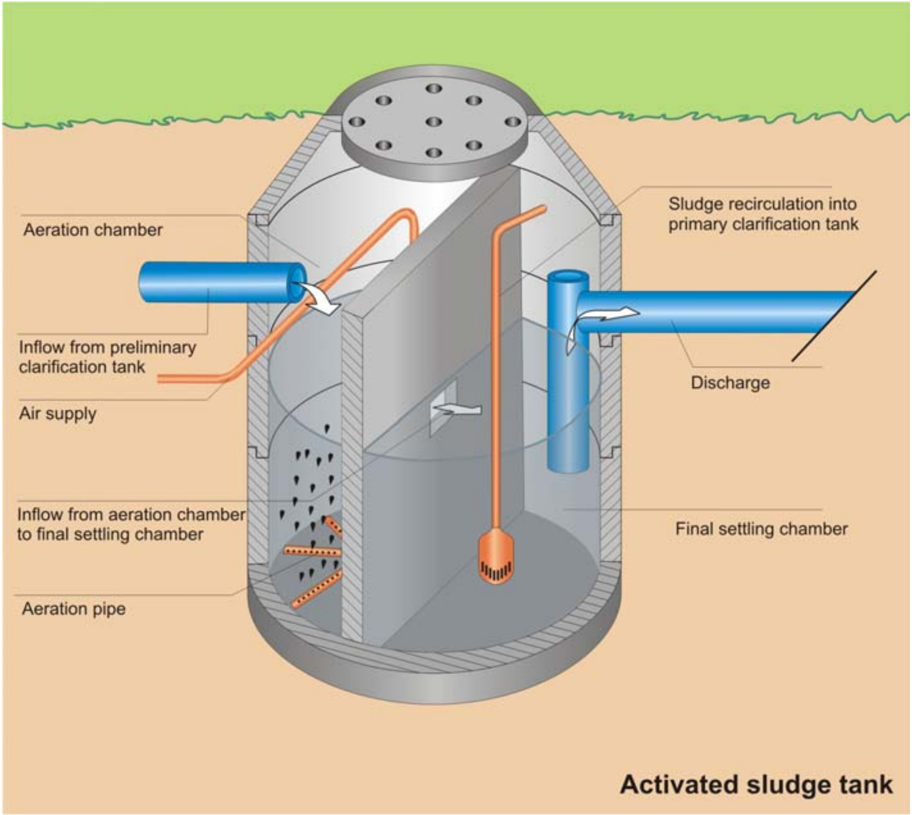
Filter tanks are relatively simple systems which are analogous to filter channels. Depending on the external conditions (nature of the ground), installing a filter tank can either be easier or more complex than constructing a filter channel.

The depth of the shaft means that filter tanks are less sensitive to low external temperatures than wastewater lagoons or constructed wetlands. Size limits mean that filter tanks are only suitable for a small number of users. They are adverse to fluctuations in inflow rate.

The filter tank needs to be serviced twice a year.

4.5.3 Methods using artificial aeration

4.5.3.1 Activated sludge tank



The wastewater must undergo mechanical pre-treatment by either a settling chamber, or best of all, in a multi-chamber settling tank.

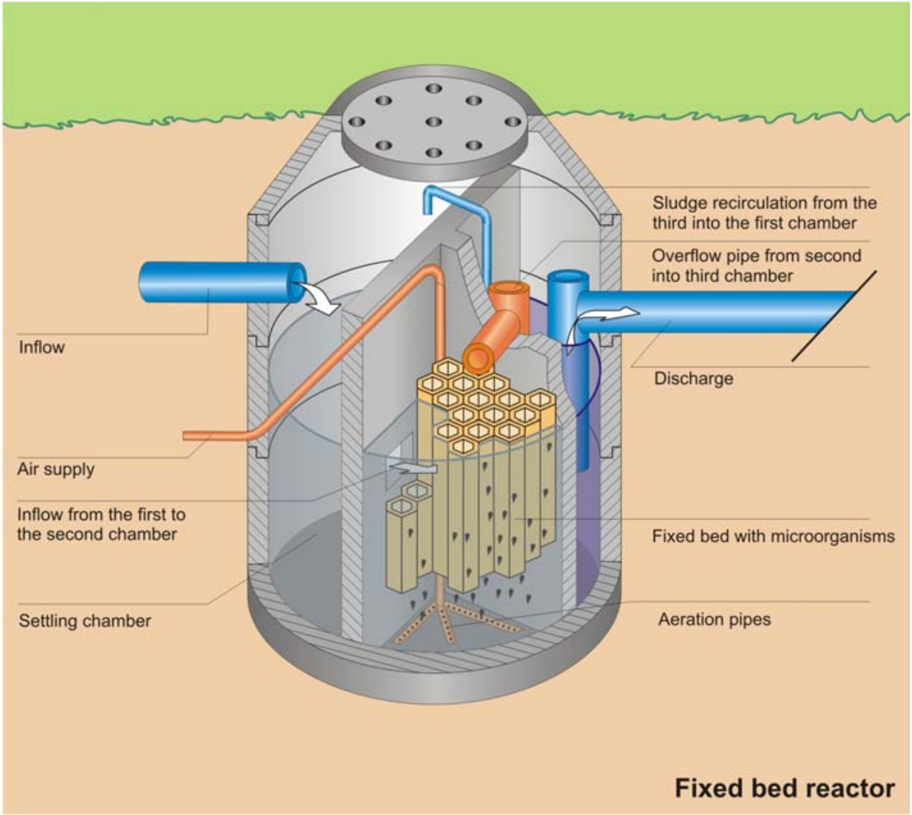
The activated sludge process is one of the high-tech measures. It requires aeration equipment installed in the aeration tank as well as pumps and mixing equipment. The sludge from the final clarification basin is partially recirculated into the aeration tank. This plant can only be operated with electricity.

The processing costs for this method are very high which explains why activated sludge methods are not usually carried out in small-scale treatment plants. The method also requires continuous flows of wastewater and is therefore only suitable for units handling at least 15 inhabitants. [Pabst/Flasche, 2004]

DIN 4261 specifies that the size of the aeration tank should correspond to approx. 0.3 m^3/capita for mechanically pre-treated wastewater. The minimum volume is 1 m^3 (DIN 4261). The space required for a plant handling the sewage from 8 persons is < 10 m^2 [Pabst/Flasche, 2004].

Activated sludge plants must be serviced three times a year and controlled daily.

4.5.3.2 Fixed bed reactor



[Münster, 2002]

A multi-chamber settling tank is required for pre-clarification.

Plastic grids are used as growing media in the fixed-bed reactors. Compressed air is used to aerate and mix up the sludge in the chamber. The fixed-bed is completely submerged in the sewage.

Fixed-bed reactors are a further development of conventional activated sludge plants. They use additional growth media for sessile microorganisms. In most cases, it involves sludge recirculation from the final clarification stage.

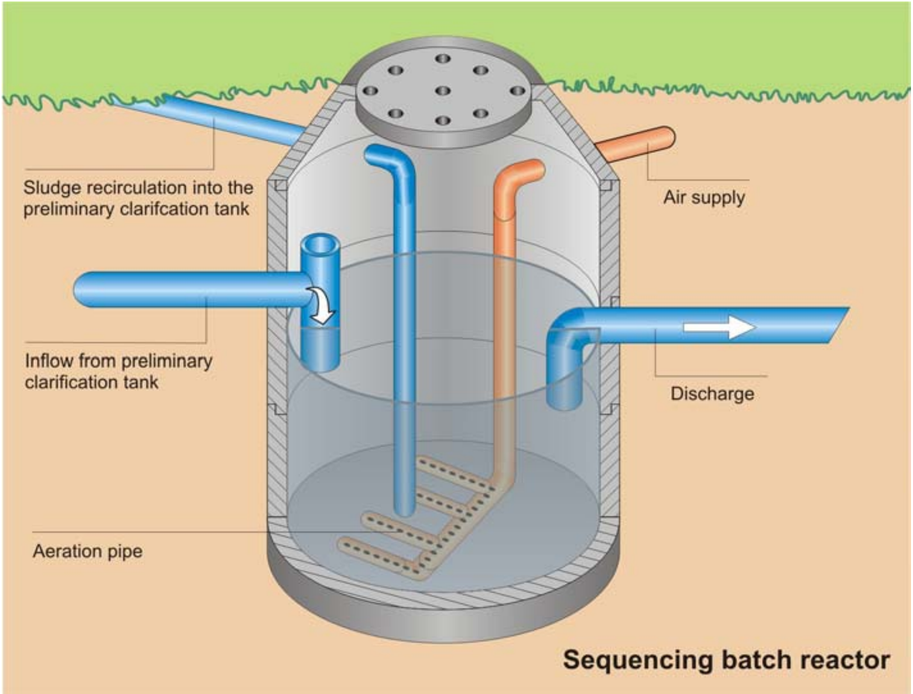
In a similar way to the activated sludge method, this high-tech equipment requires electricity and a large amount of equipment.

Aeration takes place intermittently and is externally controlled.

A plant to handle the sewage from 8 persons requires < 10 m^2 [Pabst/Flasche, 2004].

Fixed-bed reactors have to be serviced three times a year and controlled daily.

4.5.3.3 Sequencing batch reactor (SBR)



[Münster, 2002]

SBRs are discontinuous, cyclically-operated activated sludge installations. The treatment stages take place one after the other in one tank. There is therefore no need for any final clarification basin with sludge recirculation.

However, a coarse separator is needed upstream because SBRs with one tank are not completely reliable.

The processes take place successively in the reactor: mixing, aeration, sludge sedimentation, clarified water removal and excess sludge removal.

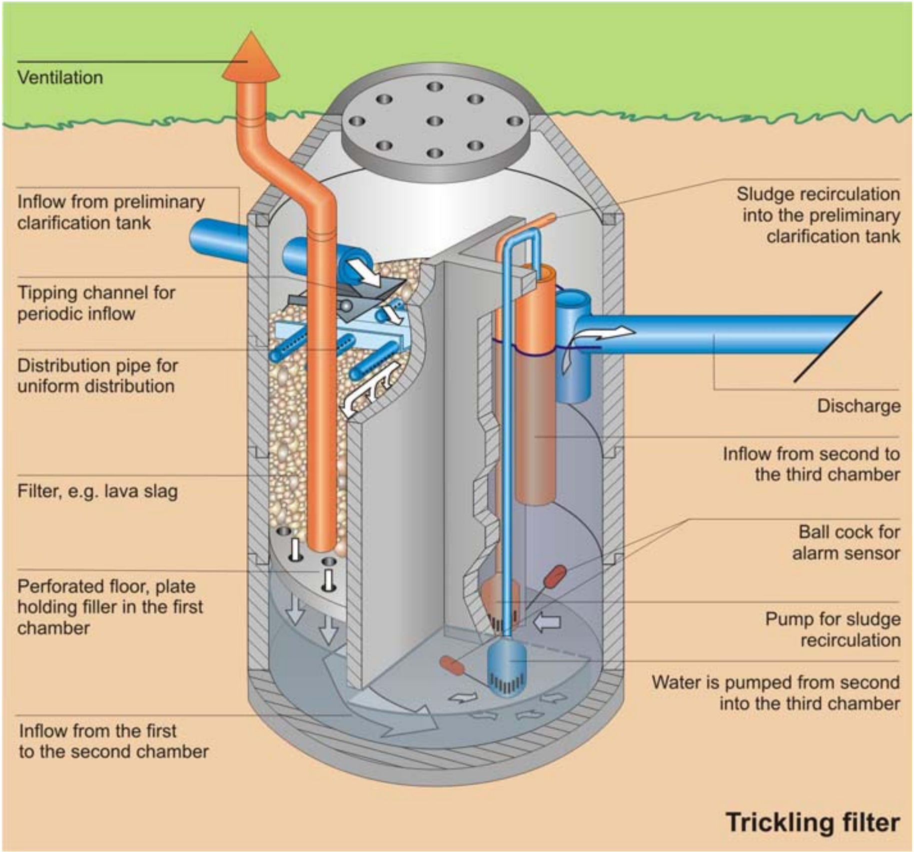
SBRs are high-tech reactors requiring electricity, pumps, sensors and aeration equipment.

A very large number of small-scale treatment plants are currently being constructed according to the SBR method. Existing septic tanks can be converted to SBR plants without the need to build any new tanks.

The size of SBRs corresponds to 0.3 – 0.5 m^3/capita. [Boller 1995] An 8-person reactor takes up < 10 m^2. [Pabst/Flasche, 2004]

SBRs must be serviced three times a year and controlled daily.

4.5.3.4 Trickling filter



[Münster, 2002]

A multi-chamber settling tank is required for pre-treatment.

Trickling filters are generally considered to be very reliable. This technique has already been used for many decades and is therefore tried and tested. It is the simplest form of high-tech system. The pumps require electricity.

The wastewater trickles over the percolating filter via distribution channels, atomising disks, stationary or rotating sprinklers. Microorganisms colonise the filter material consisting of lava slag or plastic granules to form a bio-film. The wastewater percolates through the filter from top to bottom and comes into contact with the bio-film where the microorganisms break down the constituents of the wastewater.

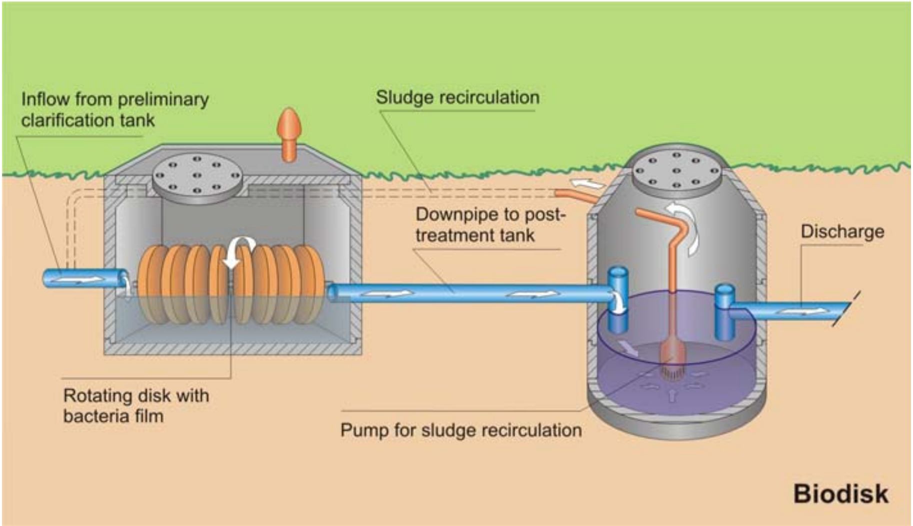
The chimney effect supports aeration. At the base of the chamber, the wastewater flows beneath a scum-board into a second chamber where the fixed biological film which may have become flushed off can settle.

The percolation filter is sprayed with wastewater several times by a pump. The frequency of pumping depends on the height of the trickling filter. A trickling filter with a height of 1.5 m needs to be sprayed three times. Higher filters need less spraying.

The basin size for trickling filters providing nitrification is calculated corresponding to 0.25 - 0.35 m^3/capita. The minimum size of the basin is 2 m^3. A plant for treating the wastewater from 8 persons occupies 10 – 20 m^2. [Pabst/Flasche, 2004]

Trickling filters must be serviced three times a year and controlled daily.

4.5.3.5 Biodisk



[Münster, 2002]

A multi-chamber settling tank is required for pre-treatment.

The plant engineering for biodisk reactors (or RBC: Rotating Biological Contactor) involves very expensive installation and maintenance. Biodisk reactors also use a great deal of electricity because the disk rotates continuously.

A partially submerged disk is fixed to and rotates around an axle. Oxygen is taken up when the disk is in the air above the wastewater. The biological films washed off the rotating disk accumulate as surplus sludge in the final clarification stage.

The size of rotating disk filter plants is calculated on the basis of a colonisation surface of ≥ 10 m^2/capita [DIN 4261]. A plant to handle the sewage from 8 people takes up less than 10 m^2. [Pabst/Flasche, 2004]

Biodisk filter systems have to be serviced three times a year and controlled daily.

The following applies to all methods with artificial aeration: designs are available which integrate within one tank the settling basin for pre-treatment, final clarification and the basin for the biological stage. **Most systems are designed for installation below ground, but surface installations also exist.**

All of the methods require electrical power for aeration and to operate the pumps. The secondary sludge generated by these processes (from the biological stage) is usually pumped into the pre-clarification basin and disposed of together with the primary sludge (from the mechanical pre-treatment stage).

Although the tanks shown here are round, they are constructed often with a rectangular shape.

4.6 Method comparison

The methods described in the previous chapters have been divided into two groups here: methods **with artificial aeration** and methods **without artificial aeration.** These two groups are also described in the literature as technical methods or natural methods. Further subdivision is also possible based on whether they use **freely suspended or sessile microorganisms**, or whether the methods are **aerobic** or **anaerobic**.

The general disadvantage of technical plants is the large **energy consumption**, the **higher sludge production** and **more frequent servicing**. A negative aspect of “natural” systems is the **large amount of space required**. Wastewater lagoons and constructed wetlands are furthermore very **sensitive to temperature**.

Capacity is strongly dependent on size. Aerobic sewage plants with large biological stages often provide nitrification. Additional technical methods are then required in most cases to promote denitrification. This means that much of the nitrogen in the wastewater is discharged in the form of nitrate.

The type and design of small-scale wastewater treatment plants is dependent on numerous constraints. Of the technological systems, the trickling filter system has a proven track record for reliability and simplicity.

All of these systems involve highly complex processes which require professional management.

Anaerobic reactors are quite unusual in industrialised countries, with the exception of digestion tanks which are primarily seen as a mechanical treatment stage. Anaerobic reactors are, however, very significant in developing countries. The **main disadvantage** compared to aerobic methods is the **lower efficiency at removal of organic matter and nutrients**. Their **main advantage** is the **simple construction and operation** of these plants as well as **low or no energy demand**.

4.7 Method selection criteria

4.7.1 Aerobic vs. anaerobic treatment

The choice between aerobic and anaerobic treatment depends on the following items:

Desired effluent quality	aerobic treatment provides higher efficiency in removal of organic matter and nutrients
Effluent use	anaerobic treatment remains more nutrients and thus effluent have higher potentials for use in irrigation
Sewage characteristics	for high concentrated sewage (BOD > 1000 mg/l) in hot climate (average sewage temperature above 20°C, minimum of 18°C over a maximum period of 2 month) anaerobic treatment is effective
Sludge handling and disposal	anaerobic treatment provides small amounts of stabilised sludge, while sludge from aerobic treatment processes is of higher volume and requires further processing

[Veenstra et al. 1997]

4.7.2 Methods without artificial aeration

	Wastewater lagoon	Baffled reactor	Anaerobic filter	Constructed wetland	Filter channel	Filter tank
Robust low-tech solution	++	+	+	++	+	+
Appropriate for urban areas	- -	+	+	- -	-	o
Appropriate for hot and wet climate	++	++	++	+	+	+
Appropriate for hot and dry climate	-	++	++	- -	o	o
Appropriate for cold climate	- -	- -	- -	-	o	o
Effluent reuse for irrigation	++	++	++	+	o	o
Low construction costs	+/- depending on soil	+	+	+/- depending on soil	+/- depending on soil	+
Low maintenance costs	++	++	++	++	++	++
No or low energy consumption	++	++	++	++	++	++

4.7.3 Methods using artificial aeration

	Activated sludge tank	**Fixed-bed reactor**	**SBR**	**Trickling filter**	**Biodisk**
Robust low-tech solution	- -	- -	-	O	- -
Appropriate for urban areas	+	+	+	+	+
Appropriate for hot and wet climate	+	+	+	+	+
Appropriate for hot and dry climate	+	+	+	+	+
Appropriate for cold climate	O	O	O	O	O
Effluent reuse for irrigation	O	O	O	O	O
Low construction costs	- -	- -	- -	- -	- -
Low maintenance costs	- -	- -	- -	-	- -
No or low energy consumption	- -	- -	- -	-	- -

4.8 Discharging into water bodies

The clarified wastewater must be discharged from the treatment plant into a water body. If the clarified wastewater percolates, it will enter the groundwater.

Determining whether the best solution is discharge into flowing surface waters or percolation into the groundwater depends on numerous external factors. For instance, it is better to discharge the clarified sewage into flowing surface waters if the groundwater table is very shallow because the generally high protection potential of unsaturated soil zone is not available when there is a very shallow water table. Flowing water has a high self-cleaning potential.

Another very significant decision-making factor in where to discharge the clarified wastewater is the use of the river water or the groundwater.

Another aspect to be taken into consideration is the location of the discharge pipe so that backflow is avoided during high water levels in rivers subject to strong fluctuations in flow rates [Finke, 2001].

4.9 Common construction defects

The following defects are common when constructing small-sized wastewater treatment plants:

No paved access roads of adequate size for lorries collecting the sludge

Inadequate ventilation via the lids (the lids are often completely covered. This means there is no guarantee that proper ventilation is taking place)

Defective connections or no backflow preventer on the outflow at the end of the discharge pipe

Rainwater not prevented from entering the treatment plant

Tanks not adequately protected from uplift when empty in areas with high water tables

Distribution channels not built perfectly horizontal

Leaks

Distance from drinking water wells too small

Scum boards not visible from the maintenance openings (poor control)

[Münster, 2002]

5 Location selection

It is often standard practice in poor and less developed areas in particular to locate latrines and drinking water wells on the same plot. It is essential in such cases to ensure that the latrine is downstream of the drinking water well with respect to groundwater flow. Generally the direction of groundwater flow corresponds with the topography.

The general rule for many soil types is for there to be a minimum distance of 15 m between drinking water wells and latrines, as well as a minimum distance of 2 m between the base of the latrine pit and the water table. [Cave, 1999]

Sanitation facilities are to be constructed in a flood-safe place.

In ARGOSS 2001 and WHO Guidelines for drinking water quality, Vol. 3 principles for the location of drinking water and sanitation facilities can be found.

Drying and composting toilets in general are less of a hazard to groundwater than latrines because many of these more highly developed systems have water-tight collecting containers.

The soil does, however, also have the potential to detain contaminants. Very effective protection is provided by the unsaturated zone which is usually characterised by very low flow rates. The key to germ reduction is the retention time of contaminants in the soil. In this context it should be noted that latrines often represent less of a hazard to groundwater than cesspits with downstream percolation because these cesspits are associated with much higher flow rates because of the volume of grey water entering the tanks. The same applies to defective sewage pipes.

[Cave, 1999] describes in detail the dispersal routes of pathogenic germs from latrines and the associated health risks.

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