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Tamás Karches

INDIVIDUAL WASTEWATER TREATMENT TECHNOLOGIES

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Individual Wastewater Treatment Technologies

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Editor

Tamás Karches

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Authors
Ferenc Bognár
Ilona Dalkó
Tamás Karches
Péter Orgoványi
Tamás Papp
László Török
Edit Vadkerti

Translation
Tamás Karches
Judit Knisz

Technical Advisor
Zsolt Németh

Ludovika University Press Non-Profit Ltd.
H-1089 Budapest, Orczy út 1.
Contact: kiadvanyok@ludovika.hu

Responsible for publishing: Gergely Koltányi, Managing Director
Managing Editor: Kata Inzsöl
Copy Editor: Zsuzsanna Gergely
Typeset and design: László Kőrösi

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Foreword

Wastewater generated in settlements without sewerage must be treated in order to relieve the burden on the receiving water body and to avoid risks to public health. Because the transportation of liquid waste in these regions is quite expensive, local solutions come to the fore. The design methodology of individual wastewater treatment and the contexts related to the operation have been known for a long time; however, the application is not widespread where centralised wastewater treatment has not been solved.

The aim of the textbook entitled *Individual Wastewater Treatment Technologies* is to acquaint the reader with the issue of individual wastewater treatment and its specialties. After general wastewater treatment concepts and operations, the concept and legal background of decentralised wastewater treatment will be presented, followed by a wide range of technologies from a wide and colourful offer of individual wastewater treatment plants. Those interested can also get an insight into the numerical modelling of wastewater treatment processes. We hope that not only students but also practitioners from design and operation engineers, those interested in wastewater treatment and those who want to do something for their environment will find useful information.

The textbook is published by the Faculty of Water Sciences of the University of Public Service EFOP-3.6.1-16-2016-00025 project on strengthening higher education in water management in the framework of intelligent specialisation, development of a decision support and expert system for the introduction of individual (small) wastewater treatment plants in Hungary.

Baja, 2020

The Editor

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Péter Orgoványi, Ilona Dalkó, Edit Vadkerti, Ferenc Bognár

Basics of Wastewater Treatment

Mechanical pretreatment

Nowadays, the primary wastewater treatment stage is used very rarely or not used at all on its own, because water leaving the treatment does not or only partially complies with regulations. The composition and concentration of initial raw wastewater can show significant differences depending on the origin of wastewater, which greatly influences the choice of the applied technology line. Physical, chemical and biological processes based on each other are used in wastewater treatment.

Mechanical wastewater treatment is one of the oldest methods used. Its engineering structures are designed with fluid dynamics in mind, influenced by physical forces (inertia, gravity, friction and cohesion forces).

The main purpose of mechanical cleaning is:

– removal of larger size contaminants
– protection of the machinery of subsequent technology and making capable the wastewater for next technological steps (e.g. elimination of coarse grained particles and fats)

The structure of the first treatment stage is shown in Figure 1, which follows the sequence of a general mechanical wastewater treatment process.

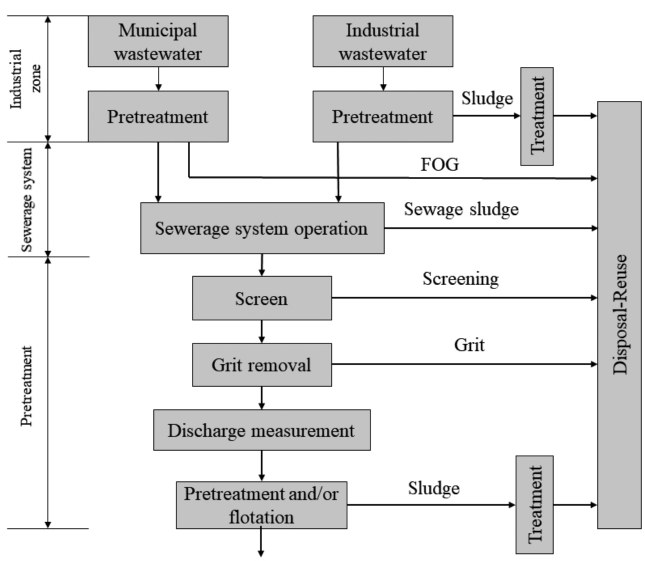

Figure 1
First treatment stage of wastewater treatment (based on [1])

The percentage removal efficiencies estimated for mechanical cleaning for major contaminants are given in Table 1 (values are indicative).

Table 1
Removal efficiency (detail [2])

Procedure	Settable solids (%)	Total suspended solids (%)	Colloidal suspended solids (%)	BOD_5 (%)	COD (%)	Heavy metal ions (%)
Grid	5–10	2–5	–	–	–	–
Sand trap	20–30	10–20	–	–	–	50–80
Settling	85–95	40–50	10–20	20–30	15–25	20–30

Physical procedures are divided into two major groups according to their operating principle:

– equipment based on the principle of size difference: grids, sieve and fabric filters, particulate filters
– equipment based on the principle of density difference: settlers, floaters (grease and oil traps)

The grouping of different mechanical equipment according to the nature of the waste to be removed is given in Table 2.

Table 2
Classification of mechanical processes [3]

Cleaning equipment	Pollutant to be removed
Stone and gravel pliers, grids, filters, shredders	Large floating and suspended materials
Sand traps	Small floating and mineral substances
Settlers	Small floating and suspended materials
Hydrocyclones	Small floating and suspended solids
Floating equipment, flotation tanks, thickeners, septic tanks	Small suspended and floating, liquid and solid materials

Wastewater can flow into the treatment plant from the public sewer by gravity or from a pressurised system.

Breakdown of coarse pollutants (based on their size and physical properties):

– rolled (gravel, stone debris)
– floating (e.g. tree branch, textile waste, plastic, etc.)
– suspended matter (finer suspended matter)

The main purpose of stone and gravel traps is to retain sediment (5–20 cm in size) from the combined sewer network. Large coarse dirt (floating and suspended solids) is removed by filtration and comminution.

Grids and shredders

Commonly used mechanical equipment of the cleaning technology includes grids, their application is important, e.g. to remove clogging materials in order to protect and relieve subsequent process equipment. When designing grids, flow velocity must be taken into account and the settling in front of the grid must be minimised (min. 0.2–0.3 m/s, or max. 0.7 m/s in case of peak load).

The grids can be used:
– in front of pumps (sewage pumping station)
– at the beginning of the technology (before sand trap and pre-sedimentation)

Grids are usually placed inside a building to protect electrical and mechanical equipment, thereby eliminating odour and the effects of the corrosive atmosphere, thus, increasing service life. In low-capacity plants, mechanical equipment is often located outside the building, in which case it is reasonable to heat it during winter (for normal operation of the technology).

According to the opening of the grid located at the beginning of the technology, some of the materials are retained, so the grids provide resistance in the path of the flowing wastewater, which causes back swelling. During the process, materials left on the grid must be removed by regular machine or manual cleaning. It is common for wastewater treatment plants to use two rows of structures, if this cannot be solved, it is worthwhile to design an emergency bypass (Figure 2) in case of possible malfunctions.

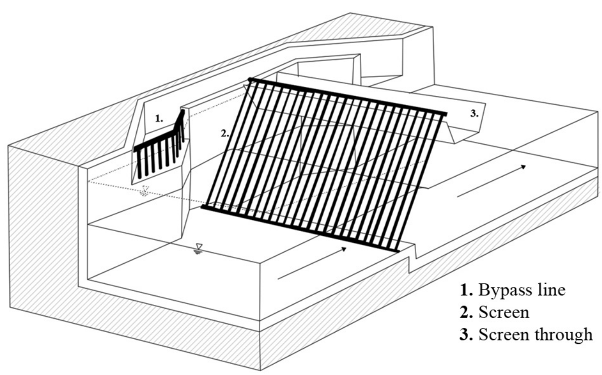

Figure 2
Design of a bypass channel at grids [4]

Grids can be grouped in several ways based on the spacing of rods, their placement, design and means of cleaning.

a) According to their cleaning method:
- manual (for small or intermittent technologies)
- mechanical (for continuous and automated operation)

Mechanical grid cleaning equipment moves slowly, so their electrical power is relatively low (max. 5 kW).

Table 3
Types of machine-cleaned rod grids [5]

Grid Type	Rake	Arched	Spinner	Basket
Built-in	Bending angle 60–80°	Vertical and horizontal	Bending angle 60–80°	–
Application in sewage treatment plant	Small capacity	Small and medium capacity	Medium and high capacity	Sewage network
Equipment	Sewer and grid chamber			Sewer shaft

a) According to rod spacing (MSZ EN 12255-3-2001):
- fine (2–10 mm, usually steel, machine cleaning needed)
- medium (10–20 mm, to prevent clogging)
- coarse (20–50 mm, in case of operation of integrated sewerage networks, screenings is more of a solid waste type, the most commonly used type is flat grid)

b) By position (angle of inclination 20–75°):
- skew
- vertical

c) According to their design:
- flat grid (Geiger filter straight surface consisting of grid bars)
- curved rods (consisting of Parkwood CM curved rods)
- standing rods (consisting of fixed built-in flat or curved grid panels)
- moving grids (consisting of Geiger's articulated grid plates formed as endless strips)

The use of flat grids is more common in larger capacity plants. It is also used for coarse and fine grids; this machine-cleaned flat grid (usually with an inclination of 80°) is illustrated in Figure 3.

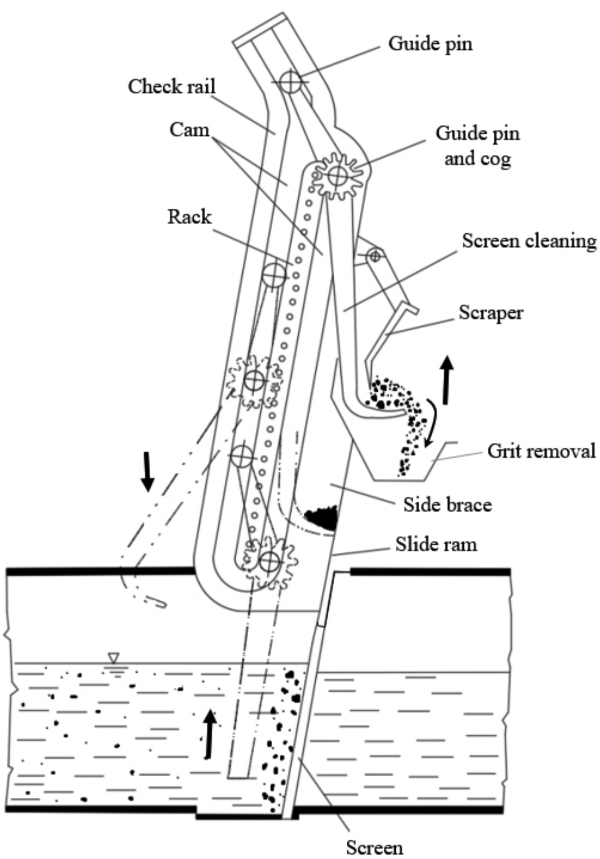

Figure 3
Machine cleaning flat grid [2]

Main types of flat grids:

- operating with an alternating cleaning device
- continuous cleaning (fixed grid)
- continuous cleaning (moving grid)

In hydraulic dimensioning of the grid, the following must be taken into account:

- the flow rate of water movement between rods, which must not exceed 1 m/s (otherwise the flowing water may take along the waste)
- flow velocity into the inlet and outlet channel should be in the range of 0.5–0.8 m/s (to prevent the deposition of minerals)
- for grids used in medium and small settlements, also the grid design and the cleaning system

In the hydraulic sizing of sewage grids, the Kirschmel relation can be applied, with which we can estimate the back swelling effect of local loss, which can be 5 cm on average. By changing the profile of the grid bar with the same dimensions, the degree of back swelling can be reduced.

Kirschmel's relation:

$$h_v = \beta \cdot \left(\frac{d_p}{k_p}\right)^{\frac{4}{3}} \cdot sin\alpha \cdot \frac{v^2}{2g}$$

where

hv: back swelling of the grid [m]
dp: width of the grid bar [m]
kp: free spacing [m]
v: average wastewater flow rate in front of the grid [m/s]
α: angle of the grid with the horizontal plane
β: form factor (depending on the cross-section of the grid cross-section –1.79; for flat steel –2.42; for rounded flat steel –1.64; for flat steel rounded only at one end –1.83)

In practice, the simplest solutions used in wastewater treatment plants below 750 m^3/d include a screening basket that is periodically emptied by manual or machine lifting.

Between 1,500 and 3,000 m^3/d, the use of both curved grids and hand-cleaned flat grids is widespread. In plants with a capacity of more than 3,000 m^3/d, machine-cleaned flat grids are used. Screenings from the equipment contains rapidly decomposing, foul-smelling, infectious substances with a moisture content of 85–90%, the amount of which is determined by the nature of the wastewater and rod space. Further treatment of the screening can be done by digestion (after proper shredding) or composting.

Instead of grids, we can also use shredding equipment, which does not remove coarse waste, but performs shredding. The purpose of shredding is to prevent additional problems during lifting, draining and cleaning; it can also be used to replace fine grid. Shredders can be commutators, barminutors, shredder or grinding wheel pumps can be grouped separately (they also carry sewage at the same time). The most commonly used shredders are commutators (knife shredders) due to their favourable wastewater technology and mechanical advantages. During their operation, wastewater flows through the openings of the drum, larger dirt gets stuck, the fixed knives do the chopping (to a size of 6–20 mm), and then it leaves with the wastewater at the bottom of the drum.

Grits

Grits are mainly used in combined or mixed sewerage networks; they usually follow the sewage grids in the technology line.

The main purpose of its application:

- reducing the content of primary particulate minerals in wastewater to protect subsequent machinery
- sedimentation prevention (in on-site interconnectors)
- reducing inorganic load in additional tanks
- reduction of excavator overload

Grits can be essentially considered settlers, so the operating principle of grits can be determined by Stokes's sedimentation formula. In a stationary environment, particulate matter is subjected to gravitational, buoyant and frictional forces.

Stokes sedimentation formula:

$$v_{ü} = \frac{g \cdot d^2}{18 \cdot v} \cdot \frac{\rho_{sz} - \rho_{water}}{\rho_{water}}$$

where

$v_{ü}$: sedimentation rate [m/s]

υ: kinematic viscosity of the flowing medium[m^2/s]

g: acceleration due to gravity [m/s^2]

d: average diameter of settled particle [mm]

ρ_{sz}: average density of settled particle [kg/m^3]

ρ_{water}: granular inorganic materials of larger density of water [kg/m^3]

If the flow rate can be kept between 0.1 and 0.3 m/s, sand and other heavier granular inorganic materials (smaller gravel grains, slag, fruit seeds, etc.) with a diameter of 0.2 mm will settle, but organic pollutants are more difficult to settle. In the case of properly subdivided tanks, sediments can be classified according to size.

The size of sand grains and the composition of the separated sand are influenced by:

- the quantity and quality of domestic effluents
- the type of sewer network (combined or separated)
- the material and condition of the sewer network
- the size of the catchment area
- hydraulic residence time

When choosing grits equipment, take into account:

- construction aspects (e.g. space requirements, groundwater, mechanical design)
- the magnitude and fluctuation of wastewater flow
- the material to be settled (in terms of quantity, storage, extraction, washing, disposal)

Depending on flow direction, grits can be divided into several groups, such as horizontal, vertical and circular flow or rotating cylindrical (horizontal axis-air-blown) grits.

Horizontal flow grits

Optimum flow rate is 0.3 m/s. Constant flow can be ensured even with variable water flow. The most widely used type is the Parshall channel-controlled grit; even Venturi channel and Sutro-tumble can be placed after the grit. Sufficient volume must be provided at the bottom of the grit to store the sand.

Types:

- long flow (Essen, sand excavation with machine excavator)
- ventilated or aerated
- tangential introduction
- vertical flow

Vertical flow grits (cylindrical, column or funnel-shaped)

The most common version is Blunk's, in which wastewater first flows vertically downwards in the structure, thus, settling the mineral (hydraulic sand separation).

Tangential (vertical axis) grits

In the tank, a circulating water movement is created, in which suspended solids are affected by gravity and centrifugal force accelerates phase separation. It is often used in a PISTA system, which is an integrated pretreatment unit where grids and grits are placed together in one unit.

Air-blown grits

It is often used in domestic plants due to its flexible controllability. The flow rate in the structures can be varied within wide limits and the removal of solid particles can be adjusted.

A spiral flow develops in the air-blown grit due to the introduction of coarse bubble (5–8 mm) air. The advantage of the technology over the long-flow grits is that the settling is efficient even in shorter structures. It is advisable to place the air intake in the vicinity of the bottom of the structure at a certain depth (Figure 4), thus, increasing separation efficiency and reducing foaming that may occur due to detergents.

The amount of air introduced into the grit is determined by its size and cross-section, and the optimal value is set on the sites with a manual flow meter, so its amount may vary from site to site. In addition to the function of grits, it is important to separate sand and organic contaminants.

If compared to the ideal air intake:

- less air is introduced, a significant amount of sludge can be deposited in the grit, thus, reducing the efficiency of biodegradation (nitrogen removal)
- air intake is operated with high efficiency (too much air), sand separation can be reduced, it can cause operational problems

The flow in the cross-sectional plane of the basin (mainly in the lower critical zone of the basin bottom) plays a fundamental role (Figure 5) and greatly influences the sand removal efficiency of the structure.

When sizing a grit, the main sizing parameters include residence time, which should be set between 3–10 minutes.

The organic matter content of the sand leaving the plant can be further reduced with a sand scrubber, the organic matter separates with slow stirring and the sand settles in the hydrocyclone.

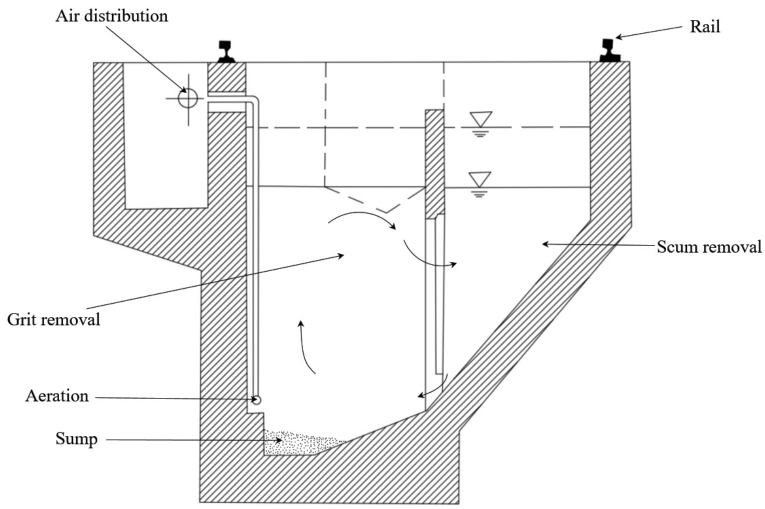

Figure 4
Cross-sectional design of an air-blown sand trap [1]

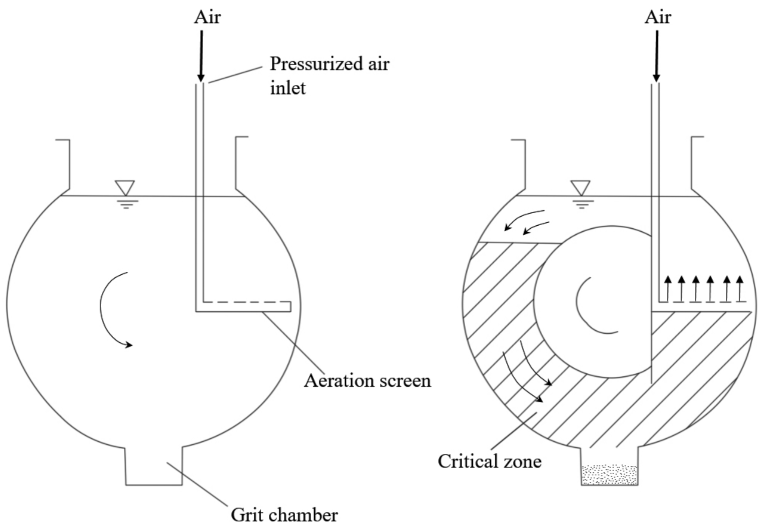

Figure 5
Functional diagram of an air-blown grit [1]

Hydrocyclone

A device operating on the principle of the difference in density; in the water space of a circular structure, the wastewater to be treated is led in a tangential direction, which performs a circular movement with a vertical axis. During the process, due to the centrifugal force the partly solid and partly water-insoluble liquids separate. Two main groups are known: closed and open hydrocyclone. In case of high sand content, a hydrocyclone can be used in parallel with the grit (Figure 6).

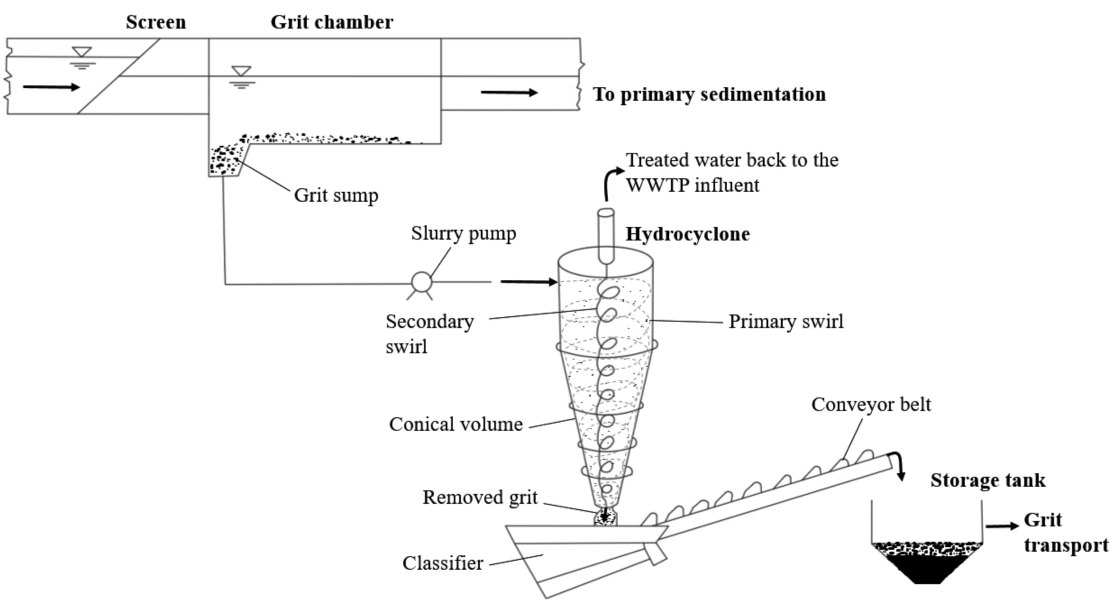

Figure 6
Sand removal by cyclone [1]

The material deposited in the grit contains infectious substances; this must be taken into account when handling it. Prior to deposition, dehydration is required due to volume reduction, for which sand-drying beds or settling tanks are often used.

Floating equipment

Wastewater can contain significant amounts of fats and oils with a lower density than water, so they rise to the surface of the water at a suitable flow rate and can be removed. Its use is necessary not only to protect subsequent machinery, but also to recover valuable material.

Depending on the origin and material of the floating waste, the structure can be:

- grease trap
- oil and gasoline trap
- defoamer
- other sludge traps

Grease and oil traps

The presence of fats and oils entering the plant impairs the efficiency of cleaning; removal of these materials is carried out before settling, mostly in combination with the grit, taking advantage of the flotation effect of the air blowing.

Adequate residence time (2–5 min) and surface area must be provided for efficient operation of the equipment. Its use is necessary if the total fat-oil concentration is higher than 50 g/m^3. Grease and oil trapping, together with sedimentation, should be carried out in a combined structure.

Flotation equipment

In order to increase the efficiency of the floating equipment, it is practical to use flotation equipment for the removal of oil, grease, petrol droplets and colloidal particles that do not float or settle, as well as for separating the emulsion.

Settler

Settlers play a fundamental role in the process of wastewater treatment technologies. These devices operate on the principle of difference in density, which is made possible by low flow rate and gravitational force. In addition to the removal of small suspended and floating materials (TSS), they also enhance the reduction of biological oxygen demand (BOD). A well-designed pre-settler can result in up to 20–50% BOI and 55–70% TSS removal.

Pre-settlers are primarily used in medium and high capacity plants where sludge stabilisation also takes place.

The Stokes law described for grits can also be applied for pre-settlers where discrete particles are deposited.

The settlers are sized for the following parameters, depending on where they are used:

- for surface hydraulic load (m^3/d)
- required theoretical residence time (h)
- surface suspended solids load (kg/m^2* h)
- vertical or horizontal flow rate (cm/s)
- tipping edge load (m^3/m* h)

Pre-settlers can be grouped according to several aspects, such as flow direction and floor plan design.

Depending on the flow direction, settlers can be:

- horizontal flow
  - longitudinal flow (Leipzig)
  - radial flow (Dorr)
- vertical flow (Dortmund)
- transitional version (Uniflow, hydrocyclone)

According to the floor plan [6]:

- rectangle (Leipzig, Uniflow)
- square (Dortmund)
- circle (Dortmund, Dorr, hydrocyclone)

Longitudinal flow (Leipzig)

They can be used primarily for pre-settlers, they are rectangular reinforced concrete structures with a rectangular floor plan, and the flow takes place in the longitudinal direction (Figure 7). The settled sludge is conveyed to the sludge sump by the arm excavator (at a speed of 10–50 mm/s), which is conveyed by centrifugation or by a mammoth pump.

Key implementation solutions:

- impacted against a sinking wall
- it flows into the tank from several nozzles (T-tubes, Stengel head)
- at the influent side of the settler, the wastewater flows through mangers into the basin, in the opposite direction to the main flow direction, and then enters the settling space under an immersion wall
- it flows through a perforated plate or grid from the pre-chamber of the settler to the actual settler

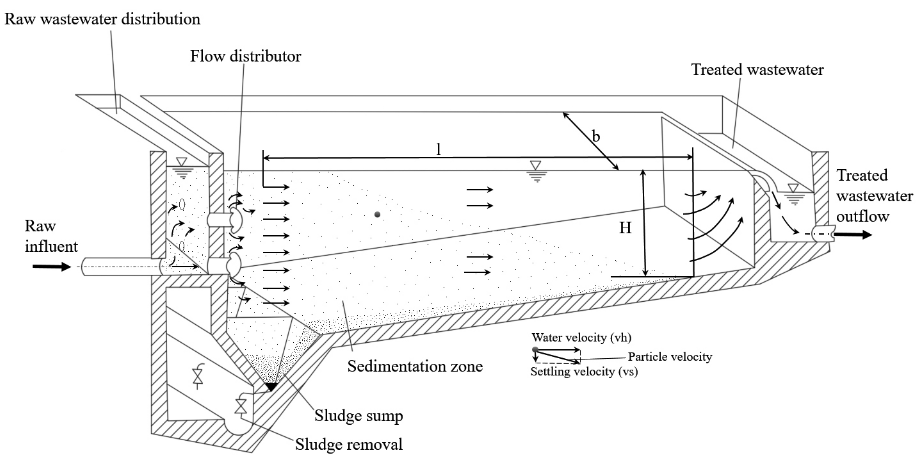

Figure 7

Design of a horizontal (longitudinal) flow Leipzig basin [1]

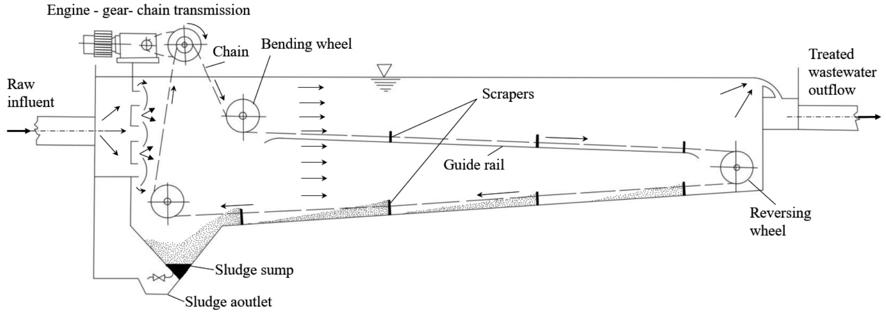

Figure 8

Longitudinal sedimentation with a chain excavator [7]

Circular floor plan, radial flow (Dorr)

According to its floor plan, the Dorr settler has a circular and a corresponding radial flow, which are used for both pre- and post-settlers. Sewage is usually introduced through the manifold of the structure, which has the role of optimising the flow rate. The treated water is drained through a collecting manger with a tipping edge placed around the circumference of the structure. Excavators are used to collect sediment and floating sludge. Dead space should be provided in the vicinity of the sludge collection sump for undisturbed sedimentation.

Vertical flow (Dortmund)

The tanks have a circular floor plan, are made of reinforced concrete, and can be used with good efficiency to settle wastewater containing flaky sludge. It is used partly as a pre-settler and mostly as a post-settler. In terms of its operation, the wastewater enters the damping cylinder, from where it flows downwards to the sludge sump, and the purified water is drained through the weir channel. The sludge leaving the settler is high in organic matter, usually denser than the sludge in the post-settler.

Two-level settlers

According to their place in the technology line, two-level settlers are mentioned together with thickeners. In sewage treatment plants, two-level settlers are becoming less common. These structures (Imhoff Basin or Emscher Fountain) can have a circular or rectangular floor plan. The upper space is the settling space, and the one below is the sludge space, where the settled sludge is decomposed.

Compactors

The process can rather be classified as a sludge treatment process aimed at reducing the volume of sludge to be treated. Settling and compaction are processes occurring at the same time next to each other; a more efficient sludge dewatering is expected.

Compactors and condensation processes can be grouped as follows [6]:

- Gravity compression (naturally or mechanically)

The process can take place in the settling tank, in a separate thickener or in combination with sludge washing. The compaction process can be influenced by several factors such as flow conditions, structure size, environmental conditions and sludge properties (physical, chemical, biological).

- Flotation compaction (air or chemical flotation or biological flotation)
- Static compression
- Dynamic compression (most often vibratory, centrifugal, filtration)

Septic tanks

They provide the supply of settlements or settlement districts that do not have a public sewer network; this small equipment was previously widespread in Hungary. They can be classified partly as settlers and partly as small wastewater treatment plants. Their design depend whether the recipient is soil or surface water.

During operation, some of the suspended solids in the wastewater introduced into the first chamber settle out and some float up. After flowing into the next chamber or chambers (it may be necessary to create 2–3 chambers), smaller suspended solids can settle after a certain residence time. The settled sludge begins to decompose under anaerobic conditions, causing some of the sludge to float up to the floating layer. Of the floated materials, after a certain time, high specific gravity particles may settle in the lower sludge layer. These structures are suitable for receiving and treating relatively small wastewater yields (1–25 m^3/d). Due to their simplicity, they can be implemented with a homemade design and their energy and handling requirements are minimal.

Biological aspects of wastewater treatment

One of the main purposes of wastewater treatment is to prevent the release of pathogens into the environment, to prevent infections and epidemics and to preserve the quality of our waters. Untreated wastewater contains numerous human pathogens. Most wastewater treatment technologies currently in use are not suitable for removing all pollutants and microorganisms, which can survive in the environment for days or even weeks and can be sources of epidemics. For this reason, it is very important to carefully choose the means of wastewater treatment and the way treated wastewater is released into the environment.

Municipal wastewater contains organic matter in high concentration, if discharged to the soil or surface water untreated, it decomposes or mineralises into its constituents, depending on the circumstances. Decomposition products produce significant amounts of carbon dioxide, nitrogen and phosphorus in easily absorbable forms, which can be used as nutrients when entering surface waters. The uptake of nitrogen and phosphorus for photosynthesising, autotrophic organisms (including plants and algae) is generally not unlimited in the environment. N- and P-containing fertilisers (whether organic or inorganic fertilisers) are also applied to agricultural land to make up for the shortfall, thus, higher crop yields are expected. When these substances enter our waters from ground or through untreated wastewater, they are utilised by autotrophic organisms, causing rapid growth of algae in surface waters and leading to the proliferation of higher plants, causing eutrophication.

During wastewater treatment, living matter is transformed by living organisms that are also found in nature, but in the treatment process, the growth of microorganisms is intensified and controlled. During intensive animal husbandry, in order to keep a large number of animals in a small area, a large amount of nutrients must be introduced, appropriate temperatures and conditions must be ensured, diseases and animal deaths must be prevented. Intensive cultivation also takes place during wastewater treatment, but our goal is to achieve the right quality of discharged water. The nutrient is given – although its quality and quantity varies; the goal is to transform wastewater to maintain the bacterial community (to ensure their growth, to exclude inhibitory conditions). In the following chapters, we get an insight into the diverse world of microorganism, their metabolic pathways. We will discuss which groups of organisms participate in wastewater treatment and why it is so difficult to provide conditions suitable for all biological processes needed for the production of treated wastewater that meets requirements.

Metabolic types of prokaryotes

Microbes or microorganisms are living creatures invisible for the naked eye. These can be prokaryotic bacteria or eukaryotes with true nucleus. Organisms that are mostly unicellular and whose DNA is not surrounded by a membrane, i.e. they do not have a true nucleus, are called prokaryotes.

Before 1977, prokaryotes only consisted of bacteria, but later the group was divided into two taxa by Carl Woese and George E. Fox based on 16S ribosomal RNA analysis: Bacteria (bacteria) and Archea (stem bacteria). Thus, organisms are currently classified into three realms (domains), the third group being eukaryotes (true nuclei). The latter includes unicellular photosynthetic eukaryotes (most algae), unicellular animals, and multicellular plants, fungi and animals.

Prokaryotes are found everywhere in the world, their role is prominent and indispensable in the geochemical cycles of the biosphere, they also play a fundamental role in the nitrogen, carbon, and phosphorus cycle, without them most multicellular organisms would perish. Self-cleaning of waters is also largely due to the activity of prokaryotes.

Most bacteria are unicellular, 1–5 micrometres, bounded by a membrane, surrounded by a peptidoglycan cell wall. Their reproduction is asexual, dividing as the cell grows to a certain size, which is called fission. Their shape include chopsticks (bacillus), spherical (coccus), twisted (spirochaeta), filamentous, oval, but their morphological variability – compared to eukaryotes – is relatively small.

The basic properties of living things include metabolism, i.e. the exchange of energy, matter and information in the organism. Microbial metabolism is much more diverse than that of the higher order organisms and can also differ according to energy and carbon source, which is the basis for the practical grouping of bacteria, though it may not reflect their evolutionary relationship. Prokaryotic metabolism is very diverse, with energy production being the most varied. Several microbial metabolic pathways have developed which are not found among higher order organisms.

In humans, after nutrients enter the body (nutrition), the breakdown of starch by the amylase enzymes in saliva begins in the mouth (beginning of metabolic processes). Amylase is a so-called extracellular enzyme that, in this case, exerts its action outside of the cell and cleaves the chemical bonds in starch (a large-molecule biopolymer) to produce smaller molecules. Breakdown of various macromolecules continues in the stomach and intestine. Through the intestinal wall, the already decomposed, smaller size nutrients are absorbed and reach the cells through the bloodstream. Through the cell membrane, substances enter the interior of the cells by active or passive transport.

In general, unicellular organisms cannot absorb large organic molecules (polymers) directly either (with the exception of e.g. DNA). With the help of their extracellular enzymes, they partially break them down and then transport the smaller molecules into the cell by transport processes.

It is very important to note that breakdown can mean several things. It may refer to the breakdown of cells, organelles, extracellular or intracellular molecules or to their transformation. During the digestion of nutrients, multicellular organisms break down macromolecules into smaller units by extracellular enzymes, thus they are easily taken up by the cells.

Biodegradation refers to the activity of decomposers that produce smaller organic or inorganic substances from organic matter in the environment. In the first step of biodegradation extracellular enzymes play an important role, they cleave macromolecules into smaller ones that are easier taken up by the cell and become part of the intermediate metabolism (see below). The leading role in this process is played by heterotrophic decomposers, primarily bacteria and fungi.

Every living thing, in addition to synthesising molecules and building itself from them, it is also able to break them down. In this case, degradation processes are defined as dissimilation that takes place in each cell, during which the cell converts and breaks down macromolecules that it has built itself.

Whether a living cell is unicellular or multicellular, metabolic processes in the cell are called intermediate metabolism.

The intermediate metabolism consists of two *biochemical* process system:

- *biosynthesis* (assimilation, anabolic processes), require energy
- *degradation* (dissimilation v. catabolic processes), produce energy

The energy needed to build cell constituents comes from outside of the cells, either as light energy, which is eventually converted to chemical energy as a result of the conversion of compounds in the cell, or by the conversion of compounds into chemical energy. In both cases ATP (adenosine triphosphate), the central metabolic currency is produced, which is the main energy storing and transport molecule of living organisms.

According to the *energy source,* living organisms can be:

- *phototrophs* (photosynthesis)
- *chemotrophs* (chemosynthesis)

Every living organism has an internal space separated from its environment, in which it maintains relative constancy (homeostasis) by regulated and controlled processes through its metabolic processes. During metabolism, a number of chemical reactions take place; some of them involve redox processes, i.e. electron exchange. The substance that releases the electron is oxidised (this is the reducing agent, the oxidation number increases), the compound that gains electron is reduced (this is the oxidising agent, the oxidation number decreases).

Metabolism (ultimately living organisms, too) can be characterised by the initial electron-donating compound (an electron source, also known as an e-donor).

If the *electron donor* is an:

- organic compound: the metabolism and the organism is *organotrophic*
- inorganic compound (e.g. H_2, NO_3^- SO_4^{2-}): the metabolism and the organism is *lithotrophic*

Organisms are also distinguished on the basis of terminal *electron acceptor:*

- *aerobic respiration:* O_2 is the electron acceptor
- *anaerobic respirators,* the inorganic electron acceptor may be:
    - oxygen containing inorganic compound (e.g. NO_3^-, sulphate reducing agents: SO_4^2)
    - other inorganic compounds (e.g. H_2S, NH_3, S^{2-}, Fe^{2+}, H^+)
- *fermentation:* organic matter is the electron acceptor (note: these are anaerobic organisms and the e-donor is also organic)

Organisms need carbon to build their cellular materials.

Based on the starting compound, *carbon sources* can be:

- inorganic carbon (CO_2, HCO_3^-, CO_3^{2-}): autotrophic assimilation, *autotrophic* organisms
- organic carbon (C-C bond): heterotrophic assimilation, *heterotrophic* organisms

Based on the types of metabolism described above, organisms can be divided into eight groups:

Table 4
Groups of organisms (compiled by the authors)

Energy source	Electron donor	Carbon source (organic or CO_2)	Name
Light Photo-	Organic –organo-	heterotrophic	1. Photo-organo-heterotrophic
		autotrophic	2. Photo-organo-autotrophic
	Inorganic –litho-	heterotrophic	3. Photo-litho-heterotrophic
		autotrophic	4. Photo-litho-autotrophic
Chemical bonds Chemo-	Organic –organo-	heterotrophic	5. Chemo-organo-heterotrophic
		autotrophic	6. Chemo-organo-autotrophic
	Inorganic –litho-	heterotrophic	7. Chemo-litho-heterotrophic
		autotrophic	8. Chemo-litho-autotrophic

Photosynthesisers convert the radiant energy of the Sun, i.e. the light energy, into chemical energy. Prokaryotic and eukaryotic organisms are also capable of photosynthesis. Phototrophic organisms are usually also autotrophic, as their majority use an inorganic C source, carbon dioxide and its dissolved forms to produce organic compounds. In green plants, under the influence of light, water molecule releases electron (-litho-: electron donor is inorganic), the electron acceptor is oxygen, so the plants are photo-litho-autotrophic, aerobic organisms (Table 4, Group 4).

Cyanobacteria also mainly use this form of metabolism, sequestering carbon dioxide in light conditions and oxygen-rich environments. Most of them are obligate oxygen-producing aerobic photo-litho-autotrophs (4). Several species can switch to anoxic photosynthesis in the presence of sulphide (4). Most of their species are able to survive in the dark as aerobic heterotrophs (5). In this case, they mainly degrade sugars, such as glucose, sucrose and fructose. Cyanobacteria are able to bind atmospheric nitrogen, thus, in many cases they cause water blooms, as the lack of inorganic N source in their habitat (water, soil) does not inhibit their growth.

In surface waters, photosynthesis takes place in shallow lakes, river waters and in the top most layers of deep lakes (epilimnion, photolytic layer). Photosynthesisers play an important role in self-cleaning processes, their main significance is oxygen production; in addition, they incorporate inorganic salts into their bodies as nutrients.

Obligate (meaning: without exception, restricted) aerobes can only survive in the presence of oxygen, while obligate anaerobes only survive in an oxygen-free environment. Facultative anaerobes grow better in an aerobic environment, but are also capable of metabolism in the absence of oxygen. Aerotolerant anaerobes are unable to utilise oxygen, but it is not toxic to them. Microaerophiles exhibit maximum growth at environments containing lower levels of oxygen than that are present in the atmosphere.

Decomposition of organic matter in water can take place aerobically (in the presence of dissolved oxygen) or anaerobically (in the absence of dissolved oxygen). Dissimilatory reactions occurring in the presence of atmospheric oxygen are called biological oxidation or aerobic respiration, in the case of other inorganic electron acceptors (e.g. nitrate, iron) the decomposition processes producing carbon dioxide are called anaerobic respiration. Fermentation is a decomposition process in which anaerobic decomposition of organic matter produces an organic molecule rather than carbon dioxide (e.g. alcohol, lactic acid is the terminal electron acceptor).

The end products of aerobic degradation are the same as the starting compounds for organic matter production, ultimately CO_2 is produced. Aerobic respiration is a typical process in aquatic carbon cycle, which typically takes place in rivers that are not overloaded with organic matter, in shallow lakes, and in the top most water layer (epilimnion) of deep lakes.

Anaerobic conditions can develop in rivers and shallow lakes overloaded with organic matter, as well as in the lower water layer (hypolimnion) of deep lakes. During anaerobic degradation, the oxidation is incomplete and CO_2, CO, CH_4 and small molecular unsaturated organic compounds may be formed as final products. The latter, among other non-carbon compounds, contribute to the development of taste and odour problems in water.

In practice, engineers use the term anoxic conditions when free (dissolved) oxygen is not available, but there is bound oxygen (i.e. in nitrate, sulphate) in the water, which can be utilised by bacteria.

Biologists use the term anoxic condition when there is a lack of atmospheric oxygen.

Organisms may be able to switch between metabolic pathways. It can occur even in human cellular respiration: in the presence of oxygen, glucose is converted to carbon dioxide (glycolysis), while in the absence of oxygen (intensive exercise), glucose breakdown is partial, and pyruvic acid is produced by fermentation.

Mixotrophic organisms, depending on the environment, can use several pathways for optimal energy production. For example, some purple non-sulphur bacteria are also capable of photolithotrophic, photoorganotrophic, chemoorganotrophic respiration and fermentation. Interestingly, not only their mode of ATP production, but the source of reducing force changes, too, as well as they switch between autotrophic and heterotrophic anabolism.

Chemosynthesising bacteria gain their energy by oxidising various substances. With the exception of the aforementioned photosynthesis, primarily all organic matter is assimilated at this level in the food chain.

Heterotrophic organisms dominate in most ecosystems in both number and activity. They can only utilise organic carbon sources. Heterotrophic organisms also gain energy in two ways. Chemo-organo-heterotrophs (Table 4, Group 5) utilise chemical energy. During the self-cleaning of waters, microorganisms belonging to this group have the most significant role in the decomposition of organic matter (biodegradation), but most pathogenic bacteria are also chemo-organo-heterotrophic.

Under anaerobic conditions, some microorganisms may utilise bound oxygen (in nitrate, sulphate and possibly phosphate). Therefore, denitrification, sulphate and phosphate reduction activity may increase under anaerobic conditions. Which process takes place, depends on redox potential. As long as nitrate is present in the water, organisms utilise this source of oxygen (redox potential = –50 mV). For the reduction of sulphate and phosphate, –200 mV and –700 mV redox potential is needed, respectively. These reduction processes are performed by different microorganisms.

All heterotrophic organisms depend on other organisms for nutrition and depending on the type of food, ecology classifies several groups. For example: carnivores, scavengers, herbivores, parasites, symbionts. Symbiosis is a type of – not necessarily nutritional – interaction that provides benefits to both parties. Syntrophy is a commonly used term in microbiology and microbial ecology: a case of symbiosis where the growth of one species is dependent on the product of another species. A term often used in microbiology or microbial ecology. In water bodies, the flow of matter and energy is realised through syntrophic connections.

Biochemical processes of degradation

Communal wastewaters contain organic matter in large concentration, with a majority of macromolecules. Certain molecules undergo physical-chemical transformation e.g. by UV or react with other molecules in the environment. However, many molecules can only be transformed by biochemical processes in living organisms during which building materials and energy is obtained.

Cells, i.e. microorganisms, too, cannot directly take up large organic molecules in their native form, only after partial enzymatic digestion. Enzymes are biocatalysts, they catalyse, speed up biochemical reactions, most of them are protein like molecule.

Breakdown or biodegradation of organic matter starts with extracellular enzymatic mechanisms. These enzymes cleave biopolymers (proteins, nucleic acids, polysaccharides) and other large molecules (e.g. lipids) into their components, oligomers, monomers, which can enter the cell through the cell wall or cell membrane. Molecules taken up are further cleaved or transformed by intracellular enzymes.

During evolution, mutations resulted in numerous degradation pathways, but there are some conservative pathways that can be found in almost every living creature.

The most common types of enzymes are listed below:

- hydrolases
- oxidases
- transferases
- liases
- isomerases

These groups contain many specific and less specific enzymes. Degradation of macromolecules requires the cooperation of several enzymes. For example, the first step in the degradation of biopolymers is hydrolysis. Hydrolases cleave the substrate molecule by the use of water. In this process, the hydroxyl group of the water molecule is transferred to one part of the substrate molecule, while its proton is transferred to other part of the substrate. Glycosidases are responsible for the breakdown of glycosidic bonds in polysaccharides; proteases are responsible for the cleavage of peptide bonds in proteins, while esterases are responsible for the hydrolysis of ester bonds in triglycerides.

Decomposition of carbohydrates

Carbohydrates are composed of carbon, hydrogen and oxygen, they are important nutrient, carbon and energy sources. Monosaccharides are the simplest carbohydrates, such as fructose (fruit sugar), mannose, galactose, glucose, the latter can be found in the form of D-glucose (dextrose) in living organisms. The names blood sugar, grape sugar, or potato sugar refer to their origin, but chemically they are all glucose. Monosaccharides easily dissolve in water, can easily be taken up by the cells and incorporated into metabolic pathways. Disaccharides are composed of two monosaccharides and include the table sugar sucrose (beet sugar), lactose (milk sugar), maltose (malt sugar) as well as cellobiose, the building block of cellulose. The latter one cannot be broken down by the human body. Oligosaccharides are composed of 3–10 monosaccharides; some of them also cannot be degraded by the human body, but provides nutrition for the gut microbiome. Polysaccharides are giant molecules composed of monosaccharide units. Starch is one of the most common polysaccharides, stored as a reserve nutrient in plants and is composed of amylose and amylopectin units consisting of glucose monomers. Extracellular amylase enzymes in bacteria and fungi break it down into smaller units, which are further broken down within the cell during intermediate metabolism.

Pectin is a water-insoluble compound found in the intercellular space of plants. It is broken down by aerobic and facultative anaerobic bacteria as well as fungi.

Cellulose is composed of glucose monomers; it is the structural component of plant cell wall. Cellulose is the most abundant organic polymer on Earth, cannot be broken down by most living things.

Natural breakdown of cellulose begins with physical fragmentation (e.g. by arthropods: ace crabs, crustaceans, twins, insects, earthworms), by increasing the surface area it will be more accessible for degrading organisms (fungi, bacteria). Cellulose breakdown usually occurs in a microbial consortium by several extracellular enzymes, the produced subunits (cellobiose, glucose) can be taken up by the cells.

Bacteria species can utilise a wide variety of carbohydrates and enzymes needed for breakdown are synthesised according to the carbohydrates available.

During wastewater treatment, to maintain a microbial consortium that functions properly, stability and continuous nutrition supply are needed. Thus, small equipment only performs properly if they operate continuously. If the equipment does not get fresh nutrient in the form of wastewater for a few weeks, it is advised to supplement carbon source in an easily absorbable form, e.g. with sucrose (table sugar).

Degradation of lipids

Lipids have a highly variable chemical structure, their common feature is that they have a poor water solubility and are biologically degradable. Examples include phospholipids (cell membrane components), neutral fats (nutrient reserves, e.g. fats and oils), steroids (hormones, cholesterol, vitamin D), and carotenoids (carotene, lycopene, xanthophyll, vitamin A). The majority of lipids cannot be directly absorbed by the cell, their degradation starts by extracellular lipases. Lipid degrading organisms include fungi, e.g. *Rhisopus sp., Geotrichum candidum, Aspergillus niger, Penicillium cyclopium* and bacteria, e.g. members of the genera *Actinomyces, Mycobacterium and Pseudomonas.*

Although microorganisms are capable of degrading lipids, it is important to avoid pouring lipids, e.g. in the forms of used cooking oil, into drains. Plant based oils or animal fats form FOG (fat, oil and grease) deposit in sewers, which over the years decrease the perimeter of the pipe and may cause blockage in both domestic and communal wastewater sewers. Greasy substances cause a coating on the surface of living organisms, decreasing metabolism and may cause the decay of organisms, both microbes and higher order ones. In wastewater treatment plants, removal of floating grease and oil may be removed by mechanical treatment, i.e. grease and oil traps (see earlier).

Degradation of proteins

Proteins are polymers composed of amino acids. Approximately 500 natural amino acids are known, 22 of them are components of proteins and 9 of them are essential for the human body, i.e. humans cannot synthesise them, can only take them up by food. Proteins include enzymes, many hormones (e.g. insulin), structural proteins (e.g. collagen), muscle proteins (actin, myosin), transport proteins (e.g. haemoglobin), toxins (e.g. mushroom toxins, snake venom).

Heterotrophic prokaryotes (Pseudomonadales sp., Eubacteriales sp.) can utilise proteins present in their environment as nutrient and energy source. Without them, they start to break down their own proteins to cover the need for amino acids. Protein degradation also starts with the help of extracellular enzymes (proteases, peptidases); amino acid breakdown is completed inside the cell.

Xenobiotics

The majority of organic pollutants are xenobiotics for most organisms, i.e. they cannot be degraded, these compounds are foreign (= xeno) for their metabolic pathways. This should not be surprising, as the development of metabolic pathways occurred during evolution, when these substances were not available for the organisms to encounter. Some xenobiotics, however, can be biodegraded by the cooperation of certain microbes. Nowadays, it is a great concern that there are no protocols for detecting various substances and their presence in the environment is not regulated. The effect of many substances can only be hypothesised, but data are lacking. Xenobiotics can be inorganic, e.g. toxic metals, but according to the types of compounds and their amount, the number of anthropogenic organic micropollutants is several order of magnitude higher. They include the majority of pharmaceutical compounds, illicit drugs, personal care products, resistance genes, pesticides, lifestyle products, food supplements, surfactants, organic disinfection byproducts, combustion byproducts, organometals, and several other industrial chemicals (e.g. plasticisers, flame retardants, gasoline additives). Some xenobiotics are not toxic to the degrading organisms of wastewater treatment plants, but reaching the recipients, they can be absorbed and accumulated in freshwater organisms and may have severe environmental consequences. Others may be very toxic to microorganisms, may cause their decay, and as a consequence, wastewater treatment cannot be completed. Thus, it is very important to minimise the discharge of chemicals into drains.

The community of activated sludge

During biological wastewater treatment, organic matter degradation, transformation of nitrogen and phosphorous forms are performed by microorganisms that can be attached to surfaces or present inside the activated sludge. Activated sludge is an artificially created and maintained community; its members live in a close network of interdependence. The living community of activated sludge is made up of bacteria, ciliated unicellulars, flagellates, amoebas and multicellular organisms. These organisms occur naturally in wetlands, surface and groundwaters, rivers, lakes. The composition of the community is influenced by artificially created environmental conditions in the wastewater. Technological elements used during wastewater treatment, the design of sewerage and operational practice all influence the species composition of the developing activated sludge.

The main technological factors shaping the community include:

- composition of raw wastewater
- residence time of wastewater in the sewerage system
- biological load of activated sludge (organic matter content)
- dissolved oxygen concentration in the aeration basin
- temperature
- treatment of decanter and leachate
- practice of storing and dewatering sludge

The term activated sludge well describes the concept, because microorganisms that make up the sludge carry out the same life activities in the natural environment as in wastewater treatment plants, but in this artificial environment, the processes take place much faster with the help of different technological elements (e.g. intensive aeration).

In the United States, the name of the sewage treatment plant technologist is bug farmer. The concept delineates a biological approach to wastewater treatment, meaning that the technologist, like a livestock farmer, strives to create optimal living conditions for bacteria.

Bacteria

Bacteria provide the basis for the community of activated sludge. They make up the majority of sludge biomass. In the course of their life activities, pollutants in the effluent entering the sewage treatment plant are consumed and/or transformed, during which bacteria gain energy and multiply. They are able to remove nitrogen, carbon and phosphorus compounds in municipal wastewater.

According to their life activities, they can be divided into three main groups:

- chemo-organo-heterotrophic bacteria: bacteria capable of removing organic matter
- nitrifying bacteria: chemo-litho-autotrophic bacteria capable of biological nitrogen removal – the scientific name of ammonia oxidising bacteria starts with Nitroso- (e.g. *Nitrosomonas*, *Nitrosospira*, *Nitrosolobus, Nitrosovibrio*), while that of nitrite oxidising starts with Nitro- (e.g. *Nitrobacter, Nitrococcus, Nitrospina, Nitrospira*) prefix
- poly-P bacteria: bacteria capable of removing biological phosphorus

Activated sludge bacteria can be present in activated sludge in the following forms:

- free-floating bacteria: bacteria not yet incorporated into the flakes
- flake-forming bacteria: bacteria form a compact community capable of settling in water
- filamentous bacteria: special bacteria whose cells are organised into filaments

Ciliata

According to traditional taxonomy, the group of *Protists* used to incorporate unicellular eukaryotes. Unicellular organisms capable of photosynthesis and plant-like metabolism used to form the various algae groups. The *Protozoa* taxon consisted of heterotrophic organisms with metabolisms similar to fungi or animals, as well as many parasites and pathogens. Some species are able to perform both heterotrophic metabolism as well as photosynthesis, e.g. flagellate Excavata *(Euglenozoa).* The currently used phylogenetic classification is based on species relatedness based on their DNA sequence, which we will not discuss here in detail; for practical reasons, in this chapter we will also use the traditional nomenclature.

Ciliata is a group of unicellular Protozoa. They are named after the cilia distributed on their cells evenly or in fields to promote nutrition and change of position. Cilia are important members of the activated sludge's food web and usually dominant in the unicellular fauna of activated sludge, thus, having a prominent role.

The main diets of ciliated unicellulars are bacteria; therefore, by consuming the bacterial population regularly, they promote their continuous renewal. There are also species that consume their own protozoa counterparts, but the ciliates themselves can also fall prey to wheelworms and other predators. In the activated sludge of sewage treatment plants, we can divide ciliated organisms into two main categories: planktonic and sessile ciliates.

Planktonic ciliated unicellulars swim among flakes formed by bacteria in search of their food, which can be free-floating bacterial cells not yet incorporated into flakes, or poorly attached organic matter on the surface of flakes, possibly living or dead bacteria. The ciliates that graze on the surface of flakes maintain flakes, because their activity help the continuous renewal of the outer surface of flakes and the formation of round, compact flakes with good settling (e.g. *Aspidisca cicada, Holophrya sp., Colpidium sp.*).

Sessile ciliates live anchored to the flakes with a stem and consume planktonic bacteria and organic debris in the space between flakes. With this activity, they allow the incorporation of contaminants with small size into the sludge that would otherwise leave the wastewater treatment plant with the treated water. Some of their species form colonies, connect to the flake with a central stem and then this stem branches and allows multiple cells to attach (e.g. *Epistylis sp.*).

Cilia are indicators of well-functioning activated sludge; their stocks of 5,000–10,000 individuals/ml usually indicate optimal conditions, while a smaller and more monotonous species composition indicates poorer performance and poorer cleaning efficiency. Their complete absence suggests the presence of toxic substances, lack of oxygen, overload, or rot.

Amoebae

The amoebae are also members of the protozoan group. Their cell shape is amorphous, constantly changing, they move with the help of their jaws, during which the internal cell stock of the living organism, the cell plasma, simply flows into the cell membrane protruding at several points of the cell. Numerous species can live in activated sludge; different species can be of different sizes, ranging in size from a few micrometres to as large as 7–800 micrometres. The most common species found in activated sludge are Mayorella sp., Amoeba proteus, or Arcella sp.

They are unicellular, simple in cell structure, surrounded by a thin membrane, the cell membrane. They are creatures with pseudopodia that do not have a flagella or cilia and ingest food with the help of their pseudopodia. Thus, under a light microscope, food-containing cavities (vacuoles) can often be seen in them.

Their diet is heterotrophic, that is, they build the material of their own cells from organic matter derived from the consumption of the cellular materials of other living things. Their presence indicates high concentrations of organic matter in the aqueous phase of the sludge in dissolved form.

Amoebae have one or more true nuclei and reproduce by mitosis. During mitosis, the gene pool of the cell doubles and then divides. The genetic stock of the two cells formed during the process is the same, which is why mitosis is called numerical division.

We distinguish two large groups of amoebae found in activated sludge: testate and non-testate amoebae. The cell structure of testate amoebae is exactly the same as that of non-testate amoebae, but they build an outer shell around themselves of iron and manganese. Their cover is yellowish in colour, which can range from quite pale to dark red.

Non-testate amoebae can be observed floating freely between activated sludge flakes, consuming bacteria, protozoa and organic debris not incorporated into flakes. Testate amoebae feed on debris and organic matter in the sewage flowing through the pores found in their testate into the cells.

Flagellate

Flagellate is a group of unicellular, protozoan organisms. They got their name from their characteristic whip-like appendages called flagella. Depending on the species, they may have one or a few flagella, with which they perform locomotion and orient themselves in their environment. They have a true nucleus and divide by mitosis. Their size is 1–200 micrometres. In the artificial ecosystem of wastewater treatment plants, they feed on organic matter and bacterial cells in wastewater.

Countless flagellate species can survive and reproduce in the activated sludge of sewage treatment plants. Small flagellates, e.g. *Bodo sp.* (size 10–20 micrometres), move with a characteristic somersault movement, while the colourless Euglena in the larger size range, e.g. *Peranema sp.* (size 50–100 micrometres) swim with their flagella extended forward.

They can be used to monitor operational efficiency of wastewater treatment plants, as changes in their numbers provide significant information.

At the beginning of the commissioning of wastewater treatment plants, their numbers are always large, approximately 10–50,000 individuals/ml, but under normal operating conditions, they are pushed into the background or even disappear from the ecosystem.

Most of the species living in the aeration basin are indicators of heavy pollution and high loads, so their proliferation during normal operation indicates rotting processes and a sudden increase in biological load, which may be caused by the following:

– excessively long storage time of removed sludge, from which the leachate returning to the technology contains a large amount of reduced S-bonds formed under anaerobic conditions as well as organic acids
– improper mixing of some reactors (sludge settles here and anaerobic rotting begins)
– permanent organic matter overload
– poor oxygen supply, defective aeration elements, reduced oxygen dissolution

Multicellular organisms

They are highly organised organisms that are very different from the protozoan organisms discussed so far. Cells of multicellular organisms form tissues, tissues form organs, and organs form organ systems. The multicellular community of activated sludge is formed by multicellular animals

(Eumetazoa), plants and fungi are not typical. Their size ranges from 50–100 µm to a few mm. Some *Nematoda sp.* can even be seen with the naked eye under the slide. Identification of higher order taxa is quite easy owing to their easily identifiable identification marks.

Their diet is heterotrophic, they can be carnivorous feeding on bacteria, flagellates, ciliated unicellulars, or their smaller multicellular counterparts, but most of them are omnivorous. They form the top of the food chain of activated sludge organisms, their dominant groups include nematodes *(Nematoda),* roundworms *(Rotifera, Rotatoria),* and ringworms *(Oligochaeta),* although in low load systems gastrotrichs *(Gastrotricha)* and tardigrades *(Tardigrada)* may also appear.

Although their reproduction is typically sexual, the majority of known roundworms is female, they multiply by parthenogenesis. The eggs are often observed in the body of the mother and also among flakes.

The number of metazoan is much lower than that of protozoa, as their reproduction takes significantly longer. Typically, 1–10 individuals can be observed in a droplet (30 µl) of activated sludge sample.

They live mainly in stabilised (old) activated sludge, so they are considered to be its characteristic indicator species. Through their filter feeding, they reduce the number of bacteria outside the flakes as well as they regulate the size of flakes. By loosening the structure of flakes, they increase oxygen supply to the inner areas. Excessive proliferation of multicellular species is undesirable, because with their active movement and nutrition they can prevent the formation of flakes and damage flake structure.

They are usually sensitive to environmental influences (especially toxic substances); decrease in their number of individuals is indicative of the decrease of the sludge age or the presence of toxic substances.

Biochemical processes of activated sludge

The function of municipal wastewater treatment is to purify drinking water contaminated by residential use. The removal of three main components is key during treatment: organic matter, nitrogen and phosphorus.

Phosphorus removal

Biological removal of phosphorus is called bio-phosphorus elimination, in which poly-P bacteria trap phosphorus in their cells. In addition to biological phosphorus removal, wastewater treatment plants often use chemical phosphorus removal using an inorganic coagulant.

When treating the sludge cyclically under aerobic and anaerobic conditions, certain groups of microorganisms (so-called poly-P bacteria) can be encouraged to take up significantly higher amounts of phosphorus and, thus, remove it with the excess sludge. In the aerobic phase, properly developed poly-P bacteria capable of removing excess phosphorus are capable of storing high concentrations of phosphorus in their intercellular stock in the form of polyphosphate.

In an anaerobic environment, however, the stored polyphosphate is depolymerised and released into solution, while the cell is able to absorb simple organic nutrients using the energy obtained from depolymerisation. The anaerobic medium is as stressful for poly-P bacteria as it is for “normal” aerobic bacteria, but they have a selective advantage due to the above-mentioned nutrient uptake. Cells also utilise accumulated polyphosphate as a source of phosphorus and as an energy source in the energy-limited anaerobic medium. Only poly-P bacteria can store such a large amount of phosphorus and only under the outlined operating conditions.

Conditions needed for efficient bio-phosphorus elimination in activated sludge system:

- there should be sufficient, easily absorbed nutrients in the anaerobic system
- the recirculation sludge must be free of dissolved oxygen and nitrate
- the residence time of the sludge in the post-sedimentation should not be too long, because due to the anaerobic conditions the cells can release the absorbed phosphate

Bio-phosphorus removal is the most cost efficient form of phosphorus removal in wastewater.

Nitrogen removal

Nitrogen is removed by the decomposition of nitrogen-containing organic compounds, during which inorganic nitrogen compounds and ultimately nitrogen gas ($N_{2)}$ is formed. The process consists of three consecutive bio-reactions: ammonification, nitrification and denitrification. The nitrogen content entering surface recipients significantly damages aquatic ecosystems in many ways (e.g. ammonia is toxic to fish and nitrate is involved in eutrophication processes), thus, effective removal of nitrogen from wastewater is an essential requirement of modern wastewater treatment technologies.

Ammonification takes place during the breakdown of organic nitrogen containing compounds; in wastewater the process is usually characterised by bacterial enzymes.

Nitrification

Nitrification is the oxidation of ammonia to nitrate in a two-step process performed by chemo-auto-lithotrophic nitrifying bacteria *(Nitrosomonas sp., Nitrobacter sp.).* In the first step, Nitrosomonas bacterial species convert ammonium to nitrite, and then in the second step *Nitrobacter* species convert nitrite to nitrate.

The first step of nitrification (conversion of ammonium to nitrite, *Nitrosomonas sp.*):

$$2\ NH_4^+ + 3\ O_2 = 2\ NO_2^- + 4\ H^+ + 2H_2O + 550\ KJ$$

The second step of nitrification (conversion of nitrite to nitrate, *Nitrobacter sp.*):

$$2\ NO_2^- + O_2 = 2\ N_3^{2-} + 150\ KJ$$

The overall reaction *(Nitrosoman sp.* and *Nitrobacter sp.):*

$$NH_4^+ + 2O_2 = N_3^- + 2H^+ + H_2O + 350\ KJ$$

Nitrification is uninterrupted under suitable environmental conditions. In this case, nitrifying bacteria completely perform the oxidation of ammonium to nitrate. Conditions for efficient, far-reaching nitrification require:

- adequate residence time: the maximum specific growth rate of nitrifying bacteria is approximately one order of magnitude lower than that of a microflora utilising highly biodegradable organic matter; in case of a water temperature of 15–20°C, it is necessary to maintain a sludge age of 5–7 days, while in winter at 10–15°C of water temperature this should be at least three times more, but there are considerable differences between small and large WWTPs in this respect
- suitable pH: pH 8–8.5 is optimal; based on pure culture experiences, the efficiency of nitrification is drastically reduced beyond this pH range
- adequate amount of available dissolved oxygen: practical experience shows that effective nitrification requires at least 1 mg/l dissolved oxygen and at most 3 mg/l can be used to increase nitrification efficiency
- suitable temperature: the optimum temperature for nitrification is 20°C; at lower or higher temperatures, nitrification efficiency decreases – the lowest limit is 12°C, below this, nitrifying bacteria are no longer able to multiply

Disturbed nitrification: if environmental conditions are not appropriate for nitrification, the oxidising capacity of nitrifying bacteria is reduced. In the nitrification process, the slowest and most sensitive process is the oxidation of ammonium to nitrite by *Nitrosomonas sp.,* so nitrite never accumulates in treated wastewater because *Nitrobacter sp.* species rapidly oxidise it to nitrate.

Denitrification

Nitrification is also known as nitrate respiration or nitrate reduction. The process of conversion of nitrate ion to elemental nitrogen gas is the third and final major step in the decomposition of nitrogen-containing organic compounds by facultative anaerobic and heterotrophic denitrifying bacteria. Denitrification is a special form of respiration in which the electron acceptor is nitrate ion instead of oxygen. Organisms performing denitrification do not belong to a single group, either morphologically or biochemically. Bacteria capable of denitrification include the *Bacillus* genus, certain genera of the *Micrococcaceae* family, *Pseudomonas aeruginosa,* or *Thiobacillus denitrificans.*

In case of activated sludge treatment, denitrification takes place in the so-called anoxic basins or reactors and requires *anoxic conditions.* The anoxic tank is one of most cost efficient ways to break down high organic matter content in raw wastewater. The energy demand of an anoxic tank is significantly lower than that of an aeration tank, so the primary goal of wastewater treatment technologists is to ensure organic matter is decomposed under anoxic conditions.

The denitrification process in brief:

$$NO_3{}^{2-} \rightarrow NO_2{}^{-} \rightarrow NO^{-} \rightarrow N_2O \rightarrow N_2$$

Denitrification equation:

$$\text{Organic matter} + NO_3{}^{2-} \text{– Organotrophic bacteria} \rightarrow CO_2 + N_2$$

Conditions for denitrification to take place:
- nitrogen must be present in the form of nitrate (or nitrite)
- dissolved oxygen-free environment (in practice this means that dissolved oxygen concentration on the reactor feed side is negligible, maximum 0.1–0.2 mg/l)
- the presence of degradable organic matter as a carbon source

Denitrification can be inhibited by high concentration of dissolved oxygen in the sludge recycled from the aeration tank. In this case, anoxic condition does not develop; *facultative anaerobic bacteria* will use free dissolved oxygen instead of using nitrate oxygen. Thus, nitrate concentration in the treated wastewater may exceed environmental limits.

Removal of organic matter

Organic matter may be removed in aerobic, *anoxic* or anaerobic ways. They are oxidised aerobically in the aeration tank and anoxically in the anoxic tank as a result of organotrophic bacteria function. From a technological point of view, it is more desirable to implement anoxic decomposition, as this can be achieved with significantly lower operating costs and also reduces nitrate concentration in the treated wastewater. During biological phosphorus removal, poly-P bacteria also incorporate organic matter into their cells in the anaerobic medium.

Biological processes of individual wastewater treatments

Similar processes take place in small wastewater treatment plants, as described in previous chapters, and the microbial community is similar. The biggest difference between the operation of small equipment and sewage treatment plants is coming from, as it is also obvious to non-professionals, their size. Even in a large plant, technological conditions can occur, which can disrupt the operation of activated sludge, therefore continuous, daily inspections and monitoring should be carried out. Changes in temperature, composition of incoming wastewater, and of oxygen content of wastewater can result in a radical change in the composition of activated sludge in a short time. In wastewater treatment plants, the amount of wastewater is relatively large compared to a small plant, which means that the effect of influent toxic substances can be less drastic due to dilution. In case of small equipment, however, drug residues, dishwashing detergents, cleaning agents and disinfectants can inhibit the growth of bacteria even in small amounts, thus, the efficiency of decomposition. Any material that is not biodegradable should not be allowed to enter drains, only materials that we would safely pour into surface waters.

Chemical wastewater treatment

From the first decade of the last century to the middle of the century, wastewater treatment plant with activated sludge system were designed to remove organic materials causing oxygen overload to recipients. However, treated waters containing phosphorus and nitrogen discharged into recipients have caused problems, as microorganisms can only absorb a fraction of nutrients (ideal ratio is C: N: P = 106: 16: 1). Excessive organic and inorganic nitrogen and phosphorus nutrient load accelerates eutrophication. The concentration and limiting factor of existing nutrient sources should be taken into account when removing components. Among the necessary nutrients, primarily phosphorus can be controlled by precipitation from wastewater. In order to protect recipients, municipal treatment technologies must be supplemented with technological stages that can ensure the implementation of regulation 28/2004 (XII.25.) KvVM.

Thus, in addition to the biological stage, in most cases chemical treatment is used (e.g. in industrial wastewater treatment, heavy metal contamination, to improve sedimentation properties, for phosphorus removal, etc.). The purpose of chemical purification is to remove phosphorus (to protect vulnerable recipients), as well as to remove sulphide, suspended and organic matter.

Chemical phosphorus removal

Chemical treatment is mainly used for phosphorus removal, which is more cost effective than biological purification. After biological purification, organic matter decomposes and most of the phosphorus is present in a soluble form (in small amounts it is present in suspended solids as well).

There is a very low concentration of phosphorus in natural waters (it can also be formed from the weathering of rocks and from the bones of vertebrates). Phosphorus gets into wastewater mostly by anthropogenic effect e.g. detergents, human metabolism. Phosphorus may enter the recipient by leaching of fertilisers, from precipitation, or other tributaries. The amount of phosphorus released per residents varies, the amount of which is influenced by our eating habits, but it can be averaged between 0.6–3.7 g/d.

There are three forms of phosphorus in raw sewage: orthophosphate ion, condensed (poly-, meta-, ultra-) phosphates, and organophosphorus compounds. The transformation forms of phosphorus are shown in Figure 9.

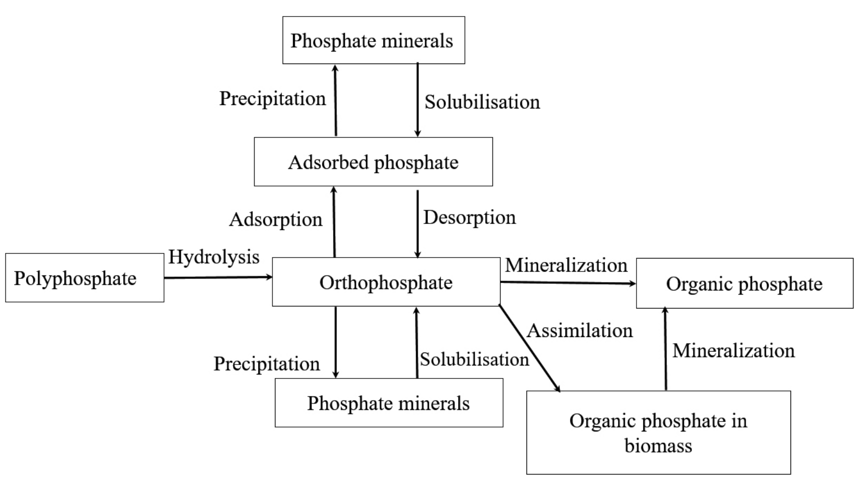

Figure 9
Phosphorus forms and their transformation products [8]

The various forms of orthophosphate are in equilibrium with each other, depending on the pH. Depending on the pH, the phosphate concentration of the system can be calculated by taking into account the solubility constant shown in Figure 10. The optimal pH range for metals is different. $FeSO_4$ and $AlPO_4$ are stable solid phases (based on equilibrium calculations); phosphate is precipitated in a low pH range, whereas calcium forms several insoluble phases with phosphate. When adding calcium compound, the amount of chemical needed and the pH of the system (keeping in mind the buffer capacity during design) should be taken into account.

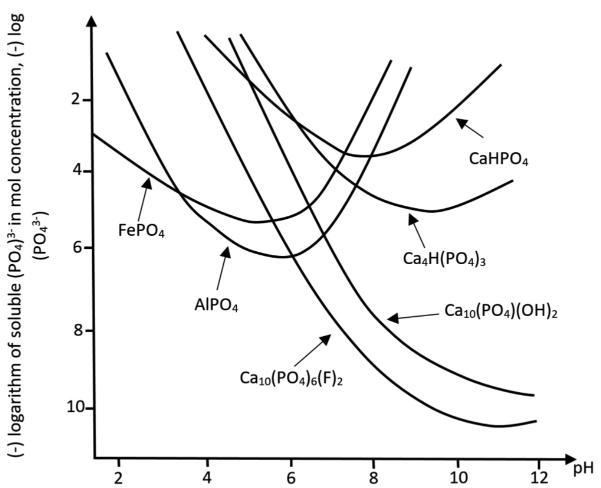

Figure 10
Solubility diagrams of different phosphates [9]

In wastewaters HPO_4^{2} occurs, thus, all phosphorus is detected gP/m^3, the value is independent of the phosphorus form.

Organophosphorus compounds form orthophosphate in which form it is the most easily precipitated. It is important to consider the amount of humic substances in the precipitation as they bind a large amount of Fe (III), thus delaying the deposition of phosphorus.

The process of the formation of metal phosphates consists of several steps:

1. After adding the chemical to the wastewater, a quick stirring for a few minutes is necessary to prevent the formation of metal phosphates or to prevent the formation of metal hydroxides. In addition to the formation of metal phosphates and metal hydroxides, carbonates are also formed.
2. Neutralisation (destabilisation) of colloidal particles with negative surface charge and clustering (coagulation) of the particles into larger units.
3. Adhesion of smaller particles to larger particles (macroflocculates), hydraulic residence time was previously 20–30 minutes. Nowadays, with chemical intensification and smaller pool volume shorter residence time of about 5 minutes can be achieved.
4. Sedimentation and removal of flocculated particles from the aqueous phase.

Factors influencing phosphorus precipitation:

- the quality and quantity of the chemical
- pH value
- raw sewage composition (PO_4-P, COD, dissolved COD, TSS, alkalinity (HCO_3,CO_3),Ca, Mg, etc.)
- mixing intensity
- contact time

The average phosphorus content of wastewater in Hungary is 7–20 g/l. Most divalent metal ions form a poorly soluble precipitate with orthophosphate ion (PO_4^{3}). The most common chemical precipitation method is the addition of aluminum salt.

Practical phosphorus precipitation is carried out using aluminum (Al^{3+}), iron (Fe^{3+}), pre-polymerised metal salt and calcium ion (Ca^{2+}). Effective removal can also be achieved by applying the chemicals together, e.g. polymers in combination with aluminum sulphate and lime.

Main aspects of chemical selection:

- concentration of influent
- suspended solids content
- alkalinity
- chemical costs
- sludge treatment equipment
- final sludge disposal
- compatibility with other treatment processes

Aluminum salts

Aluminum sulphate is the most commonly used among aluminum salts. When the chemical is added to wastewater, the pH is lowered due to the neutralisation of alkalinity and removal of carbon dioxide. The optimum pH for phosphorus removal is between 5.5 and 6.5. Aluminum reacts with the phosphate ion to form aluminum phosphate ($AlPO_4$).

Iron salts

Removal of phosphorus can be performed by e.g. iron (II)-sulphate, iron (III)-sulphate, iron (III)-chloride, all of which reduce the pH of wastewater. They are usually used in a pH range of 7–8, with the addition of lime or sodium hydroxide to raise the pH.

Advantages of applying iron salts and aluminum chloride:

- total phosphorus concentration in treated water can be kept within limits
- treatment efficiency and organic matter decomposition are more effective
- prevents the growth of filamentous bacteria
- increases the dry matter content of the sludge, improves the sedimentation and dewatering efficiency

Lime

Most often lime hydrate is used, resulting in larger amounts of precipitate and sludge to be treated. During lime dosing, the efficiency of phosphorus removal and the alkalinity of the wastewater must also be considered. Regarding the site of application, it can be used in the pre-settler and after the post-settler. Figure 11 shows the operating principle of the phosphorus removal system using lime precipitation.

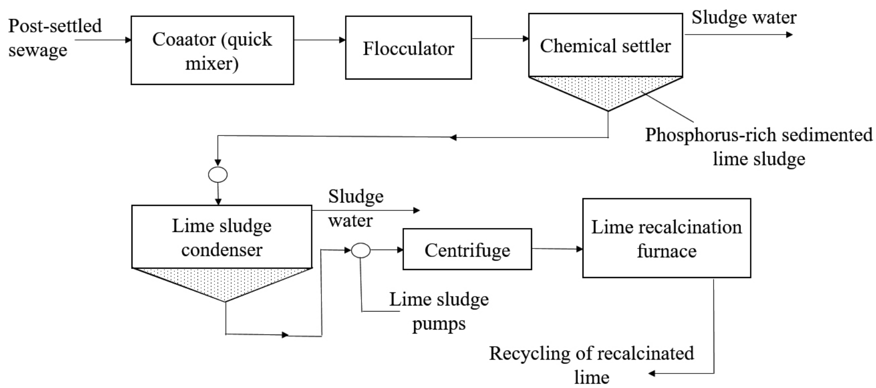

Figure 11
Principle of phosphorus removal by lime precipitation system [10]

The last step in lime precipitation is recarbonisation with one or two stages.

Depending on whether the wastewater treatment technology has biological treatment, several dosing options can be differentiated.

CEPT (Chemically Enhanced Primary Treatment) procedure

For non-biological technologies, we use this direct precipitation method. It is primarily used to increase suspended solid removal efficiency of settlers. The chemical ($FeCl_3$) is added to the grit unit.

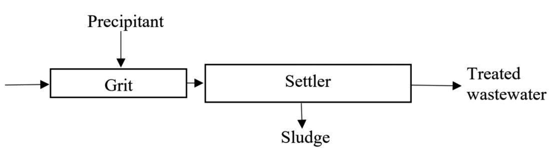

Figure 12
CEPT procedure (compiled by the authors)

Pre-, simultaneous and post-precipitation

Chemical wastewater treatment, either alone or in combination with biological treatment processes, is a more widespread solution. Depending on where the chemical is administered, the options for implementing technologies can be pre-, simultaneous and post-precipitation. It is important to consider the correct mixing of the chemical during application.

Phosphate precipitation can be characterised by the following equation.

$$Me^{3+} + PO_4^{3-} = MePO_4$$

Depending on the pH, the phosphate concentration in the system can be calculated from the solubility constant.

Dissolved phosphorus is converted to a solid by the addition of a chemical, which can then be removed according to the principle of phase separation.

$$Al(H_2O)_6^{3-} + H_2PO_4^- = AlPO_4 + 6H_2O + 2H^+$$

$$Al^{3+} + PO_4^{3-} = \mathbf{AlPO_4}$$

$$FeCl_3 + 6H_2O + PO_4^{3-} = FePO_4 + 3Cl^- + 6H_2O_3$$

$$Fe^{3+} + PO_4^{3-} = \mathbf{FePO_4}$$

Thus, based on the stoichiometry equations, 1 mol of a precipitant is sufficient for 1 mol of phosphorus. In practice, however, the amount of the chemical has to be increased because colloids react with metal salts to form iron hydroxide.

Pre-precipitation

The chemical can be added after the grit, into the pre-diffuser, and immediately before the pre-settler (Figure 13). If the chemical is applied before the primary settler, the biological treatment step should be considered, as it can greatly influence the denitrification process, namely less nutrient may remain in the wastewater and BOD_5 of the activated sludge pool may be reduced (by up to 50%). Chemical sludge is settled in the primary settler along with raw sludge, thus, its efficiency may increase (up to ~ 25%). There may be an increase in sludge index, which may cause floating in the post-settler due to the changes of the sludge structure (filamentous abundance).

All of the above-mentioned chemicals are applicable, but iron (II) salts must be prior oxidised in order to be efficiently removed in the primary settler. Pre-precipitation is used in municipal wastewater treatment plants that are overloaded, in a pre-development condition, or in industrial wastewater pretreatment.

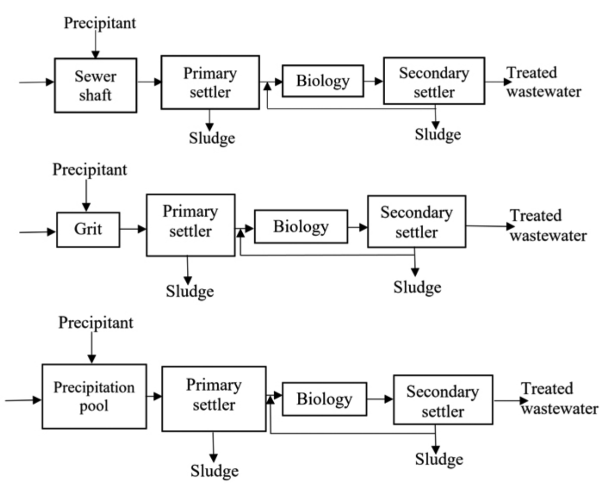

Figure 13
Optional sites for pre-precipitation [2]

Simultaneous precipitation

The most commonly used method is the addition of chemicals directly to the biological stage (possibly added to recirculated sludge). The advantages of the process include no need for building additional structure other than chemical dispensers (low investment cost), small space requirements, activated sludge with good sedimentation and adsorption capacity. The disadvantages of this process are that the chemical cannot be recovered and the phosphorus concentration of the effluent is higher. With the most commonly used technology, 1 mg/l phosphorus concentration can be maintained. Most of the chemicals listed are usable for simultaneous precipitation.

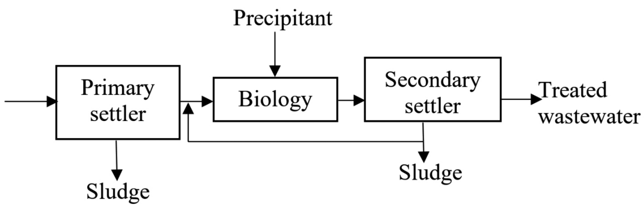

Figure 14
Simultaneous phosphorous precipitation [2]

Post-precipitation

Dosing is done after the biological step. Precipitation results in the formation of sludge, the amount of which depends on the chemical dose (2/3 of the sludge is chemical precipitate, 1/3 of it is organic colloid adsorbed on its surface). The method works reliably even under fluctuating hydraulic loads.

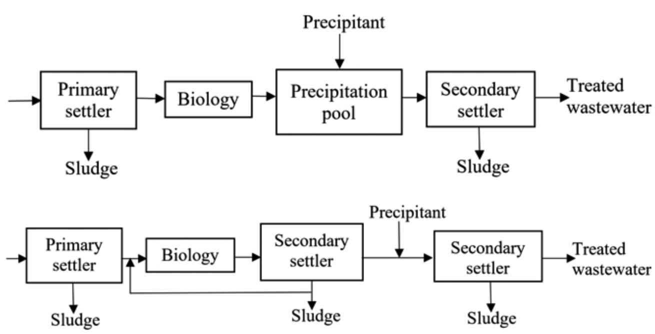

Figure 15
Possible injection sites for post-precipitation [2]

The efficiency of phosphorus removal changes in the technological phases:

- mechanical, biological and pre-precipitation 89% (influent wastewater 8 mg TP/l, effluent 0.9 mg TP/l)
- mechanical, biological and simultaneous precipitation 86% (incoming wastewater 8 mg TP/l, outflow 1.1 mg TP/l)

- mechanical, biological and post-precipitation 92% (influent wastewater 8 mg TP/l, effluent 0.6 mg TP/l)
- mechanical, biological and simultaneous precipitation, coagulation rapid filtration 96% (influent wastewater 8 mg TP/l, effluent 0.3 mg TP/l)

Maintaining the correct pH range is an important consideration for the high efficiency of precipitation and flocculation. The degree of control also depends on the chemical used. For control, acids can be added (e.g. H_2SO_4), that does not cause sludge formation. The addition of excess amounts of metal salt can also be an effective control with the disadvantage of greater sludge formation.

Chemical nitrogen removal

There are several methods for removing excess nitrogen (ammonia) from wastewater, which are the following [1]:

- Precipitation: precipitation of ammonia in the form of $MgNH_4PO_4$, optimum pH 8 (possible with high efficiency), MAP (magnesium ammonium phosphate) is used as precipitant
- Removal by ion exchange from wastewater (a continuous disadvantage of the process is that contaminants can enter the washing water, which are sensitive to suspended and dissolved organic pollutants in biological wastewater, can also clog their mechanical system, and even be chemically contaminated)
- Ammonia stripping, blowing after alkalisation of water (pH about 10)

The specific costs of the above-mentioned methods are high and are therefore less widespread.

Sludge treatment

In the last few decades, wastewater treatment has gone through significant development. However, treatment and disposal of sewage sludge, which is a byproduct of wastewater treatment, did not keep up with this development. As the sanitation and wastewater treatment program progresses, the amount of sewage sludge in Hungary is expected to increase in the upcoming years.

In the various operating units of the treatment process, residues (sand, screenings, floating materials, sludge) are formed, among which the largest mass and volume is sludge.

The type, quantity and nature of residues will depend on:

- the load of treated wastewater, i.e. the amount of wastewater and the type of constituents and their properties
- the treatment processes used, their efficiency and the constituents transformed
- materials and energy used in the treatment processes

The following sludges can be distinguished by their location and state:

- primary sludge: sludge separated in the primary settler, its dry matter content is 2–3%, its nitrogen and phosphorus content is lower compared to secondary sludge
- excess sludge (secondary sludge): sludge produced during biological treatment, mostly it consists of water and is also derived from solid particles
- chemical sludge derived from chemical treatment (tertiary sludge): sludge separated during chemical sewage treatment

– mixed sludge: a mixture of primary and other sludges (excess or chemical) removed from the primary settler
– stabilised (digested) sludge: sludge removed from the system after stabilisation with reduced organic matter content and pathogenicity
– sludge water: water containing dry matter separated during dewatering of sludge

The sites of sludge generation are shown in Figure 16 depicting the technological longitudinal section of treatment with activated sludge system and pre-denitrification.

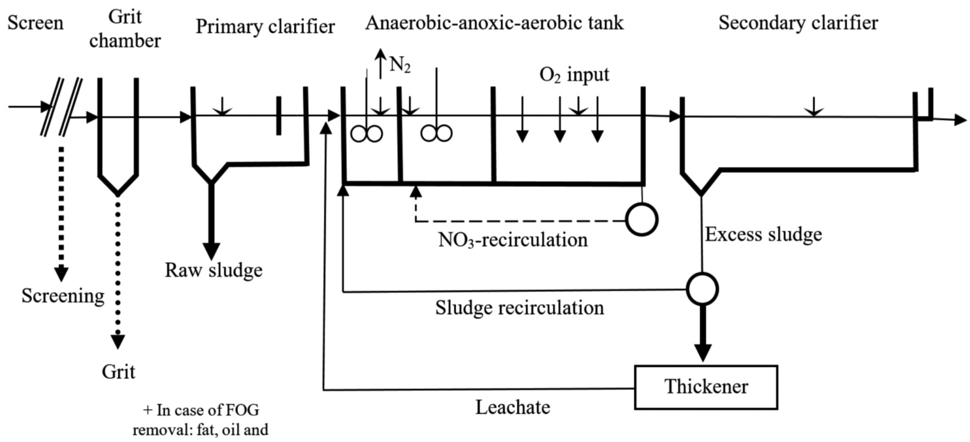

Figure 16
Sites of sludge generation in municipal wastewater treatment (compiled by the authors based on [11])

Wastewater treatment technologies determine, in addition to the composition of wastewater, the properties of residual materials as well. The major part of sewage sludge is water, which is present in three different forms in sludge (free water, bound water and intracellular water content). Based on the composition of sewage sludge, it can be divided into two groups, recoverable and inhibitory substances (Table 5). Table 6 illustrates the general properties of sewage sludge varieties.

Table 5
General composition of sewage sludge [11]

Recyclable materials	Sludge water	Free or easily removable sludge water
		Capillary water (20%)
		Moisture content of flock particles (2%)
		Chemically bound water in cells (8%)
	Crushed, ground mineral particles	Fine and coarse sand
		Other granular materials
	Organic compounds	Carbonaceous residues
	Nutrients	N
		P
		K
	Trace mineral	Metallic elements, organic chemicals

Substances that inhibit recycling (factors increasing risk)	Toxic substances	Heavy metals (Cd, Pb, Hg, Cu, Ni, Zn, Cr)
		Other Toxic Substances (As, Mo, Se, etc.)
	Pathogens	Bacteria
		Viruses
		Parasites
		Fungi
	Anthropogenic substances	Pharmaceutical compounds, personal care products, etc.

Table 6
General composition of sewage sludge varieties [12]

Typical parameters	Dimension	Sludge type					
		Raw sludge from mechanical treatment	**Excess sludge from biological treatment**	**Badly digested sludge**	**Moderately digested sludge**	**Well digested sludge**	**Fully digested sludge**
pH	–	5.0–7.0	6.0–7.0	5.6–7.1	6.8–7.3	7.2–7.5	7.4–7.8
Dry matter	%	5–10	4–8	4–12	4–12	4–12	4–12
Loss on ignition	%	60–75	55–80	55–70	50–60	45–55	30–45
Acid consumption	mg/l $CaCO_3$ mmol/l	500–1,000 20–40	500–1,000 20–40	1,000–2,500 40–100	2,000–3,500 60–140	3,000–4,500 120–180	4,000–5,500 160–220
Volatile acids	mg/l acetic acid mmol/l	1,800–3,600 30–60	1,800–3,600 30–60	2,500–4,000 * 40–70 *	1,000–2,500 15–40	100–1,000 2–15	< 100 2
Total N	% dry matter	2–7	1.5–5.0	1–5	1–3.5	0.5–3.0	0.5–2.5
Total P		0.4–3.0	0.9–1.5	0.8–2.6	0.8–2.6	0.8–2.6	0.8–2.6
Total potassium		0.1–0.7	0.1–0.8	0.1–0.3	0.1–0.3	0.1–0.3	0.1–0.3
Specific filter resistance	M/kg	10^{11}–10^{13}	10^{12}–10^{13}	5.10^{11}–5.10^{12}	10^{11}–10^{12}	5.10^{10}–5.10^{11}	10^{10}–10^{11}
Calorific value	kJ/g m_T	16–20	15–21	15–18	12.5–16	10.5–15.0	6.3–10.5

The physical properties of sewage sludge can be grouped according to water content:

- liquid (85–100%)
- viscous, non-pumpable (75–85%)
- mushy-plastic, viscous (70–75%)
- crumbly, often solid (40–70%)
- loose, very hard (10–40%)
- powder (10%)

The quality of the sewage sludge is characteristic of the given settlement and the treatment technology, so it may vary from one settlement to another.

The long-term load of 599 domestic agglomerations (602 wastewater treatment plants) is determined by Government Decree 25/2002 on National Municipal Wastewater Collection and Treatment Implementation Program and the VGT. The long-term aggregate load of agglomerations will be 12,041,042 PE (population equivalent) according to the government decree effective as of 21 November 2014. The long-term load of 236 settlements with lower than 2,000 PE is added to this and estimated to be 173,082 PE. The sum of the two gives the long-term sewage load of municipal wastewater treatment plants. Figure 17 shows the expected sludge volumes estimated by the Sewage Sludge Management and Recovery Strategic Program.

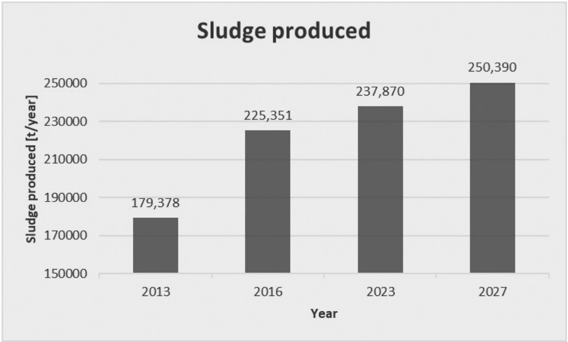

Figure 17
Expected sludge volumes in the upcoming years (compiled by the authors based on Sewage Sludge Management and Recovery Strategy 2014–2023)

Volume reduction and stabilisation procedures

Before sludge disposal, it is necessary to go through several technology units (thickening, dewatering, stabilisation, disinfection and heat treatment drying) in order to reduce its water content, its biodegradability and to decrease pathogenicity.

Sewage sludge treatment is defined as actions performed on the sludge generated at the sewage treatment plant to reduce volume and pathogenicity, and to improve manageability, recycling or disposal.

Further use or disposal determine how sludge is treated and require treatment:
- water content of sludges
- in wastewater treatment plants, the behaviour of similar types of sludge varies during different treatment processes
- presence of infectious (worms, pathogens, bacteria) and toxic substances

The most important steps of sludge treatment are:
- sludge thickening
- sludge conditioning and stabilisation
- disinfection
- dewatering
- disposal

Compaction

The first technological treatment of the primary and secondary sludge is compaction. The purpose of compaction is to reduce the volume of sewage sludge, which is intended to provide more favourable conditions for sludge incineration and disposal. To increase the efficiency of the technology, a polyelectrolyte or metal salt is added to increase solids content by up to 6–10%. Based on the compaction capacity of the sludge, three types can be distinguished, as shown in Table 7. The operator can calculate sludge volume reduction that can be achieved by compaction by taking into account the daily volume (l/d) and dry matter content (%) of pre-settled sludge.

$$daily\ dry\ matter\ content\left(\frac{kg}{d}\right) = volume\ of\ removed\ pre - settled\ sludge\ \frac{(l) * dry\ matter\ content\ of\ removed\ pre - settled\ sludge(\ \ )}{100}$$

Table 7
Sludge thickening and dewatering [11]

Sludge characteristics in terms of water content	Compaction without conditioning agents		Limits of dewatering					
			Belt filter press		Chamber press			
			Conditioning with polymer		Conditioning with iron salt or polymer			
					with lime		without lime	
	DS %	W %	DS %	W %	DS %	W %	DS %	W %
Easily compacting/dewatering sludges e.g. municipal sewage sludge from combined sewer	> 7	< 93	> 30	< 70	> 38	< 62	> 45	< 55
Moderately compacting/ dewatering sludges e.g. municipal primary sludge from segregated sewer system	4–7	96–93	18–30	82–70	28–38	72–62	35–45	65–55
Poorly compacting/dewatering sludges e.g. municipal secondary sludge	< 4	> 96	< 22	> 78	< 28	> 72	30–35	70–65
D – dry matter content								
W – water content								

Gravity compactor is a common technology used in municipal sewage treatment plants, but mechanical compactors are increasingly being used. The advantage of the technology is low specific investment cost. The technological elements of sewage sludge compaction are shown in Figure 18.

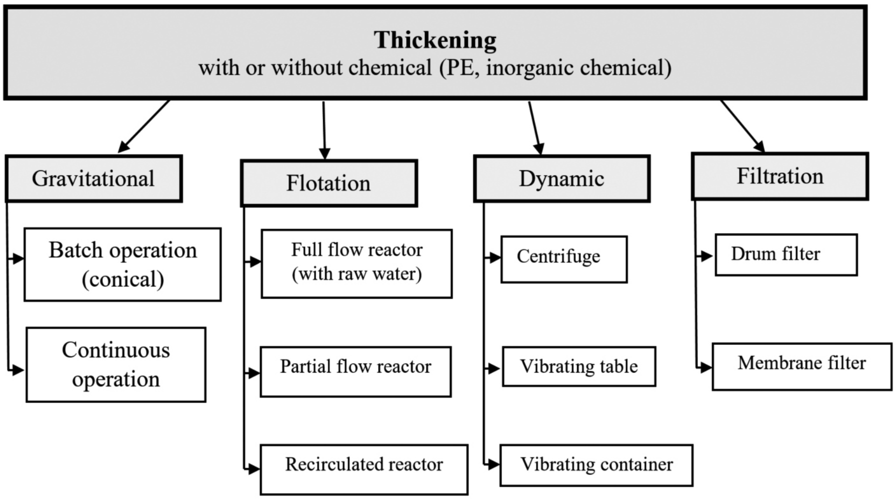

Figure 18
Technological elements of sewage sludge compaction [11]

Gravitational compaction

Gravitational compaction is practically another phase of sedimentation. It can be equally used for compacting raw, excess and mixed sludges.

In terms of structure, the following can be distinguished:

- intermittent – naturally operating “funnel compactors” (only under gravity, with or without sludge excavator and mixer, up to 5,000 PE, at least 2 parallel engineering structures are required)
- continuously operating – artificial “machine” operated (rod compactors, equipped with a mixer, structurally similar to radial flow settlers, used mainly in installations with a load above 5,000–6,000 PE, mainly used for secondary sludge compaction)

The difference between gravity settling and compaction processes is generally less well understood, though closely related. During compaction, the concentration of suspended solids increases as the solids get closer to one another. Compaction occurs in the bottom zone of the structures. During the process, solid particles are compacted by pressure from the weight of the particles above them. The site of sludge feed depends on the shape of the structure (circular – in the centre, rectangular – at one end of the pool). Compacted sludge is removed from the bottom continuously or periodically. Thickeners with circular base are more widespread, its design is illustrated in Figure 19.

The sludge inlet pipe directs the sludge into the zone above the compactor area, the sludge being introduced under the distribution cylinder flows radially into the sedimentation space, from where solid particles larger than liquid settle into the compactor space located at the bottom or into the bottom zone. The slowly rotating sludge excavator moves the compacted sludge into the sludge sump. By the slow rotation of the rods, settled sludge can be kept in slow motion, bridge-like flaking of sludge particles as well as sludge stratification can be prevented. Based on operational experience, drainpipe is a critical component of the compaction process as it has to extract high concentrations of sludge from the sludge sump. Gravity compactors are recommended to use up to

40m³/d of sludge (5,000 PE) before sludge digesters or dewatering equipment. The achievable dry matter content is 2.5–4% for batch operation and 3–6.0% for continuous operation compactors. The residence time of the sludge in the structure is approximately 6h. The operation of gravity compactors is mainly influenced by surface load.

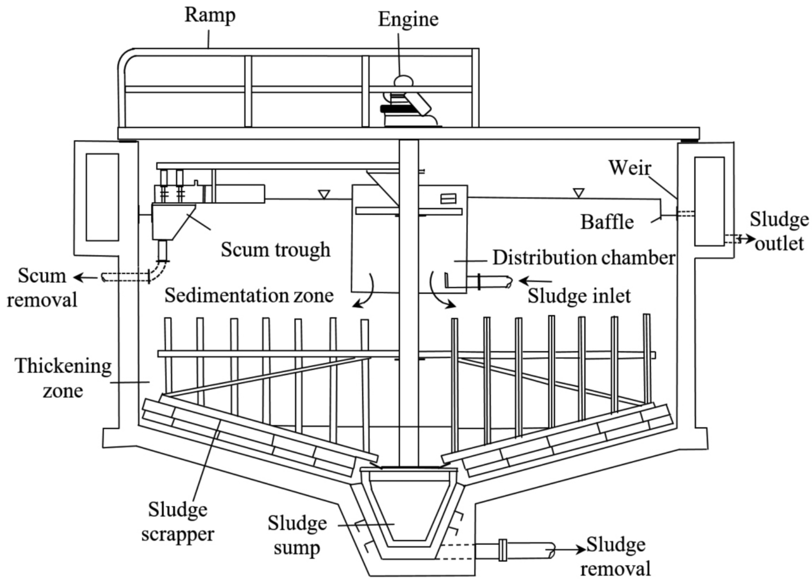

Figure 19
Gravity compactors with circular base [10]

The addition of the chemical improves the gravitational compaction of sludge by a few percent, among conditioners iron and aluminum salts as well as lime hydrates are used. The first two are more potent, the latter is a weaker coagulant. Charged organic polymers are more effective because of their dissociation moieties, since they hold the flakes together not only by hydrogen bond, but also by covalent bonding of the polymer chain. The amount of chemical needed is determined under laboratory conditions as the chemical significantly affects sludge properties.

Flotation

Flotation process is used to remove materials with a density lower than water. Separation of sewage sludge is achieved by the upward movement and flotation of air bubbles adhering to suspended particles. The attachment of bubbles, flocculation can also be improved by the use of chemicals mixed with the sludge.

Classification can be done by operating principle:

- gravitational operation (cheap to operate, but less efficient and requires a large reactor volume)
- forced air
- pressurised
- vacuum
- electroflotation (not used to compact sewage sludge)

The latter four are more efficient, require less reactor volume, but their operation is more expensive and requires expertise.

The flotation unit consists of a pressurised tank – flotation reactor – feed pump and air compressor, which are installed in various combinations due to economic aspects, shown in Figure 20.

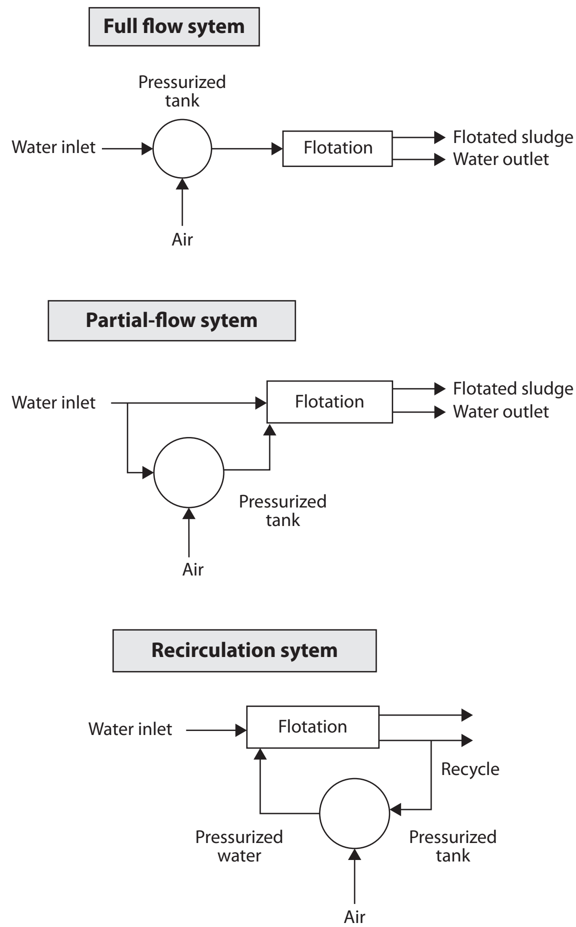

Figure 20
Flotation variations [13]

Factors influencing flotation efficiency:
- type of sludge
- air pressure (influences bubble diameter, dry matter concentration, as well as sludge quality exiting the compactor)
- feed sludge type (pre-settled sludge is generally heavier than post-settled sludge and is therefore more difficult to compact by flotation)
- sludge age (influences to a lesser extent, aged sludges tend to float naturally due to their gas-forming properties)
- recirculation rate (the recirculation fluid conveys air to the site of injection into the compactor)

– hydraulic and sludge load (in case of hydraulic load, the quality of the effluent sludge water is lower, the concentration of floated sludge decreases)
– air (A) solids (S) ratio (A/S, which is 0.02 during activated sludge compaction by flotation)
– thickness of the floated sludge layer and its dry matter content (increasing or decreasing the running speed of the scraping device results in a thinner or more concentrated sludge, respectively)
– chemical addition
– temperature

This is a less common procedure due to its mechanical components requiring more complex and expert handling. Areas of application are wastewater pretreatment units, they play a very important role in water pre-purification in the food industry, in wastewater treatment plants (for the removal of grease, oils, fibrous materials), and in sewage sludge compaction (rarely). Available efficiency is ~ 6% dry matter.

Mechanical compaction

Gravity compactors have been used primarily in municipal wastewater treatment, but recently the use of dynamic compactors is emerging. Dynamic compactors require the use of chemicals to optimise their performance. Even with the addition of a little chemical, 5–8% compacted sludge can be obtained, which is favourable for further treatment. Advantages of the compaction process include small compartment size, located in a closed space, operation is weather-independent, and its compaction efficiency is higher. Disadvantages include high operation costs, special, expensive machinery and chemical need. They can be mainly used at larger plants due to their high, variable "throughput" capacity.

The most commonly used equipment include:
– compaction centrifuges (also used for sludge compaction and dewatering)
– various shaking sieves (compaction tables)
– compacting separators
– mobile compacting (shaking) containers
– drum thickeners (operating on filter principle)

The most commonly used dynamic processes are drum thickeners, which are also used as a grid in small to medium plants, but are generally used in large plants to thicken excess sludge to increase dry matter content before digestion/stabilisation.

Filtering

Currently, the installation of filtration based sludge thickening equipment is only recommended for large plants and for special needs (due to the high costs of maintenance and filter elements). Available dry matter content is expected to be 10–15% depending on filtration. The most common methods are drum and membrane filtration.

Membrane technique is used by the industry in a number of areas, partly for separation and partly for compaction. The process is based on surface filtration that can be microfiltration, ultrafiltration, and nanofiltration. In the field of wastewater treatment, membrane filtration is intended to replace post-settling, but in special cases, it can also be used to thicken sewage sludge. Water passing through the membranes is free of bacterial contamination, thus, a costly disinfection system could be saved.

The efficiency and frequency of application of thickening processes are shown in Table 8.

Table 8
Thickening methods and their relative efficiency [10]

Procedure	Sludge type	Frequency of application and relative effectiveness
Gravity thickener	Primary sludge	Commonly applied. Sometimes (e.g. in industrial wastewater) it is used together with hydrocyclone for sand removal from the sludge.
	Primary and excess sludge	Often applied. In small plants, 4–6% of dry matter can be achieved.
	Excess sludge	Rarely applied. 2–3% of dry matter can be achieved.
Compressed air flotation	Primary sludge	Limited use. Its effectiveness is similar to that of a gravity thickener.
	Excess sludge	Commonly applied. 3.5–5% of dry matter can be achieved.
Decanting centrifuge	Excess sludge	Limited use. Good efficiency: 8–10% of dry matter can be achieved.
Tray centrifuge	Excess sludge	Its application is increasing. 4–6% of dry matter can be achieved.
Belt filter press	Excess sludge	Its application is increasing. Effectiveness: 3–6% of dry matter can be achieved.
Rotary drum dehumidifier	Excess sludge	Limited use. Good efficiency: 5–9% of dry matter can be achieved.

Conditioning

The goal of conditioning is to prepare the sludge for handling (utilisation or disposal) or to facilitate the efficiency of additional treatment steps. The purpose of conditioning is to improve dewatering, stabilise readily decomposing organic matter, to destroy, reduce pathogens and bacteria, and to improve densification and dewatering.

Small sludge particles require conditioning because they are hydrated (bind to water) and usually carry an electrostatic charge on their surface. The conditioning and exploration procedures are illustrated in Figure 21.

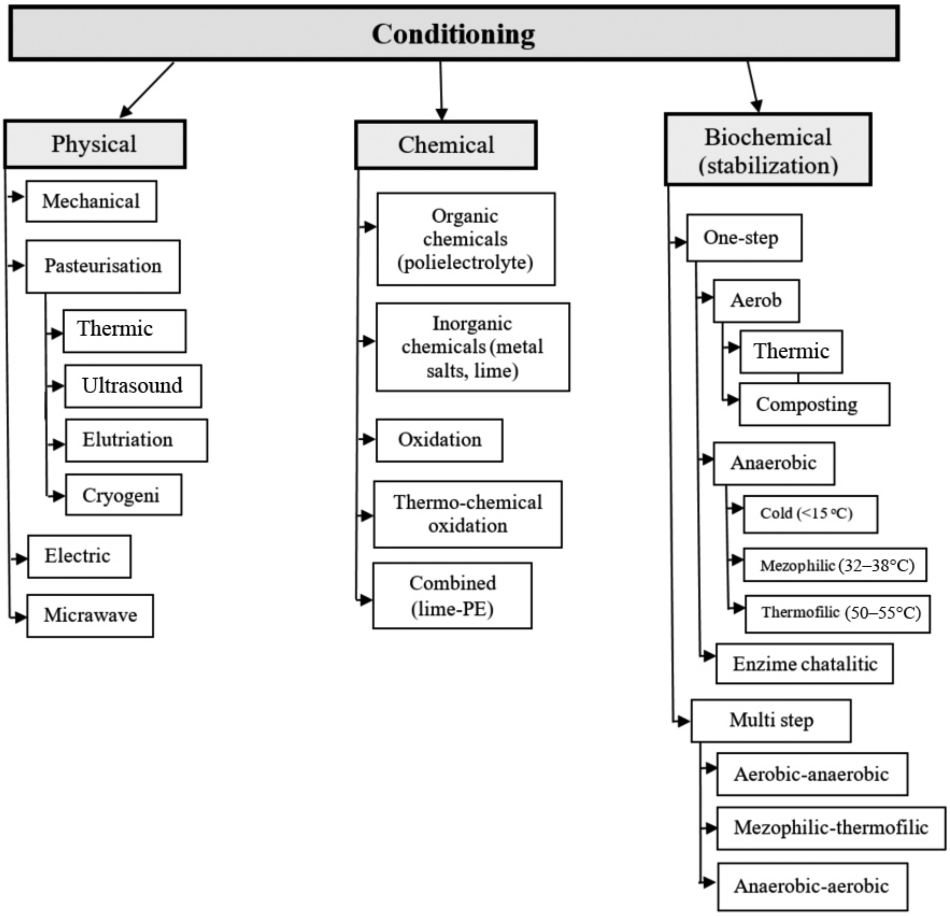

Figure 21
Main conditioning procedures [11]

Mechanical conditioning

It provides shredding of hard or fibrous materials, homogenisation of liquids, and protection of pumps and other equipment, which improves system reliability.

Mechanical digestion/conditioning techniques include shredders (macerators), mills, high-pressure collectors, rotor processes, high-pressure homogenisers and centrifuges (to reduce sludge viscosity for approximately 6%, increase in methane yield in the digester by 30–40% at most).

The advantages of mechanical exploration techniques include:

- simple operation and low investment cost
- increases enzyme activity and gas output
- improves dewatering
- reduces foaming in the digester
- reduces sludge viscosity

Pasteurisation

During the process, the aim is to reduce the number of pathogenic bacteria in raw or digested sludge used for agriculture (the process is carried out between 60–80°C and at a residence time of 15–30 minutes). In continuous operation, a two-stage countercurrent heat exchanger is generally used; the first stage serves the utilisation of heat from the preheating of pasteurised and raw material, while the second stage performs the actual pasteurisation. At larger plants, special reactors operate in batch mode; by increasing the temperature, pasteurisation time can be reduced. The method has been used less frequently because there is a potential for re-contamination in case of a delay in sludge incorporation time and it is expensive to build and operate.

Thermal process

Its purpose is to remove water bound in the cell by digesting the cell wall material of the sludge. Treatment is carried out at a high temperature (180–220°C) and under pressure, after which the sludge can be dehydrated to 40–50% solids by a chamber press and then used in an incinerator for heat production.

Benefits:

- cost-effective operation when based on waste-heat recovery
- improves gas output in the digester
- inactivates pathogens
- improves sludge dewatering (up to 50% dry matter content can be achieved by machine dewatering)
- reduces volatile organic fraction

Disadvantages:

- large amounts of toxic dioxin are produced on the heating surface (impair the efficiency of digestion and accumulate in the sludge as residues)
- the process also destroys enzymes of the biomass (a separately controlled recirculation is required)
- erosion problems
- odour problems (air purification is required)
- organic matter content of leachate is very high (excess load in liquid phase treatment)
- high investment cost

Combined methods of digestion are Cambi and BioThelys.

Ultrasonic procedure

The ultrasonic process produces a material with better filtration resistance for dewatering and also has a detectable disinfectant effect, thus, it is one of the intensive developments in conditioning technology. It has the advantage of being easy to install and operate, and also improves biodegradability (thereby biogas yield).

Washing of sludge (elutriation)

Washing results in the elution or dissolution of fine colloids. Its effect also results in a reduction of the chemical to be used (only used by large plants). Purpose of washing includes:

- reduction of bicarbonate alkalinity in sludge (acid metal salt requirement can be reduced)
- washing digested sludge dilutes sludge and reduces alkalinity
- reducing sludge alkalinity results in a reduction in the amount of lime required for pH control

The most important effect of sludge washing is to wash out 10–45% of fine sludge granules difficult to dewater, thus, improving sludge dewatering, although by directing it back to the beginning of the treatment plant, fine fraction removal is more difficult.

Freezing procedure

In the process, ice crystals break down cell walls, colloids preventing dehydration decompose. Natural winter freezing is used, because artificial cooling is not economical.

Electric conditioning

The sludge is directed into a pulsatile electrostatic space (20–30 kV) to achieve digestion of the sludge. Its advantage is short contact time, while its disadvantages are that large-scale application is not yet perfected and its electrical requirements are high. The method is not proven and rather inefficient.

Microwave conditioning

During microwave treatment, structural and flake forming properties of the sludge may also change.

During microwave energy transfer treatment, the following processes take place due to thermal effect:

- disintegration of sludge flakes
- cell membrane rupture
- hydrolysis of high molecular weight materials

In case of sludges from wastewater treatment technology using flocculants, sludge flakes disintegrate (fragment) in the first part of the treatment period, but due to the presence of flocculants, “reflocculation” mechanisms occur, flakes become more compact and their bound water content is lower than in the original flocks. Microwave processes use the frequency of 2,450 MHz and in some cases 918 MHz, though it is hardly used on large scale because of high costs in both operation and investment.

Chemical conditioning

The effect of chemicals (flocculants) is to improve dewatering and reduce the digesting capacity of the sludge.

Applied chemicals:

- organic chemicals (polyelectrolytes, prestole, zetag, hercoflock, etc.)
- inorganic chemicals (ferrous sulfate, ferric chloride, aluminum sulfate, aluminum chloride, ongroflock, lime, coal dust, etc.)

It is important to determine the appropriate amount of chemicals to be added because overdose, especially for polyelectrolytes, impairs efficiency. Selection of chemicals must also take into account the aspects of recovery and disposal.

Conditioning with organic chemicals

For dewatering of sludges, significantly greater volume reduction and dry matter content can be achieved by conditioning with polyelectrolytes compared to gravity compaction. Polyelectrolytes have a long chain structure binding the flake particles in a bridge-like manner with good efficiency. Polyelectrolytes have been adapted to all sludge conditioning tasks for the following reasons:

- a small amount (15–30%) of excess sludge is formed
- they do not reduce the calorific value of dewatered sludge
- conditioning material handling operations are cleaner
- operation and maintenance problems are reduced

In the field of conditioning agents, the development is continuous; according to the charge of ions, we distinguish three types of polyelectrolytes:

- anionic (negatively charged and used in combination with positively charged aluminum sulphate and ferric chloride)
- non-ionic (contain equal amounts of cationic and anionic polymers, charged are affected by the pH of the solution)
- cationic (positively charged, used alone or in combination with aluminum sulphate)

Cationic polymers are most commonly used to dewater sewage sludge.

The most commonly used inorganic conditioning chemical is ferric chloride, alone or in combination with lime.

- Iron (III) chloride. Upon addition to sludge, ferric chloride forms positively charged soluble iron complexes that attempt to neutralise the surface of negatively charged sludge particles, thereby providing flocculation conditions.
- Lime conditioning. Lime has a dehydrating effect on colloids and is selected for conditioning mainly due to its pH-regulating, odour-reducing and disinfecting properties. Heat generated by inoculating the lime has a disinfecting effect, inhibiting further rotting of the sludge (odour effect) for up to 2–3 months (until it decomposes). In small and medium-sized treatment plants, it is also used during temporary storage of sludge, while in larger plants it is also a preferred flocculant during chamber-filtered sludge dewatering. Lime is available in quicklime form (CaO) and hydrated form [$Ca(OH)_2$]. Hydrated lime is usually used in combination with ferric chloride.
- Oxidising agents. Oxidising agents used are ozone, hydrogen peroxide and oxygen. The advantage of the oxidation process is that it reduces the load on the digester. Disadvantages include high investment cost and significant pH shift.

Biochemical conditioning

In aerobic and anaerobic systems, bacteria further stabilise the sludge during treatment, converting it into simpler forms. Mixture sludge from pre-settlers and from systems using bound biomass and activated sludge is usually pumped into a stabilisation structure for further stabilisation.

Aerobic stabilisation is the "complete oxidation" of sludge, i.e. further aeration. Only 75–80% of the cellular material is oxidisable, the remaining 20–25% is inert and cannot be degraded. Its application is mainly recommended for small and medium capacity (2,000–7,500 m^3/year) plants.

Technology line: pre-compressed → blown mixed reactor → post-compressor.

According to the choice of reactor space, distinction must be made between "combined" and "separated" systems. A combined tank is a tank with significant volume requirement; treatment of the dissolved phase and complete (or partial) stabilisation of sludge takes place with relatively high energy consumption. In "separated" systems sludge (crude and excess activated sludge) separated during the treatment of liquid phase are stabilised separately similarly to the technological process described above, but in a significantly smaller reactor space.

Aerobic sludge stabilisation reactor can be batch-fed or continuous-fed. It is circular or rectangular in shape and open or closed depending on weather conditions.

Conditions of use:

- temperature of the mixture can be kept above +10°C at all times of the year
- periodic change of the load exceeds the ratio 1:2.5–1:3.0
- organic dry matter content of the sludge does not exceed 50 V/V%-o
- toxic industrial effluent inhibits the efficient operation of the anaerobic digester
- the result of energy test is favourable

Composting

Composting is a thermal aerobic process with the main purposes of stabilisation, dewatering and disinfection. On the sludge line, it is usually followed by dewatering.

Composting can be divided into three main parts:

- mesophilic period – appearance of mesophilic bacteria (yeast and other fungi), temperature rises to 50°C, decreases to pH = 4–5, time required: 0.5 days, during which fats, proteins and carbohydrates are broken down
- thermophilic period – thermophilic bacteria, temperature can rise up to 70°C, pH rises to 8–8.8, time required: 2–3 days, around 60–70°C all pathogenic microorganisms are killed within a few hours, except for a few spore-forming ones
- maturation stage – heat production slows down, because thermophilic bacteria have broken down available nutrients, compost gradually cools down, time required: 2–3 months

The composting process can be shortened by enzyme dosing and inoculation. It is only used in special cases due to high costs. During composting, the oxygen, moisture and nitrogen content in the organic matter must be measured (C/N ratio, the literature considers a ratio of 20:1–30:1 to be appropriate). Good compost is stabilised to such an extent that the likelihood of odour formation is greatly reduced, can be stored and transported.

Common fillers for sludge composting include:

- agricultural waste (peat, straw, shavings, shredded reeds, etc.)
- municipal solid waste (garbage)
- industrial waste (organic, non-toxic substances)

Favourable properties of compost include storage, transport, workability, favourable nutrient content, and compliance with health requirements.

The general composition of finished compost as a function of the range of occurrence is given in Table 9.

Table 9

General characteristics of finished compost [8]

Characteristics (g * 100 g^{-1} dry matter)	Occurrence range
Humidity	30–50
Inert substance	30–70
Inorganic content	10–30
pH (1:10 water mixture)	6–9
Alkalinity (as CaO)	1–20
Total salt (as KCl)	0.5–2.0
Maximum particle size (mm)	2–10
Elements (g * 100 g^{-1} dry matter)	Occurrence range
Humidity	0.1–1.8
$P(P_2O_5)$	0.1–1.7 (0.2–3.8)
$K(K_2O)$	0.1–2.3 (0.1–2.8)
S	0.5–3.0
Elements (mg * kg^{-1} dry matter)	Occurrence range
B	60–360
Cd	15–40
Cu	90–260
Fe	8,000–15,000
Hg	1–5
Mn	300–1,300
Mo	10
Pb	200–400
Zn	800–1,200

Based on their design, compost systems can be:

- prismatic, open system (batch operation, which can be manual or mechanical, mechanical mixing and mechanical air intake)
- compost, in landfills (instead of mixing, aeration through a perforated pipe system under the compost, continuous operation)
- tank, closed (small area, well controllable process, high investment cost, design: circle, square, tower or tunnel)

Autothermal Thermophilic Aerobic Sludge Stabilisation (ATAD)

Aerobic sludge stabilisation has developed significantly in recent decades. In the ATAD (Autothermal Thermophilic Aerobic Digestion) process, pre-compressed sewage sludge is transferred to aerated, thermally insulated reactors (heat is generated during aerobic decomposition of organic matter by microorganisms). The process also uses intermittently aerated mesophilic reactors operating in the temperature range of about 35°C to reduce ammonium concentration. The energy input and loss of an ATAD reactor is illustrated in Figure 22.

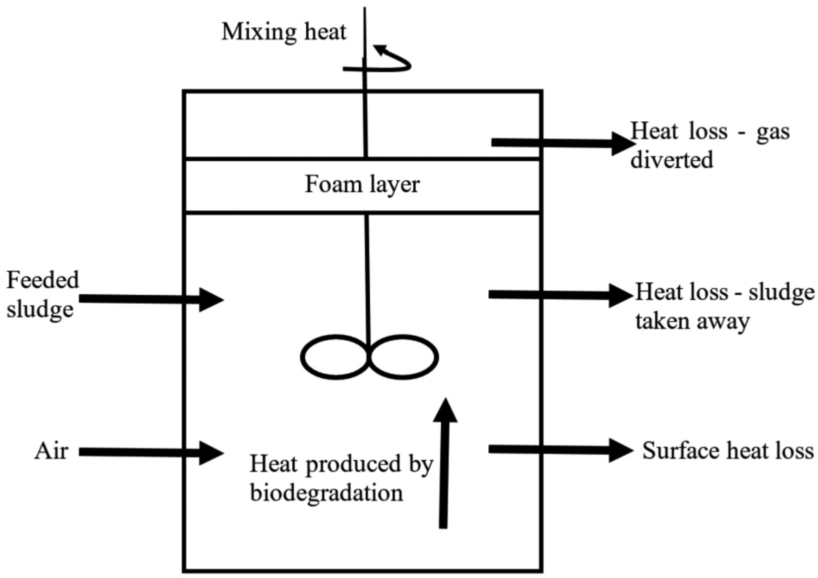

Figure 22
ATAD energy intake and loss (compiled by the authors)

Advantages of ATAD technology compared to mesophilic digestion:
- effective sludge stabilisation
- high organic matter decomposition efficiency
- indoor, odourless reactor
- pasteurised end product, can be used in agriculture without further treatment
- low investment cost
- well-dewatered, stabilised sludge
- the microbial culture tolerates fluctuations in load and food composition well

Disadvantages:
- high electricity consumption
- no recoverable biogas is generated, only heat and CO_2

The technology is autothermic, so they can operate in the thermophilic temperature range (55–70°C) without the use of external thermal energy. During the process, a thin layer of foam is formed, which promotes thermal insulation. A mechanical or hydraulic defoamer is built into the reactors.

Anaerobic stabilisation

The aim of the process is to convert organic compounds of the sludge into stabilised substances, reducing the amount and volume of sludge and forming the final product (methane) that can be used. Only used for plants above 100,000 PE due to heat loss and limited conditions.

Digestion

The process is temperature dependent, based on this the followings can be distinguished:

- cold digestion (< T15°C)

Stabilisation takes place in the sludge space of two-level settlers, residence time is 60–120 days, in sludge storage basins it is t ≅ 6 months, used in small plants, no biogas utilisation).

- mesophilic digestion (T = 30–38°C)

The most commonly used and easiest-to-handle method of digestion requires bacteria to maintain a constant temperature, which is maintained by continuous "heating" (e.g. an external heat exchanger). The residence time of the process is 18–25 days. In order to protect the reactor, the so-called "macerator" is incorporated; biogas utilisation can be a one- or two-step process, the most widely used digestion process.

- thermophilic digestion (t = 50–55°C)

The residence time is reduced to 8–15 days, its use is less recommended due to the unfavourable heat balance and sensitivity to load changes, it has the advantage of better water release of the sludge and more efficient destruction of infectious substances.

Common features include:

- requires a large residence time and reactor volume
- the resulting biogas has high methane content
- sludge dewaterability improves
- pathogen death is significant
- organic matter content decreases
- the amount of residual sludge decreases

Anaerobic digestion can be divided into 4 sub processes:

1. Mainly involves facultative bacteria (proteins, carbohydrates and fats are enzymatically cleaved into smaller compounds, such as amino acids, fatty acids, glycerol and monosaccharides during hydrolysis).
2. Mainly anaerobic bacteria produce mostly alcohols and acids from the products of the previous phase, resulting in a pH decrease.
3. More complex fatty acids are oxidised into acetic acid, carbon dioxide and hydrogen.
4. β-oxidation – methane-forming bacteria produce methane (50–70%) and carbon dioxide (30–50%). The gas produced in the process even contains water vapour.

A summary of the advantages and disadvantages of sewage sludge composting and digestion is shown in Table 10.

Table 10
Advantages and disadvantages of aerobic and anaerobic sludge stabilisation [14]

	Composting		**Digestion**	
	advantage	disadvantage	advantage	disadvantage
Treatment time		min. 60 days	ca. 20 days	
Decomposition of organic matter	fungi also break down lignin compounds			lignin-containing compounds are not degraded, lower organic matter degradation
Breakdown process	less sensitive to changes in waste quality			microbial population is sensitive to environmental factors, waste quality
Energy supply		aeration requires energy	produced biogas can be utilised for heating and mixing the reactors	
Pathogenicity	non-virulent			may contain pathogenic organisms when treated in a mesophilic temperature range
Quantity of final product		the amount of end product increases due to the addition of structural materials and other wastes	sludge decreases in weight and volume (25–50% dry matter)	
End product quality	good quality, directly usable			aerobic post-treatment or storage is required prior to recovery
space requirements		large	smaller	
Investment cost	low			requires large, closed tanks, mixing, heat exchange, gas storage, construction of gas utilisation
Operations		aeration system		mixing, reactors, heating

Two-stage stabilisation processes are used for very high or difficult to decompose organic matter content. Depending on the composition, the role of the first reactor is to mineralise faster decomposing materials and at the same time it helps to reduce the reactor space of the second stage.

More common designs of two-stage systems:

- sequential coupling of anaerobic thermophilic and anaerobic mesophilic digesters
- sequential coupling of anaerobic mesophilic and aerobic stabilisers

Anaerobic systems are also preferred for the treatment of wastewater with very high organic content (winery, citric acid production, etc.).

Post-digestion composting is increasingly being used to stabilise municipal sewage sludge, taking advantage of the combined use of aerobic and anaerobic processes.

Dewatering

Reduction of moisture content of conditioned sludge to the extent appropriate for utilisation and disposal criteria (e.g. evolution of dry matter content: injection: 5–8%, plowing: 25–40%, composting: 15–45%, drying, incineration: 40–50%). The advantages of dewatering include economical transport and optimal water content for subsequent treatment technologies.

The choice of dewatering equipment is mainly influenced by the type of sludge, the area available and the properties of dewatered sludge.

Grouping of dewatering procedures:

- Natural procedures
  - infiltration beds
  - mud reed beds
- Artificial procedures
  - dynamic dewatering (centrifuges, separators, vibratory dewatering, screw press)
  - static compression equipment (belt filter presses, chamber filter presses)
  - vacuum equipment (vacuum beds, vacuum drum filters)
  - membrane procedures
  - other combined procedures

"Natural" dewatering operates by evaporating ¼ and leaking away ¾ of excess moisture content. Infiltration beds, which are heavily exposed to climatic conditions, are now used very rarely; instead vacuum beds and mobile dehumidifiers are preferred. Alternatives to sludge dewatering beds can be sludge dewatering lagoons if sufficient land is available.

Artificial mechanical sludge dewatering covers the entire sludge treatment capacity range. Their application is preferred where, for example, land is expensive and sludge beds are harmful to the environment, or weather conditions give priority to the mechanical process and liquid sludge is expensive to transport compared to on-site dewatering.

Dry matter content obtained with centrifuges is mostly about 18–23% by adding chemicals and 18–35% without chemicals. Main aspects of selecting centrifuges are the following:

- minimum dry matter content according to the use and disposal of the sludge
- required dry matter content to be introduced into the centrifuge
- separation efficiency
- specific energy consumption (average 3.0 kWh/m^3 sludge)

Belt filters can be used for dewatering all types of sludge in small and medium capacity wastewater treatment plants. It is operated in three stages (Figure 23) by chemical conditioning (usually with electrolytes), gravity dewatering and pressure dewatering (between pressure belts).

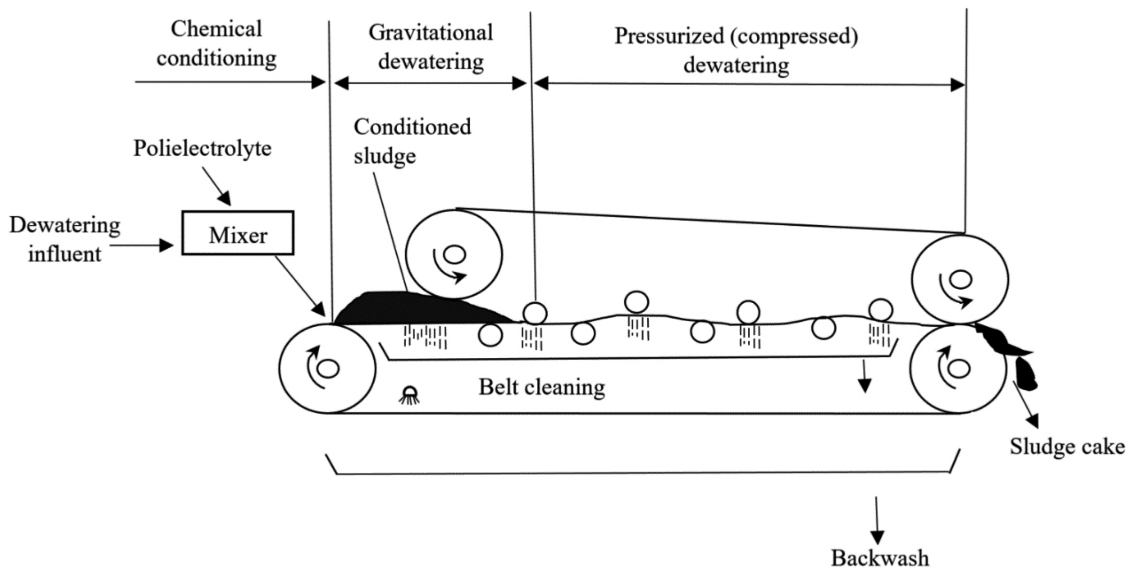

Figure 23
Basic processes of tape filtering [10]

Chamber filter presses are used when the goal is to produce a sludge cake with high dry matter content (40–50%) (incineration, deposition). Only used on larger sites (above 50,000 HPU), intermittent operation (filling, filtration, emptying).

The hydraulic principle of vacuum bed dewatering is the same as that of the sand layer of conventional sludge dewatering beds, the sludge water is always drained in a porous medium. The efficiency of centrifuges strongly depends on the pretreatment of sludge and the amount of dry matter content entering; the available dry matter content varies between 15–20%, organic polyelectrolyte is required to improve efficiency.

Membrane filters are characterised by high dry matter content and high separation efficiency. Membranes that are sensitive to clogging (e.g. greasy sludge) require a relatively large filter surface, have high energy requirements and are not yet widespread in Hungary.

Drying

The phases of water removal present in sludge are usually compaction, mechanical dewatering and drying. Drying of sewage sludge can be considered not only a pretreatment for incineration, but also a pre-drying for composting, as we have seen before. The aim of the process is to ensure that the product can be stored, bagged, transported and used more favourably. Drying also means physical conditioning, which, depending on the drying temperature (65–400°C), can result in significant killing of pathogens, which is required mainly for agricultural use. The process takes place without an adjuvant, the ammonia released during the transformations enters the air space and leaves it together with the drying gas, and therefore its subsequent washing and removal from the drying air is an essential part of ammonia and other odour-causing components removal. The final product in the form of granular material (granules, powder) is 65–85% of the final dry matter.

The most common types of drying equipment used are:

- etage (bunker) furnace (now less used)
- rotary tube furnace (in different versions)
- vortex furnace
- belt dryer
- screw dryer
- solar dryer (solar energy)

The so-called solar dryers, that use solar energy economically, have become widespread. They differ from solar dewatering in that they dewater the sludge mechanically (centrifuge, belt press, chamber press, etc.). In case of solar dryers, the temperature of the sludge, indoor and ambient air temperature, humidity of the air space, strength of the solar radiation, as well as the direction and speed of the wind are controlled. Based on these parameters, the controller operates the drying equipment and regulates drying gas extraction. As a result of biological processes, ammonia, hydrogen sulphide and other odorous compounds are also formed; therefore, they must be retained and removed from the extracted gas in specially designed cleaning stages. Domestically it does not work in winter, so temporary storage is required. There are several advantages to solar drying, including reduced sludge weight and volume, dry matter content output is selectable, reduced odour, a wide range of compatible parameters and low operating costs.

Natural dryers include composting that meets aerobic thermal conditioning conditions. In composting, the moisture content must be reduced to about 50%, while in drying it depends on the actual demand. The temperature and saturation of drying gas are slightly higher, so the amount of air required for drying during composting is less.

Among dryers functioning with dry heat transfer, rotary tube furnaces are the most common. These include a number of solutions for drying temperature, heat generation, direct or indirect heat transfer, vapour and flue gas treatment solutions.

Disinfection

Disinfection of sludge is essential if it is to be used on agricultural land or if it is microbiologically contaminated. Chlorine oxidation, heat treatment, lime treatment and composting are also used as disinfection methods. Aerobic thermal conditioning and ultrasonic treatment can also be considered a successful process. Composting introduced in Hungary also provides a favourable disinfecting effect. (Testing and classification of composts is regulated by MSz-10-509).

The virulence-reducing effect of different sludge treatment methods is shown in Table 11.

Table 11
Infectivity reducing effect of sludge treatment methods [11]

Treatment procedures	Exposure time	Reduction of infectious human pathogens (%)			
		Viruses	Bacteria	Parasites	Fungi
Anaerobic sludge treatment					
mesophilic (30–35°C)	14–30 days	> 90	Decreases by 1–3 orders of magnitude: > 90	Almost complete destruction	Almost complete destruction
mesophilic (30–35°C) long-term storage of treated sludge (at 20°C)	6 months	–	99.9	It has no effect	–
thermophilic (50°C)	6–15 days	> 95	Decreases by 2–4 orders of magnitude: > 90	Almost complete destruction	Total destruction
Aerobic sludge treatment	6 days	It has no effect	~ 20	~ 10	Partial destruction
Chemical lime treatment					
before filtration (pH = 11.5–12.5)	12 hours	–	Decreases by 2–4 orders of magnitude: > 90	Almost complete destruction	–
dewatered sludge (pH = 12.5)	14 days	–	Decreases by 2–4 orders of magnitude: > 90	Total destruction	–
Thermal treatment of liquid sludge (177–240°C and 6,000–12,000 kN/m2 pressure)	15–40 minutes	Total destruction	Total destruction	Total destruction	Total destruction
Disinfection (at 70°C)	30–60 minutes	Total destruction	Total destruction	Total destruction	Total destruction
Sludge drying (at 300–500°C)	20 minutes	Total destruction	Total destruction	Total destruction	–
Composting (at 65°C)	5 days	Almost complete destruction	Total destruction	Total destruction	Total destruction
Independent firing (at 930°C)	20 minutes	Total destruction	Total destruction	Total destruction	Total destruction

Sludge transport

The method of disposal influences the choice of transport (distance, storage capacity, service life, incorporation, dry matter content of the landfill, quantity to be transported) and the two together have an impact on the degree of plant treatment technology (compaction, conditioning, dewatering).

Basic means of transport include axis transport, pipeline transport and a combination of the two (mixed: pipeline shaft).

Factors determining the choice of sludge transport method:
– location/application technology (agricultural cultivation)
– distance between the place of formation and use or disposal of the sludge (km)
– the amount of sludge to be transported (m^3/d)
– traffic conditions (traffic, pavement, load-bearing capacity of bridges, speed limit, etc.)
– climatic conditions
– topography, groundwater (in case of pressure line)
– the planned capacity duration of the place of application
– environmental and public health factors (protected area, etc.)
– intermediate storage design conditions
– economic factors (electricity, liquid fuel, vehicle procurement, staff, utilisation of equipment capacity, etc.)
– the need for material transport for recultivation or cover
– the number of rounds that can be completed in one shift
– the amount of leachate (landfill) to be treated
– maintenance, washing and disinfection of vehicles

When transporting sludge on axis, it may only be transported in closed, mechanically operated, drip-free and odour-free vehicles approved for this purpose, which exclude odours, flies and any other insects. A transport route must be prepared (approved by the authorities) in which inhabited areas must be crossed as little as possible and should have a solid surface that can be walked on in winter and summer. Provision must be made for the possibility of cleaning and disinfection of transport vehicles.

Regulations for mandatory medical examination of operating staff (driver, attendant, etc.) are the same as for other employees of the wastewater treatment plant.

There is a risk of fire and explosion due to possible methane formation during sewage storage and transport. Compliance with the National Fire Protection Regulations, that is Annex 1 of the Decree 35/1996 (XII.29.) of the Ministry of the Interior currently in force, is mandatory. (Moderately flammable class “D”).

Sludge transport via a closed pipeline can also be applied either to agricultural recovery or landfilling. The sludge line is subjected to a permit as an accessory for the treatment plant.

It is recommended to transport sewage sludge by pressure line if:
– reception of the sludge in the area of the end point is ensured for at least 15 years
– the consistency of the sludge allows for clog-free transport over a given distance
– residence time of the sludge in the pipeline does not result in deposition or hazardous methane production (when restarting, the energy demand of the so-called sludge-breaking force requires a significant extra force)
– the capacity utilisation of the pipeline in phase I already reaches 50% (t/24h)
– reception is guaranteed at all times
– regulations related to the construction and maintenance of the pipeline (safety distances, free access, etc.) can be ensured
– regarding the material of the line, it is resistant to dynamic forces and surface wear (pipe erosion) for a specified service life
– failure of the pipeline along the route will not cause irreversible damage, does not endanger water base and other environmental and landscape protection elements, etc.

Disposal and recovery

In Hungary, in terms of disposal and use of sewage sludge, 60% is deposited (mainly in landfills) and 40% has other use (agricultural, anaerobic digestion, landscape rehabilitation). Landfilling cannot be considered a final solution because the capacity of landfills is declining.

A primary consideration in recovery is that sewage sludge should not be considered primarily a waste, but a recoverable secondary raw material.

The main possibilities of utilising sewage sludge:

– agricultural utilisation (composting, injection)
– thermal, energy recovery
– landscape rehabilitation, recultivation
– biogas production (anaerobic digestion)

The conditions of the placement methods require different consistency of material composition, different degree of stabilisation and level of disinfection. In particular, the conditions of disposal are those that change from time to time as a result of central regulation (amount, composition, treatment of sludge). On-site treatment should be chosen to adapt to quantitative and qualitative changes of external conditions.

Agricultural utilisation

The main purpose of agricultural utilisation of sludge is to ensure the demand for plant nutrients (e.g. N, P and other micro- and macronutrients) and to improve its tillage properties. Land need is advised to be sized according to phosphorus and organic matter load while considering Government Decree (IV. 29.) on the detailed rules of the action program for the protection of waters against nitrate pollution of agricultural origin, as well as the Decree on the procedure for data provision and registration.

During sewage sludge utilisation, the greatest danger lays in heavy metals contained in it (e.g. Pb, Zn, Cu, Ni, Cd), that can bind and accumulate in the soil and accumulate in plants. In addition to heavy metals, the second problem is organic micropollutants, the effects of which are still being investigated. Because of these contaminants, analytical testing of sewage sludge prior to use is unavoidable.

Tests may only be performed by laboratories accredited for sampling and testing. Soil authority (testing of soil, groundwater, sewage and sewage sludge) in accordance with Decree 10/2000 [Annex VI2] KöM-EüM-FVM-KHVM on limit values necessary for quality protection of groundwater and geological media) may also extend to the characteristics specified in its joint decree, by establishing individual limit values set out therein. Examination of parameters prescribed in this way and the mandatory application of their limit values are part of the soil expert opinion. The main requirements for disposable sludges are set out in Government Decree (EC) No. 50/2001 (IV.3.) on the rules for the agricultural use and treatment of sewage and sewage sludges (§ 3 b, fixes the concept of treated sludge that can be used in agricultural area, but exclusively regulates the production for agricultural purposes only).

The deposition of sludge on agricultural land is a licensed activity that requires:

– pedological expert opinion
– public health authorities

– environmental protection authority
– opinions of water authorities
– municipal (notarial) contribution

The competent plant health and soil protection station, as a soil protection authority, authorises it in a decision. The permit can be granted for a maximum period of 5 years.

Sewage sludge must not be used on soils which:

– has properties worse than the limit values for soils specified in the government decree
– pH less than 5.5 (if the pH of the soil is between 5.5 and 6.2, use is only possible with the simultaneous application of liming)
– on coarse sand with extreme mechanical composition
– the thickness of the crop layer is less than 60 cm
– the average annual groundwater level is higher than 150 cm

Sewage sludge must not be disposed of:

– in case of liquid sludge, where the slope of the surface is greater than 6%
– in case of dewatered sludge (dry matter 20%), where the slope is above 12%

Protected area required for agricultural disposal of sewage sludge:

– from a populated area
– from residential buildings
– at least 300 m from areas belonging to forestry

In case of agricultural utilisation of sewage sludge, the so-called aerobic thermophilic stabilisation has a favourable disinfection effect. In case of agricultural soils with acidic soils, the use of lime is considered the most favourable.

Industrial uses

There are a number of special options for the utilisation of sewage sludge in industrial areas.

Each use requires a specific set of individual requirements, which can only be met to a very limited extent at the sludge treatment plant. This is mainly limited to meeting dry matter–moisture demand. For all other needs, the treatment plant must be supplemented with a suitable procedure and equipment in accordance with technological instructions.

Thus, from the point of view of industrial utilisation, sewage sludge can be treated as a raw material, the quality of which can only be changed to a limited extent by reducing traditional organic matter content and changing consistency (from compaction to drying, reducing infectivity, etc.).

Environmental restrictions of application technologies must be determined individually for each process, the preparation of which is supported by environmental impact studies.

Some better-known procedures are:

– application as fuel (combustion in boilers)
– during road construction, the “dried” material is applied to the lowest layer as a concrete admixture
– special material is extracted from it (e.g. B12 production)

Deposition

Deposition is the long-term storage (disposal) of sewage sludge by landfilling in order to avoid adverse effects during sludge disposal on land, surface and groundwater, as well as on the environment. Deposition under controlled condition should be accomplished according to Decree 22/2001 (X.10.) of the Ministry of the Environment.

A landfill may be established and permitted if it complies with Article 1 of the Decree (the procedure for the construction of sewage sludge landfills is the same as for landfilling).

Deposition in Hungarian practice is performed in two ways that must be taken into account in a larger perspective:

- separate disposal in a local or regional landfill: industrial landfill, where only sewage sludge is deposited (this is the so-called mono disposal method)
- local or regional landfilling of municipal solid waste (garbage) (this is the so-called mixed disposal method)

In summary, Figure 24 shows potential ways of disposal and/or utilisation, residual material, and treatment options of solids removed from wastewater.

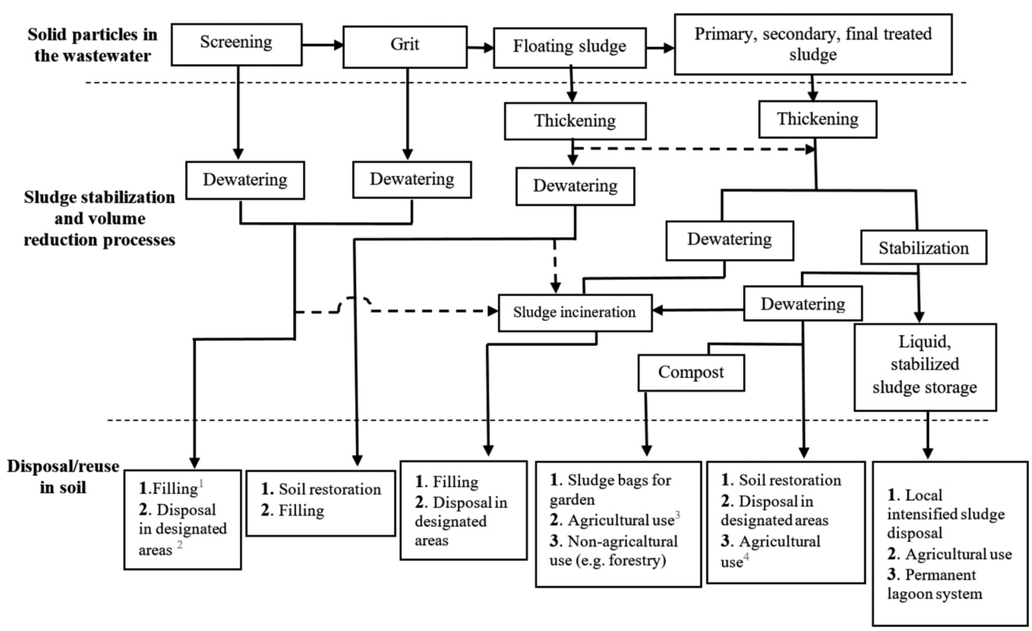

Figure 24

Residual material and treatment possibilities of wastewater treatment [10]

Note: [1] dewatered sludge cake or ashes, [2] liquid or dewatered, [3] liquid, sludge cake, compost, [4] liquid or dewatered

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Questions

1. What is the role of sewage pretreatment?
2. How would you classify grids?
3. What types of grits are used in wastewater treatment?
4. What types of settlers are used in wastewater treatment?
5. List the steps of chemical phosphorus removal.
6. At which technological step can the coagulant be dosed?
7. Explain the essence of CEPT technology.
8. What methods can be used for nitrogen removal from wastewater?
9. What are sewage sludge treatment sites in municipal wastewater treatment?
10. What are the most important steps of sludge treatment?
11. What sludge thickening procedures do you know?
12. What conditioning procedures do you know?
13. What chemical conditioning agents do you know?
14. What is the difference between anaerobic and aerobic stabilisation?
15. How can dewatering procedures be classified?
16. List at least three types of dryers.
17. How efficiently can sludge treatment processes reduce pathogenicity?
18. What factors determine the modes of sludge transport?
19. What kinds of sewage sludge utilisations do you know?
20. What are the main legal rules governing agricultural utilisation?

Péter Orgoványi, Tamás Karches, Edit Vadkerti

Decentralised Wastewater Treatment

Centralisation or decentralisation

The need for sustainable management of water resources is growing due to increasing pollution and emerging water supply shortages. Our environment suffers from repetitive and high pollutant load due to inadequate wastewater treatment. Adequate solutions can reduce the proportion of the population that cannot access clean water and increase the efficiency of wastewater treatment. The goal of environmental sustainability is to maximise the reuse of treated wastewater and the recovery of by-products. Treatment technologies must be efficient and reliable with low investment and maintenance costs in geographies, where the centralised wastewater collection and treatment is not feasible.

Features of centralised treatment

- Wastewater collection is responsible for the 80–90% of investment costs (sewerage network cost).
- In addition to regular maintenance, the entire system needs to be reconstructed every 50–60 years, disrupting traffic and other utilities.
- Large amounts of treated wastewater as point source can cause eutrophication in the receiving water body.
- Heavy rainfall or uneven industrial discharges may result in hydraulic overload of the treatment plant.
- Diluted wastewater requires more expensive treatment.
- Accidents may disrupt the system, causing severe contamination of the receiving water body.
- In case of a full-scale treatment plant, an economically sound solution can be achieved where large agglomeration with large population density needs to be covered.
- It is highly dependent on the electricity price, which represents economic and political exposure.

Features of decentralisation

- It can be applied from the individual level up to community level.
- Suitable for suburban, rural, industrial, commercial and residential areas.
- Helps in planning the development of isolated communities.
- Local wastewater treatment solutions are suitable for isolated or dispersed settlements or where the space is limited.
- Reduces or eliminates the difficulties of treated wastewater disposal and much shorter pipelines are used compared to centralised systems.
- Small wastewater treatment plants prove to be a viable option if properly constructed and operated.
- Small wastewater treatment plants should be remotely controlled.
- The cost of decentralisation technologies increasingly competes with centralised solutions.
- Small wastewater treatment plants can provide environmental sustainability by promoting the potential reuse of treated wastewater and nutrient recovery.

– Separation of domestic wastewater and rainwater can be solved, thus it avoids dilution.
– Separation of contaminants can be solved at the source, thus it facilitates the treatment process, the potential reuse and improves treatment efficiency and energy use.
– It is possible to eliminate the mixing of domestic wastewater with industrial wastewater.

It can be seen that both systems have advantages and disadvantages. The choice between the two systems always requires individual consideration. Legal, environmental, economic and technical aspects must all be taken into consideration.

List of these aspects:

– local conditions
– the recipient type and capacity against pollutant load
– the amount, composition and flow variation of the wastewater
– environmental and health conditions
– the efficiency achieved by the treatment system
– the amount and composition of the sludge produced and its disposal
– the technical feasibility of the investment
– investment and operating costs, available tender sources

Decentralisation of wastewater management has various levels: from an individual local system to larger clusters or semi-centralised sites.

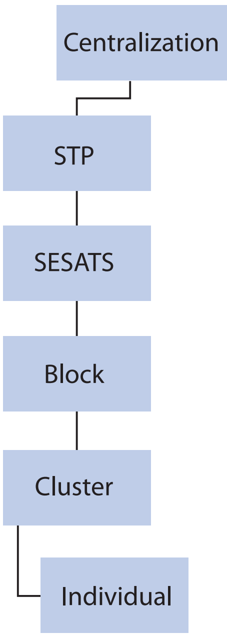

Figure 1

Transition systems between centralised and individual systems [1]

Note: STP – "Satellite treatment plant". Such a treatment plant operates independently of conventional large scale plants. Wastewater from the sewerage network is treated and the sludge, backwash and treated wastewater are returned to the network. SESATS – Semi-centralised management systems. Block – Handles wastewater from individual buildings (such as schools). Cluster – Usually 4–12 or more houses form a cluster. Individual – One home with a different treatment system.

In addition to centralised and decentralised systems, there are also hybrid solutions. In such cases, there is one central wastewater treatment plant in a given area, but decentralised solutions are also used. This can typically occur in agglomerations where wastewater discharges appear or demographic growth would result higher load in the existing centralised treatment plant. There are several reasons to consider connecting new discharges to existing systems. On the one hand, it may be necessary to re-design an existing plant, and as a result, it may need to expand it. Moreover, new pipelines to the existing sewerage network must be built. This entails significant costs and additional workload for the existing sewer system, which was also originally designed for lower capacity. In such a case, it is advisable not to fulfil the increased capacity requirement by the central plant and the sewer system, but by other solutions.

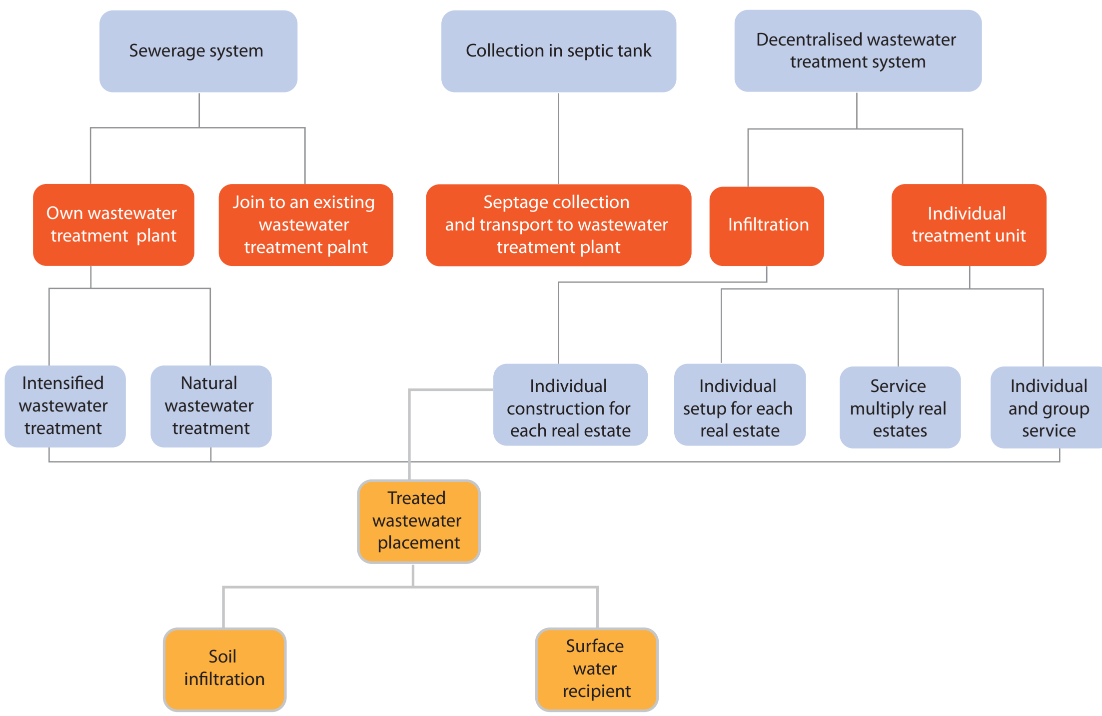

Figure 2
Wastewater treatment systems (compiled by the authors)

Decentralised wastewater treatment

Decentralised wastewater management is based on the principle of treating wastewater at the source. Wastewater should be collected in the same way, but without long pipelines, thus eliminating significant groundwork and reducing operating costs.

Generally, the design should take into account the current:
– regulations for the quality protection of surface waters
– regulation on the quality of groundwater and geological media
– regulations on emission limit values for wastewater

Although no longer in force, but Government Decree No. 174/2003 (X.28.) on the National Implementation Program for Unique Wastewater Treatment for Uncultivated Areas of Utility Drainage and Purification provided a very good classification and definition to which numerous references have been made since then. For areas where decentralised wastewater treatment is economically feasible, the regulation identifies three groups of options:

- treatment with small facilities
- use of small wastewater treatment unit
- treatment of septage (collection and disposal)

The Regulation clarifies the concepts of installations for decentralised wastewater treatment:

- *Individual wastewater treatment:* the use of individual wastewater treatment facilities, which are used for the treatment and/or final disposal or temporary collection and storage of municipal wastewater with 1 to 25 population equivalent. Depending on the environmental and water management aspects and the building density, these may include: on-site sewage facilities, individual small wastewater treatment units and closed wastewater storages. Disposal and handling of liquid, sludge and construction waste from individual wastewater treatment facilities must be carried out in accordance with a separate legislation.
- *On-site sewage facility:* A facility that reduces the environmental load of the municipal wastewater not connected to the public sewage system and disposal, but able to ensure the same degree of treatment as the large-scale wastewater treatment systems. The small wastewater disposal unit performs the decomposition of pollutants without energy input. Elements: septic tank, gravel/sand filters, which, on the whole, allow the utilisation of the residual nutrient content of the treated wastewater for the vegetation and soil in case of final release into the geological medium or harmless placement in surface waters.
- *On-site individual wastewater treatment unit:* an installation that serves for the non-utility drainage and disposal of municipal wastewater, and provides an environmental solution equivalent to the municipal wastewater drainage and treatment. The individual wastewater treatment plant carrying out the treatment of the sewage by means of energy input shall ensure the removal of the pollutants of the wastewater according to a separate legislation, recipient can be the surface water or soil.
- *Closed wastewater storage:* an installation consisting of one or more closed and watertight tanks; for the non-hazardous collection of wastewater and for the temporary storage of municipal liquid waste; the non-hazardous disposal of municipal waste collected in this area is provided after regular disposal and further treatment in accordance with specific waste management legislation.

Elements of the Hungarian regulation

Legal conditions for the application of professional individual wastewater treatment and disposal:

(1) The main rules for the application and permitting of professional individual sewage disposal are contained in the following two government decrees:
   - Government Decree 174/2003 (X.28.)
   - Government Decree 72/1996 (V.22.) on the exercise of the authority of water management authorities

(2) Pursuant to Section 2 (b) of Government Decree 174/2003 (X.28.), individual wastewater treatment is the application of individual wastewater treatment facilities (structures) that serve the treatment and/or final disposal, or temporary collection and storage of municipal wastewater corresponding to 1–25 population equivalents (persons). This may be:
a) individual small wastewater disposal facilities (septic tank and gravel or sand filter, including built aquaculture solutions, where it is possible to utilise the residual nutrient content of treated wastewater for vegetation and soil, without energy input)
b) individual small wastewater treatment units (mostly prefabricated small units where pollutants are decomposed by energy input)
c) individual closed sewage tanks (closed and watertight basins for the harmless collection of sewage and the periodic storage of municipal liquid waste [septage] from sewage)

(3) Areas delimited by legislation for individual wastewater treatment:
- settlements that are not covered by the National Municipal Sewage Drainage and Treatment Implementation Program 25/2002 (II.27.) to sewage agglomerations covered by a government decree
- 25/2002 (II.27.) the parts of the territory of the settlements belonging to the sewerage agglomeration according to Government Decree 26/2002. (II.27.), where the establishment of sewage works is not justified on the basis of inspections according to a government decree

(4) During individual wastewater treatment and disposal, it must be ensured that the individual pollutants are removed to at least the extent that the recipient is surface water or geological medium (soil) so that their quality does not deteriorate, but rather improves. To this end, the provisions of the following legislation in force must be taken into account:
- Government Decree 203/2001 (X.26.) on certain rules for the protection of surface water quality
- KöM-KöViM 9/2002 (III.22.) joint decree on emission limit values for wastewater and rules for their application
- Government Decree 33/2000 (III.17.) on certain tasks related to groundwater quality activities
- KöM-EüM-FVM-KHVM 10/2000 (VI.2.) joint decree on limit values for the quality protection of groundwater and geological media

(5) The facility (structure) for individual sewage disposal can only be established with a separate permit from the clerk of the municipality. The involvement of environmental and water management authorities – in case of group implementation – in Government Decree 174/2003 (X.28.) on the approval of the Municipal Wastewater Treatment Program in accordance with Article 72/1996 (V.22.) is necessary according to §24 and §25 of the Government Decree.

(6) During the permitting process, the applicability of individual wastewater disposal should be considered separately with respect to sensitive and protected areas.

(7) According to Government Decree 123/1997 (VI.18.) Annex 5 on the protection of water bases, long-term water bases and water facilities for drinking water supply, the use of individual wastewater disposal (domestic wastewater filtration) in the internal and external protection zones of surface and groundwater bases is prohibited.

(8) A separate study on the applicability of individual sewage disposal is required in the following areas:
   a) in order to protect groundwater, Government Decree 33/2000 (III.17.) 2/1 in karstic areas, according to point (c) of Highly Sensitive Areas “A”, where limestone, dolomite, limestone and dolomite marl formations are present on or within 10 metres above the surface
   b) in order to protect groundwater, Government Decree 33/2000 (III.17.) 2/1 in the hydrogeological protection zones A and B of operational and long-term drinking water bases, mineral and medicinal water utilisation bases according to point “d” of Highly Sensitive Areas “A” and point (c) of “B” Sensitive Areas
   c) in areas 250 metres wide from the shoreline of environmentally sensitive surface waters in accordance with Government Decree 240/2000 (XIII.23.) on the designation of surface waters sensitive to urban wastewater treatment and their catchment area
   d) in a 250 meters wide area from the shoreline of surface waters included in other protected areas in accordance with KöM-KöViM 9/2002 (III.22.) joint decree
   e) in areas with high groundwater levels (where the groundwater level is permanent – for at least 10 years above –2.0 m depth)

(9) Act LVII of 1995 on water management. Pursuant to Section 6 (4) (d) of Act No. 174/2003. Pursuant to Section 4 of the Government Decree, a Municipal Wastewater Treatment Program must be submitted in order to obtain central support. (This is not necessary to support the reference, it should be done in the first report.) It should include, inter alia:
   a) the parts of the area delimited for professional individual wastewater treatment within the settlement
   b) the types of facilities to be used and the parts of the settlement affected by each type, with justification
   c) the parts of the territory within the settlement where professional individual wastewater treatment cannot be applied
   d) local environmental requirements, main technical data and regulations for individual wastewater treatment plants
   e) development of a monitoring system (observation wells, etc.) based on scientific and technical aspects

The Municipal Wastewater Treatment Program should be based on detailed environmental assessments.

(10) Individual wastewater treatment plants are subject to a water permit (Act LVII of 1995). KHVM Resolution 18/1996 (VI.13.) Annex II on the application and annexes required for the water rights permitting procedure. Pursuant to Section 6 (i) of the EIA Decree, in case of individual wastewater drainage, the application for *water rights operation* or its annex must contain operating and maintenance instructions related to the applied technology, as well as technical and organisational data on damage preparedness and operational regulations.

(11) The removal and treatment of contaminated water, sludge and construction material waste generated during the maintenance of individual wastewater treatment facilities is regulated by Act XLIII of 2000 on waste management. Act No. 16/2002 (IV.10.) Coll., on Public Health Requirements for Municipal Solid and Liquid Waste. It must be carried out in accordance with the provisions of the EüM decree.

Government Decree 379/2015 (XIII.8.) on the List of Settlements and the Information List on the Settlement of Municipal Sewage Drainage and Treatment in Hungary, as well as on the delimitation of sewage agglomerations, states that for all settlements in Hungary, the data related to the sewage sludge – with the content according to the data provision specified in Annex 2 – shall be registered in the List of Settlements (hereinafter: List of Settlements). The notary of the agglomeration centre and the system serving the only settlement (island plant), the individual wastewater treatment plant and the individual closed wastewater storage shall send the data according to Annex 2 to the territorially competent water directorate by 30 April of the following year.

Present and future of decentralised wastewater treatment in Hungary

On 21 March 2019, a conference entitled Decentralised Wastewater Treatment was held at the Faculty of Water Sciences at the National University of Public Service, the results of which were included in recommendations by the participants, as follows.

Proposals concerning the legal, economic and wastewater strategy:

- In all cases, detailed economic and efficiency studies are required, in the framework of which the investment, subsequent operation and maintenance costs, as well as the solvency of the population must be taken into account.
- The National Municipal Drainage and Treatment Implementation Program should be reviewed and, where the program has been discontinued, an alternative solution should be proposed to continue.
- The settlements and parts of settlements where individual wastewater treatment can/should be applied instead of the traditional wastewater collection and treatment technology should be designated.
- Legislation should provide for the operation of properties provided in this way, and at the same time integrate them into the system of water utility services.
- The application system running in the Rural Development Operational Program needs to be reviewed in order to make it even more efficient and attractive for small settlements.
- The cross-sectoral and state management of the projects would be handed over to one hand and, where appropriate, to a government commissioner/ministerial commissioner by the ministry responsible for the project.
- We recommend grouping the settlements according to the average housing density, the average number of inhabitants per property and the age composition. When tendering, preference should be given to settlements that are younger and more densely populated based on their age composition, and to the provision of real estate with a larger population within the settlement. In the applicant municipalities, the municipalities also provide the number of people living on the property of the residents participating in the program.
- The application conditions for individual treatment units, small facilities and natural wastewater treatment should be regulated on a property-specific basis, taking into account that the planning unit of decentralised wastewater treatment, even in case of group-operated equipment, is the property and not the settlement.
- Each plan should include, as a comparative baseline, the estimated investment cost of sewerage. The investment and operating costs per inhabitant form the basis of comparison with the cost of decentralised wastewater treatment submitted for implementation.

- In addition to the investment cost, the application must also show the operating cost for each of the technical solutions used. Cost items should include: 1. energy costs; 2. investment and depreciation costs for transport equipment related to the collection and transport of sludge/stored wastewater to the receiving site; 3. operator wages; and 4. consumables (lyophilised bacterial culture, disinfectant, aeration membrane) replacement. Of the total costs thus incurred, the cost per inhabitant must be compared with the specific cost of the sewerage solution.
- We recommend developing a legal environment for the supervision and maintenance of built-in wastewater treatment units.

The technological solutions:

- For individual, property-by-property solutions, up to 25–30% of the uncovered surface of the property may be occupied by treatment and disposal units. (In case of a septic tank together with a spare desiccant field!) If this cannot be ensured, one of the solutions based on the separation of domestic wastewater should be used. For example, dry toilets and gray sewage dessication.
- A decentralised solution with group service (with a capacity of up to 50 PE) should be preferred to individual placement.
- In settlements with a housing density of up to 6 persons per hectare (60% of the settlements concerned belong to this category), if the number of permanent residents of the property is 1 person or 2 people are no longer of reproductive age (over 50 years), as an individual solution only soil filtration or watertight, closed wastewater storage and shaft transport can be applied for. Alternative: only black wastewater (toilet and sink water) should be fed into the tank, gray wastewater can be drained on site.
- In settlements with a housing density of less than 250 inhabitants and a maximum of 6 people/hectare, we recommend the use of a closed wastewater storage and transport to a treatment plant, with the addition that only toilet and sink water should be connected to the storage and the rest should be drained. Eligible costs must include the conversion of the internal building services outlet, without the cost of restoration work.
- In settlements with a housing density of more than 6 people/hectare, the designer must always examine the sub-areas of the settlement where small group-operated equipment can be used instead of individual cleaning. If the total cost of the ducts and small equipment leading to the equipment is not more than 20–25% higher than the total cost of the small equipment with individual placement, the group service version shall be used. (Pipes up to 150 mm can be used for the duct and the shaft/cleaning fitting on the property boundary must be fitted with a filter basket.)
- Among the requirements of the technical and professional content of the tender, it must be modified that the development must have a total capacity of at least 50 PE, regardless of the size of the settlement. In settlements with up to 500 inhabitants, it is advisable to reduce the limit to 25 PE, otherwise the original capacity can be left.
- The technical specification of small air-operated equipment must specify the ventilation with electronics that monitor its operation and send a fault signal in the event of a fault.
- In the case of septic tank-soil filtration, the technical specification should also provide for the possibility of sampling for treated effluent and the possibility of disinfection.
- The full range of technical solutions for decentralised wastewater treatment needs to be developed, with user-related advantages and disadvantages of content that can be used by municipalities, the general public and planners alike.

Decentralised Wastewater Treatment Systems (DEWATS) in developing countries

The system presented in this section is intended to summarise wastewater treatment solutions in developing countries through an integrative and system-oriented planning aid. Although it is not designed for domestic use, its approach and focus on sustainability can be an example to follow when choosing and designing any decentralised system. Water is an essential element of sustainable social and economic development. Urbanisation, industrial development and the expansion of agricultural production have a significant impact on the quantity and quality of water resources. More than half of the world's major rivers are exhausted and polluted, destroying the surrounding ecosystems, threatening the health and livelihoods of those who depend on it. It is estimated that about half of the population is exposed to contaminated water, which increases the incidence of disease; most of these people live in Africa and Asia.

At the international level, in the 1990s, a lack of development in decentralised wastewater treatment was recognised and, in response, DEWATS (Decentralised Wastewater Treatment System) was created. DEWATS systems are suitable for the treatment of both domestic and industrial wastewater with a flow rate of 1–1000 m^3/day. Such a comprehensive system can only be appropriate if it provides a reliable and efficient treatment of residential and technological wastewater in a variety of local conditions, requires short planning and execution, has medium investment costs, and has limited maintenance and operational requirements.

CBS Programmes

The program basically relies on community-based wastewater treatment, also known as CBS (Community-Based Sanitation). Each CBS must be environment-specific. The primary goal is long-term sustainability. Effective, economically sound and sustainable implementation requires the systematic involvement of stakeholder groups. The following levels can be distinguished between groups:

- primary stakeholders – residents and direct users of the intervention implemented
- secondary stakeholders – groups with direct or indirect responsibility for the program; this includes investors, planners, authorities, health and environmental institutions
- tertiary stakeholders – service providers – construction, maintenance and sludge management organisations

These programs meet the needs of people living in a particular area. In most cases, programs are targeted at people in poorer areas. As primary stakeholders, they will use the wastewater treatment plant; therefore, it must be adapted to the needs and habits that arise. In addition, they make a significant contribution to the system, whether we think of the material part of the construction, or the operation and maintenance after the construction.

The success of implementation and subsequent maintenance is based on the coordinated implementation of the work and its integration into all relevant processes. At the outset of the process, the purpose of the program should be clarified, the current situation assessed, the experience gained in similar fields gathered, the relevant stakeholder groups identified and their involvement in the project planned.

Key tasks should include:
- program management, including process monitoring
- feasibility study
- adequate information to those involved in the field, including tasks related to future operation and maintenance
- planning the construction process
- operation and maintenance tasks
- sludge management
- planning environmental monitoring

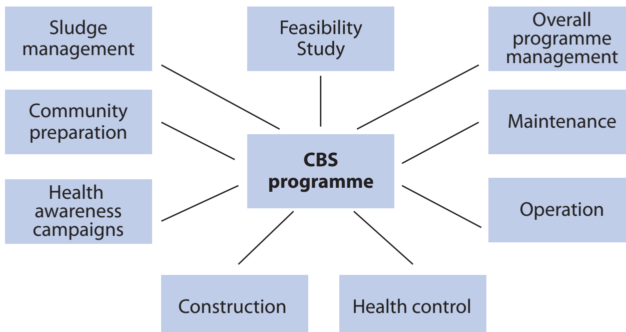

Figure 3
Main tasks of the CBS program [2]

Technological configurations of DEWATS modules

DEWATS is a modular approach to efficient wastewater treatment. The approach combines the experience of centralised and decentralised wastewater management systems, thus contributing to addressing the growing need for decentralised wastewater treatment. Not only is it a technology package, but it also includes an approach in addition to technical and engineering approaches, taking into account the local economic and social situation. It can handle both domestic and industrial wastewater, providing first, second and third treatment grades as required. In addition, the system should be considered a part of a comprehensive wastewater treatment strategy. The technology is also capable of providing a renewable source of energy through the appropriate choice of modules by utilising the resulting sewage sludge. Its purpose is to minimise external energy input during operation. The modular concept enables optimal planning based on efficiency requirements, costs and available space. The DEWATS criterion is to install units that meet a high quality standard, with construction and design by specialist chambers, thereby ensuring that wastewater treatment systems meet regulatory criteria.

Technological configuration of a typical DEWATS system in a modular system:
- primary treatment – in sedimentation ponds, sedimentation tanks, septic tanks
- secondary treatment – in anaerobic reactors, in anaerobic filters or in anaerobic or facultative pond systems
- Secondary Aerobic/Facultative Treatment – Horizontal Gravel Filters
- post-treatment – further treatment in aerobic lakes

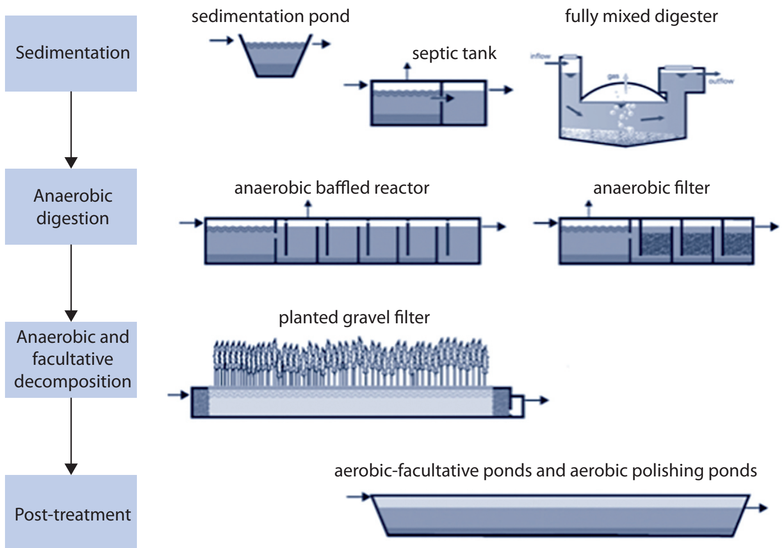

Figure 4
DEWATS Configuration Scheme [2]

When choosing the appropriate technological configuration, consider the following:
- wastewater discharge
- wastewater quality
- temperature
- soil, groundwater conditions
- available space
- costs
- legal background
- treated wastewater disposal
- social conditions

Laboratory analysis is required to determine the quantity and quality of the pollutant incoming, to determine the feasibility of treatment, to determine the impact on the environment and to determine whether the wastewater is suitable for biogas production. Because the quality of used water is constantly changing over time (e.g. seasonal variation), the analysis is never complete. Understanding the importance of each parameter during design is more important than knowing the exact formulas. In general, a design accuracy of ± 10% is sufficient for these systems with preliminary calculation of the runoff quality.

DEWATS employs the above-mentioned natural biological and physical treatments to reduce and eliminate contaminants in wastewater. Avoids the use of external power sources, chemical dosing, and the use of movable components to minimise potential malfunctions during maintenance and operation. A series of treatment units are used to meet the boundary conditions specific to various natural treatment processes and to ensure efficient operation. The stability of the system is ensured, by removing, at each treatment step, only the pollutants specified for that step.

In DEWATS, it is often easiest to provide longer retention times, so that slower microorganisms "find" their nutrients after the faster ones have undergone the necessary degradation.

DEWATS technologies respond relatively flexibly to incoming wastewater and environmental conditions. However, improper operation, improper maintenance or structural defects can cause problems. A malfunctioning system poses risks to both the environment and human health. It is important to address emerging local issues so that they do not pose a threat to the overall system over time. Accordingly, the DEWATS system also needs operator personnel who are able to measure the symptoms of malfunctions at an early stage, identify the causes of the problems, and take appropriate action to restore the system.

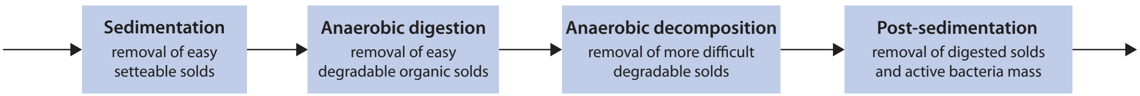

Figure 5
Multiple steps required for complete treatment [2]

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Questions

1. Compare the features of centralised and decentralised wastewater treatment!
2. Define the satellite treatment systems!
3. Define the term of individual wastewater treatment!
4. What conditions shall be met in order to apply individual wastewater treatment units?
5. What type of permission is needed for the operation of an individual wastewater treatment system?
6. What does the CBS program cover?
7. What are the unit processes of the individual wastewater treatment?

László Török

Small Wastewater Treatment Systems, Sewage Disposal Facilities

Legal background of construction and operation of small wastewater treatment plants

Legislative progress of wastewater treatment and disposal

The first Water Law and its Implementing Regulation, with a dedicated chapter on quantitative and qualitative protection of waters, were entered into force after the war, in 1964. The law specified obligations for the establishment and operation of wastewater treatment system only in connection with facilities, possibly excluding wastewater treatment plants (WWTP). To penalise the pollution of recipients, including groundwater, wastewater penalty was signed into law, essentially for factory wastewater discharges. It was based on the amount of pollutants discharged, while taking into account the effect of wastewater on the quality and self-purification of the recipient in determining the amount of fines.

The limit values for pollution and the level of fines were specified with a delay of five years by a legislation in 1969, last amended in 1978. The National Water Association published Regulation 1/1973, then the National Water Management Code, a collection of minimum requirements for water management activities, as amended by Decree No. 4/1981, which was repealed in 2008. The Code stated that the amount and quality of treated wastewater to be introduced into the recipient should be determined on the basis of the recipient's load capacity. As a precondition for draining purified wastewater, the soil should be suitable for drainage; the use of groundwater should not be restricted by drainage and should not adversely affect the groundwater body.

Based on the load capacity of the recipients, since 1978 the country has been classified into six water quality protection categories (I–VI). Priority water quality protection areas (I–V) include Lake Balaton as a priority, drinking water sources and recreational areas (II), industrial areas (III), irrigation water sources (IV), non-priority segments of the Danube and Tisza (V). The other areas were classified into the non-priority (VI) category. For each category, various limits have been set for a total of thirty pollutants. The pollutant list contains COD (not BOD) as the aggregate parameter for organic pollutants, pollutants causing eutrophication including ammonium, nitrate and total phosphorus, as well as toxic substances, i.e. cyanides and ten heavy metals.

New concepts and principles have been introduced in Act No. LIII of 1995 on the General Rules of Environmental Protection, e.g. the environmental fee system.

New concepts introduced in the Act on Wastewater Treatment are the following:

– environmental load: the direct or indirect release of a substance or energy into the environment
– requisition limit: the use of the environment or its element above a level defined in law or in official decisions which, if exceeded may cause environmental damage, according to current scientific knowledge

– best available techniques: a state-of-the-art technology and sustainable development method, operating procedure, equipment to prevent emissions, where this is not feasible, to reduce environmental impact, as well as to mitigate the impact on the environment as a whole, and serves as the basis for establishing limit values or the level of emission

In the same year, the Water Management Act came into force, replacing the Water Law of 30 years. The law was created, among others, in compliance with EU Council Directive 91/271/EEC. The law already used the term "on-site wastewater treatment" for the collection of wastewater that is not discharged into a recipient after wastewater treatment, and declared the need for an On-site Wastewater Treatment National Implementation Program concerning areas that cannot be economically equipped with public utility sewerage system and treatment plant.

Since 2000, to reduce pollutant loads affecting surface water quality, eutrophic surface waters or those vulnerable to eutrophication have been designated as "sensitive surface waters", i.e. Lake Balaton, Lake Velence and Lake Fertő [Government Decree 240/2000 (XII.23.)]. From the same year until 2008, legislation on activities that affect the quality of groundwater and geological formations were in force [Government Decree 33/2000 (III.17.)], that, among others, defined several new concepts, e.g. hazardous material, which is "a substance derived from human activities which, when entering the geological environment or groundwater, it presents a risk to the environment, human health, and environmental use due to its toxic, carcinogenic, teratogenic, mutagenic, bioaccumulative or other adverse effects".

The previous immission approach, taking into account the condition and the capacity of the recipients, has changed since 2001 and the emission-based water protection has been promoted. For the protection of surface waters – in order to comply with the European Union Wastewater Treatment Directive (91/271/EEC) – materials from technologies have been categorised according to their hazard. Depending on the hazard, first the release of certain substances from the technology was prohibited by law [Government Decree 203/2001 (X.26.)], secondly, it required the reduction of emissions of certain substances, and, thirdly, it set technological limits for a significant number of substances that could be discharged into surface water and authorised the water authority to establish a catchment specific limit depending on the susceptibility of the recipient.

Government Decree 174/2003 (X.28.) withdrawn in 2010 defined several concepts in its On-site Wastewater Treatment National Implementation Program concerning areas that cannot be economically equipped with public utility sewerage system and treatment plant:

The law defined the on-site wastewater treatment system (OWTS) within the framework of non-public utility services as the use of installations for "municipal wastewater treatment and/or final disposal, or for temporary collection and storage" if their capacity is equivalent to 1–25 population equivalent (PE).

Such installations include:

a) conventional on-site systems

b) small wastewater treatment units

c) closed sewage storage tanks

Of the three installations, the first two had a common feature of "providing environmental protection and quality of life equivalent to public wastewater drainage and treatment", but the septic tank performs pollutants degradation without energy input, while the on-site wastewater treatment system requires energy input. The legislation also defined conventional on-site systems: the septic tank and soil absorption system.

In the evolution of the emission approach in water protection, as a next step the legislator also set limit values for wastewater treatment as a process related to emission activity in the form of BOD_5, COD, TSS, TN and TP parameters. The main principle for establishing limit values was that smaller capacity units had to meet higher, while larger capacity units had to meet lower limits [Decree 28/2004 (XII.25.) of the Ministry of Environment and Water].

Emission limit values for on-site wastewater treatment plants have only been established from the end of 2012 [Decree 30/2008 (XII.31.) of the Ministry of Environment and Water).

Current legal status of wastewater treatment and disposal

Act No. LVII/1995 on water management assigned the arrangement of collection, disposal and collection control of non-sewage wastewater, i.e. collected by other means, to the municipal council's public services. As a general principle, wastewater that has not been discharged into the sewage system must be treated and then either discharged into a receiving body or collected and handed over to a public utility authorised for collection. The same applies to the disposal of sludge from OWTS.

The law defines "public water facility" as a "water utility service". The term "self-contained water facility" is used for non-utility services including the collection, treatment, utilisation and disposal of wastewater not constituting a public water facility.

For the protection of surface waters and to comply with various European Council directives, Decree 28/2004 (XII.25.) of the Ministry of Environment and Water has been in force since 2004. With regard to water protection, the legislation has introduced a triple limit system for purified wastewater, similarly to the principles of preventive regulation, combining the emission and immission approach. Emission of pollutants and emissions from various activities, including household and municipal operations, are subject to technological limits. From the point of view of the protection of the recipients, regarding the reception and immission of water pollutants, local limits must be adhered depending on the water quality protection categories. As a third element of protection, the water authority can set specific limits for specific water protection.

If the treated wastewater is discharged into surface water, wastewater treatment plants with a capacity of less than 2,000 PE must comply with the technological emission limits given in the table below. There is no limit for phosphorus and nitrogen in this equipment size, in most cases, individual limits can be set for these installations.

In case of sewage disposal agglomerations with less than 2,000 PE and surface water recipient, limit values in Table 1 apply to the quality of water discharged after treatment in:

– semi-natural wastewater treatment
– wastewater treatment at small wastewater treatment plants
– wastewater treatment with on-site wastewater treatment systems

However, the same legislation completely exempted individual wastewater discharges from the scope of the above legislation.

Table 1
Technological emission limit values for surface water recipient (compiled by the author)

Load capacity (PE)	Limit values for pollutant components[I] given in concentration (mg/l) or minimum removal efficiency (%)									
	Dichromate oxygen demand (COD_k)[III]		Biochemical Oxygen Demand[II, III] (BOD_5)		Total suspended solids (TSS)[III] From May 1 until November 15 From November 16 until April 30		Total Phosphorus (TP)		Total Nitrogen (TN)	
	as mg/l	%	as mg/l	%	as mg/l	%	as mg/l	%	as mg/l	as mg/l
< 600	300	70	80	75	100	–	–(4)	–(4)	–(4)	–(4)
601–2,000	200	75	50	80	75	–	–(4)	–(4)	–(4)	–(4)

Note: [I] Of the limit value given in concentration (daily average value) and the limit value based on removal efficiency, only one of the criteria specified in the permit shall be met. The percentage reduction should be interpreted in relation to the concentration of raw wastewater influent. [II] BOD can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if correlation can be established between BOD_5 and the substitution parameter. [III] Water samples taken after wetland treatment of wastewater – COD_k, for BOD_5 components – should be filtered prior to water quality testing, but the total suspended solids content of unfiltered water should not exceed 150 mg/l. [IV] The authority may set a specific limit in the interest of water protection.

According to this legislation, near-surface wastewater treatment plants cannot be installed in areas belonging to the 1st and 2nd water quality protection categories, while in nitrate sensitive areas they can be installed with a special permission from the authority.

Important concepts, establishment and operational conditions regarding decentralised wastewater treatment are included in Government Decree 147/2010 (IV.29.) on the actions and installations for the usage and protection of water and water damage prevention. The law replaced the former concept of on-site sewage facilities and on-site small wastewater treatment systems and provided a legal definition of known terms:

- *on-site wastewater treatment* is the treatment, disposal and even temporary collection and storage of municipal wastewater equivalent to 1–50 PE of wastewater load
- *on-site small wastewater treatment unit* is a water facility that performs non-utility, biological treatment of urban wastewater with the input of energy
- *semi-natural wastewater treatment* is a biological wastewater treatment process whereby pollutant degradation is performed by aerobic or anaerobic microorganisms attached to the substrate, sand, gravel and to the roots of plants as well as wetland solutions
- *septic tank equipped with a soil absorption system* is a treatment facility consisting of a septic tank and a septic drain field for non-utility drainage; disposal of municipal wastewater and pollutants degradation is performed without energy input

The law sets a quantitative limit for the establishment of septic tanks with soil absorption system and for on-site wastewater treatment units if the recipient of the treated wastewater is a geological formation. Such facilities can only be installed above 500 m^3/d effluent. This amount is approximately 1.37 m^3/d, i.e. approximately the average of the wastewater discharge of 10 inhabitants. Thus, according to the legislation, in the case of an emission lower than that, treated wastewater could only be discharged into a surface water recipient or could be collected and transported on axis, or a semi-natural wastewater treatment technology should be used. According to the same legislation, “depending on the amount of wastewater, efforts should be made to apply semi-natural wastewater treatment solutions”. As a conclusion, below 8–10 people (about the same PE, LE) the legislator aims to prioritise the installation of semi-natural treatment systems.

From the end of 2012, the legislation [Government Decree 30/2008 (XII.31.)] set limit values depending on whether the effluent from on-site wastewater treatment facility was discharged into surface water or into the soil. This legislation can also be interpreted to mean that in case of a surface water recipient the situation has become more complex with regards to discharges from decentralised wastewater treatment plants, while it is very unlikely that this was the intention of the legislation.

Table 2

Limit values for treated wastewater from on-site wastewater treatment unit (compiled by the author)

Pollutants	**Limit (mg/l) when discharged into surface water**
Dichromate oxygen depletion COD_k	150
Ammonium nitrogen NH_4-N	40

Table 3

Limit values for treated wastewater from a septic system when discharged into geological formation (compiled by the author)

Pollutants	**Type of sampling**	**Limit values for groundwater when wastewater is discharged into geological formation**	
		In an area with highly sensitive groundwater and high water table as mg/l	**In a non-sensitive area[1] as mg/l**
Dichromate Oxygen Consumption COD	qualified point pattern	–	150
	24 hour average sample	75	100
Ammonium nitrogen NH_4-N	qualified point pattern	–	–
	24 hour average sample	10	–
All inorganic nitrogen TN_{inorg}	qualified point pattern	–	–
	24 hour average sample	25	–

Note: [1] The type of sampling may be specified in the alternative, both should not be used together.

According to the legislation, in areas of high sensitivity groundwater or with high water table, only on-site wastewater treatment unit achieving denitrification can be installed.

On-site wastewater treatment installation can be programmatic, if the settlement adopts a program for decentralised wastewater treatment in a wastewater treatment agglomeration and delimits part of the settlements where it will be implemented in place of a public sewer. In case of a programmatic installation, a monitoring system must be established and operated in the affected area [Government Decree 147/2010 (IV.29.)].

The authorisation of the installation, operation, existence and disposal of decentralised wastewater treatment plants depends on the amount of annual wastewater discharges. The licensing authority, if the discharge does not exceed 500 m/year, is the notary of the settlement, in other cases the water authority of first instance [Government Decree 72/1996 (V.22.)].

German legislations on small equipment

The installation, operation and maintenance of small equipment can be carried out in accordance with the German Water Management Act (Wasserhaushaltsgesetz), taking into account requirements for treatment and disposal of wastewater. As a general principle, the amount and contamination of treated wastewater into surface water should be maintained at a level that can be achieved by the best available techniques. In addition to the concepts, the Wastewater Decree (Abwasserverordnung) also establishes the requirements that can be achieved by the best available techniques. In case of surface water, the decree classifies wastewater treatment plants into 5 classes, depending on BOD_5 load. Small equipment with a capacity of up to 8 m^3/d fall into the category of wastewater treatment plants with a capacity of less than 60 kg/d (i.e. 1,000 PE equivalent), therefore their emission limit values are also the same, i.e. 150 mg/l COD and 40 mg/l BOD_5. If the additional load caused by the discharge would be unfavourable, more stringent requirements should be imposed and discharge from small equipment at particularly sensitive parts of a watercourse may be prohibited.

In areas with decentralised wastewater treatment, the property owner should treat the domestic wastewater generated on the property with small equipment. The obligation to dispose sludge produced in small equipment and in septic tanks is generally in the hands of local governments, according to provincial legislations.

In the framework of decentralised wastewater treatment and disposal, only biological small sewage treatment systems can be installed. Old equipment could be transformed into a biological treatment system by a date set by provincial legislators.

For quality requirements of treated wastewater, federal states may enact legislation for displacement in soil.

These are mostly:

BOD_5	25 mg/l
COD	90 mg/l
TOC	max. 30 mg/l
30 minutes sedimentation	0.3 ml/l
NH_4-N (above 12°C)	max. 10 mg/l

Special requirements apply to ready-made sewage treatment plants. Since 2005, in order to obtain a marketing authorisation from the Deutsche Institut für Bautechnik (German Institute of Building Technology), small wastewater treatment plants are classified into five classes (see Table 4). All equipment must be suitable for the decomposition of organic matter. Class C treatment equipment must only comply with COD and BOD limit values. If criteria for recipient requires, equipment suitable for reducing nitrogen or phosphorus may be used (Classes N and D). Equipment with phosphorus removal technology is rated as class +P, and equipment for reducing fecal coliforms is +H.

Equipment that fulfils tertiary treatment requirements is generally prefabricated construction and must be approved by the Institute. In addition, their technological emissions must be verified by a test performed under operating conditions for a year.

The Swiss Association of Water Management (VSA) has issued guidelines for wastewater discharges of aerobic small equipment below 200 PE. Although they are less sophisticated than German regulations, they set stricter requirements for some discharge parameters.

Table 4
Emission requirements for different classes of equipment (compiled by the author)

40[I]/25[II] 75[I]Class	COD as mg/l	(BOD_5) as mg/l	NH_4-N as mg/l	N_{anorg} as mg/l	P as mg/l	fecal coliforms i/100 ml	TSS as mg/l
N150[I]/100[II] C	90[I]/75[II]	20[I]/15[II]	10[II]				50[I]
D	90[I]/75[II]	20[I]/15[II]	10[II]	25[II]			50[I]
+P					2[II]		
+H						100[II]	

Note: [I] From qualified point sample, simple point sample for fecal coliform. [II] 24-hour composite sample; NH_4-N and N_{anorg} $T \geq 12°C$ wastewater temperature.

Table 5
Aerobic small equipment discharge guideline values (VSA) (compiled by the author)

Parameter	Small equipment without nitrification	Nitrification equipment
TSS (mg/l)	30	20
BOD5 (mg/l)	30	20
COD	90	60
DOC (mg/l)	20	10
Visual acuity (Snellen) (cm)	> 30	> 30
NH_4-N (mg/l)	–	3
TP (mg/l)	–	–

Small equipment standards, technical specifications, guidelines

The domestic standardisation technical directive and the professional practice are traditionally consistent with the German (German–Austrian) approach, often following it. The first standard for domestic wastewater treatment equipment in Germany was published in 1942. The standard could rather be used as a guide and described sizing rules for treatment units. Domestic WWTS meant a simple settler, or a septic tank suitable for long-term sewage storage and digestion, subsoil irrigation, trickling filter and infiltration shaft. For sizing 150 l/person/day "normative" wastewater emissions were included in the standard. A small equipment in the post-war standard meant treatment units capable of serving up to 500 inhabitants.

In the title of the 1970 edition of the DIN 4261-1 standard, a clarification of "equipment without wastewater aeration" appeared, indicating, on the one hand, it was time for the introduction of aeration technology into small equipment as well, and on the other hand an upcoming new standard. The standard (DIN 4261-2) was indeed published, although, only after 14 years.

In 1952, the Ministry of Construction issued a mandatory sewer design and sizing regulation for domestic wastewater treatment equipment as a technical specification, clearly based on the German regulatory model that had already been accepted among Hungarian professionals. The regulation dealt with small appliances for domestic wastewater treatment and has not yet used the term small equipment or other related generic term. By the term of mechanical treatment appliances, the regulation meant two, or three-chamber engineering structures and the two-tier settler. Biological digesters meant an expanded septic tank, the infiltration shaft and the trickling filter. The regulation defined minimal editing rules for engineering structure design and also provided sample drawings. For the treated wastewater to be suitable to be discharged into surface water recipient, depending on the type of equipment, the regulation defined various guideline values (500–100-fold), in case of biological treatment with "post-settler" a 50-fold dilution was defined. With regards to discharge into soil, infiltration can only be planned if there is at least 1 m difference between the lower plane of drainage and the water table. At the same time, it also mentioned the "infiltration wells" as the equipment for the disposal of biologically treated wastewater into "deeper soil layers", though with the comment that it cannot result in dangerous groundwater contamination.

In 1962, the MSZ 15302 standard "Sewer Design and Sizing – Wastewater Treatment" related to small domestic wastewater treatment equipment still referred to the previous regulation. The object of the standard is the engineering structure of soil absorption systems, their sizing and design, as well as the rules of their placement. According to the standard, the soil filter meant a disposal on an agricultural area. The concept of "oxidising power" of soil appears in the standard for the first (and last) time, which provides the basis for sizing the filter along with permeability. For the BOD_5 to be removed by the sand filter, the values for the oxidation capacity expressed in g O_2/m^2 and the emission expressed in m^3/d.ha for various soils the following values are included:

Table 6
Oxidising capacity and load capacity of different soils (compiled by the author)

	Oxidising potential g/m²	**Load m³/d.ha**
Sand	4–8	100–300
Sludge	2–4	50–100
Cob	1–2	25–50
Clay	0.5–1.0	15–25

The standard provided methods for discharging treated wastewater into recipients, and methods for calculating the load-bearing capacity based on oxygen consumption measurement, furthermore, as a simplification for treatment technologies, various dilution rates and estimation methods were provided.

In 1971, the National Water Agency issued sector-specific technical guidelines related to domestic wastewater treatment structures for the design and technical solution of septic tanks, two-tier settlers, biological trickling filters and sand filters. Sand filter was considered an alternative to septic tank. The concept of "population equivalence" (PE) appeared in the directive, but in terms of discharge (1 PE = 100 l/person). If wastewater was biologically treated (for example, by a sand filter after septic tank), lakes with at least 10 m^2/PE water surface were also considered suitable recipients if their load capacity otherwise allowed it.

In 1976, the Construction Sector Standard entitled *Wastewater Treatment and Design Requirements for Wastewater Treatment Facilities* came into force, in which a separate section was dedicated for small wastewater treatment equipment with a capacity of up to 1,250 m^3/d, they were denominated as domestic wastewater treatment equipment with $Q_{dmax} \leq 15$ m^3/d, compact wastewater treatment equipment with 3–75 m^3/d, and small wastewater treatment equipment with 75–1,250 m^3/d. Soil absorption is once again emerging in the standard, now combined with high-speed filters and micro drum filters in the physical post-treatment category. Soil oxidation capacity previously used for sizing the soil filter has been removed from the standard, while the guideline values of load capacity have increased significantly compared to the previous standard: for sandy soil 400–1,200 m^3/d.ha, for silty soil 200–400 m^3/d.ha. There are no guiding values for impermeable soils, but the load capacity for drained sand filter appears as 4,000 m^3/ha.d. The concepts of biological treatment, equipment with complete oxidation technology and immersed disc structures have appeared in the standard. In connection with these, as a criterion for biologically treated wastewater, 25 mg/l BOI_5 concentration should be applied.

As part of the Municipal Wastewater Treatment Plants' technical directive series, in 1984 a separate edition was published for septic systems, which is a revision of the previous sectoral technical directive. The directive defined an upper limit of 75 m^3/d for small structures and small appliances treating domestic wastewater. The subjects of the directive were essentially the simple and extended septic tanks as well as the sizing and design of drainage and sand filter trenches, with only a faint reference to manufactured small wastewater treatment units already applied.

The Hungarian Standards Institution issued a standard in 2000 entitled *Municipal Wastewater Treatment Plants. Small Wastewater Treatment Structures and Small Appliances,* which is also in force at the time of writing this manuscript. The scope of the standard is the treatment of domestic wastewater not exceeding 75 m^3/d. In the standard the (simple) septic tank and extended septic tank are listed as pretreatment structures, together with the grease traps. Although the world "biological" does not precede the heading of *Treatment of Wastewater,* the chapter deals with biological treatment methods, indicating that the content of suspended solids, the amount of dissolved pollutants should be reduced and the anaerobic nature of wastewater must be eliminated. Among biological treatment technologies, sand filter trenches and fields are discussed among conventional treatment processes. The standard describes the place of application of activated sludge, trickling filter and immersed disc equipment, but their sizing and design features are not discussed. The standard mentions "natural technologies", essentially meaning root zone and lake treatment. Root zone technology is described as a "closed-loop" technology; cassette and lake treatment technologies are considered applicable only at higher loads. Soil drainage structures appeared in the spirit of previous technical publications. Regarding the so-called drainage coefficient, it can be considered a significant change that is based on the drainage capacity of the soil recipient; less favourable soils were also designated as applicable. (The drainage coefficient is the water-absorbing capacity of the soil as determined by an on-site drainage test.)

Table 7
Changes in the infiltration factor in the former Hungarian technical regulatory publications (compiled by the author)

Drainage factor min/cm	OVHMI 146/7-71	MI 10-127/9-84	MSZ 15287: 2000
	Infiltration surface needed for 1 m³/d wastewater m²		
Up to 1	14	14–15	14–15
1–2	18	16–17	16–17
2–4	25	18–26	18–26
4–12	28 (4–6 min/cm) 37 (6–12 min/cm)	Avoid if possible	27–39
Above 12	45 (12–18 min/cm) 50 (18–24 min/cm) Not suitable for drainage (> 24 min/cm)>		Avoid if possible

According to the standard, only biologically treated wastewater can be discharged into surface water.

Since 2000, we have introduced the EU standards for small equipment in Hungary. The process lasted until 2013, when the last standard was released, while the already published pages have changed several times.

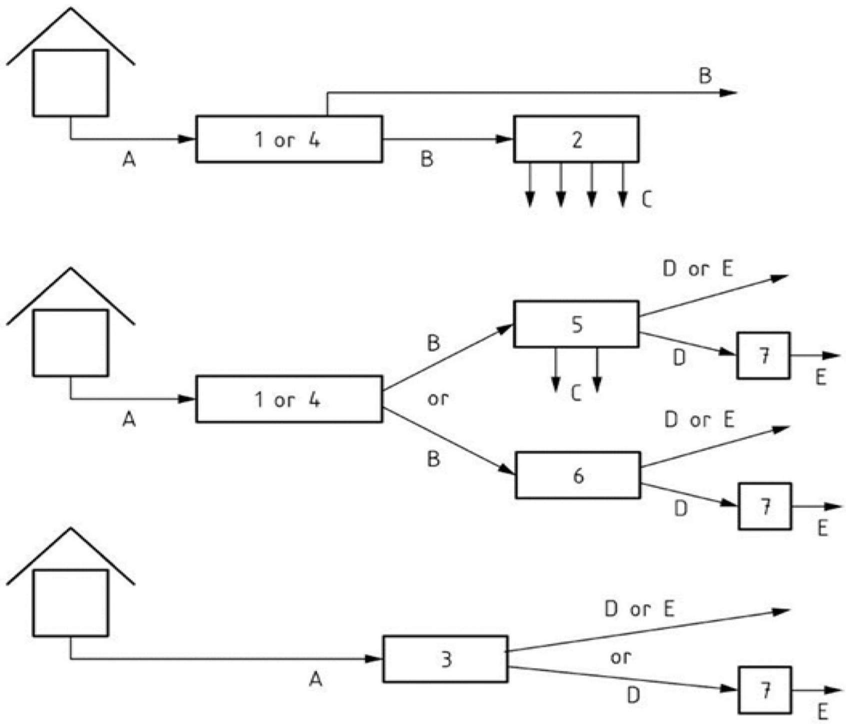
The EU-harmonised standard entitled *Wastewater Treatment Systems up to 50 Total Population Equivalent,* consists of five parts:

Part 1: Prefabricated septic tanks
Part 3: Ready-made and/or site-assembled domestic wastewater treatment units
Part 4: Septic tanks assembled on-site from prefabricated elements
Part 6: Prefabricated treatment units for septic tank effluents
Part 7: Prefabricated, tertiary treatment units

They appeared as MSZ (Hungarian Standard) EN, but they are in English. As their translations – like many other standards – have not been performed, many engineers and lawyers question their legal relevance, especially because English is not an official language in Hungary.

The standard series contains requirements for testing of small appliances that are prefabricated or assembled on site using prefabricated elements. Tests required are aimed at permeability, structural-dynamic features, durability, fire resistance, hazardous material compliance and control of operational efficiency. In the case of septic tanks, the standard requires a test of "hydraulic efficiency", i.e. testing sedimentation efficiency. Appendix B of the third section of the standard series deals with the conditions for testing the technological operation of small appliances prefabricated or assembled on-site using prefabricated elements. The standard describes in detail the criteria for selecting test sites, lower and upper limits of wastewater quality parameters discharged into the equipment, the duration of the tests at various loads (nominal as well as upper and lower load limits), the daily schedule of wastewater feed, sampling methods and number, and the parameters to be tested. It also deals with peak loads as special operating conditions, such as a 24-hour power failure at nominal load, at a load analogous to a single or multiple bathtubs draining, as well as under conditions without load.

Conformity of the product with the standard is certified by the manufacturer with a CE certificate, which contains the following information: name of the manufacturer, year of CE conformity, the mark of the relevant standard, general product characteristics, and data related to cleaning efficiency, size and capacity, water tightness, stability, durability, and resistance to fire and hazardous materials.



Explanation of Symbols

A domestic sewage
B Sewage from septic tank
C desiccation of treated wastewater
D Treated wastewater
E tertiary treatment of wastewater

1. Pre-fabricated septic tank
2. Soil absorption system
3. Prefabricated and / or on - site assembly of domestic sewage treatment plants
4. On - site septic tank of prefabricated elements
5. Soil absorption system for pre-treated domestic sewage
6. Prefabricated treatment units for effluent from septic tank
7. Prefabricated tertiary tretament units

Figure 1
Application Scheme for EN 12566 series (compiled by the author)

CE

9876

Any Co Ltd, P.O. Box 21, B-1050

16

0012014-09-30

EN 12566-6:2016

Prefabricated treatment units for septic tank effluent

— - Product's reference code: "BWV 41"

— - Material: CONCRETE

To be used outside buildings for septic tank effluent

Effectiveness of treatment:

Treatment efficiency (at tested organic daily load BOD_5 = 0,9 kg/d)	COD: 80 %
	BOD_5: 80 % SS: 70 % P NPD KN NPD
Number of desludging during CE test	0
Power consumption	0,2 kWh/d
Microorganism reduction	E. Coli: 1 000 cfu/100 ml 2 log unit Intestinal enterococci: 1 000 cf/100 ml 1,5 log unit
Treatment capacity (nominal designation):	4 PT
Watertightness: (water test)	Pass

Crushing resistance:

Load bearing capacity	Height of backfill 0,5 m WET 1,20 m

Figure 2

Example of CE conformity certificate (compiled by the author)

The numbering of the parts of the standard shows that there are holes in the system. The Standing Committee has published two documents for filling the gaps, one for soil drainage systems (Part 2) and one for filtration systems of pretreated sewage (Part 5), which can be considered a Code of Practices.

Screens

There is no separate screen function unit installed in small equipment. Materials that are removed from the grid in larger municipal wastewater treatment plants are deposited in the sludge or slurry in the sedimentation unit in small equipment and are discharged together with sewage sludge. For small wastewater treatment plants of more than 50 PE, a separate screen unit as well as design and operation of the screen should be considered.

With today's technical capabilities and operational attitudes, it is indisputable that there is a rationale for mechanical screens in installations with a capacity of 50–500 PE near the upper limit. It is practical to choose a mechanical screen that is compact and suitable for dewatering and compacting the mesh. Near the lower capacity limit, simpler basket screens or manual coarse screens could also be considered.

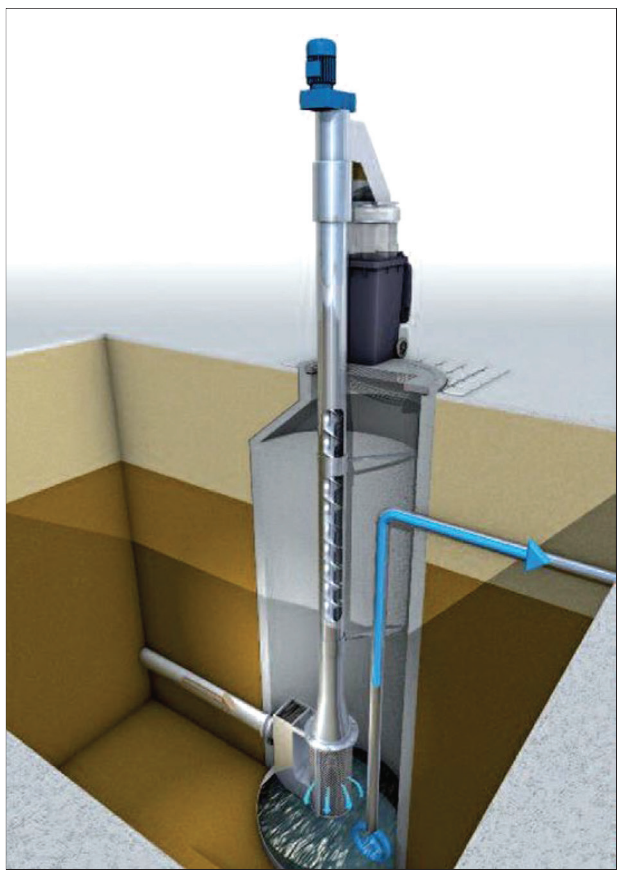


Figure 3
Fine screens installed into shafts (Huber) (compiled by the author)

Floating oil skimmers

Floating skimmers are designed to remove fats, oils, waxes, soap, free fatty acids, wood and cork pieces, vegetable oil, etc. Such materials come in larger quantities from kitchens and restaurants.

The floating structure must be designed to allow lighter materials to float to the surface, and deposits to settle on the bottom, while wastewater should be drained from above the bottom sludge space or below the training wall.

The construction of such a structure can be reasonable for small appliances over 50 PE, but even in these cases, it should be constructed near or at the source as a pretreatment unit before draining into the external base canal.

Simple and expanded septic tanks

For small treatment units, the screen, the oil skimmer and the pre-settler are incorporated into a multi-chamber structure. In septic tanks, wastewater particles sediment to the bottom of the tank, and substances with a density lower than water float to the surface. The settled sludge, which mainly contains organic matter, starts to rot due to significant residence time.

In the expanded septic tank, the flow rate drops to 0. The coarse materials remain in the first chamber.

As a result of sedimentation and floating, sludge – bottom sludge – is formed in the expanded septic tank. The bottom sludge forms two zones with different oxygen supplies: the upper layer is rich in oxygen (aerobic), the deeper layers are anaerobic.

In the upper, oxygen rich layer, very little organic matter is decomposed. Nutrients decompose by rotting in the anaerobic sludge. The gas produced gets into the air. The sludge that is formed in the expanded septic tank is also referred to as faecal sludge, referring to its faecal origin. In the term "septic tank", the term "septic" refers to the fact that the floating organic matter that can be settled is substantially hydrolysed during residence time and converted into dissolved organic matter. The settled sludge partially decomposes, which – in biochemical terms – means the degradation of organic matter under anaerobic conditions. The degradation of organic matter, the stabilisation of the sludge, i.e. the reduction of its rotting capacity in the expanded septic tanks is not complete. Partial stabilisation of organic matter can also be measured as a reduction of BOD_5. BOD decrease is due to high – more than a half or a whole year – residence time. Despite the high rotting time, organic matter degradation is only partial, mainly due to low temperature (< 25°C) and the lack of sludge homogeneity, leading to the development of inhibitory environment (e.g. acidification) and processes preventing organic matter decomposition. As a result, the anaerobic bacteria consortium that could effectively perform organic matter degradation cannot develop.

The advantages of septic tanks, besides their efficiency of reducing floating materials and debris, are their reliability, their favourable quantitative and qualitative balancing effect for the next treatment stage.

Expanded septic tanks have been used as pretreatment for sand filters and wastewater ponds; today they can still be used as a pretreatment for semi-natural treatment technologies (ponds, root zone) and for aerobic small equipment providing full biological treatment.

Simple septic tanks have a relatively short residence time (theoretically three days). In order to reduce sludge drift, the structure is divided into chambers; the first chamber takes up two-thirds of the useful volume of the structure.

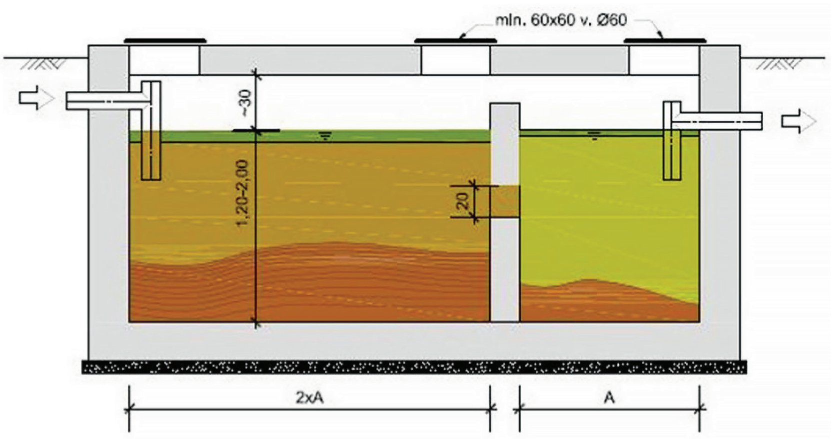


Figure 4
Traditional simple septic tank design (compiled by the author)

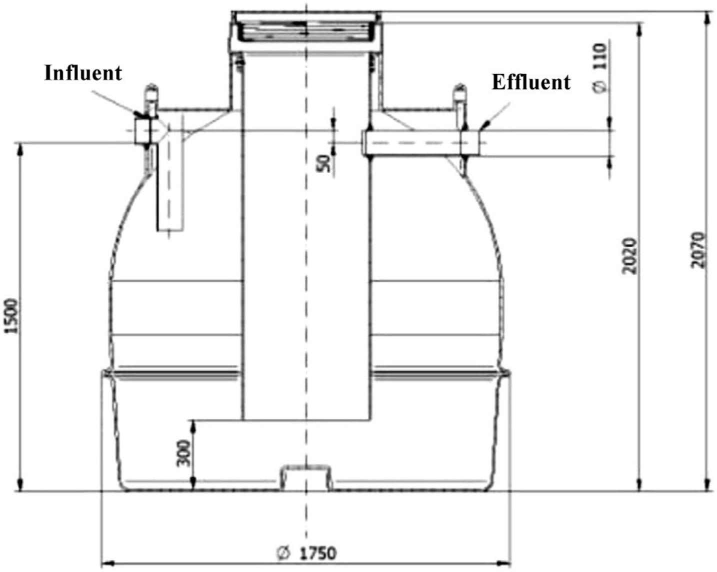


Figure 5
Simple septic tank from Polyethylene (Polyduct) (compiled by the author)

In the expanded septic tank, residence time is significantly higher (6–10 days), which promises better floating and organic matter removal efficiency. They are mostly three-chambered, with the first chamber accounting for half of the total useful volume, while the other two account for a quarter each.

The inlet must be at least 5 cm above the water level inside the structure, thus preventing back swelling in the sewer in case water level increases. In addition, wastewater should be directed to the upper third of the useful height by a submerging wall or a vertical "T" pipe. A transfer hole with a size of approximately 20 cm should be at around the upper third of the water level. Wastewater must also be discharged from the last chamber to prevent drifting away of floating solids by means of a "T" pipe or a submerging wall, in a way that wastewater is removed from the upper water layer with the lowest suspended solids content. If the effluent discharged from the septic tank is fed to a sand filter, it is advisable to install a filter with a pore size of 1.5 to 2 mm into the outlet pipe, inside or outside of the septic tank.

Useful water depths are, according to practice, 1.2 to 2.0 m above the water level with at least 30 cm air space. Beside of these parameters, if the installation depth of the inlet sewer is about the preferred 80 cm, the structure can be installed above groundwater. For good management (debris removal, sludge removal), reinforced concrete structures must be constructed with openings of at least 60 × 60 cm, or rather of 80 × 80 cm at the inlets and outlets, or at transfer holes between the chambers for handling. The openings can be closed with a cast iron or ribbed plate (usually light) cover with a load bearing capacity fit to the expected load at the site.

If the structures are built with proper sewage design, a separate ventilation is not necessary; the structure could be ventilated through a pipe located on the vertical side of the sewage with an outlet above the roof.

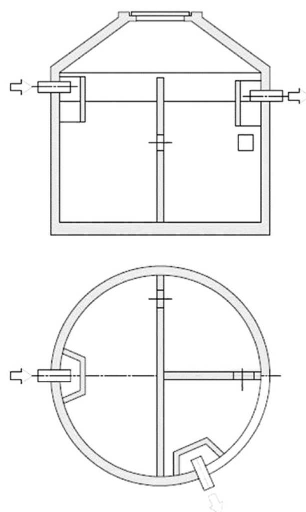


Figure 6
Expanded septic tank construction (compiled by the author)

Continuous flow activated sludge systems

The two main units of the equipment are the aeration tank and settling tank. Wastewater enters the aeration tank gravitationally or by pumping after a simple filtration (e.g. basket screen). Aeration required for activated sludge function, decomposition of organic matter, or for the stabilisation of nitrification or activated sludge is mostly performed by fine bubble diffusers.

During aeration, not only the maintenance of aerobic conditions required for biomass function occurs, but also homogenisation and "mixing" of the wastewater-activated sludge mixture to prevent settling of the activated sludge in the reactor.

From the aerated space, wastewater-activated sludge mixture flows into the settling tank gravitationally, where the separation of activated sludge and wastewater takes place gravitationally. The flow in the settling space is vertical hydraulically. This is the most space-saving settling tank design, conditions for the gravitational sedimentation of activated sludge are favourable and the settled sludge can be collected under favourable conditions (sufficient dry matter content).

Most of the settled sludge must be returned to the aerated tank to ensure that there is always sufficient functional biomass available for the biological degradation processes. During biomass function, pollutants in the wastewater are partly integrated into the biomass upon their degradation, increasing the amount of biomass. From the point of view of stable operation, it is practical to maintain the activated sludge at a quasi-constant concentration, thus, the produced excess sludge (surplus sludge) should be removed.

The passage from the aerated tank to the settling tank is either on the top or on the bottom. In the top passage, the mixture with the least dissolved oxygen content is deposited in the settling tank and the floating foam is also skimmed.

At the bottom passage, the wastewater-activated sludge mixture passes through the lower part of the partition wall located between the aeration and settling tanks. In this case, there is no need for a flow deflector (e.g. damping cylinder), the wastewater flows right up while sludge flakes settle. Due to higher sludge density at the bottom of the settling tank, an equilibrium develops between the lower parts of the settler and the activated sludge reactor; as a result, there is no need for mechanical sludge recirculation – an auto recirculation develops.

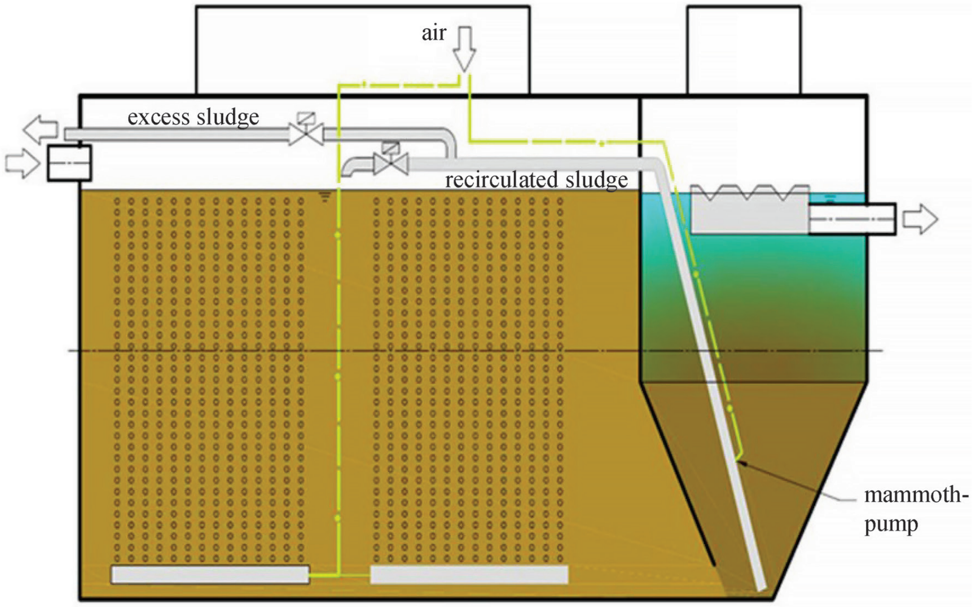


Figure 7

Activated sludge system with bottom passage and auto sludge recirculation (compiled by the author)

The sludge growth and surplus sludge can be directed to the settling tank and stored with the primary sludge. If there is no settling tank, a separate storage unit should be provided for the surplus sludge, either as a standalone structure or in a dedicated compartment of the small equipment.

Air injection technologies are most suitable for biomass aeration, which are fed by air blowers using low-pressure air.

The fine bubble diffuser is mostly in the form of disc, plate, tube and hose.

Figure 8
Plate diffuser (Lausitzer Klärtechnik) (compiled by the author)

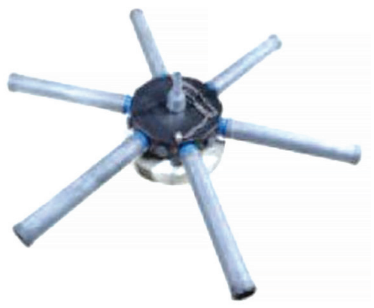


Figure 9
Radial pipe diffuser (Lausitzer Klärtechnik) (compiled by the author)

Silent membrane blowers can be used in small treatment units. Depending on the type, the airflow of the small membrane blower is approximately 30 l/min to 250 l/min, the pressure range is 10 to 20 kPa, the power consumption is 30 to 130 W. Their air nozzle is suitable for connecting a small hose. Their size (~ 200 × 200 mm – 200 × 400 mm), their weight is below 10 kg.

Figure 10
Air membrane blower (Nitto Kohki) (compiled by the author)

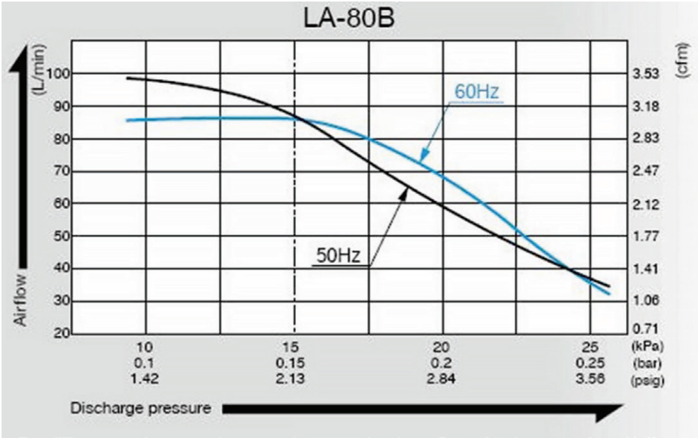


Figure 11
Air blower air delivery (Nitto Kohki) (compiled by the author)

Small units with SBR

Until the 1990s, OWTS were built and installed with continuous flow mode of operation and were hydraulically gravitational (apart from sludge recirculation). In order to make better use of the reactor volume available in the equipment, the SBR systems used in large wastewater treatment plants also appeared in the world of small units. The SBR is an acronym for Sequencing Batch Reactor and refers to the subsequent technological processes occurring in the same reactor space. Due to the cyclic operation of the biological unit, there is no need for a settler to separate the sludge from the sludge-wastewater mixture.

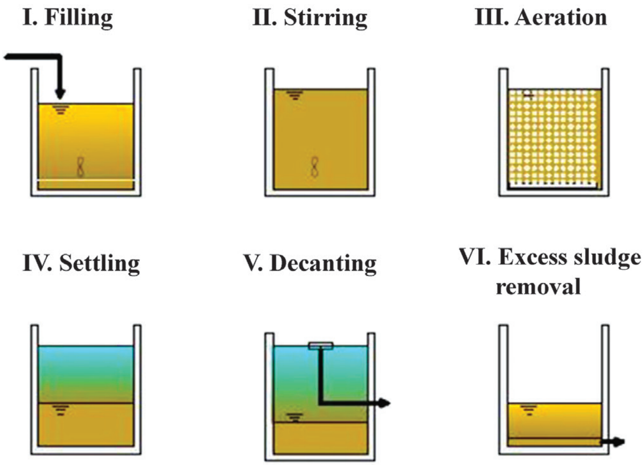


Figure 12
Operating cycles of an SBR system (compiled by the author)

The cyclical operation of the SBR reactor is also favourable for reducing fluctuations in wastewater yields. This effect primarily occurs during wastewater pretreatment (settling) stage, while the pretreatment area also functions as a wastewater reservoir.

Small equipment with SBR technology usually operates with three or four time-controlled cycles per day.

Within this, several versions of wastewater discharge are possible.

a) wastewater is discharged once per cycle from the settling tank to the SBR reactor after settled sewage is removed

b) wastewater is discharged several times per cycle between several internal aeration stages

In addition to cycle-based operation, there is also state-controlled operation as well as the combination of time and status control. A typical case of state control is that wastewater discharge from the settling unit is continuous until it reaches a maximum level. It results in the followings: 1. residence times in the reactor space will always be varied, at lower wastewater yields residence times are longer, while during days with higher wastewater yields the opposite happens; 2. the quality of treated wastewater will also vary accordingly; 3. it is practical to design the pretreatment reactor space for substantial balancing capacity.

For this type of operation, the unit must be equipped with a level switch or sensor or a pressure sensor built into the aeration system.

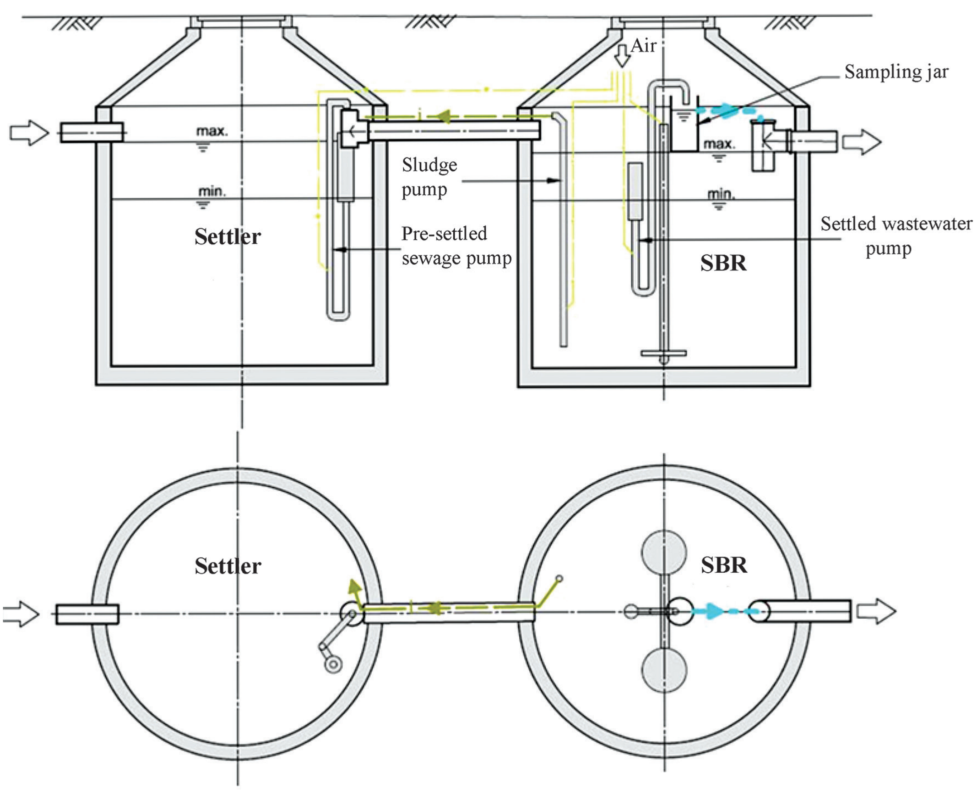


Figure 13
SBR design with two structures (compiled by the author)

Small equipment with SBR system consists of two units: the (pre) settler and the SBR reactor. For the smallest equipment, the two units are developed in a single structure, in the larger ones the primary settler and the SBR unit are located in separate engineered structures. The settler is also a buffer space with varying water levels, so the settled sewage can be pumped to the SBR unit. From there, the (post) settled sewage can be decanted by a pump into the sampling vessel, from which it can be directed gravitationally to the post-clarifier or the receiver. Time to time, the excess sludge is pumped back into the primary settler. Similarly to the continuous flow sludge systems, in small SBR equipment mammoth pumps are used, aeration elements and blowers are also similar to those used in activated sludge systems.

Small equipment with trickling filters

Trickling filter treatment is an aerobic treatment process, in which the microorganisms performing the biological degradation are bound to a surface and form biofilms. The media carrying the biofilm is a rock material or a ring-shaped plastic element. For small equipment, mostly basalt, lava and similar rocks are used. The mechanically pretreated wastewater can be evenly distributed over the surface of the media. The effluent that drains through the media gets into contact with the biological membrane while absorbing dissolved oxygen from the air flowing through the gaps. Microorganisms in the biofilm primarily decompose organic materials and incorporate them into their bodies. During these processes, the biofilm thickens, the inner layers of the biofilm are less oxygenated, die slowly and the biofilm sometimes detaches. This detachment process is also supported by the wash-down effect of the wastewater. The detached biomass can be pumped out by pumping it into the settler after the trickling filter. The sludge (and settled sewage) settled in the sump will be transferred to the mechanical pretreatment unit by an intermittent operation pump installed in the sump. By recirculating the wastewater, the hydraulic load increases, wastewater dilutes and shock loads are also reduced. The sludge is stored with the settled raw sludge. In more sophisticated means of recirculation, a separate pump located in a pump area after the trickling filter pumps the wastewater back to the trickling filter and to the primary settler.

The medium is supported by a slotted bottom, which is permeable for air and wastewater containing the detached biofilm. Due to the chimney effect, the air directed under the bottom flows through the medium. Flow direction depends on the temperature of the outer area and of the temperature inside the medium.

In smaller appliances (up to 8–10 PE), trickling filters are located in a single structure together with the secondary settler, while in larger equipment the two technological units are separated into two structures.

On the surface of the trickling filter, wastewater must be evenly distributed. In small equipment with a diameter of a few meters, water dispensers with jointed arm common in large trickling filters cannot be installed. Instead, they use simpler water dispensers, plate dispensers, tipping tray, manifolds, etc.

The wastewater flowing through the medium is pumped to the post-settler from which the settled wastewater can be discharged gravitationally. The settled sludge is pumped into the pretreatment unit (e.g. expanded septic tank), which is an essential part of the trickling filter technology.

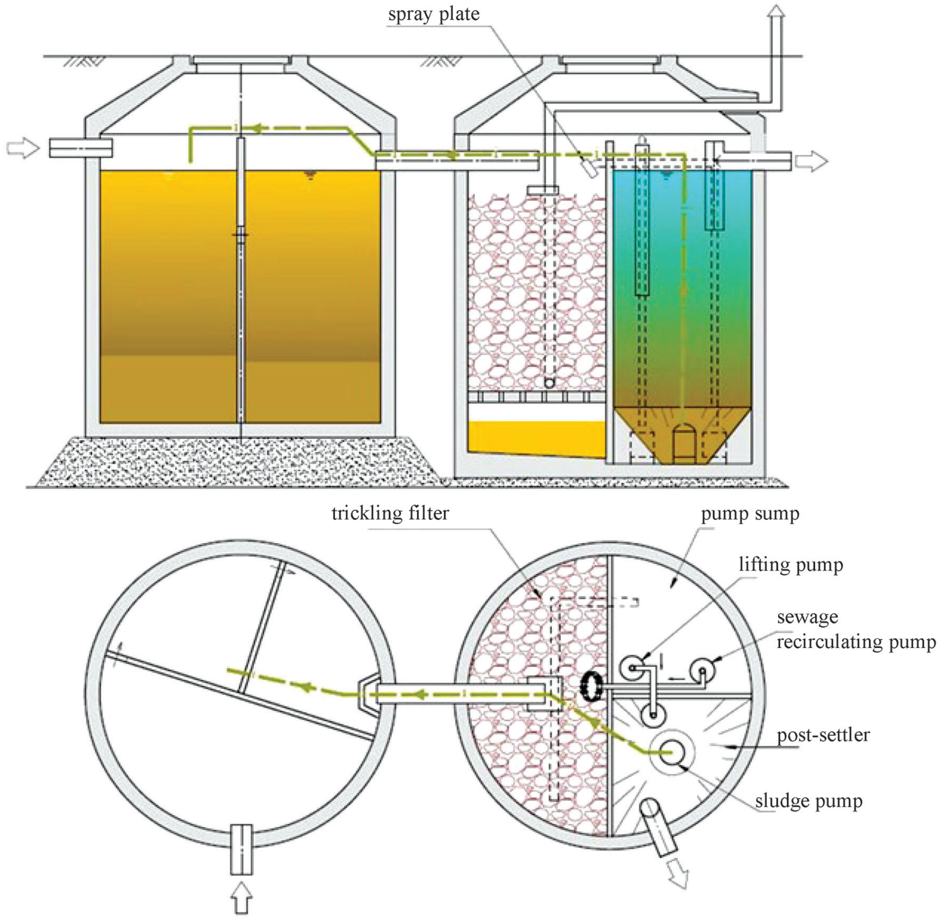


Figure 14
Designing a small equipment trickling filter with two engineered structures (compiled by the author)

Rotating contactors with immersed disc

Rotating contactors with immersed disc consist of discs 15–20 mm apart or clustered plastic medium mounted onto a common axis. The axis of the immersed bodies is located above the water to allow one-third of them to be immersed in the wastewater. During rotation, discs are alternately submerged into the wastewater or are above water. When immersed in wastewater, the biofilm attached to surfaces absorbs dissolved organic matter, and, when in contact with air, absorbs the oxygen needed for biodegradation. During operation, the thickening biofilm detaches from time to time, partly remaining in the reactor space as an active biomass, partly settling into the secondary settler and being taken away as a quasi-humified biomass. The sludge can be pumped back into the pre-settler.

The raw wastewater first flows into the pre-settler, where a large proportion of the suspended solids settles, and the settled wastewater flows – usually gravitationally – to the immersion disk unit. The wastewater is transferred from the primary settler of the structure to the biological reactor with a uniform load, in which organic material degradation occurs. Trickling filters with immersed disc are configured in a two-step way in small appliances in the upper capacity range or over of 50 PE. In the second biological stage, primarily nitrification should take place. The secondary settler is the last element of the technology line, which is, in case of small equipment, a chamber after the trickling filter, while in larger equipment, a separate secondary settler structure is built. In the solution shown in Figure 15, wastewater is supplied to the primary settler or to the recirculation well by a chain pump. With recirculation, the treated wastewater and waste particles are returned to the primary settler. This is necessary for the continuous operation of biological processes during periods without load as well as for levelling irregularities of wastewater discharges.

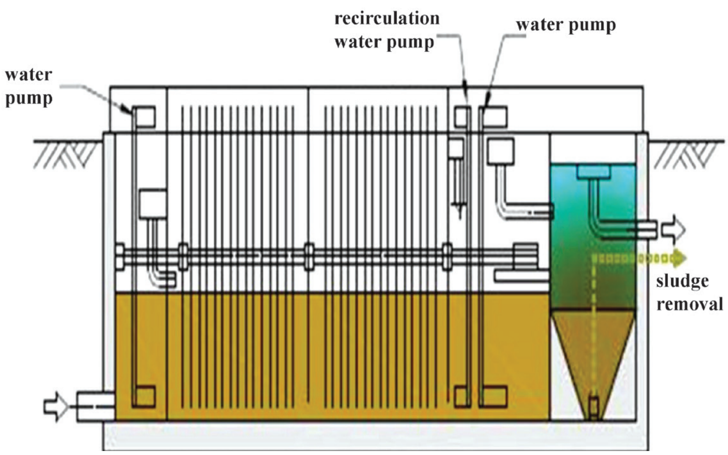


Figure 15
Technology design scheme for trickling filter with immersed disc (compiled by the author)

Treatment technology using immersed body and floating bed

In these biological appliances, microorganisms that settle on the surface of plastic media with high specific surface area and voids volume perform the biological treatment of wastewater. The plastic elements are designed with inner sinuses allowing the wastewater to move freely while it comes into contact with the biofilm attached to the surface of the medium.

The aeration is carried out by fine bubble aeration elements diffusers located under the immersion body. In addition to continuous aeration and long sludge age, the technology is suitable for organic matter decomposition and nitrification. It can also be adapted for denitrification by applying batch-type aeration. In aeration-free periods, anoxic condition required for denitrification processes develops.

The floating bad technology is a microbiologically similar operating principle. In this case, mostly ring-shaped plastic elements with a structured surface float in the pre-settled wastewater. Plastic elements also have a high specific surface area and large biofilm develops on them. Floating away of plastic media forming the floating bed is prevented by a filter located at the pipe draining into the secondary settler.

The secondary settler and sludge recirculation are part both of the fixed and floating bed reactor technologies.

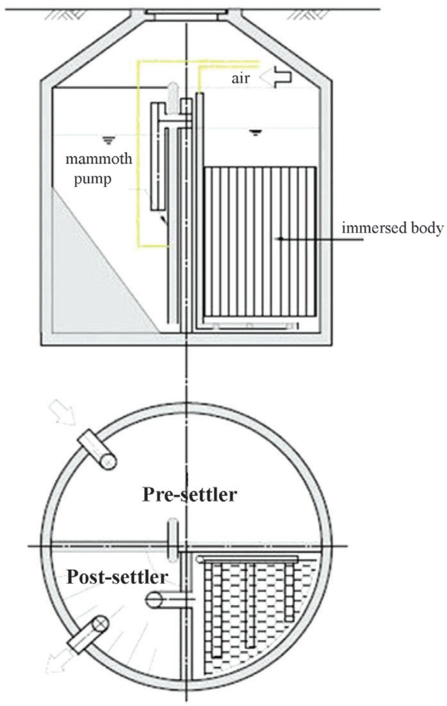


Figure 16
Technological design scheme for small equipment with immersed body (compiled by the author)

Figure 17
Immersion body (compiled by the author)

Membrane bioreactors (MBR)

Membrane bioreactors are a combination of continuous flow sludge technology and membrane filtration. In principle, a biological reactor can mean any activated sludge technology – e.g. simultaneous sludge stabilisation, aerated, pre- or post-nitrification, biological excess phosphorus removal, etc., but the secondary settler used as the last unit of a conventional biological treatment is replaced by a membrane filter. As there is no need for a secondary settler, this space-saving technology is also well suited for its application in small equipment. Mass production of membranes aids their use in small equipment. Most of the manufacturers of prefabricated small equipment also incorporated membrane bioreactor engineered structures into their portfolio; technically, it is not problematic to subsequently incorporate a membrane filter unit into a small appliance composed of several structures or chambers.

The use of MBR small equipment is obvious in light of the current requirements of water protection and legal provisions, the release of treated water into surface water used for recreational purposes, for certain water utilisation purposes or to achieve water reuse.

Appliances using membrane technology consist of four technological units: a mechanical filter, a settler, an activated sludge biological reactor and a membrane filter chamber. For small appliances, these four technological units can be created in a single engineered structure, while in small wastewater treatment plants it can be built into three separate units. The mechanical filter retains physically easy-to-filter pieces and fibres in the millimetre range. The filter is inserted in the settling unit at the end of the inlet pipe. In the settler mostly organic sludge, that easily settles gravitationally, and floating materials settle. Wastewater flows into the subsequent activated sludge reactor gravitationally. According to its operation principle, it can be a conventional, floating, as well as fixed bed reactor. A diffuser is used for the aeration of wastewater-biomass mixture; the compressed air is supplied by a fine bubble membrane diffuser. The next unit is the membrane filtration chamber into which the wastewater-biomass also flows gravitationally. Dip membrane filter unit(s) used for separating wastewater and biomass are located in the membrane filter chamber. The biomass continuously remaining on and detaching from the filter is retained in the reactor space, resulting in a significantly higher activated sludge concentration compared to conventional sludge technologies, typically 8–12 g/l, which is beneficial for nitrification and also for denitrification if the reactor is configured properly.

Based on their pore size, membranes are classified into micro-, ultra-, nanofilters, as well as into reverse osmosis category. In activated sludge biological treatment, ultrafiltration membranes can be used to filter out a wide range of wastewater materials.

The range of pore size of micro- and ultrafilters is approximately 0.1 and 5 μm, which not only allows filtering of flaky activated sludge, but effectively removes bacteria and viruses as well. The goodness of separation is basically determined by the nominal pore size, but during continuous operation, a dynamic biofilm layer develops on the membrane surface as a result of the quasi-continuous operation, which increases membrane performance.

The membrane design is interesting from several aspects, i.e. separation, the amount of fluid flowing through the membrane (fluxes) and the energy use required for membrane performance. The energy demand on the two sides of the membrane depends on the transmembrane pressure – the in-pressure difference between activated sludge concentrates and filtrates or permeates. In case of micro- and ultrafilters, the pressure required for operation is theoretically between 0.1 and 10 bars, but the flux used for sludge separation is near the lower value.

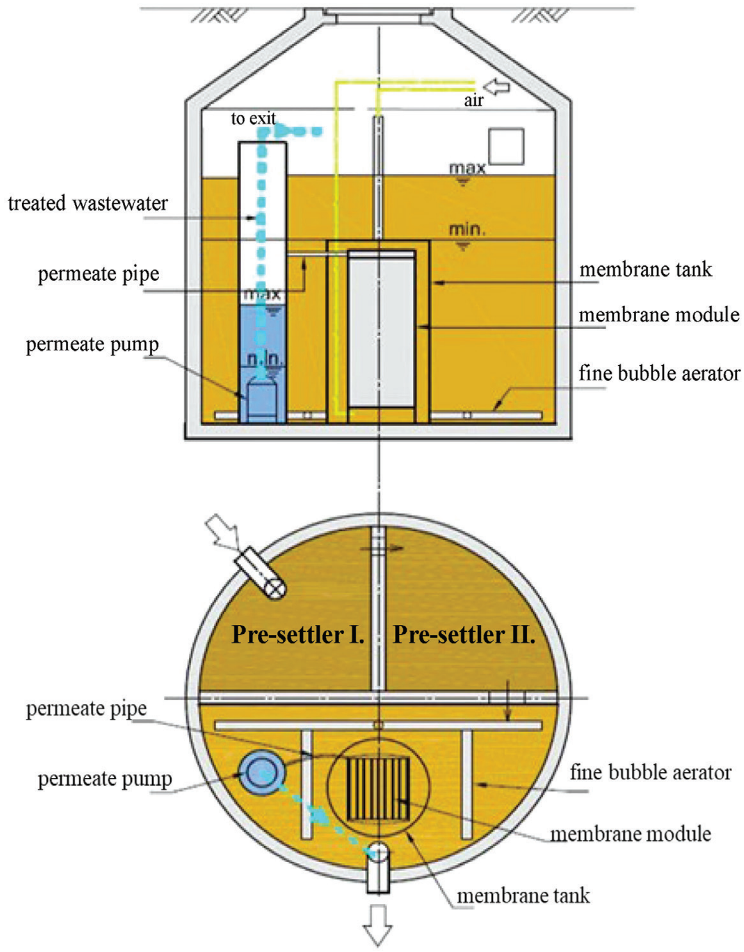


Figure 18
Small membrane bioreactors (compiled by the author)

The membranes are geometrically filamentous or flat membranes. For small appliances, most manufacturers prefer flat sheet membranes. The membrane sheets are assembled vertically with a distance of 2–6 mm between them. The assembled membrane sheets form a filter module that is immersed on the legs into the activated sludge reactor. The wastewater-sludge mix flows between the sheets from the bottom to the top in the module. Wastewater flows through the filter sheets from the outside to the inside. From the permeate channel within the membrane sheet, filtered wastewater enters a collecting duct wrapping around the module from which a pump sucks it out, or the hydrostatic pressure difference between the reactor water level and the end of the collecting tube forces it into the permeate collection chamber.

On the surface of the membrane, a thin layer of film is quickly formed from the biomass decreasing the membrane flux. The membrane permeate performance can be maintained by continuous and intense air supply. The blown air bubbles keep the effluent sludge mixture in motion during up wash; the membrane surface is continuously cleared by the turbulence, while in case of filamentous membranes, the wavy movement of membrane fibres aid in cleaning the membrane.

Figure 19
Membrane module (Huber Catalogue) (compiled by the author)

The activated sludge stored temporarily in the activated sludge reactor should also be removed on occasion. The excess sludge can be moved back to the mechanical settler.

The BOD_5 and COD concentration of treated wastewater can be well below legal limits and can be discharged into microbiologically sensitive surface water recipient or can be reused.

The microbiological efficacy of membrane filters can be characterised by a decrease in total coliforms indicating the degree of microbial contamination. Depending on the pore size, decrease in coliforms is in the order of 5 to 10, and its effectiveness greatly depends on the pore size of the membrane used.

Coliform removal capacity of membrane filters can be qualified depending on the load defined by the recipient or the purpose for which treated wastewater is used. For surface waters, either total coliform number or *E. coli* colony number is tested depending on the purpose of the application. In case of a surface water recipient, if it is used for bathing, quality requirements laid down in the Bathing Water Directive 2006/7/EC and in the corresponding Government Decree should be applied.

Table 8
Water quality requirements for natural bathing water (compiled by the author)

Parameter	Excellent quality	Good quality	Tolerable quality
Fecal Enterococci (cfu/100 ml)	200[I]	400[I]	330[II]
Escherichia coli (cfu/100 ml)	500[I]	1,000[I]	900[II]

Note: [I] 95-percentile. [II] 90-percentile

Semi-natural wastewater treatment is a biological wastewater treatment, in which microorganisms attached to the soil, granular aggregate, root of plants perform the biological (either aerobic or anaerobic) treatment and it includes wastewater lagoon system solutions as well.

Under domestic conditions, wastewater lagoon treatment is a viable solution for agglomerations below 2,000 inhabitants.

Types of wastewater lagoon treatment plants include:

– sedimentation lake
– non-aerated wastewater lagoon
– aerated wastewater lagoon
– conditioning lake

Sedimentation wastewater lagoons are lakes used in front of aerated or non-aerated wastewater lagoons to settle the settable materials of raw wastewater.

Non-aerated wastewater lagoons are also called lakes with facultative or naturally aired ponds, because air can only get into the water through the water surface. In principle, they are also suitable for biodegradation of organic materials. In the near-surface water layer aerobic and anaerobic microorganisms, while above the bottom mostly anaerobic microorganisms perform the treatment of wastewater. Oxygen intake and photosynthesis take place naturally through the water surface, mixing can be initiated by wind and temperature stratification.

Aerated wastewater lagoons are suitable for treating raw wastewater, but they are more suited for the biological treatment of mechanically purified, settled wastewater.

Conditioning lakes can be used as a post-treatment stage for biological wastewater treatment.

In practice, for decentralised wastewater treatment facilities aerated or conditioning ponds can be considered, the previous ones above 50 PE and the latter under 50 PE.

Microorganisms located in the water-mud interface, in the bottom, or on the bench as well as floating microbes participate in organic matter decomposition. By aeration, biodegradation can be significantly improved compared to non-aerated ponds. The aeration can also be controlled; thus the quality of the treated wastewater can be controlled to a certain extent.

Wastewater lagoons must be insulated with e.g. local soil that is at least 30 cm thick with at least $\leq 10^{-9}$ m /s water permeability. Alternatively, a thick (at least 1 mm), UV- and root-resistant foil could be used instead. Foil insulation should be laid on a fine-grained bedding or straining cloth. The insulating foil should be fixed into the soil above the water level or to the edge of the bank.

Sewage inlet is above water level, possibly stretching away from the edge of the bench, this way the inflowing water is aerated.

Wastewater inlet and outlet must be designed at a location where short circuit cannot develop; water exchange should be as even as possible in all parts of the pond. Wastewater outlet must be designed in a way that water is removed from below the surface water, surface debris should be prevented from floating away, and plugging should also be prevented if the water surface is covered with vegetation. A sampling point should be selected downstream of water withdrawal.

One of the options for converting wastewater ponds into aerated lagoons is to develop an SBR technology (Constant Waterlevel Sequencing Batch Reactor) with constant water level. The technology is a technological implementation of SBR in a wastewater pond. In this technology, the pond with constant water level is divided into a primary reservoir, an SBR reactor, and a balancing area by foil curtains anchored to swimmers. Depending on the size of the wastewater inlet, or on the pump controlled filling and discharge among areas, foil curtains move horizontally and the size of the areas with different functions varies, while the water level remains quite constant in each area.

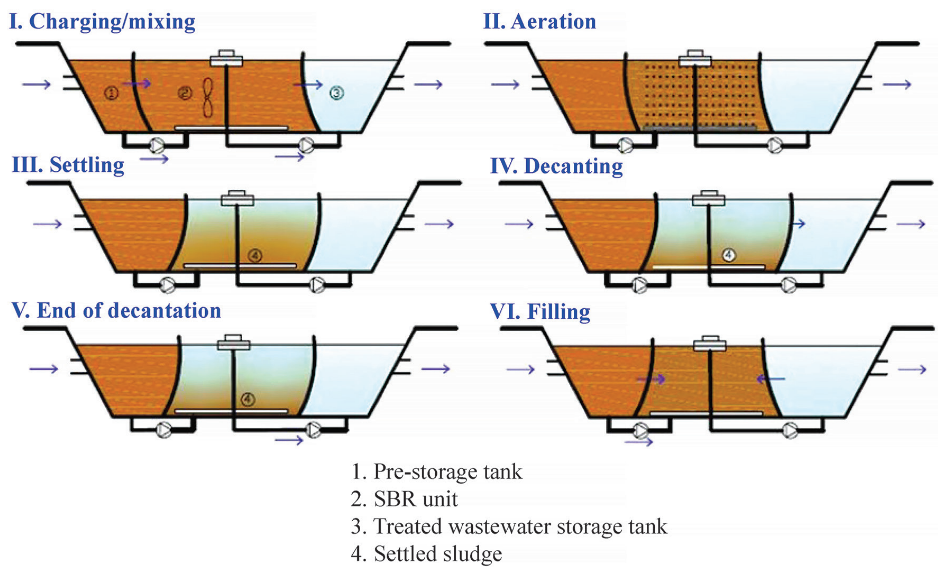


Figure 20
Implementation of constant level SBR technology in aerated wastewater lagoon (compiled by the author)

The purpose of conditioning lakes is to improve the quality of wastewater purified at least biologically. The expected improvement in quality is characterised by the reduction of residual BOD and COD representing organic matter that cannot be eliminated in previous stages, nutrients that can be absorbed by aquatic plants, as well as filterable suspended solids causing turbidity.

For proper functioning of a conditioning lake, microorganism diversity as well as favourable volumetric and geometric design is required, i.e. preferably, it should have large volume and surface and water depth should be low to favour light conditions.

Sand filter fields and ditches

In order to discharge wastewater that has been treated mechanically or partially anaerobically from septic tanks into the recipient, it was necessary to further reduce the amount of suspended solids and organic matter in wastewater, by accelerating and intensifying processes similar to natural drainage in soil, artificial sand filters have been built in the soil to further protect surface water, soil, or groundwater. In fact, sand filters have to perform a second aerobic biological treatment after the anaerobic stage, along with decreasing suspended solids. Applying it after a septic tank, it performs biological treatment as a biofilter.

In order to better protect the environment, using the best available techniques, biological treatment systems should be used. To further reduce residual BOD, COD and suspended solids in the effluent, the above-mentioned artificial, underground sand filters could also be used, not as a second biological treatment step but as dedicated post-treatment step.

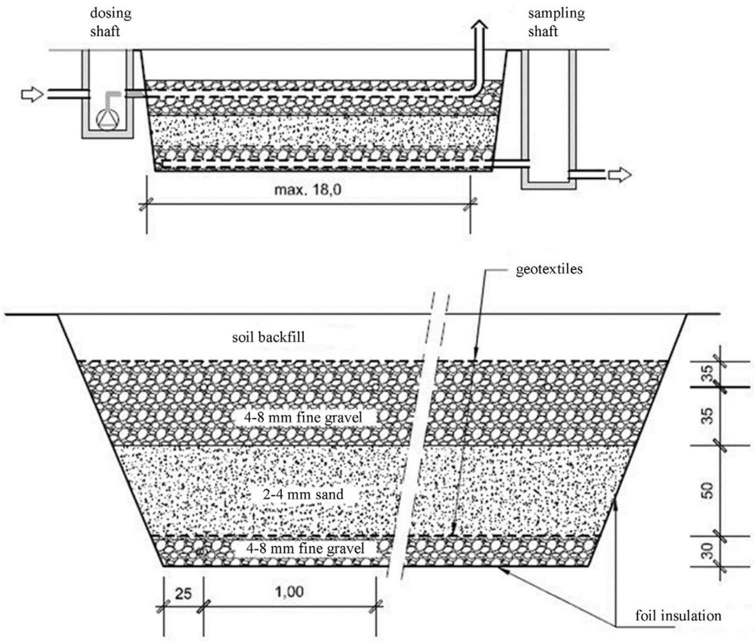


Figure 21
Sand filter field (compiled by the author)

The drains can have vertical and sloped design. The minimum width of the drains is 1.8 m and the bottom width is 0.5 m. The length of the ditches should be 18 m the most for good ventilation.

The drainpipe must be installed in a way to distribute wastewater as evenly as possible into the infiltration body below. Therefore, the slope of the drainpipe should be around 2‰. The recommended size of the drainpipe is DN 100. Wastewater loaded into the drainage system should fill at least the quarter of the pipe to allow uniform distribution. This condition can be met if wastewater discharge is intermittent. The intermittent discharge is also recommended because the drainage body can be aerated between wastewater discharges. For ventilation, the end of the drainpipes should be placed above the surface level.

Some manufacturers offer wind-powered fans that can be installed at the end of the ventilation pipe and requires no extra energy.

Figure 22
Wind powered ventilation fan (compiled by the author)

For designing filter trenches and fields, design data according to changing domestic regulatory documents are summarised in the table below, supplemented with values defined in the DIN standard.

Table 9
Design data for filter trenches and fields according to different guidelines (compiled by the author)

	MSZ 15302-1962	OVHMI 146/1-71	ÉSZ 5 11-75	MI 10-127/9-84	MSZ 15287: 2000	German recommendations
Sand filter trench width	–	1.20–1.50 m	–	–	1.20 m	0.5/1.8 m
Filter layer thickness Grain size	–	0.65–0.70 m 0.5–2 mm	–	0.55–1.0 m 1–3 mm	0.75–1.0 m 1–3 mm	1.0 m 4–8 mm (0.5 m) 2–4 mm (0.5 m)
Max. ditch length	–	25m	–	–	25m	18m

The filter systems are intermittent to support aerobic biological treatment and to reduce clogging of the filter layers and becoming anaerobic. To do this, a dosing shaft is installed driving the pretreated wastewater to the drainage-filtering unit. The dosing is carried out by a pump installed in the structure, by a siphon or a tipper. Today, the least demanding, reliable operation is pumping.

Constructed wetland technology

Plant beds, root zone technology are natural biofilters, utilising micro- and macroorganisms, occasionally plants and sunlight, based on natural self-purification processes without artificial oxygen supply to decompose contaminants.

Plant-based wastewater treatment systems are semi-natural wastewater treatment plants. The two main characteristics of semi-natural treatments are that the majority of wastewater contaminants are degraded while penetrating through the granular medium and the plants and their root system also define this process.

Artificial plant-based wastewater treatment plants can be divided into three groups:

– horizontal subsurface flow systems, when wastewater flows horizontally between the inlet and outlet below the plant bed
– vertical subsurface flow systems, when the wastewater is directed to the surface of the plant bed flowing through the root zone vertically and the filtered sewage is collected at the bottom of the plant bed and discharged
– flooded, i.e. free water-surface systems also belong to plant beds

These main solutions may differ from each other in the geometry of the plant bed, in the filling materials used, in the composition of the plants used, and also in their mode of operation (e.g. intermittent flooding, filling-discharge operation).

Plant bed systems should be preceded by a high-efficiency mechanical and partial biological treatment. The basic prerequisite for their proper functioning is the low suspended solid content of the inlet wastewater in order to avoid colmation. It can function well as a post-treatment unit after a biological sewage treatment system. Plant bed systems are not recommended without a mechanical pretreatment, but applied frequently for biological cleaning.

Horizontal subsurface flow systems are also suitable for nitrification along with decomposition of dissolved organic materials. Their wastewater supply can be continuous, but if possible, it is better to have intermittent influent.

The plant bed must be insulated at the bottom and at the side. For insulation a sloped wall is preferred. The best way of insulation is the use of UV resistant, at least 1 mm thick foil with a high enough resistance against puncture. Foil insulation should be made preferably by using a wide, seamless roll. In case of narrow foil rolls, welding at overlaps should be done carefully according to the manufacturer's instructions. The foil on the slopes must be fixed 20–30 cm above the bed in the surrounding soil, covered with earth. The insulation can also be made of insulating materials based on minerals. Insulation may only be omitted if it is certified that at the site of the installation at least the upper 1 m of soil has a water permeability of less than 10^{-8} m/s. Insulation compliance must be verified by a water retention test. No insulation is required if the plant bed is placed in a prefabricated plastic container, which is suitable for wastewater up until a few PE.

In horizontal subsurface flow plant beds, an inlet-distributor section is developed on one side of the plant bed, mostly of coarse particulate material with or without a distributor drain. On the opposite side of the bed, the treated wastewater is collected by a drained section with gravel and discharged into the sampling shaft, and then the purified wastewater can be drained into the soil or discharged into surface water.

It is practical to design the length of the effective plant bed between 3–6 m. At least 50 cm thick filter layer is needed for effective biological treatment. The 0.5–1.0 m thick layer can be filled with fine gravel of fine particle size, or with medium-sized, washed sand. The filter body should have a good water permeability; it can be considered to be adequate if the permeability coefficient is between 10^{-3}–10^{-4} m/s. The filter layer can be constructed by using sand of 1–4 mm size, gravel of 4–16 mm size, if in each fraction the $U = d_{60}/d_{10}$ inequality coefficient is less than 5. Prior to installation, the particle-size distribution should be checked by the sieve analysis used in geotechnics.

In the horizontal subsurface-flow system with two or more horizontal plant beds, layers can be developed in the direction of the flow, starting from the gravel layer distributing the wastewater; the first layer is composed of a gravel fraction followed by sand and the drain-collector layer.

For horizontal subsurface flow systems, the treated wastewater must be separated by a gravel layer spread in the entire width of the filter bed with a ratio of at least 1:3. The extended rectangular layout is more favourable for a more uniform flow and to prevent short circuits.

For horizontal subsurface flow systems, treated wastewater is collected by a gravel layer (e.g. 32–64 mm) filling the entire width of the filter bed and is drained with a drainpipe.

For horizontal subsurface flow systems, collecting slotted tubes should be laid on the bottom in longitudinal and transversal directions as a 20 cm thick drainage layer. The drainage system must be suitable for the complete drainage of the wastewater effluent from the filter layer above it; bulking should not develop.

For vertical flow plant beds, the filter bed from the water distribution system to the collecting drain system should be constructed on the same principle, to prevent stagnation and to allow the filter to drain.

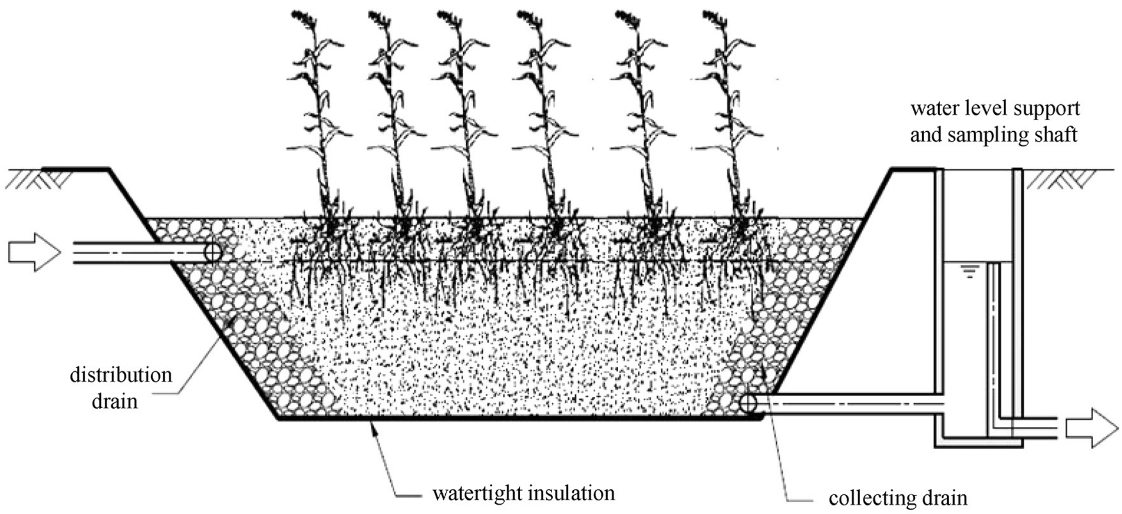


Figure 23
Horizontal subsurface flow plant beds (compiled by the author)

Vertical flow plant beds must be fed either in batches of small quantities or, if the system is completely flooded, sufficient time should be allowed for aeration after draining. With this system, nitrification is even more difficult in summer and the environment in the plant bed is not suitable for denitrification.

The bed must be loaded evenly with sewage in batch operation. The feeding system is a distribution drainage system located near the surface of the filler body. The drainage system is a drainpipe network laid on the bottom under the bed.

The drainage system should be developed with a vertical venting tube at the opposite side of the inflow or outflow to allow natural air exchange in the filter made of particulate material.

For horizontal subsurface flow plant beds, the inlet must be protected against winter freezing, a simple surface distribution duct is not recommended. The drain hose with a slot of at least 8–10 mm should be laid in the coarse gravel distribution bed.

For vertical-flow plant beds, slotted distribution pipes are laid close to the surface with longitudinal and transverse branches in a way to have a bed surface no larger than $5m^2$ for outlet mouths. The vertical-flow systems must be fed intermittently with large wastewater doses.

For batch or shock-like feeding of plant beds, a dosing shaft (pumped, siphon) is a good solution. In case of pumping, pump is level controlled. To indicate pump failure, additional level switches must also be installed below the backwater level of the inlet pipe. If possible, the dispenser tank can be equipped with a reservoir for storing overflowing wastewater (in larger cleaners). The pump pressure pipe must be constructed with a rising angle, and the pressure pipe must not be equipped with fittings preventing backflow to allow the pipe to drain back into the feeding shaft after the pump has stopped (frost protection).

A monitoring well must be installed on the outlet pipe exiting the plant bed. For sampling the tube must be connected to the monitoring well at least 10 cm above the bottom. For larger installations, it is practical to design the well to measure flow rate, too.

The best plants for plant beds are halophytes with rhizomes and deep-roots. The plants can clean the wastewater with their large root systems, root hairs that can go down to greater depths (~ 1 m) of the substrate. Biological treatment is carried out by microorganisms living on the root system. Basic vegetation can be planted using common reed *(Phragmites australis).* In addition to common reed, other complementary plants are also preferred: yellow iris *(Iris pseudacorus),* broadleaf cattail or bulrush *(Typha latifolia),* water mint *(Mentha aquatica),* soft rush *(Juncus effusus),* etc.

There is efficient removal of organic matter in case of load with moderate BOD (v. COD). Phosphorus removal can also occur by adsorption in plant beds. The microbiological efficiency of the systems is good; coliforms are reduced by one or two orders of magnitude; in multistage systems even greater reduction can be achieved.

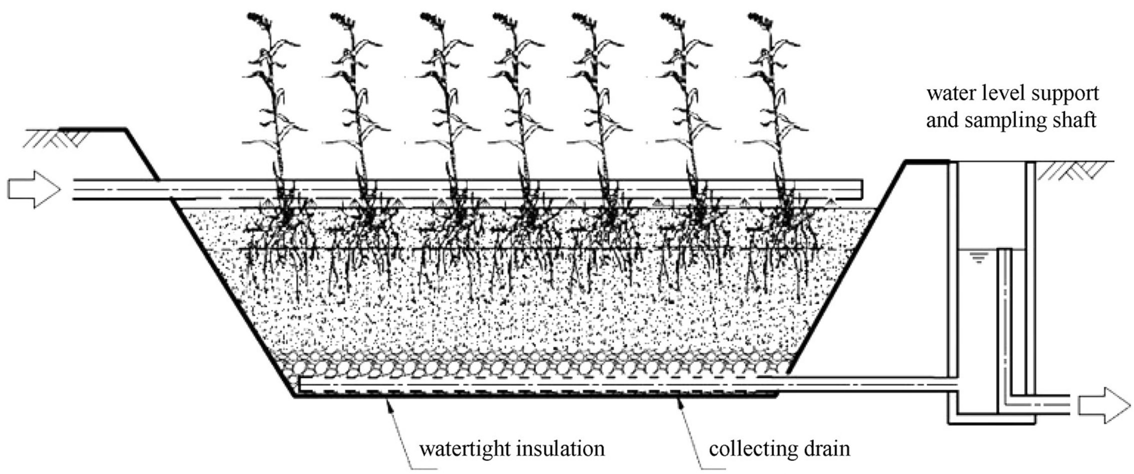


Figure 24
Vertical-flow plant beds (compiled by the author)

Disinfection

If the goal of wastewater treatment technology goes beyond organic matter removal, nitrification, denitrification and treated wastewater quality has to meet water quality requirements to be suitable for discharge into a surface water recipient, disinfection might be required.

Disinfection or pathogenicity reduction of treated wastewater may be necessary if the wastewater is highly pathogenic (wastewater from health institutions), or if wastewater is discharged into a running or stagnant water suitable for bathing, used as a drinking water source, or used for other purposes, e.g. service water or irrigation.

Even after mechanical-biological treatment – in case of a surface water recipient – a large number of relevant microorganisms can still occur. Coliforms indicating fecal contamination may still occur in the order of 10^4–10^6 colony forming units/100 ml, which exceeds legal quality requirement limits of natural bathing waters.

Based on various literature data, the number of *E. coli* bacteria present in treated effluent of each OWTS is expressed in colony forming units/100 ml in Table 10.

Table 10
Number of E. coli bacteria (colony forming unit/expressed in 100 ml) (compiled by the author)

Wastewater Treatment Unit	*E. coli* bacteria (TKE/100 ml)
Vertical flow plant bed	30 -> 4,000 >
SBR	> 20,000 -> 30,000 >>
Fixed bed	> 10,000 -> 30,000
Trickling filter	> 30,000
Membrane biology	< 100
Conditioning lake	0 -> 4,000

Note: Where the > sign is present, the number is an estimated value without an accurate count.

Different technologies remove pathogens present in wastewater to varying degrees. Wastewater treatment plants, with the exception of membrane technology of which the efficiency could be as high as 99.9%, are only modestly suitable for the removal of fecal bacteria. However, well-functioning plant beds perform well in coliform retention.

Various methods can be used to disinfect treated wastewater, if needed.

In case of small appliances, sodium hypochlorite and calcium hypochlorite disinfection are possible as a chemical option. They are typically used only occasionally.

Of physical disinfectants, UV light can be used for small equipment. UV light equipment is suitable for the continuous disinfection of wastewater, their use is warranted in surface water needing protection, and the remnants of chlorine disinfectants do not pose additional load to the recipient.

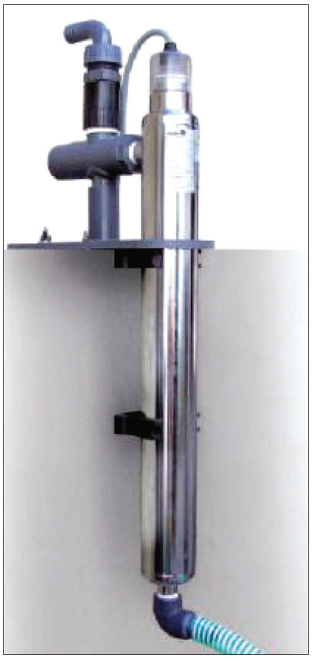


Figure 25
UV disinfection system (Lausitzer Catalogue) (compiled by the author)

Biologically treated wastewater flows through a UV lamp at 254 nm. UV lamps used are usually low-pressure UV emitters. If wastewater emission is intermittent (e.g. in SBR equipment), UV disinfectant should also be operated intermittently for cost savings. In other cases, it is advisable to pump the water to be disinfected from the intermediate storage unit to the UV unit to allow adequate load according to the nominal volume flow rate and to have proper radiation intensity. The UV lamp reaches its nominal power a few minutes after switching it on, thus pumping should start with a delay of 4–5 minutes. The UV equipment is particularly sensitive to the turbidity of treated wastewater, thus, it is necessary to install a mechanical filter in the pipeline before the UV disinfection unit and to clean it with a frequency defined based on turbidity measurements.

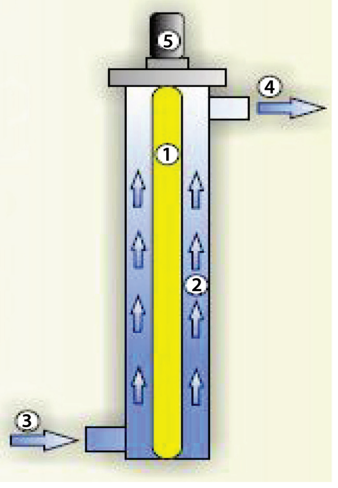


Figure 26

UV disinfection system structure (compiled by the author)

Note: 1 UV lamp, 2 irradiation area, 3 wastewater injection, 4 disinfected sewage, 5 UV housing with electrical connection.

Specific aspects of small sewage system design

When sizing small wastewater treatment plants, the methodologies used to determine basic design criteria shall be different from those used for conventional municipal wastewater treatment plants, due to the quantitative characteristics of effluents, especially their temporal variability as well as their quality and pollutant loads.

When considering water saving, water re-use should also be taken into account, new quality classifications should be added in addition to standard quality classes. These are the types of wastewater that can only be generated within a property or facility and interpreted accordingly.

Yellow water refers to urine with or without flush water, while brown water refers to toilet wastewater without urine. The yellow and brown water together are called blackwater that originates from the use of usual toilet types. Greywater is household wastewater without blackwater, i.e. originates from bathing, washing, cleaning and kitchen use. It should be noted that in the case of grey wastewater reuse, it is advisable to exclude kitchen wastewater from the concept of grey wastewater due to their grease, oil, etc. content, which is particularly disturbing in case of reuse.

The most prominent use of small appliances occurs in residential properties. The population size of settlements or parts of settlements to be provided with on-site wastewater treatment and disposal facilities should be taken into consideration during sewerage agglomeration surveys, studies, etc.

The classification of settlements by population may vary from country to country; e.g. according to the UN category, a settlement above 20,000 is considered a town, while the lowest limit of a city is 250 people in Denmark.

In Hungary, the settlements are classified by population number:

- city: over 100,000
- large town: 20,000–100,000
- small town: 5,000–20,000
- village: under 5,000

A more sophisticated classification of smaller settlements is the following:

- small village: 500–1,000
- extra small village: under 500 people
- hamlet: under 200 people

In Hungary, 25% of the total population lives in small and extra small villages. According to data from 2010, 178 people lived in hamlets.

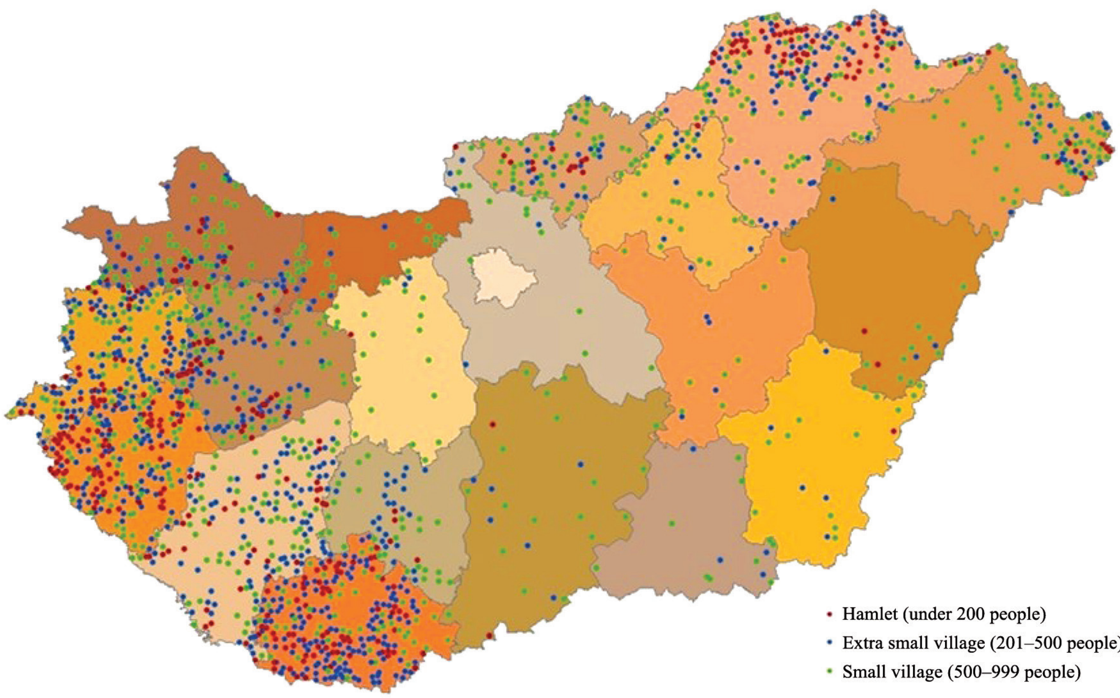


Figure 27
Small villages, extra small villages and hamlets in Hungary [1]

Among the factors determining the number of inhabitants per settlement and the number of inhabitants per property, only the followings are mentioned: age (the population of Hungary is aging), employment (there is a large number of settlements that can no longer be called either urban or agricultural).

Wastewater dischargers to be considered per property in large villages and towns are the following:

Table 11

Drinking water consumption per apartment by settlement types (compiled by the author based on [2])

Location Type	**Specific number of residents [Person/Property]**	**Specific consumption [l/capita.d]**
Large villages	4–3.1 3.1–2.7 2.7–2.2	**90–130** **80–110** **70–90**
Small towns	**3.5–3.1** **3.1–2.7** **2.7–2.2**	**110–140** **90–130** **80–110**

In case of small villages, the average number of people per property is around 2.5 and is mostly stagnant; in case of the smallest settlements, the population will probably be declining.

When examining a residential property as an individual sewage discharge unit, social and economic circumstances of a particular location should be taken into account. Furthermore, it should also be taken into consideration that the installation of public utility replacement equipment is a long-term investment and the decision to be made should have significance beyond the current population situation or the status of residential building(s) located on the property(s). If all of these things are considered and the installation of a small on-site treatment plant is justified, it is recommended to calculate with at least 2 people per a property of 60 m^2, and at least 4 people above it. The Hungarian Water Association (HWA) suggested otherwise, arguing that in settlements with a declining population, 2 elderly people would be a significant oversizing, resulting in an unnecessarily high investment and operation cost. On the other hand, as the capacity of the smallest on-site appliances is 4 PE, it is unlikely that manufacturers would be willing to produce smaller capacity appliances without large enough market needs.

The most reliable way to determine the discharge of individual properties is to use actual water consumption data if available. The method is based on statistical analysis of historical data of water consumption if water is supplied by a utility. The water consumption data of public utility water suppliers are sporadic and many service providers only perform water meter readings once a year. However, the largest daily consumption or the smallest daily consumption can be estimated by applying the inequality factors. If the property has its own water supply or if its water supply will be realised in the future, various values – e.g. elementary and total consumption values; total consumption values used in sanitary engineering; total consumption values derived by the nature of building use – or methods estimating the number of drainage equipment and their concomitant use could be applied to estimate the probable wastewater discharge.

The effluent values from small group wastewater appliances are traditionally calculated using the methods applied in sanitary engineering, considering the number of sanitary apparatus, the specific discharges and their simultaneous use. Alternatively, calculations can be made by using the number of discharging units (people, guests, etc.) and the related number of specific discharges as well as by using the factor for building function.

According to EN 12056, the peak characteristic yield *(Q_m)* is defined by the following equation:

$$Q_m = K.\sqrt{\sum DU} \qquad \text{l/s}$$

where K is the flow number l/s
DU is the sum of the values of the sanitary appliances

For major installations, EN 12056 contains specific values for sanitary appliances.

Table 12
Characteristics of sanitary equipment (compiled by the author)

Sewage sanitary appliances	DU
Wash basin	0.5
Bidet	0.5
Shower without drain valve	0.6
Shower with drain valve	0.8
Pissoir with a rinse tank	0.8
Pissoir with pressure rinse	0.5
Standing pissoir (pissoir wall)	0.2
Sewage sanitary appliances	**DU**
Bathtub	0.8
Kitchen sink	0.8
Household washing machine	0.8
Washing machine (max. 6 kg load)	0.8
Washing machine (6–12 kg charge)	1.5
Toilet with 4 l flush tank	n.a.
Toilet with 6 l flush tank	2.0
Toilet with 7.5 l flush tank	2.0
Toilet with 9 l flush tank	2.5
Floor drain DN 50	0.8
Floor drain DN 70	1.5
Floor drain DN 100	2.0

Note: Calculations based on the former Hungarian standard (MSZ 04-134) results in higher (~ 15%) values for residential buildings.

Under the auspices of the British Water, several environmental organisations have jointly published specific discharge values for BOD and ammonium N to calculate the load on small wastewater treatment plants, pocket plants (up to 1,000 PE). These values are indicative in the absence of domestic investigations.

Table 13
Specific values for home and other community discharges (compiled by the author)

Discharger	BOD (g/person. or activity.d)	NH_4-N ([g/person. or activity.d)	Wastewater discharge l/person. or activity.d
Homes			
Resident	60	8	200
Recreational vehicle with full comfort	75	8	180
Operational facilities			
Service/industry without kitchen	25	5	50
Service/industry with kitchen	38	5	100
Industrial area (e.g. under construction) without kitchen	25	5	60
Staff full time (8 h)	38	5	90
Staff part-time (4 h)	25	3	45
Educational institutes			
No boarding, with kitchen	38	5	90
No boarding, no kitchen	25	5	50
Boarding school			
Students	75	10	200
Staff	38	5	90
Catering services			
Hotel Guest (Luxury Hotel)	105	12	300
Hotel Guest (3 or 4 stars)	94	10	250
Guest (without meals)	50	6	80
Conference facility guest (full service)	150	15	350
Conference Facility Guest (without accommodation)	25	2.5	60
Beverage shop, pub, etc.	15	5	12
Holiday home with wooden houses	94	10	227
Housekeeping staff	75	10	180
Restaurant			
Luxury category	38	4	30
Heating kitchen	30	2.5	25
Snack-bar dishes	19	2.5	15
Separate room with buffet supply	19	2.5	15
Fast food (e.g. by road)	12	2.5	12
Fast food chain (burger, etc.)	15	4	12
Dormitory (accommodation only)	56	5	100
Recreational facilities			
Toilet block (per use)	12	2.5	10

Discharger	BOD (g/person. or activity.d)	NH_4-N ([g/person. or activity.d)	Wastewater discharge l/person. or activity.d
Toilet (per use)	12	2.5	10
Pissoir (per use)	12	2.5	5
Toilet block for daytime parking/truck parking	19	4	10
Shower (per use)	19	2	40
Golf Club	19	5	20
Local Sports Association (e.g. squash, football)	25	6	40
Swimming pool	12	2.5	10
Sport club/centre	19	4	50
Camping with tents	44	8	75
RV area			
Occasional visitors without other services	44	8	100
Permanent user without other services	44	8	100
Permanent user (full service)	75	8	180
Hospitals, sanatoriums			
Elderly Home, Nursing Home	110	13	350
Small hospital	140	n.a.	450

Table 14
Specific PE values of other discharge types according to German data (compiled by the author)

Discharger	Unit	PE value
School with showers	per student per student	0.2 0.1
Baths	per visitor	0.15–0.3
Cinema, sports ground	in some places	0.05
Restaurant, inn	in some places	1
Discharger	**Unit**	**PE value**
Highway motels	per bed	1.5–2.0
Ports	per ports	3.5
Campsite	per tent places	1.75
Hotel, resort	per bed	1
Office, shop	per employee	0.2–0.4
Workshop (without shower)	per employee	0.5
Industrial plant without industrial wastewater (with showers)	per employee	1
Bakery, confectionery, hairdresser	per employee	1–1.5
Butcher shop	per employee	15
Hospital	per bed	1.5–3.0
Barracks	per person	1.2–3.0

Some standards (e.g. DIN 4261) consider installations small equipment if the sewage load is no more than 8 m^3/d. According to the EU harmonised standard, the 50 PE limit results in LE_Q = 200 l/PE.d. However, according to the standard MSZ EN 12566, prefabricated small on-site appliances shall be designed for a specific effluent discharge of 150 l/person.d.

Table 15
Equivalents of various small group dischargers according to Mall AG (compiled by the author)

Description	Unit	PE
House, cottage	1 bed or 1 room	1
School	4 students	1
Sports hall	15m² hall area	1
Administrative building, office buildings, factories (without industrial wastewater)	3 employees	1
Catering, hotel	1 bed	1
Restaurant	3 slots	1
Great hall or garden of a restaurant	20 places	1
Frequent restaurants, e.g. highway rest area, guest house	1 seat	2
Movie	40 seats	1
Campsite	1 ha	80
Military housing	1 bed	1
Hospital, nursing institution	1 bed	2

Small appliances can be sized based on the number of residents. At least 4 people per > 60 m^2 and 2 per < 60 m^2 should be calculated. For other buildings (offices, workshops, taverns, etc.) the corresponding equivalents are calculated according to the tables above.

In the case of residential properties, no domestic measurements or research are available for intraday discharges. In accordance with the MSZ EN 12566 standard, the standard values of hourly discharges for homes and residential properties with few homes may be taken into account according to the figure below.

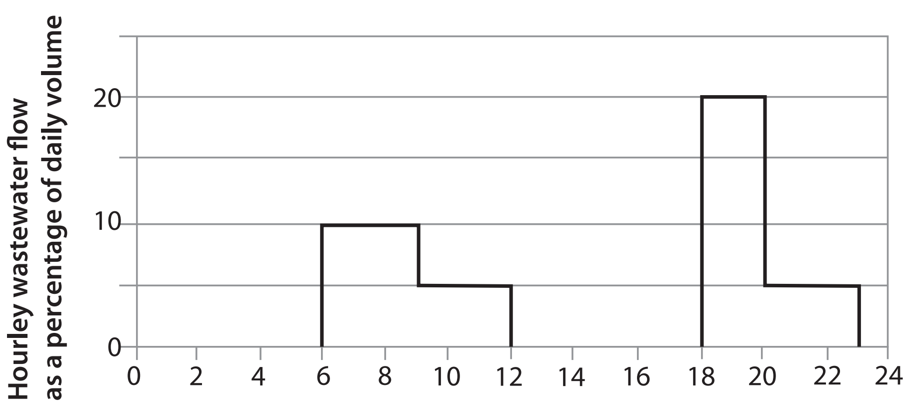


Figure 28
Intraday fluctuations of sewage yield (compiled by the author)

Up to 10–12 PE, bathtub draining – 200 l of water in 3 minutes – can be considered peak discharge, which is approximately 1.1 l/s or 4 m^3/h.

Specific quality characteristics of wastewater

The temperature of wastewater is basically determined by the temperature of the drinking water used. There are water basins in the Great Plain where the temperature of the extracted water is well above 20°C, sometimes near 30°C. Although water treatment, storage and distribution have temperature-reducing effects, due to domestic and institutional use, the temperature of wastewater, even in winter, is well above the normal temperature. Regardless, the temperature of wastewater entering the small equipment, or at least its first unit, is higher than that of the sewage entering wastewater treatment plants, because the transport route is no more than a few tens of meters inside the property and the amount of waters with temperature reducing capacity (precipitation, infiltration, etc.) is small, or, in case of expert channel design and use, it is negligible.

The temperature of wastewater affects oxygen solubility, which influences the oxygen delivery capacity of the aeration unit. Biological activity is also temperature dependent; a slightly higher temperature is favourable for biochemical processes.

The pH of fresh domestic sewage is slightly higher than that of the sewage in municipal sewage networks. However, in anaerobic cleaning units the rotten state lowers the pH.

The microbiological load of wastewater basically arises from human water use and wastewater discharge. Microbiological characteristics of wastewater are mainly characterised by two parameters: total coliform bacteria and fecal coliform (CFU/ml). These two parameters are highlighted because coliforms and fecal coliforms are indicators of pathogenicity, are routinely tested in microbiological laboratories, and are affordable. Additionally, there are a large number of various microorganisms in wastewater. Of these, only certain groups are identified as specific target groups, mostly pathogens, e.g. viruses and streptococci.

Some microbiological characteristics of raw and treated wastewater are summarised in Table 16.

Table 16
Concentration ranges for some microorganisms in raw and treated wastewater in industrialised countries (compiled by the author)

	Raw sewage (e/ml)	Treated wastewater (e/ml)
Total coliform	10,000–1,000,000	500–20,000
Fecal coliforms	3,000–500,000	100–15,000
Fecal streptococci	500–50,000	20–1,500
Viruses	100	–10

Pollutant loads on small wastewater treatment plants

The majority of wastewater generated in settlements is domestic wastewater. In terms of environmental load, the most significant is organic matter expressed as BOD_5 (or COD) in wastewater. The PE number is currently used to determine the capacity of sewage treatment plants. Currently, people equivalent (PE) of 60 g/person.d is considered for specific domestic discharge that has been set as a standard in the EU Water Protection Directive and has been included in the relevant Hungarian legislations. With this specificity, organic matter loads from non-residential wastewater discharger (e.g. industrial) can also be expressed.

Note that the population equivalent of BOD_5 is a specific non-universal constant that varies among countries and in time. In Hungary, in the 1960s, PE of 38 g/person.d was used, whereas in the United States it is 75 g/person.d today.

Further specific discharge parameters per capita used in Hungary and other EU countries expressed in g/PE.d are the following:

Table 17

Hungary specific pollutant emission parameters per 1 PE (compiled by the author)

BOD_5	**COD**	**TSS**	**N**	**P**
60	120	70	11	2–2.5

Table 18

Specific pollutant loads per population equivalent, according to MALL, a manufacturer of small appliances, probably based on U.S. data (compiled by the author)

Total solids	**90 g TS/d**
BOD_5	75 g/d
COD	150 g/d
TOC	50 g/d
TKN	14 g/d
NH_4-N	7g/d
TP	2.2 g/d

These data are above normal European standard values and should be treated with caution.

Concentrations depend on the amount of wastewater per capita. In Hungary, specific domestic wastewater discharge can be between 80 and 130 l/capita. Within these limits, for three specific wastewater discharges, the concentrations for the above five parameters are the following:

Table 19

Pollutant concentrations at different emissions (compiled by the author)

Wastewater discharge l/PE.d	**BOD_5 as mg/l**	**COD as mg/l**	**TSS as mg/l**	**total N as mg/l**	**TP as mg/l**
80	750	1,500	875	138	25–31
100	600	1,200	700	110	20–25
130	460	920	530	85	15–19

The specific pollutant discharges for segregated domestic wastewater may be taken into account according to Table 20.

Table 20

Discharge values for specific pollutants in greywater (compiled by the author)

Parameter	**Quantity g/PE.d**
BOD_5	24.6
COD	49.2
total N	0.33
TP	0.18

Table 21

Discharge values for specific pollutants in yellow water (compiled by the author)

Parameter	**Quantity g/PE.d**
BOD_5	7.2
COD	14.4
total N	9.57
TP	0.9

Table 22

Discharge values for specific pollutants in brown water (compiled by the author)

Parameter	**Quantity g/PE.d**
BOD_5	28.2
COD	56.4
total N	1.1
TP	0.72

For household wastewater parameters BOD_5, COD, total N and total P the following values could be considered, broken down by water use:

Table 23

Pollutant concentrations (g/m³) from discharges from different domestic water uses (compiled by the author)

Place of origin type of wastewater	**BOD_5**	**KOI_k**	**total N**	**TP**
Kitchen wastewater	10	13	0.5	0.7
Bathing, showering	4	4	–	0.05
Hand washing	3	4	–	0.05
Toilet use	36	84	11	1.6
Washing	7	15	0.5	0.1
Altogether	60	120	12	2.5

The above data refer to raw sewage. Even in case of small wastewater treatment plants, after mechanical pretreatment (settling tank, septic tank), wastewater quality changes and this should be considered.

Wastewater quality after mechanical treatment can be taken into account by using values given in Table 24 (Swiss data):

Table 24

Wastewater quality parameters after mechanical treatment (Mall) (compiled by the author)

Parameter	Concentration mg/l
TSS	120
Organic solids	80
BOD_5	150
COD	280
DOC	45
total N	32
TKN	30
Dissolved TKN	25
NH_4-N	20
NO_3-N	1
TP	7
Dissolved P	5

In case of settled wastewater, values in the following table may be taken into account for the relationship between the various parameters:

Table 25

Quality parameters of settled wastewater (compiled by the author)

Average values of settled wastewater (Switzerland)	as mg/l	Empirical values of Canton Schwyz mg/l
COD/TOC	3.4	3.7
COD/BOD_5	1.8	2.8
$KMnO_4$/BOI_5	2.8	
TOC/BOD_5	0.53	0.7

The average concentration of nutrients in raw sewage of domestic sewage: nitrogen ~ 100 g/m^3, phosphorus 20 g/m^3, potassium 60 g/m^3.

Ideal nutrient ratios for biological treatment:

COD: TKN: P = 100:5:1

BOD_5: NH_4-N:TP = 500:4:1

COD: NH_4-N:TP = 100:4:1

Non- or slowly degradable substances include salts, metals and toxic metals, surfactants, antibiotics, contraceptives, hormones and other drugs, as well as endocrine disruptors.

Salts – mostly chloride, sulphate, nitrate, and to a lesser extent phosphates – pass through sewage treatment processes without reduction, in fact, during the process of organic matter decomposition their concentration increases and burdens the recipients.

Surfactants can be found in laundry detergents, softeners, shampoos and reduce the surface tension of water. Their impact on wastewater treatment processes and soil is rather unknown. However, it is known that during the decomposition of surfactants other surfactants may be formed.

Municipal wastewater contains ions of various metals and heavy metals that are discharged from the wastewater treatment processes partly via treated wastewater effluent or incorporate into sewage sludge and get discharged with it. Domestic wastewater discharges are a minor source of metal and metal compounds. To the best of our knowledge, it is not a problem in small-scale treatment processes, but they are present in the sludge.

Pharmaceutical compounds and drug residues used in households can also be found in domestic wastewater. If they are not decomposed, they can clearly end up in the soil and groundwater as well as in sewage sludge.

Endocrine disrupting substances can enter the raw sewage from certain products (medicines, paints, etc.). They are numerous and their amount in the raw or on-site treated domestic wastewater is unknown.

The intraday fluctuations of pollutants vary depending on the pollutant parameter. Fluctuations can be taken into account according to Table 26.

Table 26

Intraday fluctuations in wastewater yields and pollutants (compiled by the author)

	Sewage yield	TSS	BOD_5	TKN
Max./min. load	3.1	6.3	7.6	5.5

Quality parameters of wastewater collected in the sewage tank can be taken into account according to Table 27 (based on the former ME 10 459-1 1994):

Table 27

Quality parameters of wastewater collected in wastewater storage tank (compiled by the author)

Parameter	Value as mg/l
BOD_5	110
COD	2,900
SS	2,200
NH_4-N	60
TP	34
pH	6.5–7.5

Loads for small appliances are usually expressed in BOD_5 (alternatively in COD). In the absence of either, the missing data can be replaced by the BOI_5/COD ratio, or they can be mutually verified knowing that BOD_5 concentrations have a high deviation.

The daily values of pollutant loads are given. In order to consider these values representative, the concentration should be measured by using 24-hour composite samples in proportion to volume or yield and to multiply it by the daily yield. Thus, for calculating daily pollutant loads, the point sample is inaccurate, misleading. In general practice, sampling every 2 hours and applying the associated 2 hours average yield are considered appropriate.

To dimension wastewater treatment equipment and to determine the concentration of each pollutant, the practice recommends using weekly averages that can be calculated based on four calendar days.

Targeted sampling can also be used to determine these data with a 4–6 week monitoring period, which should include winter (cold) periods and, if appropriate, seasonal large or low load periods.

If longer time series (up to one year) are available, analysis of wastewater temperature, COD, COD weekly average, COD/BOD_5, TKN/COD, TSS/COD, TP/COD ratios can help eliminate seasonal effects.

Dimensioning of settlers

Despite the fact that the size of settlers used in wastewater treatment is based on different sedimentation theories, routine calculation methods based on residence time and surface hydraulic loads are in principle applicable to decentralised wastewater treatment plants, too. At the same time, the intermittent nature of wastewater discharges must be taken into account, which does not occur in municipal sewage treatment plants with continuous-load settlers used. Furthermore, the geometry of settlers should also be considered which only takes building and manufacturing aspects into account as opposed to the geometric ratio required for large settlers' hydraulic conditions.

Therefore, septic tanks that are mostly non-partitioned and used for small wastewater treatment equipment can be dimensioned by using guide values of resident number or population equivalent as a rule of thumb. This time it is preferable to use values BOI_5 (LE_Q). In Hungary, the LE_Q value should be between 100–130 l/person.

The specific gravity of the settling tank can be added as follows:

- 500 l/LE_Q for standard equipment with a minimum working capacity of 2.0 m^3
- 500 l/LE_Q applied before a constructed wetland with a minimum working capacity of at least 4.0 m^3, or above 4 LEQ the volume can be further increased by 75–25%

In the upper capacity range of small wastewater treatment equipment or above 50 PE, a two-story settler could be a technical solution that pre-settles sewage in an engineered structure and is also suitable for storing and cold digesting settled sludge. The disadvantage of this application is high clear height, which is unfavourable from a construction point of view in areas with high groundwater levels and requires pumping power during installation.

If the settler or the sludge space is also used to receive and store excess sludge from biological treatment, the volume can be further increased depending on the technology of the biological equipment (see further chapters).

Table 28

Reference values for dimensioning two-level settlers based on former Hungarian technical standards and guidelines (compiled by the author)

	MS 15302-62	OVHMI 146 / 1-71	ÉSZ 511-75	MI 10-127 / 9-84
Specific useful volume of the settler l/PE	–	30	–	
Settling space min. useful volume m³	–	1.5	–	
Specific useful volume of digestion area l/PE	–	60	–	
Min. useful volume of digestion area m³		3	–	

Note: 1 PE = 100 l/person

Dimensioning of septic tanks

Septic tanks are traditionally designed based on per capita volumes. In case of a simple septic tank, the specific volume is 300 l/capita according to DIN. The smallest total volume is 2 m³, or 4 m³ in the case of two-chamber structures. The expanded septic tank serving up to 6 people has a specific volume of 1,500 l according to DIN 4261-1 and a minimum volume of 6 m³. At the same time, the DWA-A 262 gives a specific useful volume of an additional 750 l/capita up to 10 people and 5,000 l/person for over 10 people for plant beds.

For sizing the standard volume of septic tanks, the following relation is known (Ireland):

$$V = 0.15 \times N + 2.0 \ [m^3]$$

where N is the number of dischargers, with at least 4 people

From this relation, the useful volume of the smallest septic tank is 2.6 m³.

Table 29

Changes in design parameters of septic tanks in Hungarian regulatory publications (compiled by the author)

	MS 15302-62	OVHMI 146 / 1-71	MI 10-127 / 9-84
Specific useful volume l/PE	–	300	–
Minimum useful volume m³	–	3	3

Note: 1 PE = 100 l/person

According to DIN 4261-1, the decrease of organic matter expressed in BOD_5 can be considered by using the following values:

- for simple septic tanks 10 g/person.d
- for expanded septic tanks: 20 g/person.d

Small wastewater treatment systems with activated sludge

Small activated sludge systems can be scaled by methods used in wastewater treatment. However, in small SBR systems fluctuations in wastewater yields are not only much greater than those occurring at large SBR sites, but the lengths of both small and large discharge periods are long, can even be months. As a result, the importance of long-term equalising storage increases. However, to adequately scale the offsets, it is necessary to be able to estimate not only the fluctuations of discharges but also their length over time.

Trickling filters and immersion disc biological treatment equipment

Trickling filter technology can be scaled using techniques commonly used in wastewater treatment. When calculating the BOD_5 load of the trickling filter, BOD_5 decrease due to pretreatment should also be considered. The BOD_5 volumetric load value is usually low unless an equalising storage is available to provide uniform load.

As a guide value, a volumetric load of 0.15 kg BOD_5/m^3.d (or below) and a minimum fill height of 1.50 m may be considered.

In addition to the above method, a simplified method for sizing filters can be used; a specific filling volume of 150 l/PE is used, but to ensure non-clogging operation and comply with discharge requirements, a minimum of 2.0 m^3 of filling should be built in.

The table below summarises the specification recommendations of the former Hungarian technical regulatory publications, which essentially corresponds to DIN data.

Table 30

Changes in design parameters of septic tanks in Hungarian regulatory publications (compiled by the author)

	MS 15302-62	OVHMI 146 / 1-71
Specific filling volume	–	0.3m^3/PE
Min. filling volume m^3	–	15 m^3
Filling height	–	1.5–2.5 m
Filling particle size	–	3–8 cm

Note: 1 PE = 100 l/person

Immersed disc trickling filters can be scaled based on specific surface loading of BOD_5. In case of immersed disc trickling filters, with equipment of less than 50 PE lower surface loads may be used compared to structures for 50–500 PE. The recommended surface BOD_5 load should not exceed 0.004 kg BOD_5/m^2.d.

The post-settling can be scaled for residence time and surface hydraulic load. Due to the balancing effect of antecedent structures (sedimentation-septic tank, biological reactor), 1/10 of the daily standard yield can be used. Recommended design parameters:

- residence time: ≥ 3.5 h
- surface hydraulic load: ≤ 0.4 m/h

Due to the usual engineering constructions, a minimum water depth of at least 1 m and a minimum sedimentation area of 0.7 m^2 are usually achieved.

In case of a separate storage compartment for the storage of excess sludge, its size can be calculated by using a specific volume of 100 l/PE.

Membrane bioreactors

In principle, equipment with membrane filtration and activated sludge system can be operated with up to 20 kg/m^3 of activated sludge, but in practice, due to rapid clogging of membranes and difficulties in quasi-continuous cleaning, they are scaled up to 8–12 kg/m^3 of activated sludge.

Other sizing parameters used in wastewater technology:

BOD_5 volume load	< 0.75 kg BOD_5/m^3
sludge load	< 0.05 kg BOD_5/kg dry matter/d

The guiding design value for determining the volume of the membrane reactor is 0.25–0.2 m^3/PE.d. The lower value should be used for small equipment for 50 PE, the higher value is for a few PE.

Otherwise, design methods applied for large facilities can be used for membrane technology with activated sludge systems.

The filtration capacity, the filtration performance of the membranes is expressed in flux. Flux is the volume flow rate of permeate flowing through a unit of membrane surface, generally expressed in l/m^2.h. The magnitude of the flux depends on the magnitude of the transmembrane pressure. Considering this, the term permeability is used, which is the flux at a given transmembrane pressure and is generally expressed in l/m^2.h.bar. Both parameters are characteristic of a given membrane, but the latter also indicates membrane blockage during operation.

For membranes used in small installations, the filtration capacity ranges between 2 and 10 l/m^2.h. Manufacturers also make membrane modules with a filter area of 3.5–6 m^2 for small equipment (4 PE). In small equipment with larger capacity, these modules are built in side by side or above each other. In engineered structures or container wastewater treatment equipment, large membrane modules are used.

Wastewater lagoons

The minimum depth of aerated wastewater lagoons is 1.2 m. There is no domestic regulation for sizing small wastewater treatment plants. The sizing is based on resident number, taking into account a lagoon surface of 15–20 m^2 per capita, as well as by using the following equation:

$$A = N\frac{185 - N}{9} \quad [\mathrm{m}^2]$$

where N is the population

To be on the safe side, the smallest lagoon is 100 m^2.

In non-aerated lagoons, residence time is about 20 days, in aerated lagoons it can be reduced to about one third (min. 6 days).

In case of lagoons replenished with roof water or storm water runoff, an additional lagoon surface of at least 10 m^2/100 m^2 can be calculated.

In sewage filtration and disposal systems using particulate matter (infiltration, sand filtering, wetlands, etc.), decomposition of residual organic matter treated at least biologically continues. The efficiency of decomposition depends on the aeration of the disposal system. Gaps in the three-phase particulate medium are filled with air along with water, which will be intermittently – preferably for most of the operating time – in contact with the atmosphere. Limiting factors of biochemical oxidation processes include biomass of microorganisms adhering to the surface of particulate medium or to suspended particles, as well as the transfer oxygen from the gaps of the filling medium. Characteristics of the gas phase, which is important for oxygen transfer, are influenced by geotechnical, biological and partly climatic conditions.

The gas phase is usually confined to coarse pores; water present in medium-sized pores represents usable water capacity, while fine pores are occupied by dead water.

When examining the change in the distribution of air along depth, it can be assumed that the ratio of the gas phase decreases by depth, possibly even by approaching groundwater. The reason for this is that water content increases downwards. The gas phase is distributed between air ducts in the inner air circulation connected to the atmosphere and blisters or so-called inclusions. The latter develop when sewage trickles from top to bottom and air ducts become clogged, making it difficult for or preventing the air to escape from the pores. Inclusion can also occur when anaerobic conditions are formed, provided that sufficient readily biodegradable organic material is available which, upon anaerobic decomposition, predominantly produces hydrogen and methane. Downwards in the infiltration or filter material mixture water content increases, the gas phase becomes increasingly significant in larger pores, and the proportion of air inclusions decreases.

The composition of air may differ significantly from that of atmospheric gases, mainly caused by organic matter decomposition. In wetlands, if the system is not anaerobic, along with aerobic processes, root respiration also plays a significant role in using oxygen and increasing carbon dioxide content.

The ratio of carbon dioxide to atmospheric air is significantly higher and the amount of oxygen is reduced to the same extent.

The relative humidity of the air in the pores is high, can be 100% in an operating system due to the large water-air interface relative to the size of the pore space.

The composition of air is also influenced by temperature, at lower temperatures, oxygen is more soluble in water and the oxygen content of the air is lower. Changes in air composition due to temperature fluctuations are significantly mitigated by the temperature equalising effect of continuous wastewater supply.

Oxygen transfer for organic matter decomposition in natural aeration sand filtration systems has been found to be 15–25 g O_2/m^2.d, while in reed systems it is 13–20g O_2/m^2. Oxygen demand is substantially influenced by oxidisable substances present in wastewater (organic matter, ammonium) in addition to the oxidising capacity of granular media in semi-natural wastewater systems.

Processes are fundamentally similar to those of trickling filters. However, there are significant differences. Wastewater is in contact with both the biomass and air for a short time, contact time is low and hydraulic load is relatively high due to intermittent feeding. These adverse effects cannot be counteracted by the theoretically stable functioning of sessile biomass.

By comparison, specific design values for residence time and population equivalents for each wastewater treatment system according to the literature are shown below:

Table 31
Some design data for different wastewater treatment systems (compiled by the author)

	Surface/PE m²/PE	Volume/PE m³/PE	Contact time
Non-aerated lagoon	10	15–20	> 20 d
Soil infiltration	4–20	7–12	–
Non-aerated lagoon	3	4–7	> 3–6 d
Sand filter	4–6	4–6	1 h – 7 d
Trickling filter with nitrification	0.17–0.3	0.45–0.6	6–10 min.
Activated sludge	0.12–0.25	0.35–0.6	1–3 d
SBR	0.1–0.2	0.3–0.5	1–3 d
Trickling filter tray with immersed disc and nitrification	0.1–0.18	0.17–0.25	10–20 h
Trickling filter without nitrification	0.05–0.08	0.13–0.18	3–6 min.
Trickling filter without nitrification	0.04–0.07	0.07–0.13	8–15h
Biofilter with nitrification	0.005–0.01	0.02–0.03	30–50 min.
Biofilter without nitrification	0.004–0.01	0.013–0.03	20–40 min.

In sand filtration systems, the efficiency of biological treatment, and thus the operational safety, can in principle be improved by increasing the filter medium volume, reducing the hydraulic and biological load and by intensifying aeration. A realistic increase in filling medium volume is possible by increasing the length of filter trenches and fields, which is often hindered by lack of space. Biological load can be reduced by recirculating the filtered water or by aerating the wastewater entering the filter. Aeration of the filling medium of the filter can be improved by auxiliary technical solutions aiding natural air exchange through drainpipes or by switching to artificial aeration.

Sand filter trench and field

The design of sand filter trenches or fields varies from country to country. It is designed by considering specific infiltration surface or ditch length for one resident or population equivalent, although we can see examples in Hungary for design based on surface load. Loading values of sand filter trenches related to the bottom surface area, bottom surface load or to the length of the filter bed are summarised in Table 32; for comparison, DIN standard values are also provided.

Table 32
Values of parameters for sizing sand filter trenches in national technical regulatory publications are shown below (compiled by the author)

MS 15302-62	–
OVHMI 146 / 1-71	2m²/PE[I]
ÉSZ 511-75	–
MI 10-127 / 9-84	0.25–0.35 m/d
MSZ 15287: 2000	0.1–0.15 m/d
German recommendation	6 m/per capita[II]

Note: [I] 1 PE = 100 l/person. [II] Approximately corresponds to 3m²/per capita.

The values in the table show a rather varied picture of design principle and of the design data. The data has been incorporated into regulatory documents from engineering practice, and over time, filtering surfaces have become larger based on the parameters, pointing to a lower specific load. In practice, the most acceptable method is dimensioning for surface loading.

According to CEN/TR 12566-5, the load capacity of sand filters is 4 $l/m^2/d$, which is significantly lower compared to the data in the table.

Sizing of plant beds

It is very important to emphasise that only mechanically treated wastewater can be fed to plant beds. The conventional sizing of bed filters is based on per capita surface area, specific surface load expressed in COD and surface hydraulic load.

According to DWA-A 262 guidelines, design parameters applicable to effective bed thickness of at least 50 cm are summarised in Table 33.

Table 33
DWA-A 262 guidelines

	Constructed wetlands with horizontal subsurface flow	**Vertical flow constructed wetland**
Specific bed surface area m^2/per capita	≥ 5	≥ 4
Minimum bed surface area m^2	≥ 20	≥ 16
Surface organic matter load g COD/m^2.d	≤ 16	–
Surface hydraulic load l/m^2.d	≤ 40	≤ 80

UV disinfection

If UV equipment is used for disinfection, the UV dose for disinfection shall be 250–400 J/m^2. Irradiation time should not be less than 3 seconds under normal design conditions at maximum load.

The electrical power consumption of UV equipment is 10–13 W/m^3. Total power requirement must be calculated taking into account the power absorbed by the pump pumping water to the UV system, which can be calculated by using a specific value of 35–70 W/m^3.

Note: Higher specific values should always be considered for smaller capacity units.

Disposal of treated wastewater

Recipient of treated wastewater can be either surface water or soil (and through it groundwater). Among subsurface waters, principally groundwater found in the unconfined aquifer is affected.

Discharge of treated wastewater is prohibited if the location of the property is subjected to conditions of connection to the municipal sewage system; if discharge into surface water is not possible due to technical, economic, ecological or water hygiene criteria; if infiltration is close to drinking water or reserve water catchments; if the area is sensitive or highly sensitive to pollution; if water permeability of the soil layer or layers affected by infiltration is unfavourably low.

General requirements for infiltration of treated wastewater include:

– Wastewater with domestic wastewater quality is treated at least mechanically and biologically.
– Biological purification shall include at least nitrification technology. If groundwater is contaminated with nitrate (above the limit value), the treatment technology should also be capable of denitrification.
– Infiltration should be near-surface, but should not result in open water surface.
– Infiltration should preferably take place in a homogeneous soil layer.
– Infiltration should be designed to be protected against freezing in winter.
– Professional operation of the treatment and disposal system is ensured.

Design of soil absorption systems

Surface infiltration is elemental. Direct discharge of wastewater into groundwater is not permitted. There is no direct connection if the deepest point of the absorption system is at least 1 m above the highest groundwater level.

Options of soil infiltrations:

– infiltration
– surface infiltration trenches
– infiltration shaft
– infiltration shaft and field

In case of near-surface infiltration, water is evaporated into the atmosphere and is absorbed by surface vegetation and soil microorganisms, and predominantly, the sewage seeps into deeper soil layers and fills their gaps. Soil infiltration can be used if the soil is capable of infiltrating wastewater treated at least biologically.

For hygienic reasons, only biologically treated and at least post-filtered water can enter the infiltration unit.

Infiltration trench and field sewage disposal are sometimes referred to as underground irrigation. These solutions perform mechanical filtration and aerobic biological treatment before the effluent is filtered into the soil or possibly reaches groundwater.

Drainpipe is laid in a gravel layer that must be sealed at the top. Geotextile, which permeates water but prevents soil particles penetration, is suitable for this purpose. A layer of at least 10 to 20 cm thick soil is placed above the infiltration unit, into which short-rooted plants can be planted. The best solution is grassing, which is easily maintained and causes minimal damage to vegetation when the filter media is changed.

The purpose of a thicker infiltration body at the bottom of the infiltration trench is temporary storage of treated wastewater. It is beneficial to construct a thicker infiltration layer consisting of an upper coarse particle layer and a lower finer sharp grit. The slit drainpipe in the upper layer of the infiltration body serves the even distribution of wastewater. The drainpipe has a slit size of about 3 mm and the particle size of the surrounding infiltration layer should be selected according to the filter rule.

For the construction, ventilation and feeding of the drain line, the same rules apply as for sand filters.

The lower level of the infiltration unit must be 1 m above the highest groundwater level – according to national regulations. Internationally, mostly similar regulations are in effect.

Table 34 shows the most important parameters for designing infiltration trenches and fields based on Hungarian regulatory documents; for comparison DIN data are also shown.

Table 34
Evolution of design parameters for the formation of infiltration trenches in Hungarian regulatory publications (compiled by the author)

	MSZ 15302-62	OVHMI 146 / 7-71	ÉSZ 511-75	MI 10-127 / 9-84	MS 15287: 200	German recommendation
Min. bottom width	0.5 m	0.5 m	–	0.6	0.6 or 0.9 m	1.8–0.5 m
Drainpipe distance	min. 2 m[I] min. 3 m[II]	–	–	2 m	min. 2 m[I]	min. 1 m
Max. drain branch length	30 m	30 m	–	25 m	25 m	min. 7.5 m max. 15 m
Drain layers thickness particle size					min. 10 cm 5–10 mm	1.0 m 4–8 mm (0.5 m) 2–4 mm (0.5 m)

Note: [I] With 50 cm trench width. [II] With 90 cm trench width.

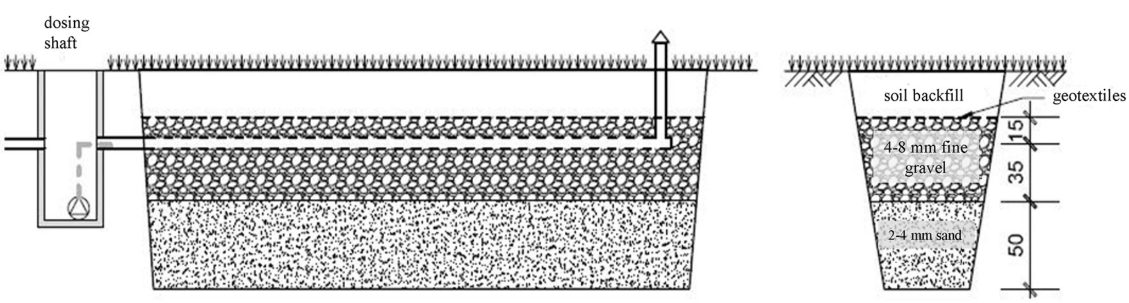


Figure 29
Design of infiltration ditches (compiled by the author)

The infiltration shaft is made of concrete or reinforced concrete of at least Ø 1 m, its wall is perforated at the bottom and its bottom is open. The perforated part is filled with fine gravel with at least 50 cm of sand on top of it. A concrete plate is placed under the inlet pipe to prevent leaching.

Infiltration blocks and tunnels originally used for the infiltration of rainwater are suitable for the infiltration of the treated sewage into soil. Both types of infiltration elements are hollow inside with a pierced surface on each side. The column-shaped infiltration elements can be optionally assembled, tunnel elements can be arranged in a longitudinal direction. Infiltration elements are assembled on a gravel bed at the bottom of the raised trenches, then the infiltration body is covered with geotextile and the space between the trench wall and the elements is filled with gravel. The infiltration body can be filled with a sewer pipe attached to its end or with a drainpipe installed above it.

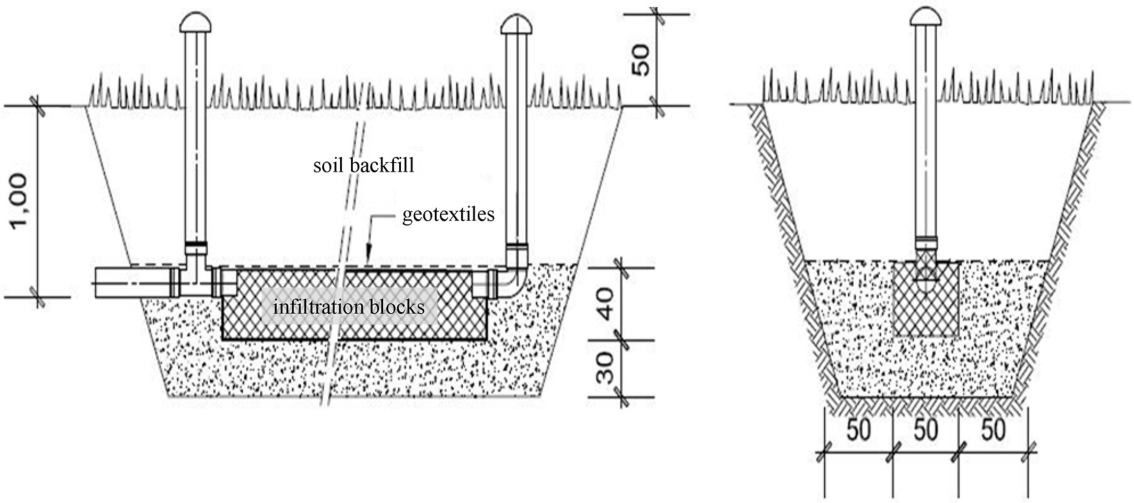


Figure 30
Infiltration unit with infiltration block (compiled by the author)

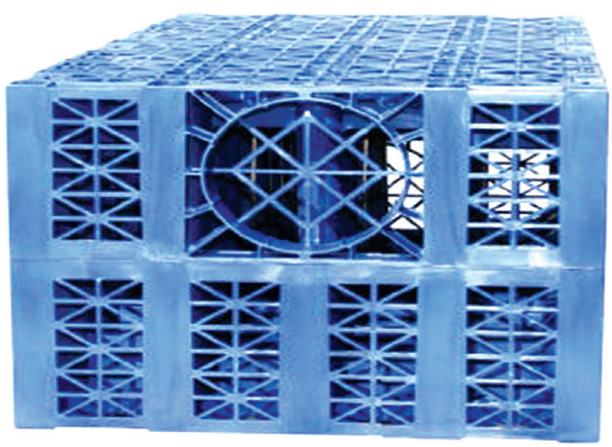


Figure 31
Plastic infiltration block (Mall AG) (compiled by the author)

Sizing of sewage disposal facilities

Calculating the deposition of treated wastewater in soil is based on the capacity of soil infiltration. The infiltration capacity of the soil can be tested. Water should infiltrate within an hour without leaving puddles. The infiltration surface can be determined from this, but it must be safely increased, this may differ among different sources, but we can find examples of up to 50% increase.

The Pönninger method is used for infiltration test. For performing the test, a research shaft must be opened at the site to a depth of the planned level of infiltration. At the bottom of the shaft, a 30 × 30 cm deep pit should be dug and filled with water. For pre-wetting the soil, two additional fillings are needed. The pit should then be filled with water up to a height of 25 cm. During infiltration, the level of water is measured every minute. The average value of data obtained from triplicate repetition of the test gives the infiltration factor in min./cm.

The infiltration factor should be assigned to the soil type of the infiltration layer according to the classification based on sand-sludge ratio.

Table 35

Specific load bearing capacity of trenches according to various regulatory documents (compiled by the author)

	MSZ 15302-62	OVHMI 146 / 7-71	ÉSZ 511-75	MI 10-127 / 9-84	MSZ 15287: 2000
Specific load $m^2/(m^3/d)$	In sandy soil 16 In clay sand 25 In light clay 50	See the relevant chapter (Small equipment standards, technical specifications, guidelines)			

The sizing of infiltration is used to determine the surface size of the infiltration area required. Horizontal and vertical parts of the infiltration surface can be considered as useful infiltration surfaces.

According to some regulations (e.g. MI 10-127 / -9), in addition to the size of the lower plane of the infiltration unit, if the soil adjacent to the side of the infiltration unit is also suitable for infiltration, 1/3 of the height above the bottom may be considered infiltration surface. For vertical infiltration surfaces, DIN standard defines a value of 1 m^2/per capita.

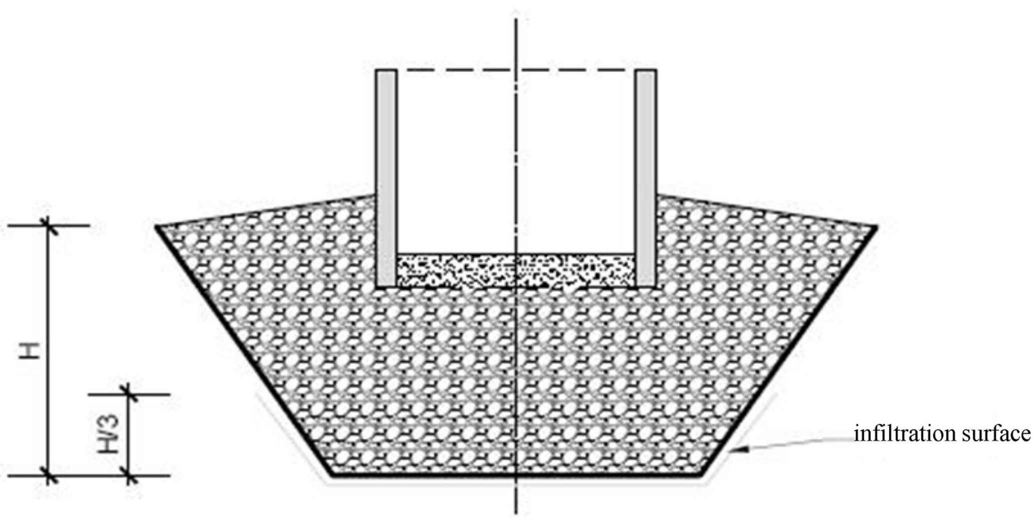


Figure 32

The infiltration surface to be considered (compiled by the author)

According to CEN / TR 12566-2: 2005, with a trench depth of 0.5 m at least 18 rm of infiltration trench per capita should be considered, irrespective of the soil infiltration capacity. The length of a trench is up to 18 m.

Disposal of wastewater treatment by-products

During wastewater treatment, by-products, such as screenings, sewage sludge and other substances such as plant residues in plant beds systems and lagoons remain.

Screening is waste containing a large amount of inorganic and relatively little organic matter (mostly polymers). Screen formed during mechanical treatment in small wastewater treatment equipment should be dewatered, compacted and stored in a container or bag, if the mechanical grid is of a suitable design.

Sewage sludge is a potentially significant source of water and nutrient as well as a potential source of environmentally harmful substances. In addition to heavy metals, other organic and inorganic materials may be present in sewage sludge.

Long-term, well over ten years sludge accumulation in aerated sewage lagoons is well stabilised and rotted. For this reason, it is only worth transporting it to a wastewater treatment plant for dewatering; further mineralisation at the wastewater treatment plant is not necessary.

Sludge produced from non-aeration lagoons can be used in agriculture. Compliance with the legislation on the use of sewage sludge in agriculture is needed. For agricultural utilisation, the composition of sewage sludge should be checked at regular intervals (every five years). If sewage sludge is of poor quality for agricultural use, other ways of disposal should be considered.

Regulations for installing small appliances

Wastewater flows from sanitary wares (washbasin, toilet, bath, shower, washing machine) through the branch line and drain line into the main line. Because these pipes need to be ventilated over the roof, air enters the water, thus, reducing concrete corrosion. In addition, due to the chimney effect, the small equipment is also aerated, especially at the pretreatment unit. For that, the duct and intermediate wires leading to the small unit should have a size of at least DN 100.

Sites that are sensitive to groundwater quality, areas with high groundwater status, water basins and future water basins, as well as karst areas, are not suitable for installing on-site wastewater treatment equipment. In these areas, it is a minimum requirement that the municipal wastewater treatment program allows their installation, or infiltration is not prohibited for reasons of water protection.

Choosing the site of installation: should be accessible at all times and transport of sludge can be achieved by conventional vehicles.

Operation and maintenance

General rules

Decentralised sewage treatment plants must, in principle, be operated by the owner, but the obligation is transferable. Where facilities are installed as part of a program in a well-defined area, the operation may be carried out by a responsible service provider with a high level of specialist training. The responsible service provider is responsible for keeping a logbook, maintaining, sampling and examining samples, sending the data to the water authority and performing any other operational tasks (e.g. repair).

If the installation is a single installation and the emissions exceed 500 m^3/year, the sampling should be performed annually and samples should be tested.

Modelling of on-site wastewater treatment plants

For on-site wastewater treatment plants, the method of wastewater sampling will depend on the nature of the recipient: for surface water a qualitative grab sample, for soil infiltration a qualitative grab sample or 24-hour composite sample should be used.

Qualified grab sample is a mixture of at least five grab samples with a sampling interval of at least 2 minutes taken within a maximum of two hours. For the 24-hour composite sample, grab samples should be taken at least every hour and a sample is taken from the mix, or continuous sampling (with an automatic sampler) may also be used.

In case of lagoon treatment, the sample should be free of algae and should therefore be filtered through a glass cloth.

Figure 33
Sampling vessel (Lausitzer Klärtechnik Catalogue) (compiled by the author)

Dichromatic oxygen consumption (COD_k) and ammonium nitrogen (NH_4-N) should be measured, while in case of soil infiltration, all inorganic nitrogen (TN_{inorg}) also has to be measured. Determination of other parameters is optional, the facility operator will decide on target parameters necessary for inspection.

These include in particular:
- dissolved oxygen
- temperature
- pH
- settable materials
- sludge level

Biological wastewater treatment plants are expected to decompose organic matter only, thus, its efficiency should be judged. Measuring nitrogen compounds and phosphates may be necessary to comply with regulatory requirements.

Operational tasks for OWTS

Substances interfering with the treatment process shall not be introduced into small equipment. For example, industrial wastewater (if their quality differs from that of domestic wastewater), other waters (drain water), cooling water, swimming pool drainage, rainwater, bulk materials, fats, oils, acids, untreated condensation water of fire protection systems, strong cleaning agents, disinfectants, medicines and other chemicals if their amount and concentration exceed that of found in domestic sewage.

In case of settlers and septic tanks, it is advisable to check the inlet more frequently in order to prevent backflow due to plugging.

It is sufficient to remove sedimented sludge from settlers and septic tanks once a year or, as a general rule, if half of the useful volume of the structures is filled with sludge. In case of septic tanks, at the time of removal approximately 20 cm of sludge layer should be left in the first compartment to "inoculate" the newly settled sludge. Floating sludge must be removed from each compartment during sludge removal. In settlers at sludge removal, the structure can be completely emptied; there is no need to leave sludge for inoculation.

The operational control of biological wastewater treatment plants is different, depending on, for example, whether the owner is a non-professional or a competent specialist with appropriate equipment.

The concentration of activated sludge is important for an experienced person. The right concentration of biomass in the system is an important condition for the operation of activated sludge equipment. This can be verified by a simple 30-minute sedimentation test by sampling the sewage sludge from the aeration into a 1 l measuring cylinder. During sedimentation, activated sludge and sewage must be separated by a sharp boundary. After 30 minutes of sedimentation, the amount of sediment should be recorded in ml, the result is the sludge volume concentration. The sludge is considered suitable when the volume is between 120 and 600 ml. Below 120 ml, sludge content is too low, for SBRs, 400–600 ml/l is the normal range, above 600 ml it is too high.

If sludge concentration is too high, a part of the sludge, the excess sludge must be removed. Sludge can be taken off by a pump and usually passed to the pretreatment unit.

Sufficient oxygen must be available in the reactor for proper biomass function. An oxygen concentration of 1–2 mg/l is suitable. Too low oxygen concentration can be caused by too high pollutant load; it can occur if too much influent wastewater reaches the equipment compared to its capacity or the organic matter content of the wastewater is too high. Such situation can occur very suddenly if a lot of organic matter is discharged into the sewage (blood from animal slaughter, alcohol from wine making, etc.). Oxygen concentration can only be measured by a suitable probe. The easiest way to test oxygen supply is to measure it shortly after the blower is turned on. In this case, air bubbles should be fine and evenly distributed on the water surface of the diffuser. If bubbles do not meet this requirement, it may be a result of improper function of the diffuser; most often, a part of the membrane is not permeable for air. If bubbles of cm size appear on the surface of the water, air may escape from the air inlet pipe at the connection, or the membrane is ruptured. The above problem can be solved by repairing the seal; in case of a membrane rupture, the diffuser must be replaced.

In SBR units, the activated sludge settles after the aeration cycle according to the set cycle time. After the settling phase, settled wastewater is pumped by a pump or syphon into the drainpipe or into a sampling container of a few litres preceding the drainpipe. Sedimentation is measured by measuring turbidity, or by visual inspection. Turbidity measurement requires a turbidity meter, which is usually only available in the laboratory. By visual inspection, the transparency of wastewater is easily measured. Transparency is a measure of the degree to which the water loses its transparency due to the presence of suspended solids.

In the settlers of aerobic equipment, deposit may develop as a result of the flotation of activated sludge flakes. Floating sludge can be removed with a simple pot with a handle. The sludge removed can be placed into the sludge space of the pretreatment unit.

In case of activated sludge systems, serious problems occur during periods without long-term wastewater supply. Most of the activated sludge systems recover from a 7 to 10 day period without wastewater supply. For that long or slightly longer periods without wastewater supply, a storage system with quantitative and qualitative balancing storage unit provides a good solution. But for longer periods, if small appliances supply one housing unit (e.g. 4 PE), e.g. residents during vacation, the equipment has to be switched to an economy mode. Economy mode means that during the wastewater-free period, a minimum amount of water and nutrients – at least some carbon source – for keeping the biomass functioning must be replenished. Replacement wastewater can be obtained from purified wastewater, but the system must have a smaller storage tank for treated wastewater of up to 100 l of useful volume, from where it can be recycled to the biological unit. This can be done with a pre-installed, low-flow, level-controlled pump. In principle, it is possible to obtain sludge water from a sludge storage tank (settler, septic tank), but it requires a technically costly and complex solution. A more convenient and technically simpler solution may be the intermittent introduction of an external carbon source (e.g. acetic acid) into the activated sludge reactor or to the recirculating water stream. The dosing unit consists of a dosing pump, a solution tank and a control unit (essentially a timer).

In case of a trickling filter system, conditions for achieving the appropriate wastewater quality are the following:

- wastewater with low suspended solid content can be led to the trickling filter, which requires high efficiency pretreatment (settling)
- wastewater shall be introduced intermittently onto the trickling filter and distributed evenly over the surface medium
- organic matter load should be kept low, the trickling filter should be prevented from drying out, and for both requirements treated wastewater should be recirculated intermittently
- for a proper ventilation of the filling medium, the right size of medium should be chosen

Development of puddles on the surface of the filling medium indicates blockage, which may be recovered by either washing the top layer with high-pressure water or by extracting the thicker layer of the medium and flushing the sludge clogging the gaps. The use of disinfectant (hypo) is contraindicated as it causes severe damage to the biofilm.

According to the law, the municipality is responsible for organising the safe disposal of sludge from the equipment.

Economic aspects

The spread of professionally designed and constructed small appliances can be expected if their installation and operation costs do not exceed specific installation costs of centralised sewage systems, or the standard sewage fees in the area. Central wastewater treatment and disposal systems are implemented only through some form of financial subsidy, thus, it can reasonably be expected from the government to develop and operate an equivalent system supporting the installation of small appliances. The creation of a joint unit of up to 50 PE for group sewage dischargers should be particularly supported, provided that operation is undertaken by the agglomeration sewer service provider.

The investment cost of developing a sewage pipe between the given property and the public sewage system, as well as the calculated unit cost of central sewage treatment capacity may be a theoretically feasible, rational financial support source for the installation of small equipment.

Operating costs include maintenance and restoration costs (e.g. replacement of filling medium, membrane, etc.), amortisation costs of the installation, energy costs where appropriate, costs of removal, treatment and disposal of sludge generated.

In case of small appliances, the life-cycle cost approach should also be emphasised.

The cost of installing small appliances is particularly difficult to estimate, especially due to the diversity of products, the wide range of supply by manufacturers, and the huge variation in installation and construction costs.

The approximate investment costs of 700–800 thousand HUF/property for the CE-certified septic tanks and 1,100–1,200 thousand HUF/property for small equipment are included in the 2016 recommendations of HWA for individual wastewater treatment and disposal. In the same recommendation, the operating costs of 450–500 HUF/property for septic tanks and 4–5 thousand HUF/property for small equipment are heavily underestimated, especially in the life cycle approach.

A chart based on 300 different small equipment, manufacturers' price lists and offers, as well as installation and operating costs provide a more sophisticated view of sewage treatment plants up to 50 PE (Germany, 2003). It is clear from the chart that unit costs have a wide range; there can be up to 1.5–2 times difference between the upper and lower values in smaller size equipment, while the difference is smaller, about 0.6–0.7, in larger equipment.

Major operating costs include maintenance costs, electricity costs and sludge removal costs. Maintenance costs include the cost of periodic inspections, wastewater analysis, warranty and repair costs. The costs of operating small equipment depend on the type of equipment and its size. For smaller units, the difference between the minimum and maximum unit costs can be up to three times, and for larger units this difference is two-fold. Electricity costs, according to 2003 figures, were well above 100 Euros for an average household, and much lower for semi-natural sewage treatment systems. The annual electricity cost per resident was around 10–30 Euros for engineering structures and 2–5 Euros for semi-natural systems.

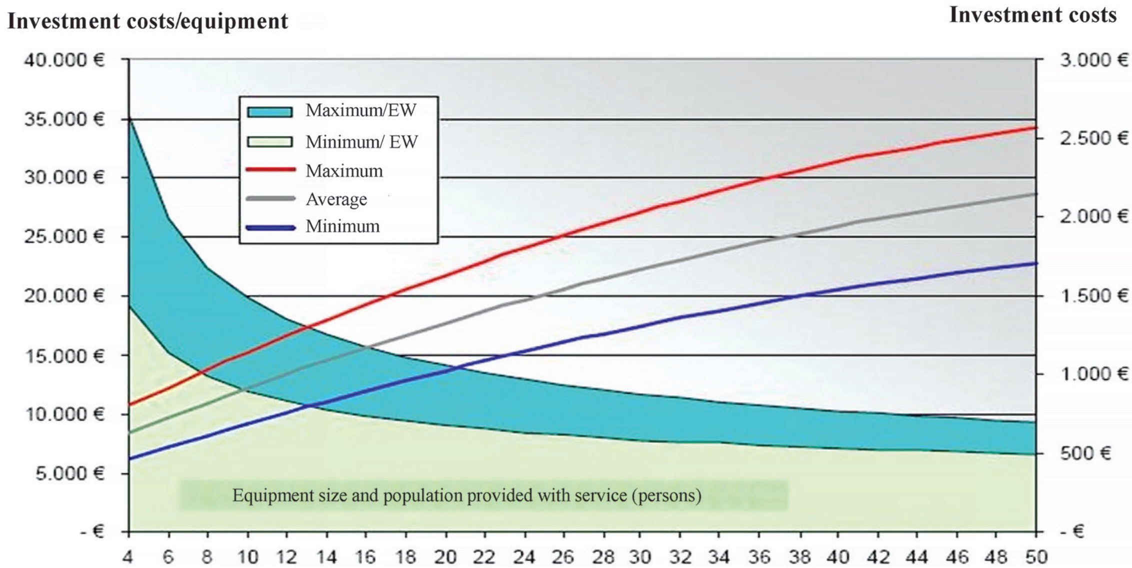


Figure 34
Specific investment costs (compiled by the author)

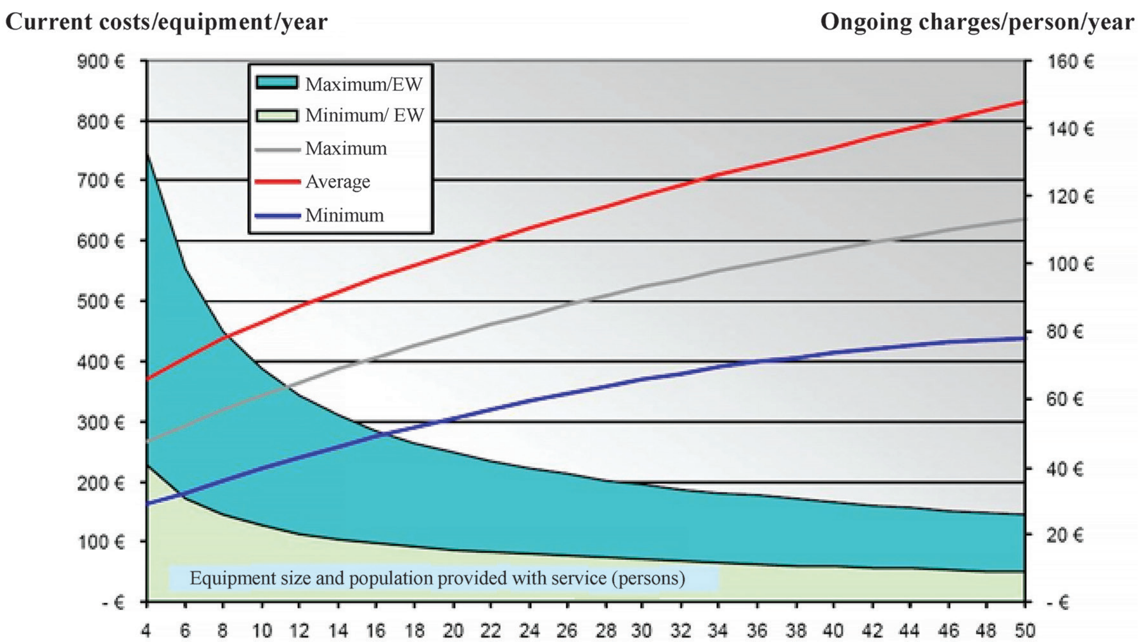


Figure 35
Running costs of small equipment operation (compiled by the author)

The following table shows energy requirements of small wastewater treatment equipment broken down by technology based on different U.S. sources:

Table 36
Energy requirements of small wastewater treatment plants depending on different technologies (compiled by the author)

Technology	Hydraulic load m^3/d	Specific energy consumption kWh/m^3
Facultative lagoons + rapid infiltration	3,786	0.11
Facultative lagoon + surface infiltration	33,786	0.16
Aerated plant beds	5,500	0.16
Intermittently flooded plant beds (filling–emptying)	1,000	0.18
Oxidation ditch	3,786	0.51
Trickling filter with nitrogen removal	3,786	0.61
With activated sludge nitrification	3,786	0.76
Complete oxidation equipment	3,786	1.06
SBR	303	1.13
Living machine	3,786	1.51

Table 37
Specific installation and operating costs (compiled by the author)

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="3">Net per property</th><th rowspan="2">30 year net installation and operation costs (HUF)</th><th rowspan="2">Cost ratio compared to the most expensive 30 years net installation and operational cost (%)</th></tr>
<tr><th>Construction cost (HUF/ property)</th><th>Operating cost (HUF/ m³)</th><th>Operating cost (HUF/ year)</th></tr>
<tr><td colspan="2">Closed sewage storage system</td><td>500,000</td><td>1,580</td><td>156,000</td><td>2,726,263</td><td>100</td></tr>
<tr><td colspan="2">On-site small wastewater treatment unit</td><td>750,000</td><td>170</td><td>16,700</td><td>954,688</td><td>35</td></tr>
<tr><td rowspan="2">Sewerage + sewage treatment plant</td><td>< 600 PE</td><td>1,100,000</td><td>1,000</td><td>98,550</td><td>2,452,844</td><td>90</td></tr>
<tr><td>600–2,000 PE</td><td>980,000</td><td>920</td><td>90,400</td><td>2,255,054</td><td>83</td></tr>
<tr><td rowspan="2">Sewerage + semi-natural sewage treatment</td><td>< 600 PE</td><td>850,000</td><td>640</td><td>63,300</td><td>1,705,522</td><td>63</td></tr>
<tr><td>600–2,000 PE</td><td>750,000</td><td>570</td><td>55,800</td><td>1,519,574</td><td>56</td></tr>
</table>

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Standards, rules, regulations

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Standards

OVHMI 146 / 1-71 Domestic small sewage treatment equipment.
SE 511-75 Sewage treatment and sewage treatment structures. Design requirements.
MI 10 127 / 9-84 Treatment plants for municipal wastewater. Small wastewater treatment structures and appliances.
MSZ 15302-62 Sewage design and dimensioning. Sewage treatment.
MSZ 15287: 2000 Wastewater treatment plants for municipal wastewater. Small wastewater treatment structures and appliances.
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Questions

1. What are the rules for designing simple and extended septic tanks?
2. Outline the conceptual design of a small continuous flow activated sludge unit by indicating each material flow.
3. What is the operating principle of the SBR system? Which specific operating alternatives would you use in small appliances?
4. What is the conceptual design of trickling filters and how do they work?
5. What is the conceptual design of immersion discs and how do they work?
6. How do membrane bioreactors work?
7. What are the small, semi-natural wastewater treatment plants and what are the main design methods?
8. How can treated wastewater be disposed of? What are the principles for sizing small wastewater disposal plants?

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Tamás Karches

Wastewater Treatment Modelling

Wastewater treatment modelling and simulation software

Simulation and prediction of wastewater treatment processes is already required at the stage of designing. These models generally apply dynamic approaches; therefore, the processes and process variables are described in function of time. Unsteady simulations are performed due to the uneven raw wastewater discharge based on the daily, seasonal flow variations and possible industrial sources.

As a result of the unsteady behaviour of the incoming load, the wastewater treatment plant (WWTP) shall not be sized solely for average conditions and the operation should take into account the parameters coming from composite samples rather than using grab samples. Dynamic modelling shall reflect the complexity of wastewater processes, thus the simulation environment is system-based, well-structured and the model elements are similar to an interlocking cog.

The model elements are the following:

- input model: determines the wastewater constituents, fractions and transforms to process modelling variables
- clarifier model: predicts the separation of particulate matter
- biokinetic model: determines the biomass amount required for biological processes and calculates the reactor volumes
- pump model: operation of pumping and calculates energy demand
- sensor model: determines the relation between the measured concentration of the model parameter and the signal of the measurement device
- controller model: gives feedback from the measured value to the operation
- hydraulic and transport model: fluid flow in the reactors and related transport models, including the result of the simplified reactor models originating from multi-dimensional problems
- aeration model: determines the relation between the biological oxygen demand and the air flow introduced to the system through diffusers
- output model: generates composite variables (treated effluent wastewater quality) from the model variables

The connectivity between the model elements is determined by the input and output data. For example, wastewater characterisation provides COD fractions as a result, which is the input data of the biokinetic model. The reactor effluent ammonium concentration determined by the sensor model has effect on air quantity (ammonium control), and thus the aeration and controller models are also affected.

Some model elements are tied closely, e.g. biokinetic and hydraulic model. In this case, one element is idealised in the other sub-model. For example, the complexity of the fluid flow is simplified in biokinetic modelling; the multidimensional behaviour is reduced to its effect on mixing characteristics and assumes well-mixed compartments in the reactor cascade model. Figure 1 represents the model elements and the connectivity among them. This modelling approach was created by the IWA (International Water Association) GMP TG (Good Modelling Practice Task Group).

Figure 1

Elements of wastewater modelling (compiled by the author based on [1])

Note: 1: input model; 2: biokinetic model; 3: clarifier model; 4: pump model; 5: sensor model; 6: hydraulic and transport model; 7: controller model; 8: aeration model; 9: output model.

The complex simulation system gives us the opportunity to design, size and operate wastewater treatment processes; predictions, trends, optimisation could be also performed. However, this complexity can be simplified in real life scenarios.

Sizing wastewater treatment processes requires the determination of reactor volumes, the chemicals applied, the aeration demand and the amount of wasted solid. This calculation requires the input model, the biokinetic model, the clarifier model, the aeration model and the output model. User-friendly simulation applications could handle all of the model elements together. There is a huge variety of simulation tools on the market, the following criteria should be considered:

- easy to use, user-friendly platform
- technical support
- upgradability, flexibility
- affordability, value for money

Moreover, a simulation tool is preferred that does not need advanced coding knowledge, provides stable model runs and online support is available. The acquired product should be capable not only for performing general well-known tasks, but it should be upgradable, expandable for specific issues. Price also matters; the value gained by the software (e.g. optimised operation of a WWTP) should cover the costs. It is worth considering, if we have enough experience, to use a free open-source software or a user-friendly simulation environment having technical support for the licensing period. Some selected simulation environment for performing wastewater treatment process modelling:

- Stoat: continuously developing environment with sewerage models, it is advisable for low complexity problems

- WEST: developed by the DHI, flexible environment
- GPS-X: developed by Hydromantis, widespread applications, valuable support; self-developed models (e.g. Mantis model)
- Simba: originally it was spread in German speaking countries, but thanks to the latest improvements it became world-famous
- BioWin: competitor of GPS-X in wastewater industry; complex modelling system in designing and operation of WWTPs; user-friendly environment
- SUMO: new generation tool with high speed simulations

Others simulation tools are AQUASIM, JASS, EFOR, ASIM.

Simulation protocols

It can be seen that a huge variety of models embedded in simulation softwares exist and these have to provide the same results, which is close to the actual conditions. For this purpose and for the comparability of the simulation tools and their results, international protocols were introduced. Some selected simulation tools are the following:

- STOWA protocol: developed by the Dutch Foundation of Applied Water Research, its basis is the Activated Sludge Model Nr. 1 (ASM1)
- Biomath protocol: calibration procedure for the entire ASM model family
- WERF protocol: developed by the Water Environment Research Foundation; it controls the wastewater fractions and introduces multi-level calibration processes
- HSG guideline: general, uses model-independent data

However, the main concept is similar, it is visible that the above-mentioned protocols put emphasis on different processes; the differences are in the details. Consequently, the models applying different protocols are not comparable. The International Water Association (IWA) has an objective to introduce the good modelling practice and standardise wastewater modelling.

Mass balance based (biokinetic) modelling

Biokinetic modelling requires the knowledge of the basic physical, chemical and biological processes and process units. The time dependent processes are based on the required biomass quantity and substrate kinetics.

The conversions of the biological wastewater treatment are the following:

1. growth of the organisms
2. hydrolysis
3. degradation of substrate

Growth of the organisms

Microorganisms in wastewater treatment perform degradation/transition of simple structured molecules for their growth. The molecules used are acetic acid, ethanol, methanol, propionic acid, glucose, ammonium, nitrite, etc. The growth is an enzyme-catalysed reaction and its process follows the Monod kinetics applying the reproduction kinetics and can be described with the following equation:

$$\mu = \mu_{max} \cdot \frac{S}{K_S + S}$$

where

μ: specific growth rate [t^{-1}]

μ_{max}: maximum specific growth rate [t^{-1}]

S: substrate concentration [mg/l]

K_S: half saturation constant of the substrate, which is the substrate concentration at the half of the maximum specific growth rate [mg/l]

Based on Monod kinetics a yield can be introduced reflecting the amount of biomass (sludge) produced from 1 kg organic matter.

$$\frac{dX}{dt} = Y\frac{dS}{dt}$$

where

X: daily produced biomass amount [kg/d]

S: daily incoming substrate amount [kg/d]

Y: yield [kg/kg]

Based on the above-described equations the kinetic equation for the substrate is the following:

$$\frac{dS}{dt} = \frac{-1}{Y}\mu_{max}\frac{S}{K_S + S}X$$

There could be various kinds of substrates of course; in that case, individual equations shall be written for each substrate.

Hydrolysis

Conversion of the large molecules to smaller size molecules (these can be particulate or dissolved). In this biochemical process, hydrolases – a type of enzyme operating outside the cell (extracellular enzymes) – are responsible for the splitting of large size organic matter (e.g. biopolymer). The resulting smaller molecules could be taken up by the cells and convert to molecules required for the growth and reproduction, and parallel the biomass amount increases. Since hydrolysis kinetics is generally slower compared to biological growth, this process is the "bottleneck" in wastewater treatment.

Decay

Decay of microorganisms is important in the conversions and mass balance of the wastewater treatment processes. By this process, a certain amount of slowly biodegradable substrate is introduced to the system. This can hydrolyse resulting growth causing reduction in dissolved oxygen and/or nitrate concentration.

These were the main conversion processes in wastewater treatment. The removal processes can be divided to organic matter removal, nitrification and denitrification. The model build-up is presented step-by-step in the following. Matrices are used for the structured description, where the processes (rows) and components (columns) are listed.

Step 1: Growth of heterotrophic organism. Anaerobic degradation of dissolved organic matter: the process takes place in the presence of oxygen. It requires dissolved oxygen and heterotrophic biomass. Model components are the following:

- soluble oxygen *(SO_2)*
- soluble biodegradable organic matter *(SS)*
- soluble inert organic matter *(SI)*
- heterotrophic biomass *(XH)*

The components and process matrix can be seen in Table 1.

Table 1

Growth of heterotrophic biomass (compiled by the author)

Component	**SO_2**	**SI**	**SS**	**XH**
Growth of heterotrophic biomass	$1–1/Y_H$		$–1/Y_H$	+1

The process rate of aerobic heterotrophic growth:

$$\mu_H \cdot \frac{SO_2}{K_{H,O_2} + SO_2} \cdot \frac{SS}{K_{H,SS}} \cdot X_H$$

The model calculates the aerobic heterotrophic growth based on Monod kinetics and takes into account the process rate, oxygen concentration and the biodegradable organic matter. The heterotrophic organism yield is about $Y_H = 0.67$ g/g, the maximum heterotrophic growth rate is $\mu_H = 4.1$/d. The half saturation coefficient for oxygen is $K_{H,O2} = 0.2$ g O_2/l, the half saturation coefficient for substrate is $K_{H,SS} = 5.0$ g SS/l.

Based on Table 1 and the process rate, the transport equations of the model components are the following:

- soluble oxygen concentration

$$\frac{dSO_2}{dt} = \left(1 - \frac{1}{Y_H}\right) \cdot \mu_H \cdot \frac{SO_2}{K_{H,O_2} + SO_2} \cdot \frac{SS}{K_{H,SS}} \cdot X_H$$

– soluble biodegradable organic matter

$$\frac{dSS}{dt} = \left(\frac{-1}{Y_H}\right) \cdot \mu_H \cdot \frac{SO_2}{K_{H,O_2} + SO_2} \cdot \frac{SS}{K_{H,SS}} \cdot X_H$$

– heterotrophic biomass

$$\frac{dXH}{dt} = (+1) \cdot \mu_H \cdot \frac{SO_2}{K_{H,O_2} + SO_2} \cdot \frac{SS}{K_{H,SS}} \cdot X_H$$

Namely, the component variation over time equals the coefficient coming from the table multiplying with the process rate. In the next step, the model is expanded by lysis, which reflects the decay of microorganisms and conversion to biodegradable matter. In this case, one new process will appear in the matrix, the component number remains the same (Table 2).

Table 2
Growth of heterotrophic biomass (compiled by the author)

Component	SO_2	*SI*	*SS*	*XH*
Growth of heterotrophic biomass	$1–1/Y_H$		$–1/Y_H$	+1
Lysis			+1	–1

It can be seen from the table that the decay of the heterotrophic organisms causes an increase in the biodegradable organic matter. The process rate is proportional to the heterotrophic organisms ($=b_H*XH$), where the heterotrophic decay constant is $b_H = 0.4$ 1/d.

Thereby the transport equation for the organic carbon is the following:

$$\frac{dSS}{dt} = \left(\frac{-1}{Y_H}\right) \cdot \mu_H \cdot \frac{SO_2}{K_{H,O_2} + SO_2} \cdot \frac{SS}{K_{H,SS}} \cdot X_H + 1 \cdot b_H * XH$$

Despite the detailed description of the process, the simulations revealed that this equation resulted rapid transition between the biomass and the available substrate. The decomposed cells first form large molecules, then these hydrolyse and split to smaller molecules. In Step 3, the hydrolyses process is introduced to the model system. A new component is needed to be taken into account, which is the slowly biodegradable organic matter. That leads to a change in the lysis process as well; the coefficient of +1 does not belong any more to lysis, but the process of hydrolysis.

Table 3
Decay of organic matter (compiled by the author)

Component	SO_2	*SI*	*SS*	*XH*	*XS*
Growth of heterotrophic biomass	$1–1/Y_H$		$–1/Y_H$	1	
Lysis			–	–1	+1
Hydrolysis			+1		–1

Hydrolysis process rate:

$$k_H \cdot \frac{XS/XH}{K_X + XS/XH} \cdot \frac{SO_2}{K_{hidr,O_2} + SO_2} \cdot XH$$

where

k_H: kinetic constant of hydrolysis: 1.6 g/g

K_X: half-saturation coefficient for heterotrophic lysis: 0.04 g/g

$K_{H,O2}$: half-saturation coefficient for oxygen: 0.1 g O_2/l

The model handles the oxygen consumption appropriately, but underestimates the sludge production. The reason behind this is the fact that the end product of the cell lysis is not entirely biodegradable, particulate inert matter could appear in the system. To develop the model particulate inert fraction of organic matter (*XI*) is introduced. This fraction is about 8% of the biomass (f = 0.08).

Table 4

Aerobic degradation of organic carbon with XI fraction (compiled by the author)

Component	SO_2	*SI*	*SS*	*XH*	XS	XI
Growth of heterotrophic biomass	$1–1/Y_H$		$–1/Y_H$	1		
Lysis				–1	1–f	f
Hydrolysis			1		–1	

Further development of the model could be achieved by the introduction of biological N-removal process, which can happen more conveniently via nitrification and denitrification sub-processes. As a first step, the nitrification shall be built-in the calculation, which results 3 new components in the model. Nitrification is performed by autotrophic organism; therefore, it is necessary to separate the heterotrophic and autotrophic processes. New model components are the autotrophic biomass *(XA),* ammonium-nitrogen *(SNH),* nitrate (nitrite) – nitrogen *(SNO).* New processes are autotrophic growth and the autotrophic lysis. Table 5 can be created by the expansion of Table 4 with 3 components and 2 processes.

Table 5

Organic matter degradation and nitrification (compiled by the author)

Component	SO_2	*SI*	*SS*	*XH*	*XS*	*XI*	*SNH*	*SNO*	*XA*
Growth of heterotrophic biomass	$1–1/Y_H$		$–1/Y_H$	+1			$(1–Y_H)/Y_H*i_N$		
Lysis				–1	1–f	f			
Hydrolysis			+1		–1				
Autotrophic growth	$(Y_A–4.57)/Y_A$						$–i_N–1/Y_A$	$1/Y_A$	+1
Autotrophic lysis					1–f	f			–1

autotrophic growth process rate:

$$\mu_A \cdot \frac{SO_2}{K_{A,O_2} + SO_2} \cdot \frac{SNH}{K_{A,SNH}} \cdot X_A$$

autotrophic lysis process rate:

$$b_A \cdot XA$$

In the denitrification process, the heterotrophic growth will be affected and the autotrophic rate remains the same. In anaerobic conditions, the hydrolysis process rate would be slightly different.

Phosphorous removal in wastewater treatment can be a chemical and biological process. Chemical P-removal has three processes: 1. oxidation; 2. precipitate formulation; and 3. re-dissolving. Process parameters can be determined by stoichiometric analysis. Excess biological phosphorous removal is more complex with numerous new components and processes.

Activated sludge models

It was demonstrated that the biokinetic model build-up and extension required various processes and components. It is not necessary to apply the whole set of processes; for a specific case, a subset of processes and components could be enough. The most widespread modelling family is the activated sludge model developed by IWA.

ASM1 – Activated Sludge Model

The model includes 13 components and 8 processes which covers the oxygen consumption, sludge production, carbon and nitrogen mass balance. The task group tried to find equilibrium between the crowd of equations and the completeness of the processes, i.e. reduced the computational cost at simple base cases.

The model components are the following:

1. *SI:* soluble inert
2. *SS:* soluble biodegradable inert
3. *XS:* slowly biodegradable particulate
4. *XI:* non-biodegradable particulate inert
5. *XBH:* heterotrophic biomass
6. *XBA:* autotrophic biomass
7. *XP:* inert particulate products
8. *SO:* soluble oxygen
9. *SNO:* soluble nitrite and nitrate
10. *SNH:* soluble ammonium
11. *SND:* soluble organic nitrogen
12. *XND:* particulate organic nitrogen
13. *SALK:* alkalinity

Model processes:

1. Aerobic growth of heterotrophic biomass
2. Anoxic growth of heterotrophic biomass (denitrification)
3. Aerobic growth of autotrophic biomass (nitrification)
4. Decay of heterotrophic biomass

5. Decay of autotrophic biomass
6. Ammonification
7. Aerobic hydrolysis
8. Anoxic hydrolysis

The ASM1 model does not take into account the effect of pH, it assumes constant stoichiometric and process parameters. For the elimination of this restriction ASM2 was released in 1995, and ASM2d in 1999 as an upgraded version. ASM2 calculates the excess biological P removal and chemical P removal. ASM2 includes 19 components and 19 processes; the ASM2d uses also 19 components, but 21 processes.

Nitrogen forms (ammonia, ammonium, nitrite, nitrite) are extended with dinitrogen. There is no separate equation for organic nitrogen fraction, since it is in the other equation. As for the biological process, there are equations for heterotrophic organisms, nitrifying autotrophic organism and phosphate accumulating organism. This latter one covers the storage of fermentation products, intermittent polyphosphate accumulation, growth and lysis of poly-P bacteria. During the lysis, the stored product could be realised. The kinetic parameters in the model have temperature dependence.

ASM3

This model was issued by the development of the ASM1 model. It has 13 components and 12 processes that cover the following:

- hydrolysis is independent of the electron donor, thus it occurs at the same rate under anoxic and aerobic conditions
- anoxic yield differs from the aerobic yield
- biomass decay is based on endogenous respiration
- includes the heterotrophic COD storage
- different anoxic and aerobic nitrification cell lysis is introduced
- alkalinity is introduced as a limitation parameter

ASM3 basically does not include the P-model, but leaves an opportunity to be extended.

Mantis model

The Mantis model originates from ASM1 except for a few modifications; the kinetic parameters are dependent from temperature, aerobic denitrification is introduced and two additional growth processes are introduced: one for autotrophic organisms and one for the heterotrophic organisms at low or high ammonium concentration, where organisms could uptake nitrate as a nutrient source. The role of the aerobic denitrification is to distinguish and set individually the anoxic and aerobic half-saturation coefficients.

Mantis 2 model

Mantis 2 is a comprehensive model and it comes from ASM2d and the Mantis model. It includes the side stream wastewater processes like the struvite precipitation and anammox technology. It is capable to integrate the sludge line calculation and ADM (Anaerobic Digestion Model) with carbon, nitrogen and phosphorous mass balance modelling. It introduces 48 state variables and 56 processes. Ions (potassium, calcium, magnesium) appear in state variables and precipitation processes are also appropriately described. The processes are the following:

1. Adsorption of colloidal COD to heterotrophic biomass
2. Aerobic hydrolysis of heterotrophic microorganisms: slowly biodegradable substrate transforms to readily biodegradable COD
3. Anoxic hydrolysis
4. Anaerobic hydrolysis
5. Ammonification: converts soluble organic nitrogen to ammonia nitrogen
6. Growth on fermentable substrate using O_2 as electron acceptor
7. Growth on acetate using O_2 as electron acceptor
8. Growth on propionate using O_2 as electron acceptor
9. Growth on fermentable substrate using NO_3 as electron acceptor
10. Growth on acetate using NO_3 as electron acceptor
11. Growth on propionate using NO_3 as electron acceptor
12. Growth on fermentable substrate using NO_2 as electron acceptor
13. Growth on acetate using NO_2 as electron acceptor
14. Growth on propionate using NO_2 as electron acceptor
15. Decay of heterotrophic microorganism
16. Growth of ammonia oxidiser
17. Growth of nitrite oxidiser
18. Decay of ammonia oxidiser
19. Decay of nitrite oxidiser
20. PHA storage by PAO using acetate
21. PHA storage by PAO using propionate
22. PAO growth on PHA using O_2 as electron acceptor
23. XPP storage on PHA using O_2 as electron acceptor
24. PAO growth on PHA using NO_3 as electron acceptor
25. XPP storage on PHA using NO_3 as electron acceptor
26. PAO growth on PHA using NO_2 as electron acceptor
27. XPP storage on PHA using NO_2 as electron acceptor
28. PAO decay
29. XPP lysis
30. PHA lysis
31. Growth of methylotrophs on methanol using O_2 as electron acceptor
32. Growth of methylotrophs on methanol using NO_3 as electron acceptor
33. Growth of methylotrophs on methanol using NO_2 as electron acceptor
34. Decay of methylotrophs
35. Growth of fermentative bacteria at low H_2 partial pressure
36. Growth of fermentative bacteria at high H_2 partial pressure
37. Decay of fermentative biomass
38. Growth of acetogens on propionate
39. Decay of acetogens
40. Growth of hydrogen trophic methanogens

41. Decay of hydrogen trophic methanogens
42. Growth of acetoclastic methanogens
43. Decay of acetoclastic methanogens
44. Growth of anammox organisms
45. Decay of anammox organisms
46. $CaCO_3$ precipitation
47. $MgNH_4PO_4$*$6H_2O$ (struvite) precipitation
48. $MgHPO_4.3H_2O$ precipitation
49. $Ca_3(PO_4)_2$ precipitation
50. $MgCO_3$ precipitation
51. $AlPO_4$ precipitation
52. $FePO_4$ precipitation
53. CO_2 absorption/desorption
54. N_2 absorption/desorption
55. CH_4 absorption/desorption
56. H_2 absorption/desorption

The activated sludge system can be operated as a continuous flow system (Conventional Activated Sludge), but also as a batch system SBR (Sequenced Batch Reactor). SBR also applies suspended biomass for biological processes, but instead of spatial separation, cycles and time based separation is introduced for each process (feed, mixing with or without aeration, settling and decanting). Cycle times provide the basic sizing parameter and in addition, the simulation should be transient.

SBR can be also equipped with aeration and/or MLSS control. MLSS control provides the stable biomass amount in the reactor, which is 3.5–4.5 mg/l in CAS, whereas it is 5.5–6.0 in SBR. The higher MLSS in SBR is due to the compact sludge structure formed in cascaded reactors. As a user input, cycle times needs to be set. Processes may happen parallel; e.g. biological processes could occur during the feed or settling and decanting could happen simultaneously. For modelling purposes, the following processes are defined:

- mix and fill: wastewater discharges and homogenisation
- aerate and fill: provides aerobic condition
- mix only: provides anoxic condition
- aeration only: post-aeration
- settling: with or without biology
- decanting: treated water removal
- settled sludge removal

Previously, only a part of the activated sludge systems was described, the technologies for large WWTPs (e.g. oxidation ditch) were neglected.

Biofilm models

The ASM and related models were developed for activated sludge system, but these models can be applicable for attached growth (biofilm) processes with some extensions. Processes in the attached growth system are the same compared to processes occurring in flocs of suspended biomass; the difference is only the position of the biomass. In the activated sludge system, the biomass is in suspended form and homogenised within the reactor, whereas in biofilm systems the biomass is attached to a carrier. The carrier can be moving or stationary. If the carrier is at a certain location (fixed) then the fluid flow is not only responsible for providing the necessary mixing intensity, but the substrate shall be transported to the surface of the biofilm and the end products of metabolism shall be transported out of the system. As a consequence, mass balance modelling shall be coupled with hydrodynamic simulations in biofilm systems.

In the biokinetic modelling environment, the total carrier surface area and maximum biofilm thickness are the user input data. This approach assumes that the carrier is evenly distributed within the system. The calculation of the actual biomass amount is based on the surface area and the actual biofilm thickness in the dynamic simulation. Biofilm could be sliced to a certain amount of layers, where each layer has a different substrate concentration; biological activity also differs between the inner and outer layers. Outer layers close to the bulk flow are supplied by oxygen, thus aerobic condition is present. Contrary to this, the inner layer oxygen supply is deteriorated if the biofilm is thick; therefore, anoxic and anaerobic conditions could appear resulting in simultaneous denitrification and enhanced biological P removal in some cases.

Diffusion is the dominant mass transport through biofilm layers, thus it requires an appropriately high level of shearing and local turbulence. The outer biofilm layer has a high importance; thus, this could communicate the bulk flow. On the surface of the biofilm, a laminar boundary layer may form, which has a hydrodynamic resistance and bottleneck of mass transport. Enhancing mass transport between the bulk and biofilm needs to reduce this boundary layer thickness, which is governed by local turbulence and high velocity gradient. The higher the bulk liquid velocity and the biofilm (carrier) surface roughness, the thinner is the laminar boundary layer. Shearing is developed between two fluid layers with different velocities, resulting swirls (rotation), which could increase the transport process efficiency between the biofilm and bulk flow.

Carrier fill is an important parameter, which presents how much water is replaced by the carrier and also shows the volume of the carrier. Total carrier surface area can be calculated by multiplication of the carrier fill with carrier specific surface area. Specific surface area is calculated by the carrier surface area in 1 m^3 of carrier material. The simplified biofilm model assuming constant biofilm width is summarised in Table 6 for soluble states and Table 7 for particulate states.

It can be seen from the Table 6 and Table 7 that transport processes of the soluble and particulate states are different in the process of attachment and detachment. This process is regulated by the erosion velocity; the ± sign shows that if erosion velocity is higher than the attachment velocity then it is a detachment process, if the erosion velocity is smaller than the attachment velocity, the substrate attaches to the biofilm. Model extension is possible with introducing mass transport between two biofilm layers, which is not detailed here.

Improvement of the model is possible by applying dynamic biofilm width. In this case, the previously described processes are still valid, but with the condition that the amount of biomass is in function with time $[V_{b,f} = V_{b,f}(t)]$. The amount of biomass can be calculated by an additional transport equation and it has effect on the soluble and the particulate states; therefore, the transport equation system also needs to be extended.

Many applications are developed for the attached growth system. One classification is about the position of the carrier and water surface, the other takes into account the fixed or moving behaviour of the carrier. Biofilm systems can be trickling filters, submerged rotating biofilm contactors, biofilters and two types of hybrid systems: MBBR-t (Moving Bed Biofilm Reactor) and IFAS (Integrated Fixed Film Activated Sludge) technologies, which are detailed in the following.

Table 6
Fixed biofilm width – soluble states (compiled by the author)

Bulk mass	in layer of k	Process name
$\frac{dS_{b,i}(t)}{dt} =$	$\frac{dS_{k,i}(t)}{dt} =$	
$+(S_{,i} - S_{b,i})\frac{Q}{V_b}$		convection
$\sum_{j=1}^{n_p} R_{i,j}$	$\sum_{j=1}^{n_p} R_{i,j}$	biological process/reaction kinetics
$-\sum_{k=1}^{n_l} +D_i(S_{b,i} - S_{k,i}) \cdot \frac{A_{b,k}}{R_d}\frac{1}{V_b}$	$+D_i(S_{k-1,i} - S_{k,i}) \cdot \frac{A}{R_{bfk}}\frac{1}{V_{bfk}}$ $-D_i(S_{k,i} - S_{k+1,i}) \cdot \frac{A}{R_{bfk}}\frac{1}{V_{bfk}}$ $+D_i(S_{b,i} - S_{k,i}) \cdot \frac{A_{b,k}}{R_d}\frac{1}{V_{bfk}}$	diffusion

Table 7
Fixed biofilm width – particulate states (compiled by the author)

Bulk mass	in layer of k	Process name
$\frac{dS_{b,i}(t)}{dt} =$	$\frac{dS_{k,i}(t)}{dt} =$	
$+(S_{,i} - S_{b,i})\frac{Q}{V_b}$		convection
$\sum_{j=1}^{n_p} R_{i,j}$	$\sum_{j=1}^{n_p} R_{i,j}$	biological process/reaction kinetics
$-\sum_{k=1}^{n_l} +D_i(S_{b,i} - S_{k,i}) \cdot \frac{A_{b,k}}{R_d}\frac{1}{V_b}$	$+D_i(S_{k-1,i} - S_{k,i}) \cdot \frac{A}{R_{bfk}}\frac{1}{V_{bfk}}$ $-D_i(S_{k,i} - S_{k+1,i}) \cdot \frac{A}{R_{bfk}}\frac{1}{V_{bfk}}$ $+D_i(S_{b,i} - S_{k,i}) \cdot \frac{A_{b,k}}{R_d}\frac{1}{V_{bfk}}$	diffusion
$-\sum_{k=1}^{n_l} S_{b,i}A_{b,k}v_a\frac{1}{V_b}$	$+S_{b,i}A_{b,k}v_a\frac{1}{V_{bfk}}$	attachment
$\pm\sum_{k=1}^{n_l} S_{k,i}A_{b,k}v_e\frac{1}{V_{bfk}}$	$\pm S_{k,i}A_{b,k}v_e\frac{1}{V_{bfk}}$	detachment

Nomenclature: S: solute concentration (mg/l); *Q:* discharge (m^3/s); *R:* mass flux of reaction rate (mg/l.s); *D:* diffusion coefficient (m^2/s); *A:* surface area (m^2); *V:* volume (m^3); *v:* velocity (m/s)
Indexes: b: bulk; *k:* biofilm layer of k; *i:* component in the transport equation; *j:* process variable (e.g. growth; decay; hydrolysis etc.); *p:* number of processes; *bf:* biofilm; *bfk:* biofilm layer; *l:* number of biofilm layers; *a:* attachment; *e:* erosion, detachment

Trickling Filters (TF)

Modelling of trickling filters requires the following assumptions: the wastewater discharge is continuous and loads the reactor evenly. The model does not take into account fouling and is not capable to determine the hydraulic loss. Distribution of raw wastewater flow is not in the model. The mass transport rate between the biofilm and bulk is different for soluble and particulate states; therefore, the time steps are also different in the numerical model.

Figure 2
Trickling Filter [2]

Since there is an inhomogeneity of variables in biofilm systems, the multidimensional modelling need is high, but the computational capacity of a 2D or 3D model is so elevated that these models are often limited to 1D approach. Model inputs are the reactor depth, carrier surface area and specific surface area. The active biomass amount and substrate in biofilm layers are model variables, thus these provide the model output.

Rotating Biofilm Contactor (RBC)

RBC model assumptions are the following: wastewater discharge is continuous, the even load of the reactor is assumed. The model approach does not take into account the fouling and fluid flow is idealised. The rotation speed and the related biofilm detachment are not built in the model. The model elements are the plates; within each plate, biofilm layers are defined. Each biofilm layer assumes completely mixed hydraulics; between the layers, diffusion is the dominant transport process.

Figure 3
Rotating Biofilm Contactor [3]

Three physical parameters as model inputs are needed: effective water volume, carrier volume and carrier specific surface area. From these parameters, the effective biofilm surface area is calculated. If this surface area is multiplied with biofilm width, the total active biomass amount could be determined.

Aerated biofilter

The simplified aerated biofilter model integrates the 1D biofilm model and permanent aeration model. The model uses horizontal biofilm layers and assumes a plug flow reactor model. Wastewater flows vertically from bottom to top through the biofilm layers and oxygen transport is calculated in each layer separately.

Figure 4
Aerated biofilter [4]

Actually, the process is batched due to backwash requirement, but in modelling the mass flows are continuous and the washed-out particles are taken into account as a point-like sink term. Solid capture expresses the retained particles in the model. There is a possibility to run time-dependent model with the actual phase cycle times, but it is worth starting with a simplified permanent model to get a picture of the processes.

Hybrid biofilm systems

Suspended and attached biomass is simultaneously present in hybrid systems. In modelling, the previously detailed ASM models are combined with the 1D biofilm model. Input parameters are the reactor volume, carrier fill and specific surface area of the carrier.

Figure 5
MBBR carriers [5]

Sub-models in wastewater treatment

Wastewater characterisation

Some fractions of the raw wastewater could be unknown; therefore, the model input cannot be set completely by solely on measurement data. In wastewater characterisation, the fractions are determined applying the measured composite parameters. Depending on the data available, the following wastewater characterisation models can be defined:

- BOD based
- COD based
- COD–TSS based

BOD based fractionation requires BOD_5, TKN and TSS values as input. From these, the readily biodegradable substrate, particulate substrate, inert particulate, free ammonia and ammonium nitrogen, soluble and particulate nitrogen are determined. BOD_5/BOD_∞ ratio is 0.66 by default, which comes from the stoichiometry. This model assumes that BOD_∞ equals to the total biodegradable COD. Soluble BOD_∞ can be measured by filtered sample and then the particulate fraction can also be calculated. By addition of each COD fraction, the total COD can be determined. It also needs to be noted that due the uncertainty and specialty of BOD measurement this approach is not widely used.

COD based fractionation requires total COD, TKN, TP and COD fraction ratios as input. With the help of COD fraction ratios and total COD, each concentration of the COD fraction can be calculated. COD fractions determine the biomass amount, the organic/inorganic ratio, particulate/soluble states ratio and with the help of these, the TSS can be gained. This model approach has less uncertainty over BOD based models, but it requires additional measurements on fraction ratios (e.g. COD measurement from filtered and homogeneous sample, NUR test for readily biodegradable COD etc.)

The advantage of COD–TSS based model is the simple determination of input parameters. For composite parameters, solely total COD and TSS shall be set and the usage of two following ratios is advisable: VSS–TSS ratio and particulate COD–VSS.

Aeration model

Aerobic biological processes require the presence of soluble oxygen. Open reactors could receive oxygen through diffusion from the air, but in large-scale municipal wastewater treatment systems, this is insufficient for biodegradation, thus an aeration system shall be installed. There are two types of aeration systems: 1. surface aerators; and 2. submerged systems. The latter one has advantage in aeration efficiency; therefore, these are applied widespread. Submerged systems could include diffusers, sparger turbines or jets.

Sizing of aeration devices requires the dynamic description of a two phase air-water system. At the initial stage, the oxygen demand of biomass should be determined, which can separate organic matter removal, nitrification and denitrification processes. Organic matter removal and nitrification consume oxygen, whereas denitrification provides chemically bound oxygen (sink term in oxygen concentration transport equation). If all theoretical demands are summed, field conditions, such as oxygen gas dissolution process to water phase shall be taken into account, which shows us the oxygen to be introduced into the system. The last step is to calculate the air quantity that contains the previously determined oxygen amount and with this number, the aeration device can be selected.

Theoretical oxygen demand can be calculated as follows:

$$OC = (f_c \cdot (OU_c - OU_d) + f_n \cdot OU_n)$$

where

OC: total theoretical oxygen demand [kg/d]

*OU*c: oxygen demand for organic matter removal [kg/d] = specific oxygen demand of organic matter multiplied by the removed BOD_5

*OU*d: oxygen from denitrification [kg/d] = 2.9x removed nitrate-nitrogen

*OU*n: oxygen for nitrification [kg/d] = 4.3x nitrified ammonium-nitrogen

f_c, f_n: safety factor, which is in function of SRT, population equivalent and load

The next step is to determine the oxygen amount that needs to be introduced into the system:

$$\text{AOTR} = \text{SOTR} * \beta * (C_s - C)/C_s * 1{,}024^{T-20} * \alpha * F$$

where

AOTR: actual oxygen transfer rate (theoretical oxygen demand) [kg/d]

SOTR: standard oxygen transfer rate (oxygen needed to be introduced into the system) [kg/d]

β: correction factor of salts, surfactants (saturation oxygen concentration ratio in wastewater and in water) = 0.95 [–]

C_s: saturation oxygen concentration at a given pressure and temperature [g/m^3]

C: dissolved oxygen concentration, which is equivalent with DO [g/m^3]

T: wastewater temperature [°C]

F: fouling factor of the diffuser related to diffuser material and clogging, for clean diffuser 0.9 [–]

α*:* correction factor for oxygen diffusion [–]

The correction factor for oxygen diffusion denotes the oxygen mass transfer ratio from gas phase to liquid phase in wastewater and in clean water. It can be stated that this is a transport between two phases from the oxygen side; therefore, the mass transport equation is the following:

$$\frac{\partial C}{\partial t} = \text{KLa} * (C_s - C) - r_m$$

where

KLa: oxygen diffusion coefficient [1/s]

r_m: oxygen consumed by the microorganisms in unit volume and time [g/(m^{3}s)]

Transport equation includes the oxygen from external source and the biological oxygen uptake. For the determination of the *KLa,* the oxygen uptake shall be neglected; therefore, in the laboratory experiment it is advisable to use clear water. This can be performed at the start-up of a wastewater treatment plant. As a first step, the dissolved oxygen shall be removed from the water filled basin by application of e.g. sodium-sulphite and then the oxygen dissolution curve shall be detected. *KLa* can be determined from the slope of the curve, where the axis (time and concentration) is in a logarithmic scale.

The previously calculated actual oxygen demand shall be modified with the air bubble retention time in the system. *SOTE* (Standard Oxygen Transfer Efficiency) reflects the oxygen dissolution in 1 meter. SOTE depends on the aeration system, generally 5–6% is applied, but latest researches revealed that it could be as high as 8–9%. This value has a dependence on the diffuser density as well.

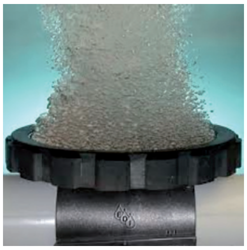

Figure 6
Disc diffuser [6]

In a flow through system, the transport equation shall be extended, the terms are to be multiplied with the reactor volume as follows:

$$V\frac{dC}{dt} = QC_{in} - QC + KLa(C_s - C)V + r_m V$$

where

V: reactor volume [m^3]

Q: wastewater discharge [m^3/d]

C_{in}*:* oxygen concentration in the influent wastewater [mg/l]

The saturation oxygen concentration depends on the wastewater temperature, the particulate matter, the surfactants, concentration of ions and air pressure. This can be formulated as follows:

$$C_s = \tau \cdot \beta \cdot \omega \cdot C_{s,20°C}$$

where

τ: correction factor for temperature [–]

β: correction factor of particulate matter, surfactants and ions [–] its value is approximately 0.95

ω: pressure correction factor, it can be calculated as follows:

$$\omega = \frac{P_b + p_d - p_v}{P_s + p_d - p_v}$$

where

P_b*:* barometric pressure [Pa]

p_d*:* effective pressure at diffuser depth [Pa] see calculation below

p_v*:* vapour pressure at wastewater temperature [Pa]

P_s*:* standard barometric pressure – 101 325 Pa

The following expression can be used for the determination of barometric pressure:

$$P_b = exp\left[\frac{-gMz}{RT}\right]P_s$$

where

g: gravitational acceleration, 9.81 m/s^2

M: molar weight of air, 29 g/mol

R: universal gas constant, 8.314 Nm/mol.K

T: air temperature [K]

z: altitude [m]

The effective pressure at the diffuser depth can be formulated as follows:

$$p_d = (\delta - 1) \cdot (P_s - p_v)$$

where

δ*:* depth correction factor for pressure fine bubble aeration

$$\delta = 1 + 0.03858 \cdot d$$

coarse bubble aeration

$$\delta = 0.99 + 0.0291 \cdot d$$

where *d* is the distance between the diffuser position and the water surface

Based on the previous formulae, the *OTR* (Oxygen Transfer Rate) and *SOTR* (Standard Oxygen Transfer Rate) can be calculated:

$$OTR = Kla_T(C_s - C)V$$
$$SOTR = Kla_{20}(C_{20})V$$

Model input for aeration is the volumetric air flow and the achievable DO concentration.

Clarifier model

The clarifier model is a type of the mass transport model, which is based on phase separation and describes the solid phase removal for liquid in gravitational field. The settleable matter can be discrete or group of flocs. The settling of discrete particles can be described by applying Stokes's law if the sedimentation is laminar. The settling velocity depends on the size of particulate matter, the viscosity and the density difference between the solid matter and the fluid. In case of hindered settling, the particles form groups of flocs and the settling velocity is defined for the entire aggregated flocs. This velocity has a function with the solid concentration.

Figure 7
Dorr type clarifier [7]

The homogeneous sample at the initial stage starts to thicken and this makes the phase separation process slower. In clarifiers, the influent flow also interacts with the settling making the process description even more complicated. This complex settling–thickening process can be handled at different levels. In the zero-dimensional models (point models), the incoming and outflowing masses are taken into account and settled solids, which are introduced in the sludge line, can be calculated.

If the settling zone is separated to some layers vertically, we can get the one-dimensional multilayer model. Within this layer, the components are completely stirred. Mass transport may present through the layers due to the concentration difference resulting diffusion, which is not present in real life. This false diffusion (numerical diffusion) may occur if a small amount of layers is applied. Increasing the number of layers, this numerical error can be minimised. Practically 7–11 layers could be enough.

Figure 8 shows the mass flows vertically. The incoming flow *(Q_f)* is separated into two lines: sludge flow *(Q_u)* and treated effluent flow *(Q_e)*. In this flow, the settleable solid concentrations are the following: X_f, X_u and X_e. Mass flux between the layers is denoted with *J*.

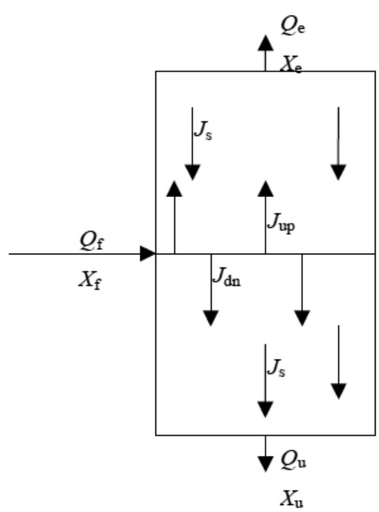

Figure 8
1D vertical multilayer model (compiled by the author)

Continuity (mass balance) for the entire system:

$$Q_f = Q_e + Q_u$$

Component equation can be gained by multiplying the flows with concentrations:

$$Q_f X_f = Q_e X_e + Q_u X_u$$

Mass flux between the layers:

$$J = J_{\mathrm{konv}} + J_s = \mathrm{vX} + v_s X$$

J is the total flux and it is the summation of the convective flux *(J_{conv})* and settling flux *(J)*. (Convective flux can be separated to an upflow and a downflow term. The v is the velocity of the flow, v_s is the settling velocity. The general form applying partial differential equation is the following:

$$-\frac{\partial X}{\partial t} = v\frac{\partial X}{\partial y} + \frac{\partial v_s X}{\partial y}$$

For the settling velocity exponential term

$$v_s = k\exp(-\mathrm{nx})$$

or raising to the power of n

$$v_s = \mathrm{kX}^n$$

can be applied, where k and n are settling parameters.

Imre Takács upgraded the previously applied one exponential (Vesilind) model to a two exponential model, incorporating the free and hindered settling. The following formula gives the settling velocity:

$$v_s = v_0\left[\exp(-r_h(x - x_0) - \exp(-r_p(x - x_0)\right]$$

where

- v_0: maximum settling velocity in a condition when the settling is free; no hindering effect occurs due to the other particles
- r_h: parameter for hindered settling
- r_p: settling parameter for low concentrations
- x_0: minimum concentration of settleable fraction

Model parameters are determined via laboratory or field measurements. Hamilton extended the above-mentioned scalar transport equation and a pseudo diffusion term was introduced, which is approximately D = 0.54 m^2/h.

$$-\frac{\partial X}{\partial t} = v\frac{\partial X}{\partial y} + \frac{\partial v_s X}{\partial y} - D\frac{\partial^2 X}{\partial y^2}$$

With the extension of the 1D settling model, multidimensional hydrodynamic model coupling with mass transport can be formed. It should be noted, however, that the applicability of such models is restricted by the computational cost.

The vertical velocity is now substituted by a two-velocity component field. The velocity values are calculated for each simulation point. With the extension of the turbulent fluid flow, the transport equations are the following:

Continuity

$$\rho\frac{\partial V_x}{\partial x}+\rho\frac{\partial V_y}{\partial y}+\frac{\rho V_y}{y}=0$$

Navier-Stokes (momentum) equation

$$\rho\frac{\partial V_y}{\partial t}+\rho\frac{\partial V_y^2}{\partial x}+\frac{\partial\left(V_xV_y\right)}{\partial x}=-\frac{\partial p}{\partial y}+\frac{1}{y}\frac{\partial}{\partial y}\left(2y\mu_t\frac{\partial V_x}{\partial y}\right)+\frac{\partial}{\partial x}\left[\mu_t\left(\frac{\partial V_x}{\partial y}+\frac{\partial V_y}{\partial x}\right)\right]-2\mu_t\frac{V_y}{y^2}$$

Turbulent kinetic energy

$$\rho\frac{\partial k}{\partial t}+\rho\frac{\partial V_xk}{\partial x}+\frac{\partial\left(V_yk\right)}{\partial y}=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x}\right]+\frac{1}{y}\frac{\partial}{\partial y}\left[y\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial y}\right]+G_k+G_b-\rho\varepsilon$$

Turbulent dissipation

$$\rho\frac{\partial\varepsilon}{\partial t}+\rho\frac{\partial V_x\varepsilon}{\partial x}+\frac{\partial\left(V_y\varepsilon\right)}{\partial y}$$
$$=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x}\right]+\frac{1}{y}\frac{\partial}{\partial y}\left[y\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial y}\right]+C_1\varepsilon\frac{\varepsilon}{k}\left(G_k-C_3\varepsilon G_b\right)-\rho C_2\varepsilon\frac{\varepsilon^2}{k}$$

Sludge mass transport

$$\rho\frac{\partial C}{\partial t}+\rho\frac{\partial(V_x+V_s)C}{\partial x}+\rho\frac{\partial\left(V_yC\right)}{\partial y}=\frac{\partial}{\partial x}\left(\frac{\mu_t}{\sigma_c}\frac{\partial C}{\partial x}\right)+\frac{1}{y}\frac{\partial}{\partial y}\left(y\frac{\mu_t}{\sigma_c}\frac{\partial C}{\partial y}\right)$$

The settling process is influenced by:

- inflow velocity magnitude
- inflow velocity fluctuation
- geometry of inlet section
- energy dissipation baffle walls
- time for settling
- outlet section

Reactor configurations are not built in (or only in a simplified way) in mass balance models. If the 1D settling model is applied, the settling parameters like SVI (Sludge Volume Index) is fed to the model. SVI or the Mohlmann index (ml/g) is the ratio of settled sludge volume and sludge concentration (SVI = SV30/MLSS). MLSS is the mixed liquor concentration, SVI30 is the volume of settled sludge after 30 minutes of sedimentation. SVI is the general way to describe the sludge settling and thickening behaviour. If SVI is below 100 ml/g the settling is good, if SVI is higher than 150 ml/g the settling is poor.

Controller model

The controller model defines the relation between the process variable and the achievable values (setpoint), e.g. DO = 2.0 mg/l in aerobic reactors. The basis of the control process is the difference between the setpoint and the measured value, which is the error. Disturbance is present in the control process, the setpoint shall be achieved even if there are any disturbances. If the setpoint and measured value are equal, there is no need for the controller to change the status. If the setpoint and measured value are different, the error signal is not zero, the controller shall generate a signal to interfere in the process. The error function is time-dependent [e(t)], and our aim is to minimise the error function in time. As a result of the control process, the system shall be stabilised; in other words, despite the fluctuation in the control parameter due to disturbance it should be relaxed in an equilibrium.

The controller shall consider various attributes of the process. P is the proportional, I is the integral and D is the derivative term. The relation between the control terms is described by the controller term coefficients. The controller terms in the control loop are parallel (see Figure 9).

P: proportional term, the control output is proportional to the control input over time

I: integral of error function, i.e. the residual errors are summed, it may show over prediction in the control output

D: derivative term, shows the changes of error function over time, it increases stability, but it may have a damping effect

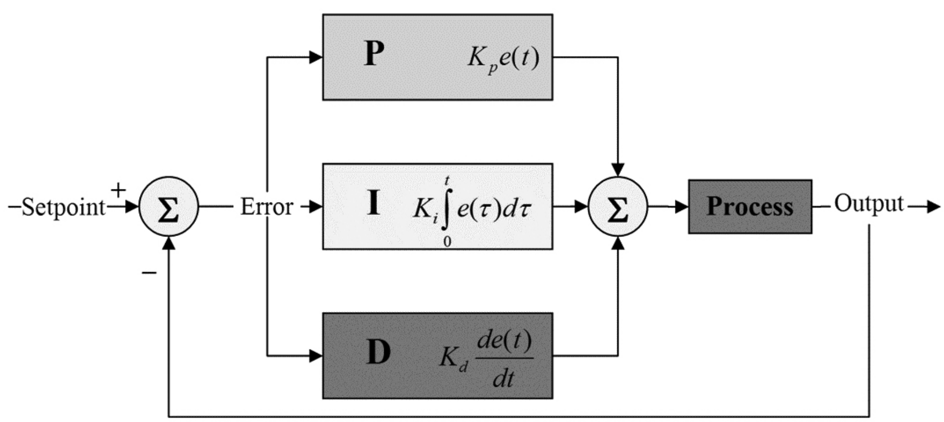

Figure 9
PID control loop [8]

Overall, the control output can be formed as follows:

$$K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

Control strategies in wastewater treatment can be classified as follows:

- direct control: the signal reaches the control loop directly
- on/off control: turning on and off could open and close the control loop directly
- cascade control

Cascade control shall be applied if – besides the process variable – another measurable variable exists, which follows the disturbances more rapidly than in the original process variable. This measured variable in the secondary loop filter the disturbance faster than it does in the primary loop.

Cascade control may be applied in the aeration control in biological wastewater treatment that uses the dissolved oxygen concentration as a process variable. DO value is transferred to the control loop and as a control output, the valve in the aeration system is opened and parallel a pressure transmitter transfers signal to the blower to increase its performance (see Figure 10). Higher order of controls also exists: for example, ammonium control calculates the actual oxygen demand based on the measured NH_4-N. Calibration of P, I, D control terms is basically based on measurements, but numerical modelling tools can support the calibration process as well.

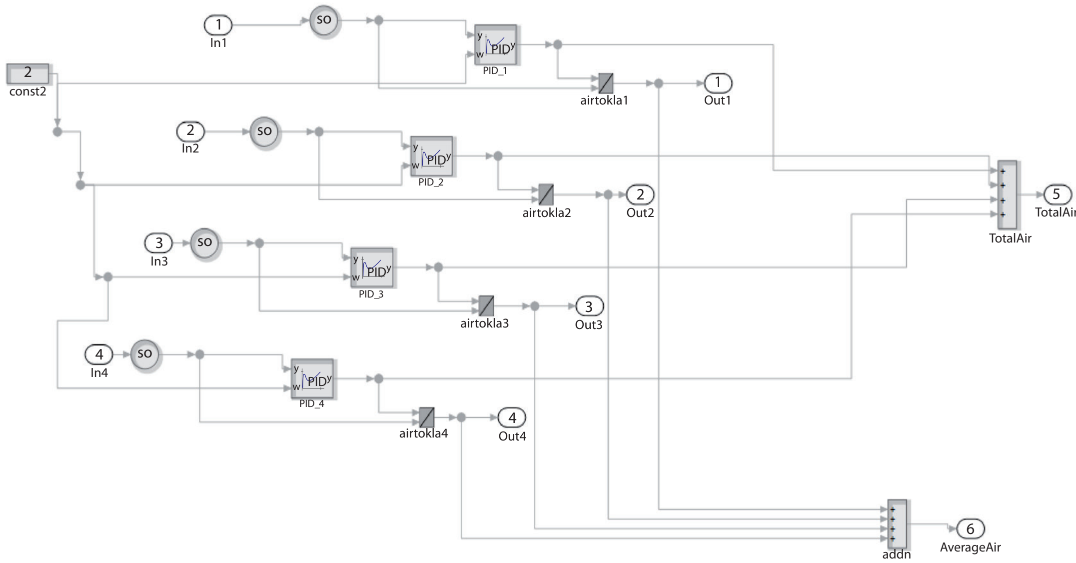

Figure 10
Aeration control loop (compiled by the author)

Reactor models

Ideal and real reactor models

Biological wastewater treatment could take place in concrete basins, or in ditches, natural lakebeds, but whatever the site is, these could be handled as a reactor and reactor models could describe the processes. The classification of reactor models is primarily based on the component distribution within the reactor and the size of the reactors are secondary. If there is no significant concentration difference within the reactor and the concentration varies only with time, the operation can be batch or continuous. One important property of this kind of a reactor is that the effluent concentration equals to the concentration within the reactor.

The reactor mode can be stationary or transient. In stationary reactors, the effluent concentration depends on the influent concentration, whereas in the transient mode not only the influent, but also the concentration inside the reactor matters. CSTR is a generally applied reactor type that is a Continuous Stirred Tank Reactor, the influent of which is continuous. In PFRs (Plug Flow Reactor), there is a spatial variance in concentration distribution, its mode could be stationary or transient, but as for operation, there is no batch type PFR.

Despite the fact that PFRs have good performance in conversion or biological degradation, they are not widely used in wastewater applications. CSTRs have better mixing properties, thus the influent concentration drops rapidly when it enters the reactor; therefore, the biomass shall not suffer from high load of pollutants and has a less inhibition effect of the process (e.g. heavy metals for nitrification, pH, VFAs).

These reactor types (PFR and CSTR) are idealised regarding the concentration profile. Actually, the completely stirred tank reactor and plug flow reactor without longitudinal dispersion do not exist, the actual condition is somewhere between the two endpoints. It is indispensable to determine the actual reactor model for the estimation of the wastewater treatment performance. Non-ideal reactors can be developed from ideal reactors by introducing one variable (cascade model and dispersion model), two variables (by connecting the ideal reactors) or without using any variables (segregation model, maximum mixedness model). There are two ways to develop a non-ideal reactor model using one variable:

– introducing the dispersion coefficient in PFR; if this coefficient is zero, ideal plug flow can get back, if the dispersion is infinite, CSTR can be formulated
– putting CSTRs in series; ideal CSTR is a one element cascade; if the reactor number tends to infinity, PFR can be gained

It can be seen that two scales can be introduced. One scale depends on the dispersion coefficient, the other uses the number of elements in a CSTR cascade. The two scales are interconnected; therefore, one variable could be useful, which describes the two approaches. For this purpose, the convective and diffusive transport ratio (Peclet number) can be introduced.

$$Pe = \frac{u \cdot L}{D_x} = \text{convective/conductive transport}$$

where

Pe: Peclet number [–]
u: characteristic velocity [m/s], which may be the average velocity within the tank
L: characteristic length [m], which may be a dimension of the tank (regularly the height)
D_x: longitudinal dispersion coefficient [m^2/s]

Pe number in wastewater treatment is between 1 and 50, in case of CSTR $Pe < 0.5$.

The plug flow condition can be present in biofilm systems easily and in this case, the dispersion model is a good choice. Based on operational variables, an optimal Peclet number can be determined, where high biodegradation is expected. The optimal Peclet number changes with the biofilm detachment rate.

It is worth to examine the general transport equation and reformulate it in a dimensionless form:

$$\frac{\partial c}{\partial t} + \underline{u}\nabla c = \mathrm{D}\nabla^2 c + \lambda c$$

where the first term is the concentration changes in time, the second term is the convection (mass transport induced by the flow field). On the right side of the equation are the diffusion term and the first order kinetic term.

The dimensionless form of the transport equation requires the introduction of dimensionless concentration, time and velocity. It should be noted that operator nabla also introduces a division by length scale; * refers to the dimensionless variable.

$$c^* = \frac{c}{S^c}, \qquad t^* = \frac{t}{S_t}, \qquad \underline{u}^* = \frac{\underline{u}}{S_{\underline{u}}}, \qquad \nabla() = \frac{1}{S_L}\nabla^*$$

By substituting the dimensionless variables:

$$\frac{\partial(c^* \cdot S_c)}{\partial(t^* \cdot S_t)} + \left(\underline{u}^* \cdot S_{\underline{u}} \cdot \frac{1}{S_L}\nabla^*\right) c^* \cdot S_c = D \cdot \frac{1}{S_L^2}\nabla^{*2}(c^* \cdot S_c) + \lambda \cdot c^* \cdot S_c$$

Reordering the variables and constants:

$$\frac{S_c}{S_t} \cdot \frac{\partial c^*}{\partial t^*} + \frac{S_{\underline{u}} S_c}{S_L} \cdot \left(\underline{u}^* \cdot \nabla^*\right) c^* \cdot = D \cdot \frac{S_c}{S_L^2}\nabla^{*2} c^* + \lambda \cdot c^* \cdot S_c$$

By introducing the characteristic time, velocity and length:

$$S_t = \bar{t}, \quad S_{\underline{u}} = \underline{v}, \quad S_L = L$$

dimensionless transport equation can be gained, where the diffusion term includes the reciprocal value of the Peclet number. Since the convective term includes the value of 1, the ratio of convection and diffusion is the Peclet number:

$$1 \cdot \frac{\partial c^*}{\partial t^*} + 1 \cdot \left(\underline{u}^* \cdot \nabla^*\right) c^* \cdot = \frac{D}{\underline{v} \cdot L}\nabla^{*2} c^* + \lambda \cdot \bar{t} \cdot c^*$$

The Pe number is basically influenced by the flow; therefore, it is necessary to know the hydrodynamic conditions of the given reactor and to calculate the convection/diffusion ratio. The determination of this ratio is easily accomplished by a tracer experiment: a tracer is introduced to the liquid stream entering the reactor, and the concentration of the tracer is measured in the effluent (or any other reactor point). The requirement for the tracer is to follow the wastewater flow, not to settle or tend to float, preferably to be conservative, i.e. no chemical reaction. Its concentration in the wastewater should not be comparable to the background concentration (or have information on the background concentration distribution), it should be easily accessible and should not be harmful to the environment. Dosing can be instantaneous or continuous.

If the measurement results of the tracer experiments are plotted against time, a residence time distribution is obtained. It is advisable to normalise the measured tracer concentration with the total amount of tracer introduced into the system to obtain the function of E(t), which reflects the residence time distribution (RTD: Residence Time Distribution) of the tracer. It is easy to read from the curve that there is a short-circuit and/or dead zone in the system. The hydraulic short-circuit refers to the early appearance of the tracer, and the dead zone is characterised by the trapping of the tracer and is then slowly discharged by turbulent diffusion transport, i.e. the tracer can be measured even after a long time. Figure 11 shows an example of an RTD curve.

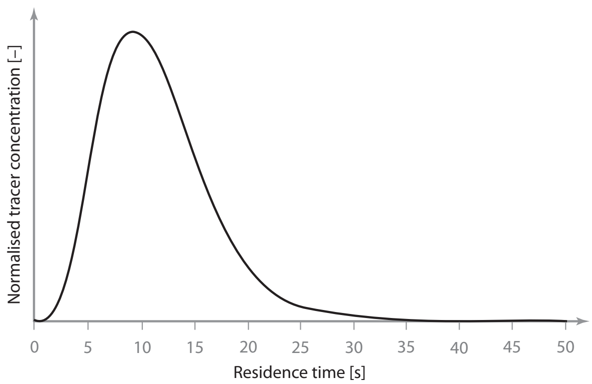

Figure 11
RTD curve (compiled by the author)

The tracer distribution function returned as a result of the RTD analysis – F(t) – can be written as follows by introducing the dimensionless time (Θ), which is defined as the ratio of the elapsed time to the average residence time *(t/t_m)*.

$$F(\theta) = \frac{1}{2}\left[1 - erf\left(\frac{1}{2}\sqrt{Pe}\frac{1-\theta}{\sqrt{\theta}}\right)\right]$$

from this you can obtain the density function, which takes the following form:

$$E(\theta) = \frac{1}{4\sqrt{\pi\,\theta^3/Pe}}exp\left[\frac{-(1-\theta)^2}{4\,\theta/Pe}\right]$$

of which the second-order moment gives the variance of the dimensionless residence time:

$$\sigma_\theta^2 = \frac{\sigma^2}{t_m^2} = \frac{2}{Pe} - 2\left(\frac{1}{Pe}\right)^2(1 - e^{-Pe})$$

By performing the tracer experiment, we get the RTD curve from which the Peclet number can be determined by statistical tools. If a tank-in-series reactor model is applied, the number of *n* elements can be calculated as follows:

$$n = \frac{1}{\sigma_\theta^2} = \frac{t_m^2}{\sigma^2}$$

from which it follows that, as an approximation, the cascade number is equal to *Pe*/2.

As we have seen, the distribution of the residence time does not determine the biological conversion and thus the effluent concentration, but it can be used to determine a parameter of the real reactor models.

If a tracer study is performed in an existing system, the number of elements of the CSTR cascade is determined, then the result is not necessarily the actual reactor number. As a consequence, the reactor number thus obtained is referred to as the virtual reactor number. Mass balance models in wastewater treatment also shall be fed with this virtual reactor number to provide the actual kinetic process description. In other words, a process engineer who uses the real reactor number in mass balance modelling does not acknowledge the real hydrodynamic conditions, and will idealise the fluid flow, and does not determine the actual reactor size, air and chemical requirements, or sludge yield. It follows that the sizing process must include the virtual reactor elements (these elements can also be referred to as mixing zones). However, experimental tracer tests have several difficulties. It is impossible to perform this test without an existing system. For this case, or for existing systems, numerical analysis could be cost and time effective, if a reliably convergent approximation could be reached at the given hydraulic parameters.

With the help of numerical fluid dynamic simulations (CFD: Computational Fluid Dynamics), the fluid flow of the reactors can be determined by knowing the initial and boundary conditions, the tracer can be introduced into the given velocity field and the RTD analysis can be carried out. Numerical fluid flow simulations solve a partial differential equation system describing fluid movement, including mass balance and momentum equations. In case of turbulent flow, it is necessary to calculate the virtual stress, for which a turbulence model can be used. Among the many turbulence models, the most widespread are the k-ε model assumed isotropic turbulence, or the RSM (Reynolds Stress Model), which applies turbulent stress tensor.

The analytical solution of the partial differential equation system is not possible in case of complex geometries; therefore, numerical method is applied. Finite volume method divides the given reactor volume into finite number of volume elements and solves the equations for each element starting from the boundary and initial conditions. Communication between the cells is possible through the cell interface.

The values of the variables are stored in the centre of the cells, which must be projected onto the boundary of the cell, i.e. interpolated. The result of the calculation depends largely on the numerical scheme used and the resolution that must be independent of the calculation. Because of the number of mesh elements and the magnitude of the numerical capacity, it is mostly an iterative, i.e. step-by-step approach, which must be continued until the solution converges. If a solution converges, the difference between the actual and calculated value is within a range. In this case, the convergence of the calculation can be accepted based on the unchanged iteration residuals or any other variables (e.g. velocity field).

When describing the fluid flow of reactors used in wastewater treatment, the movement of the liquid phase is also influenced by the movement of gas bubbles introduced into the water during aeration. To describe this process, the user could choose among the several multiphase models. The so-called mixture model solves the momentum equations for the primary phase, and a scalar transport equation for the secondary phase, which specifies the volume ratio of the primary phase to the secondary phase for each cell. The primary phase is called the phase that is present in the system at a significantly higher mass. The mixture model may be used if the weight ratio of the secondary phase is less than 10% of the primary phase. If this is not the case, then with the Euler–Euler model, the dynamic equations must also be solved for the secondary phase.

We can apply a multiphase modelling approach even if we only have one component and one phase, but we want to handle and label a part of this flow. This may be necessary for tracer experiments, since the tracer must follow the main flow; it must be the same as all its properties. First, it is worthwhile to run the calculation only for the water phase, and then, at a given time, the tracer is introduced into the system. Then, in the same way as in the physical experiments, the effluent (or any other internal point) concentration is detected and the RTD curve is determined.

However, with this model approach, we may find it difficult to compute, as the tracer will be diluted to a small concentration that can lead to rounding errors. In order to eliminate this, in the model it is advisable to add the tracer from a certain time to the influent, so that the original water phase can no longer be present at the inflow. Influent boundary conditions are determined as follows:

$$0 < t < t0, \text{ Q(water)} = \text{wastewater discharge, Q(tracer)} = 0$$

$$t0 < t, \text{ Q(water)} = 0, \text{ Q(tracer)} = \text{wastewater discharge}$$

In this case, the phase ratio of the tracer at the exit point can be increased from 0 to 1 as a function of time. Distribution function of the RTD analysis is given by deriving E(t).

The mass balance and hydrodynamic coupled model can be set up in two ways as discussed above. On the one hand, in the hydrodynamic simulation environment, the range of equations to be solved can be extended with transport models describing the flow. Furthermore, in the mass balance simulation environment, the reactor model can be developed. The method outlined in this chapter is the latter one, the model development involves examining the circumstances that may affect the reactor model. The basin geometry, the discharge, the mixing energy from an external source can influence the current flow field, in which the role of recirculation, aeration and cascading are examined in detail.

The effect of recirculation on the reactor model

There are several types of recirculation streams in wastewater treatment technologies that vary in size and role. The mandatory part of the activated sludge technology is the aerated basin followed by phase separation, where the settled biomass is recycled back to the former basin, resulting in an increase in the sludge retention time (SRT). The primary role of sludge recycling is to maintain the 3–6 g/l biomass concentration in the aeration basin.

The MLE (Modified Ludzack-Ettinger) reactor arrangement uses a pre-denitrification zone in which the anoxic reactor is followed by aerobic (oxic) zone. Nitrification takes place in the aerobic reactor, the final product of nitrate is returned to the anoxic zone by means of recirculation. Thus, nitrate, as an electron acceptor, enters into a zone where the readily biodegradable organic matter, which is essential for heterotrophic microorganisms, is available.

Nitrate recirculation or in other words, the internal recirculation, is generally 1.5–2.5 times the raw wastewater discharge, but it can even reach 4–5 times higher flow in some cases. The actual recirculated water flow is determined empirically. Based on empirical design considerations, it is not advisable to further increase the internal recirculation rate if the NO_3-N concentration is higher than 2 mg/l at the end of the anoxic reactor zone. Conversely, if the NO_3-N concentration is too low, then the given anoxic space will still be able to further denitrify, so it is worth increasing the internal recirculation.

More complex reactor arrangements can also be developed if we want to combine the biological nitrogen removal with biological excess phosphorus removal. Such a method is, for example, the UCT (University of Capetown) process, where the previously described MLE system is expanded with anaerobic volume used as the first reactor. The reactor sequence is then anaerobic, anoxic, aerobic. Recirculation and their roles:

- sludge recycling from secondary clarifier to anoxic volume – return of biomass
- nitrate recirculation from aerobic to anoxic – returning nitrate to denitrifying microorganisms
- recirculation from anoxic to anaerobic zone – return of biomass

Separation of biomass is important as sludge recirculation cannot directly deliver nitrate to the anaerobic compartment, because there is chemically bounded nitrogen in it. The UCT process assumes perfectly mixed reactors, which means that the nitrate concentration entering the anoxic zone suddenly dilutes, and taking into account the ability of the denitrifier conversion capacity, the effluent nitrate concentration shall be close to zero. If it does not work appropriately, it would inhibit the excess biological phosphorus removal.

It has been mentioned previously that in order to achieve better conversion or degradation, the plug flow reactor should be approached. If the given anoxic volume is divided into two parts, the recirculation from the second reactor with a gradual nitrate concentration profile will probably contain a smaller amount of nitrate-nitrogen. From this idea, the modified UCT procedure has been developed (Figure 12).

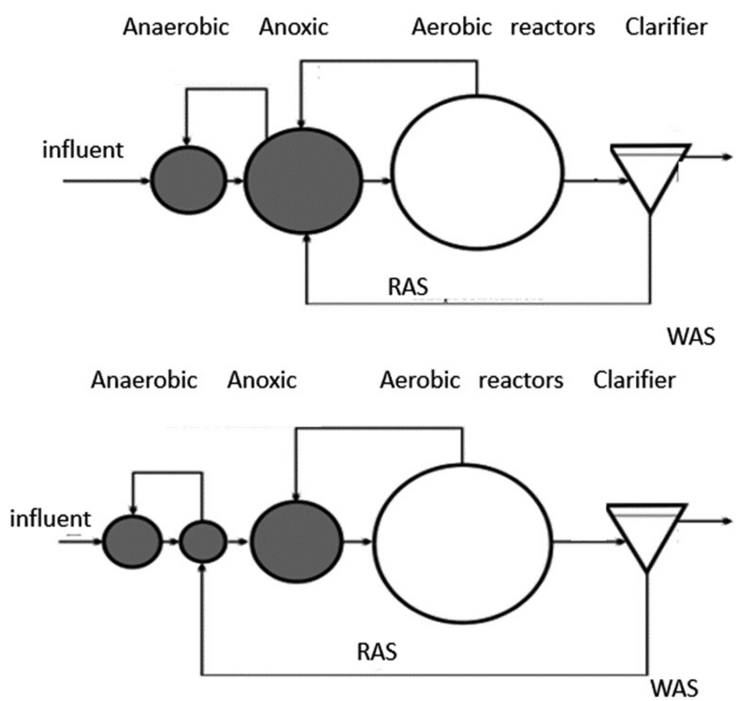

Figure 12
UCT and modified UCT process (compiled by the author)

If the concentration profile of the tank-in-series cascaded reactor should be described, then the concentration inside the tank and effluent concentrations can be calculated by the following formula:

$$C_n = \frac{C_0}{[1 + (k/n \cdot \tau)]^n}$$

where

C_n: concentration in the n -th reactor [g/m^3]

C_0: influent concentration [g/m^3]

k: kinetic constant [1/s]

n: number of reactors [–]

τ*:* residence time (V/Q) [s]

The formula of residence time has to be upgraded by the increased water flow due to recirculation(s):

$$\tau = \frac{\tau_0}{1 + R}$$

where

R: recirculation ratio [–]

The recirculation ratio expresses how many times higher the flow due to nitrate and sludge recirculation compared to the raw influent wastewater flows. With the introduction of recirculation, the fluid exits faster from the basin since the velocities increase significantly in the tank. The concentration profile also changes, the shorter residence time calculated by the above formula results in a higher effluent concentration. However, these assumptions significantly simplify the kinetics of the biological processes.

GPS-X 6.5 is a simulation environment developed by the Hydromantis mass balance modelling and is applied to determine how the reactor model is affected by recirculation. For demonstration purposes, an existing plant in Hungary with MLE process was investigated.

The effect of aeration on the reactor model

Biological wastewater treatment is mostly carried out by aerobic microorganisms, whose living conditions require the presence of dissolved oxygen. Oxygen can naturally be dissolved in the water following the Henry-theorem, but the biomass used in intensive technologies consumes oxygen much faster than the oxygen dissolution. Furthermore, the dissolved oxygen concentration must be maintained at least at 1.8 to 2.0 mg/l to diffuse the oxygen into the activated sludge flocs (or in case of biofilm systems diffuse to the inner biofilm layers). For this purpose, oxygen is supplied to the water phase by using external energy, which ultimately results in better mixing by the bubbles introduced. Since the basis of the reactor models is hydrodynamics and the aeration rearranges the energetic conditions of the fluid, its effect can be significant. In the following, the aeration requirement is discussed from the design point of view, then the flow generated by the air is examined, and finally the effect of this altered flow field on the reactor model is analysed.

The aeration systems used in wastewater treatment can be divided into two tiers, surface (vertical and horizontal) and subsurface aeration. Aeration systems are expected to have the most efficient oxygen transport, which is measured by the energy delivered projected to one kg of oxygen introduced to the system. Based on the result, the surface aerators are not widely used in everyday practice any more, subsurface aeration (diffusers) are more common. The diffusers are located close to the bottom of the basin, and these can be plate, tube or disc diffusers. Generally, better oxygen diffusion efficiency is achievable in deep basins, but for construction and operational considerations, there is a limit for a depth of about 5 m.

Aeration has effect on the flow field in the reactor, generating vertical flow in a basically horizontal through flow basin and it helps in mixing. Generally, the diffuser distribution is uneven in the basin, the upward and downward circulating zones are separated. The performance of a given reactor depends to a large extent on the fluid flow that depends on the diffuser distribution.

However, it follows that the design basically determines what the plant will probably perform later, during the operation. Operation could have effect via process parameters, but the hydrodynamic conditions rely merely on the pre-defined design parameters. From this point of view, it is crucial to know the fluid flow in detail in the design phase, but this is often neglected in practice. However, the system is complex at such a level that each individual basin should be subjected to undergo hydrodynamic analysis separately.

Physical testing is not possible before the construction of the basin; therefore, CFD analysis should be performed, even if there are guidelines for diffuser distribution pattern to use. The hydrodynamic calculations should incorporate RTD analysis, since the aeration has also effect on the RTD curve. Aeration primarily increases turbulent diffusion, but convective transport also cannot be neglected. From the point of view of reactor models, all these statements mean that, for example, if the reactor is a plug flow type with high Pe number, the Peclet number starts to decrease as the diffusion increases.

The above-described process primarily analysed the macro-effect of the aeration, which can help in particular with the biofilm systems applying fixed film. Since the biofilm is attached to a carrier, the flow plays a role in delivering the substrate to the biofilm surface and removes the end products from the biofilm surface. Organic load on the biofilm attached to a carrier differs at each location within the basin; therefore, various microbial compositions of biofilm can be observed at the beginning and end of the reactor: first we encounter heterotrophic organisms, while samples taken from the end of the basin show the autotrophic dominance responsible for nitrification. In fixed film systems, the placement of mechanical mixers is difficult; therefore, aeration is primarily responsible for mixing. It is sometimes necessary to use aeration in the anoxic reactor, preferably with a coarse bubble size and with intermittent operation. In the latter case, efficient mixing is achieved at conditions where the oxygen dissolution is the lowest.

From the point of view of reactor models, the macro description is sufficient, but it is worth examining the micro-level analysis of the liquid-air multiphase flow. The model should describe the evolution of the initial bubble diameter (adhesion to other bubbles), the break-up of the bubble, and the momentum transfer between the gas and fluid. To solve the complex problem, an anisotropic turbulence model of multiphase flows, large eddy simulation, or direct numerical simulation can be used.

Bubble dynamics is primarily determined by rising velocity, but it is also influenced by the horizontal flow of wastewater. As the bubbles are rising, the drag force has a downward position; the magnitude of the force depends on the shape and velocity of the bubbles. Behind the bubble, there may be a dead zone (with a function of the Reynolds number) and the swirls from the bubble surface can deflect the vertical motion. Therefore, transient phenomena can be observed with constant background flow and constant airflow rate, as the “bubble plume” develops. The plume is expanding towards the water surface. When placing the diffusers, attention should be paid to the development of the quasi-free flow, i.e. the development of the air-driven flow giving the appropriate space for the flow zone. If there is no free flow, so-called airlift reactors can also be created as alternatives to pneumatic loop reactors. The zones with different densities are used to create upward and downward zones. The microbubbles are injected into the reactor with a 10–100 Reynolds number, the liquid oscillation helps to prevent the bubbles from becoming larger, thus providing a longer residence time and a larger contact area, resulting in the circulation zone being multiple times the reactor depth.

Sludge reduction by cascading the reactors

So far, we have seen the effect of reactor volumes (reactor geometry) and aeration on the fluid flow, which are two output design parameters out of three. However, the third design parameter, the amount of sludge production, is a consequence of reactor designs, i.e. it does not affect the reactor model, but contrary, it is a result. Further on, the effect of different reactor models on sludge yield is analysed.

The sludge yield shows the amount of solids generated in the wastewater treatment plant in one day. This amount should be wasted every day to keep the biomass in balance during biological cleaning. However, it follows that × kg/d dry matter (TS: Total Solid) appears on the sludge line to be treated. In addition to the total dry solid, sludge contains a significant amount of sludge, many of which can be removed mechanically or by chemical dosing during thickening and dewatering. However, these methods focus on reducing the sludge volume and not on reducing the solids content. Sludge is wasted from primary clarifiers, in biological treatment (wasted activated sludge or detached biofilm) or from chemical P precipitation.

Specific sludge yield can be introduced which compares the amount of sludge generated to an input quantity, such as BOD_5 or COD. There is no consensus of what rate should be used; therefore, it is possible to use the TSS/COD, TSS/BOD_5, VSS/BOD_5 ratios, each of course having different values. This specific quantity depends on the sludge age (SRT) significantly; the higher the SRT, the lower the sludge yield. However, the total oxidation of sludge requires not only a large reactor size, but also consumes more oxygen.

Reducing sludge yields can be done at aerobic or anaerobic environment, but where it is possible, anaerobic solutions are preferred, since energy recovery can be achieved. Anaerobic treatment, which is often connected with pre-treatment, is only possible at high capacity plants. In smaller municipalities, however, the reduction of sludge yield is a fundamental interest. One type of solution is based on accelerating the reuse of cellular material after cell death, i.e. cell lysis is promoted by external intervention. The released substances can form new cells that are involved in biological processes. This type of reproduction is also called cryptic growth. Cell lysis can be done mechanically by using ultrasonic or hydrodynamic cavitation or other shearing technologies or with chemicals (chlorination, ozone) or heat treatment.

Another option to reduce sludge yield is to maximise the energy required for maintenance processes. Part of the energy of the microorganisms is focused on maintenance, which includes the renewal, maintenance of the cellular material, the transport of the nutrient through the cell membrane, and the other part of the energy creates new cellular material. The aim is not to make the latter significant, that is to say, should not have high microorganism growth and high sludge mass. Maximising maintenance energy in municipal wastewater treatment can be achieved through low nutrient supply, chemicals, or changes in the oxic/anoxic environment.

One such method is the OSA procedure, which refers to the alteration of the oxic-sedimentation-anaerobic processes. The settled sludge is "starved" in the anaerobic basin on the side of the sludge recirculation, and when returned to oxic conditions, the substrate obtained is primarily used for rebuilding itself and not for reproduction. However, if the anaerobic basin is designed for the entire recirculated sludge stream, then an unnecessarily large volume is obtained. Experiments have shown that it is sufficient to separate some of the recycled sludge and lead it to a separate reactor where aeration is controlled, with very low dissolved oxygen concentration. After the "shock", the sludge is directed back to the aeration pool.

Primarily due to the high sludge age and the localisation of biomass in biofilm systems, it may happen that higher order organisms live with predation by lower order organisms, which also results in sludge reduction. However, it also appears that the plug flow reactor or cascaded reactor favours the reduction of the sludge yield of the waterline, which can be attributed to protozoa and flagellant organisms as higher order organisms. For their development the following conditions should be fulfilled, DO = 1–3 mg/l, TKN < 30 mg/l, BOD_5 < 530 mg/l, which occurs at the end of the biological basin. The development of the food chain is also advantageous to us, because the nutrient conversion of the superior bodies is weaker and the energy loss is higher. In addition, metazoids reduce the turbidity of water by consuming freely floating bacteria. According to literature, sludge production can be reduced by up to 20–40%, but two-stage cleaning is recommended in an activated sludge system.

Mass balance modelling for individual wastewater treatment unit

Raw influent characterisation, model setup

The GPS-X 6.5 simulation system was used to perform analysis in a certain small wastewater treatment unit. The purpose of the modelling was to determine the actual capacity. The treated wastewater quality can be calculated by setting the raw wastewater quality and the small equipment parameters in the mass balance model.

The test system was a small treatment unit of the Polydox 50 type discussed in detail in *Annex: Examples for Individual Wastewater Treatment Units,* the capacity of which was provided by the manufacturer in 50 population equivalents and 6.0 m^3/d of wastewater. The unit has a volume of 8.4 m^3, from this 70% is aerated and the rest is for clarification and sludge thickening.

In terms of inlet, two types of wastewater were tested according to the water consumption and the associated daily wastewater discharge. On this basis, we distinguish Central European average wastewater and concentrated wastewater. In terms of organic matter, COD varies between 750–1200 mg/l, BOD_5 between 300–650 mg/l, TKN and TP are relatively high compared to other countries.

Table 8
Raw influent characteristic (compiled by the author)

mg/l	average wastewater	concentrated wastewater
COD	750	1,200
BOD_5	310	650
TSS	400	800
TKN	80	100
TP	12	18

In the absence of field data, the following COD fractions were determined in the COD–TSS-based fractionation in the average influent:

- soluble inert COD: 16 mg/l
- readily biodegradable COD: 62 mg/l
- particulate inert COD: 270 mg/l
- slowly biodegradable COD: 402 mg/l
- substrate fraction of the particulate COD: 0.6 mg/l
- organic content of the total suspended solids: 0.8 mg/l

In case of concentrated wastewater, the COD fractions were as follows:

- soluble inert COD: 24 mg/l
- readily biodegradable COD: 96 mg/l
- particulate inert COD: 194 mg/l
- slowly biodegradable COD: 886 mg/l
- substrate fraction of the particulate COD: 0.82 mg/l
- organic content of the total suspended solids: 0.75 mg/l

Simulations performed and results

The model layout is shown in Figure 13, where it can be seen that in addition to the incoming raw wastewater, other wastewater sources can be specified (septage: municipal liquid waste). The wastewater is transported to a buffer tank with a function of equalisation. Thereafter, the biological processes occur, which is aerated. In the model, it is also possible to add external carbon source and/or chemical. The aerated basin is followed by a clarifier where most of the biomass is retained and returned to the system after thickening. The thickening/dewatering combined unit has been set to about 5% solid capture. Treated wastewater flows to a storage tank at the end of the process. The model does not take this further into account.

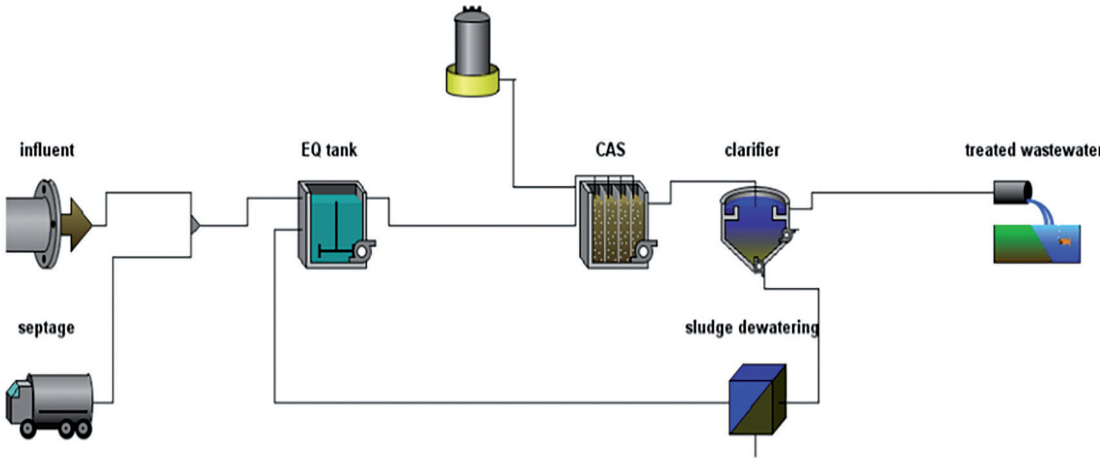

Figure 13
Conventional activated sludge GPS-X 6.5 model layout (compiled by the author)

Steady-state model runs were performed. In the first step, the nominal load of 6.0 m^3/d was taken into account. The dissolved oxygen concentration was 2.0 mg/l in the aerated basin. The sludge production was 1.35 kgTS/d and the dry solid content was 0.78%. The amount of thickened and dewatered sludge is 6.4 l/d. Quality of effluent:

– COD: 50 mg/l
– TSS: 24 mg/l
– NH_4-N: 25 mg/l
– TN: 27 mg/l

This shows partial nitrification; nutrient removal does not happen if the nominal capacity is taken into account. In the next step, nitrification efficiency was determined in function of the amount of influent flow. This could be done in several steps, iteratively, with the trial and error method. As a result of the runs, the wastewater systems could treat approximately 50% of the incoming flow based on the average Central European wastewater quality. If concentrated wastewater quality was considered, it is an additional 20% capacity reduction. In this latter case, it is recommended to increase the operating parameters, i.e. DO = 2.0 mg/l to increase to DO = 3.0 mg/l to avoid capacity loss.

Simulations revealed that despite the steady-state incoming load, there are variations in the effluent in the first few days. The reason for this is that initially there was no biomass in the system and it had to be built. While the biomass was built up, biodegradation was limited. For this, as can be seen from the following series of figures, it took about 10–12 days. Figure 14 shows the TSS and its organic content, the VSS. About 60 mg/l of suspended solids remained in the biologically treated wastewater (without sedimentation). After sedimentation, it decreased further to 5–10 mg/l.

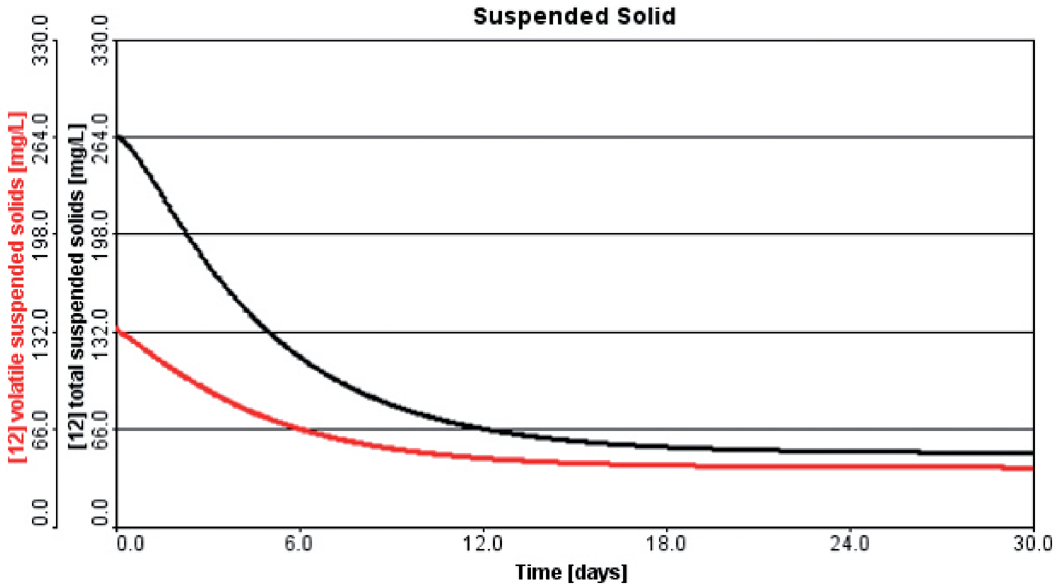

Figure 14

Treated effluent TSS and VSS (compiled by the author)

With respect to organic matter, the effluent COD concentration was 68 mg/l, which is more than 90% treatment efficiency. BOD_5 decreased to 20 mg/l.

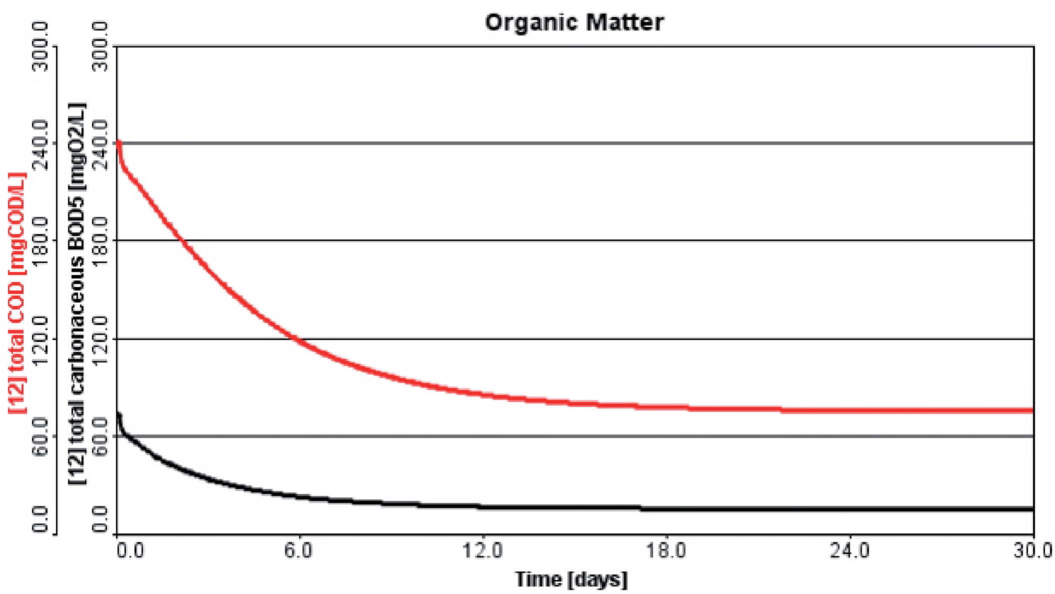

Figure 15

Treated effluent COD and BOD_5 (compiled by the author)

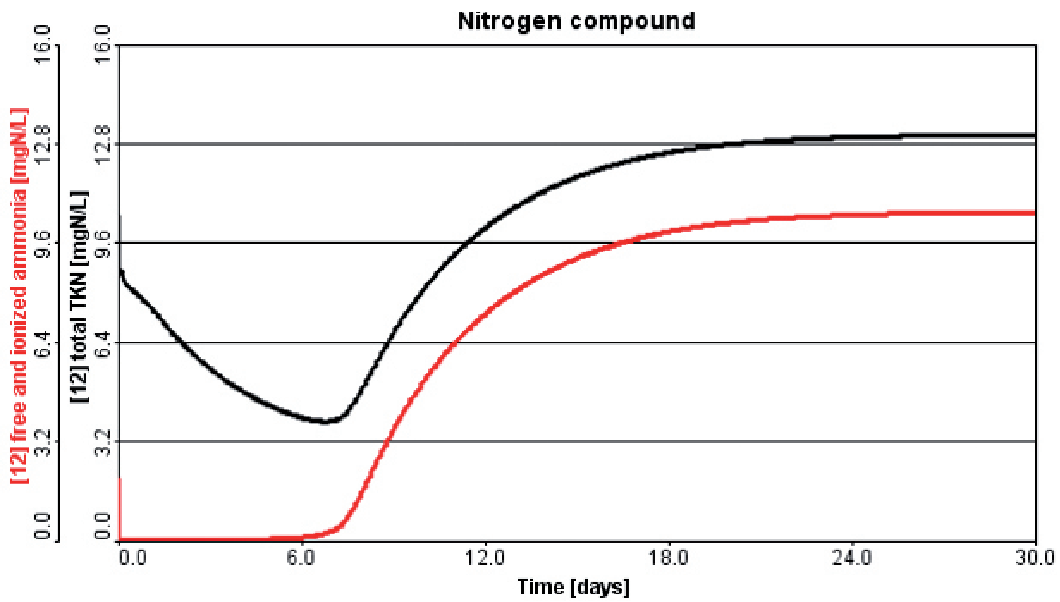

Figure 16
Treated effluent nitrogen compounds (compiled by the author)

Effluent nitrogen concentrations stabilised after 15–18 days. Organic nitrogen is about 3 mg/l and ammonium-nitrogen is about 9 mg/l. With aeration control, further fine tuning is possible.

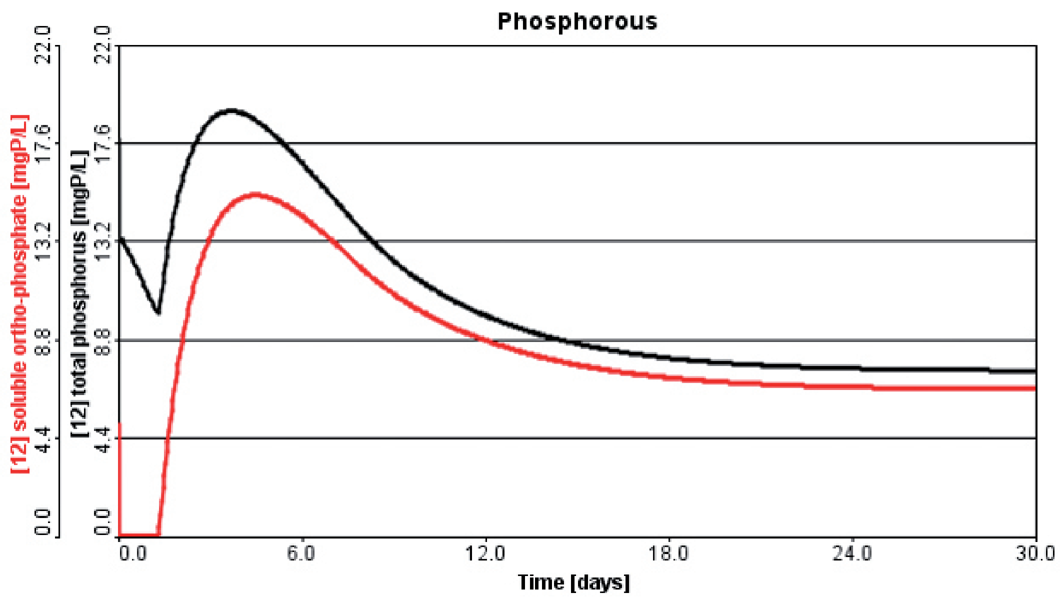

Figure 17
Effluent phosphorus concentration (compiled by the author)

For phosphorous forms, the ratio of orthophosphate/total phosphorus in treated wastewater is high. We could remove as much phosphorus as the biomass would take. It follows that if a higher degree of nutrient removal is desired, chemical precipitation is essential.

SBR system

With batch reactors, high treatment efficiency can also be achieved. The essence of the technology is that instead of spatial separation of the reactor zones, time cycles are applied and the entire treatment process takes place in one basin. This means that cycles that are usually 6–8 hours long can be divided into the following processes:

- feed
- biological processes (mixing and aeration or mixing without aeration)
- sedimentation
- decanting

The steps and cycle times should be designed in such a way that an entire number of cycles take place in one day. The general rule of thumb is that the feed is approximately half an hour, the settling is 1.2–1.5 h, decanting is minimum half an hour. The rest of the time has been developed for biological processes. The mixing and aeration time creates aerobic conditions, the mixing but non-aerating part is anoxic. Separation of individual processes is not necessary. Decantation can also occur simultaneously with the sedimentation supposing the exact knowledge on sludge blanket level changes in the basin.

The design of SBR plants is usually done by the analogy method: the conventional activated sludge technology is scaled and these reactor volumes and ratios are changed over time (using the hydraulic residence time $t = V/Q$).

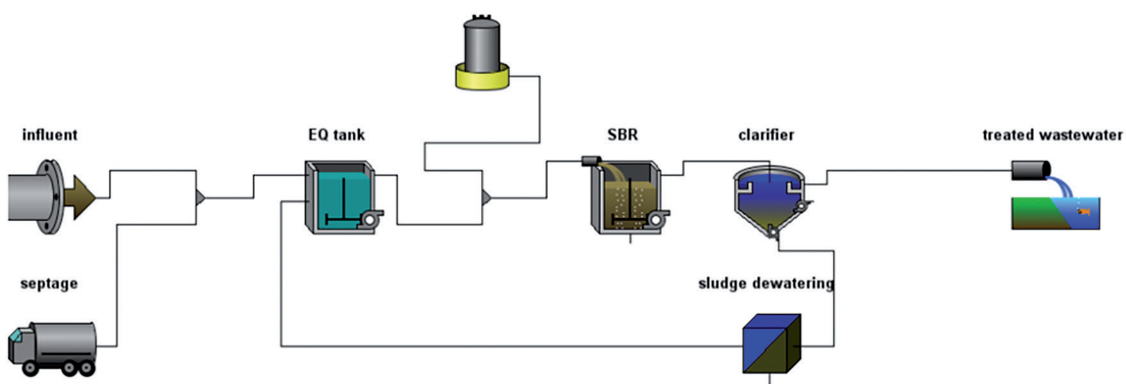

Figure 18
SBR system GPS-X 6.5. model layout (compiled by the author)

Sizing of SBR is also based on mass balance modelling. Here, the input time parameter should be the cycle times in addition to the usual flowrate volume, DO, MLSS, recirculation. When using SBR, you may need to use equalisation basins. The advantage of SBR over the conventional sludge system is:

– easy operation (automation)
– flexibility (you can change cycle times, operating volume cannot be changed)
– better settling sludge
– higher allowable MLSS concentration
– relatively small space requirement

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Questions

1. What is the difference between a model and a simulator?
2. What are the basic processes for building an activated sludge model?
3. What input parameters are required for a mass balance modelling for fixed carrier systems?
4. Describe the Takács sedimentation model!
5. Define AOTR and SOTR! What is the relationship between them?
6. Describe the PID control logic!
7. What kind of ideal reactor models do you know?
8. What are the effects of recirculation in wastewater treatment technologies on the reactor model?
9. What is virtual reactor number?
10. How does cascading affect sludge production?
11. How does the model layout of a small wastewater treatment unit look like?
12. What simulation steps should be taken in mass balance modelling of small treatment units?
13. What can you say about SBR systems?

Tamás Karches

Decision Support Systems and Adaptation

Decision support systems

There are countless decisions to make in our lives that always affect the future. Our goal is to make an optimal decision under the given conditions. The optimal decision assumes that we are in possession of complete information, and we can prioritise the possible alternatives. Knowing all the variations of action and the expected results associated with it, is a prerequisite for decision-making processes. If any of the above conditions are violated, i.e. we do not know all the alternatives or we do not have all the information available, we can only make a limited rational decision.

The probability of occurrence for the decisions is different. If we can give this value, we are talking about risk, if we cannot give it, we are talking about uncertainty. The random variable is between 0 and 1 in case of risk. In most cases, however, the system has many uncertainties due to the effect of the environment. In this case, the decision is based on parametric decision theory. If you are talking about probability variables and risk values, you can easily generate the expected utility. The decision rules can then be:

Laplace criterion: The probabilities of the occurrence are unknown; therefore, all is considered to be equal. The calculation could be simplified because the expected results of the alternatives directly determine what to choose.

Maximax criterion: The best possible result is the best-performing alternative. This decision rule is quite optimistic, as we do not produce the best possible result continuously, but we also choose the best one.

Maximin criterion: The selection among the alternatives is based on the assumption that the lowest result is the highest compared to the other alternatives. Thus, in the worst period of time (for example, in wastewater treatment technology, the plant performs the best in winter compared to other alternatives).

The principle of the minimum regret: Here the lost profit is considered, not the results. We choose the option where the lost profit is the minimum. This principle is also called the minimum regret principle.

A decision support system is considered to be any system that can help in making decisions. For example, such a system may be a simple Excel spreadsheet, a website, a search engine (e.g. Google) or even a LinkedIn profile, if we are looking for human resources for a particular project. It can be seen that there is a wide range of tools for decision support; these should be further specified and should contain the following elements:

- interactivity
- computer-based
- applies databases, models
- helps to solve a non-structured problem

The interactivity condition seems to be clear, for example, based on values extracted and processed in a structured way from a large data set; it displays the information relevant to the decision-maker in a form that can be easily processed.

Visualisation can be considered an essential element, based on the fact that human perception primarily relies on vision. Figures and graphs from datasets can highlight trends that can be used to make future estimations. All this can be accomplished efficiently with computer tools.

The decision support system often uses large amounts of datasets, possibly making model approximations and estimates. Mathematical models are designed to establish and manage the relationships between the data elements. The definition of a non-structured problem is that the alternatives and/or relative preferences are unknown.

In the following, the features of decision support systems and management information systems are outlined.

Decision support systems:

- designed mainly for tactical decisions
- supports the decision-making process, such as planning and data collection, the choice of alternatives
- solves specific problems
- has an interactive interface, the format is flexible
- the information is created by mathematical models and simulations
- flexible systems

Management information systems:

- primarily for operational tasks
- prepare structured decisions
- support for solving common problems
- has a pre-determined shape
- produce information by converting existing data
- hard to modify the system

If the structure of decision-making systems is considered, we can see that the starting point is the database. Then there is an internal, modelling layer and the front-end application for the user.

(1) Database
The decision support system has an own database or may have external source by providing the database or connection. The database is already in the filtered state, pre-processed to the extent necessary to make the decision. Not only the content, but also the structure is determining in the decision-making.

(2) Modelling layer
The task of the modelling layer is to generate information from the data. It uses a variety of functions and algorithms. Here you have to define the rules and the information production method.

(3) Front-end application
The decision-makers meet this interface through which they can view the results. These results are filtered; only relevant information is used. Appearance usually contains many visualisation elements.

In terms of software technology for decision support systems, the following options can be considered:

- data warehouse technology
- Multidimensional Database Management (OLAP)
- column-based database management
- data mining technologies
- reporting tools

Data warehouses

The Data Warehouse is an object-oriented, integrated, lasting and time-dependent data collection for management decision support. Object orientation means that the functions and tasks of our applications are in the centreline. In general, data grouping organises around the user and its preferences, collects them in one place and standardises them. Efforts should be made to keep the data unchanged. However, if you need to change the source data, you need to use appropriate time stamps, as reproducibility is a key issue. Time must always be assigned to the data, as analyses are usually based on data from past periods.

OLAP (Online Analytical Processing) systems

Standardised analysis system with the following features:

- multidimensional view
- transparency
- adjustable permissions
- handling queries
- client–server model
- definition of dimension
- dynamic sparse-matrix treatment by the multidimensional model storage (in numerical analysis of partial differential equations it is a cost-effective storage)
- user support for competitors
- unlimited dimension operations
- intuitive data management for end-user
- flexible reporting management
- unlimited dimension number and aggregation level, which helps in multiscale problems

Column-based database managers

When database managers are applied, the use of a dimensional data model is common, where fact and dimension data can be separated. Dimensions can be linked to the fact table. The fact tables usually contain few columns, but contain many records, the dimension tables are opposite; they consist of a few lines, but many columns.

Data mining technologies

From a huge dataset (e.g. sensor data) we can process information, either by averaging, choosing the right scales or highlighting relevant data. Data mining is the process by which useful information can be discovered automatically in large datasets. Input data can be stored in different formats (text files, tables, or relational tables) that can be distributed between a central data store or multiple locations.

During the pre-processing, the raw input data can undergo in a format conversion, the noise can be removed, and the relevant data can be marked. Pretreatment of data is the most time-consuming process since the standardisation is based on a variety of raw data.

Feedback in the system is the implementation of the results of data mining into decision support systems. The post-processing step ensures that only valid and useful results are incorporated into the decision support system. Often, as part of post-processing, statistical tests and/or hypotheses must be performed to remove misleading data mining results.

Reporting tools

It is widespread in the field of Business Intelligence (BI), but it can be used in other areas, it improves data availability, provides easier, faster access to relevant information with the following possibilities:

- preparation of reports, extracts, minutes
- data visualisation
- planning, forecasting, modelling – run what-if scenarios
- time series analysis
- balanced scoreboard
- preparing dashboards

There may be a different kind of grouping of decision support systems, which is rather theoretical, but knowledge of proper terminology is essential.

- data-driven data management (e.g. OLAP)
- model driven data management (e.g. optimisation models)
- guided by knowledge data management (e.g. expert systems)
- document controlled data management
- communication driven data management (user can provide data, which has effect on data processing)

The following table shows the processes and technologies that can be assigned to each decision support system, which includes the Client–Server connection, the stand-alone PC, and the Web interface.

Table 1

Processes and applied technologies for decision support models (compiled by the author based on [1])

	Process	**Applied technology**
Data-driven	Query from the data warehouse	Client–Server
Model-driven	Decision analysis	Client–Server, PC, Web
Knowledge-driven	Collecting internal information	Client–Server, PC
Document controlled	Web pages, documents	Web, Client–Server
Communication driven	Collaboration	Web, Client–Server

The process of decision

Linear programming

In decision support, we strive for optimum, i.e. based on our available information, we choose between options based on criteria. To do this, the system has a default state, where utility is associated with each alternative. The utility function is a combination of weighting variations and utility. Conditional functions and target functions can be distinguished. In general, our task is to find the minimum or maximum of the target function under some restrictive conditions. If the conditional functions and the target function are linear, then the problem requires linear programming. If any of the functions is not linear then the problem is also non-linear. If the conditional functions and the target function can be written as the sum of single variable functions, dynamic programming is used.

In addition, the programming task may be continuous, discrete or hybrid depending on the type of function. If probability variables are included in the task, then it is a stochastic programming task, but in the absence of probability variables, the problem is deterministic. In general, the following system needs to be resolved to maximise the target function:

$$A \cdot x \leq b$$
$$x \geq 0$$

where matrix A refers to the technology, the elements are the technological coefficients. The matrix consists of *n* lines and *m* columns:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{bmatrix}$$

Vector *b* is the capacity vector and vector *c* is the target function and *x* is the unknown.

$$b = \begin{bmatrix} b_1 \\ \cdot \\ b_n \end{bmatrix}, \quad c = \begin{bmatrix} c_1 \\ \cdot \\ c_n \end{bmatrix}, \quad x = \begin{bmatrix} x_1 \\ \cdot \\ x_n \end{bmatrix}$$

Target function can be written as follows:

$$c^T x \rightarrow \max$$

The solution could use a graphical method, which has the advantage that we can get results quickly with a small number of restrictive conditions and few variables. However, if our system is multivariate and automation is important, it is worth using the simplex method. The solution to your problem is practically the solution of the linear equation systems.

Simplex method

The starting table of the simplex method is a table with the technology coefficient matrix in the upper left corner, the capacity vector in the upper right corner, and the target function coefficients in the bottom line:

Table 2
Initial table of the simplex method (compiled by the author)

	x_1	x_2	...	x_m	b
u_1	a_{11}	a_{12}	...	a_{1m}	b_1
u_2	a_{21}	a_{22}	...	a_{2m}	b_2
	...	...	...	...	...
u_n	a_{n1}	a_{n2}	...	a_{nm}	b_n
$-c$	c_1	c_2	...	c_m	0

The steps of the simplex method are:

a) Select the generator
The selection of the generator can only be made from the column where the coefficient of the target function is not negative, values of $c_1, c_2, \ldots, c_n$ can be considered. It is possible to select all non-negative elements in principle, but it is advisable to find and select the max ($c_1, c_2, \ldots c_m$) value. Create a column for the generator j. To select the row of the generator, the line with the lowest b_i/a_{ij} is considered. This is the so-called bottleneck in the calculation.

b) Definition of the new base applying base transformation with the help of the generator
The new base vector is selected by writing the reciprocate in place of the generator, then multiplying the column of the generator by the –1 times the reciprocal of the generator and multiplying the row of the generator by the reciprocal of the generator.

c) Iterative repetition of the process
The procedure should be continued until the value in the lower right cell of the table continues to decrease. Then the maximum is reached.

To solve the following equation system, use the simplex method:

$$x_1 + 2x_2 + x_3 \leq 3$$

$$3x_2 + x_3 \leq 5$$

$$2x_1 + 3x_2 + 3x_3 \leq 7$$

where all of the variables are positive,

look for the maximum of the function of $c(x) = 3x_1 + x_2 + 4x_3$

In the first step, write the starting table:

	x_1	x_2	x_3	b
u_1	1	2	1	3
u_2	0	3	1	5
u_3	2	3	3	7
$-c$	3	1	4	0

Then find the generating element. There are positive numbers on the bottom line. It is then advisable to select an element with a zero in the column. If we divide *b* by line with the values linked with the column and select the smallest (7/2 or 3/1) then we get the following generator element:

	x_1	x_2	x_3	b
u_1	**1**	2	1	3
u_2	0	3	1	5
u_3	2	3	3	7
$-c$	3	1	4	0

Then we multiply the line of the generating element with the reciprocal, its column by the reciprocal value times –1, then by doing elementary base transformations:

	u_1	x_2	x_3	b
x_1	**1**	2	1	3
u_2	0	3	1	5
u_3	–2	–1	1	1
$-c$	–3	–5	1	–9

Continuing the procedure in an iterative way:

	u_1	x_2	x_3	b
x_1	1	2	1	3
u_2	0	3	1	5
u_3	–2	–1	**1**	1
$-c$	–3	–5	1	–9

Conversion to another base and after base transformation:

	u_1	x_2	u_3	b
x_1	3	3	–1	2
u_2	2	4	–1	4
x_3	–2	–1	**1**	1
$-c$	–1	–4	–1	–10

That is, $x_1 = 2$, $x_3 = 1$, which means that $x_2 = 0$. Thus, the maximum value of the function c(x) is 10.

If the reader would like to have a deeper knowledge in this field, the web is full of literature, just type *linear programming* in a search engine.

The structure of the decision support system

Selection of small sewage treatment plants is based on the decision support systems and the professional requirements. Simplicity and transparency for both the system operator and the user are the primary considerations when creating the system.

The user communicates with the elements of his/her own preferences entered into the user interface with the elements of the decision support system, i.e. he wants to treat a certain amount and quality of wastewater according to the regulations. The user interface matches this input data to the user environment element of the decision theory and transfers it to the logic engine, which is the decision algorithm.

Approaching from the other side, the database contains the space of possible alternatives (action space), i.e. which technological solutions can come into play. By modelling the biological-physical processes, this action space is modified: it becomes narrower and fits better with the user's preference. With the help of the narrower space of action and the vectors of the environmental space, the solution that is best suited to the needs of the user is selected from the elements of the result space and the space, which is returned to the user with the help of the user interface.

According to the above description, there are two possible ways of integrating mass balance modelling into the system:

– connects to the database alternate space
– is connected to a decision algorithm

In the latter case, it must run dynamically, in parallel with the process initiated by the user, at each query, which is a slow and costly process. Therefore, as a solution in the optimised system, the mass balance modelling with GPS-X updates the static database, thus reducing the number of required simulations, and the user will only choose from this updated database.

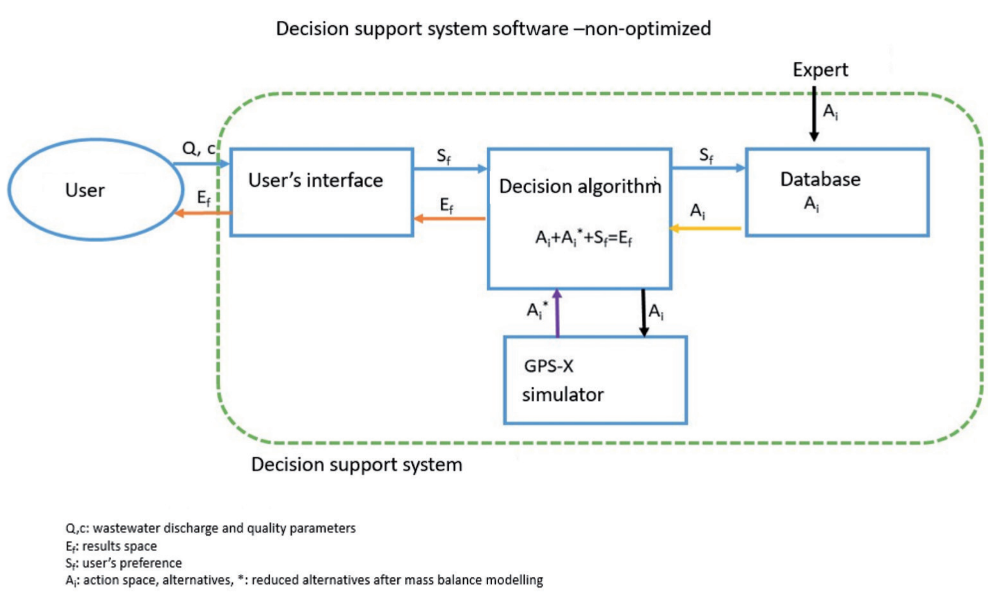

Figure 1

Schematic of decision support algorithm for small equipment – not optimised (compiled by the author)

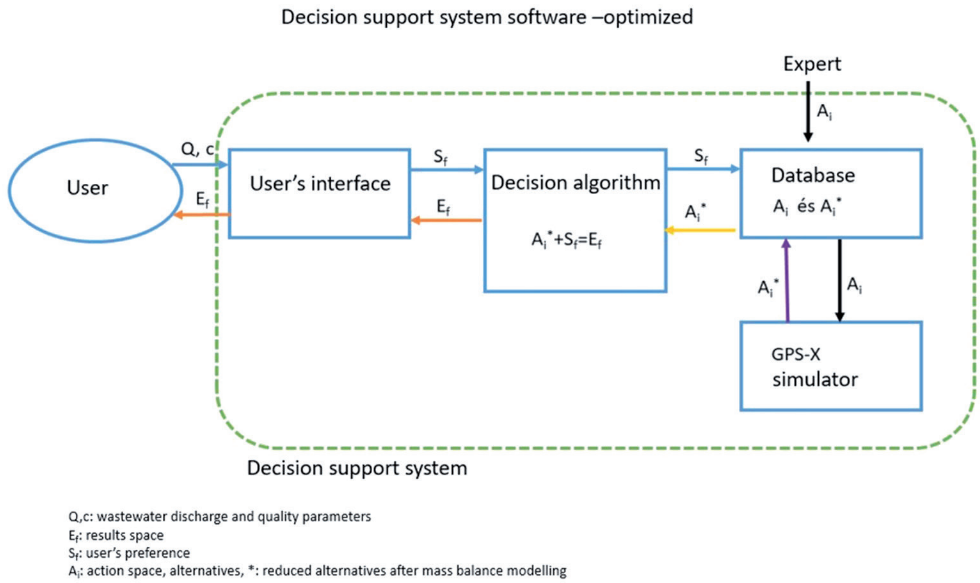

Figure 2

Schematic of decision support algorithm for small equipment – optimised (compiled by the author)

Application of the decision support system

Database

As it can be seen from the structure of the decision support system, the core of the system is the database. The database contains the main features of each small wastewater treatment unit, but besides the nominal capacity, the calculated capacities assigned to the given wastewater quality had to be determined. Therefore, the database uses the results of the mass balance model. For each small wastewater treatment unit, the simulation environment defined the actual capacity data as described in the previous chapter. The average wastewater quality was taken into account for this calculation. If the wastewater quality differs from this, operational parameters can be fine-tuned (e.g. air quantity).

The table contains the equipment described in *Annex: Examples for Individual Wastewater Treatment Units.* However, this does not prevent the database from expanding over time. Moreover, the basic criterion for a decision support system is to use up-to-date data. Therefore, if a new alternative is introduced, it is needed to take the following steps and answer questions:

- examine that the certain technology could be an alternative to the decision support system
- gathering technical specifications for each alternatives
- preparation of the layout in a mass balance model simulation environment
- run at nominal capacity for the given wastewater quality
- iteratively find the capacity where the quality of the treated wastewater is adequate
- expanding the database with the given element and simulation results
- updating the database in the decision support system

Table 3
Capacity data for small wastewater treatment units (compiled by the author)

Type of the small wastewater treatment unit		Nominal capacity		Calculated capacity
		LEÉ	**m³/d**	**m³/d**
POLYDOX	Polydox 6	1–8	0.9	0.38
	Polydox 12	8–12	1.8	0.76
	Polydox 30	30	4	1.7
	Polydox 50	50	6	2.5
ÖKO TECH Home	A, B Clear 6	6	0.78	0.42
	A, B Clear 8	8	1	0.53
	A, B Clear 10	10	3	1.6
GRAF	One2Clean 1-3 EW	3	0.45	0.24
	One2Clean 4-5 EW	5	0.75	0.4
AS-VARIO COMP	5K ULTRA	3–5	0.6	0.38
	8K ULTRA	6–10	1.2	0.77
	15K ULTRA	11–17	2.25	1.45
	20K ULTRA	18–24	3	1.9
	30N	25–33	3.75–4.95	2.7
	40N	34–44	5.1–6.6	3.5
	50N	45–55	6.75–8.25	4.6
	60N	56–70	8.4–10.5	5.8
	80N	71–90	10.65–13.5	7.6
	100N	91–110	13.65–16.5	9.2
	125N	111–135	16.65–20.25	11.8
	150N	136–155	20.4–23.25	14.1

Decision algorithm

From the user's information, the capacity table should be used to map the result with a selection algorithm. The user should be asked questions that can be easily interpreted, easily answered and filled quickly. If professionals are asked, they could provide water consumption trends, diurnal pattern, raw wastewater COD, BOD, TSS, TN, TP and other physical parameters (e.g. temperature) and desired treatment efficiency. In this case, the responsibility of the user would be higher. However, the decision support system developed within the framework of the project should be clear and consist of few (not high level professional) questions, so the system will process the response for the following questions from the user:

a) How many people need to treat their wastewater?
b) Water consumption per capita.
c) Land use – an option among several alternatives.

The desired treatment efficiency is not included in the questions, as it is always set to remove 90% organic matter and close to full nitrification.

Determination of load and number of units with actual capacity

It is assumed that 100% of water consumed becomes wastewater. The hydraulic load of the system is the number of inhabitants multiplied by the water consumption per capita. The load data must be compared with the actual (based on the mass balance model) of each unit and the appropriate system recommended. The decision support system does not suggest a kind of treatment unit, but offers several alternative offers and determines the number of units to be procured.

Determination of aeration requirements – concentration of dissolved oxygen in an aerobic zone

We start with water consumption per capita and daily specific emissions (60 gBOD5/person.day, 120 g COD/person.day, 14 g TKN/person.day, 1.5 g TP/person.day). If the water consumption per capita is below 100–120 l/person, the hydraulic load is lower but the wastewater is more concentrated. It is recommended to maintain DO = 3–3.5 mg/l in the aerobic zone. If the wastewater output per person is greater than 120 l/person, then DO = 2–2.5 mg/l may be sufficient for that volume.

Sludge production estimation

Depending on the daily load of organic matter, sludge production can also be determined for communal wastewaters (0.85 kg TS of 1 kg COD), which gives the number of kg TS/d generated. Assuming 3.5–5% concentrated sludge, we can say the consumed litres per day (or the annual amount in m3).

Recommendation for operation

For proper operation and maintenance, it is necessary to provide a user manual for each system detailing what to do daily, weekly, monthly and yearly. The integration of this information into a decision support system is necessary to ensure that the responsible decision is supported not only from the investment side but also from the operational side.

User's interface

Decision support systems communicate with the user via a user's interface. A simplified projection of the user interface to the system contains information relevant to the user. It also provides communication between the user and the decision support system. To meet today's challenges, a web-based technology should be used to ensure easy access, and the easiest solution is to create a website.

The website is located on the web server to access the so-called URL. URL is tagged and identifies a web page allowing a unified link. The use of unified syntax is supported by protocols. Well-known protocols are HTTP and FTP. Figure 3 shows that the client uses the URL to access the web server via the web. The result of the visit of the URL is that the server sends the document/web page to the client in response.

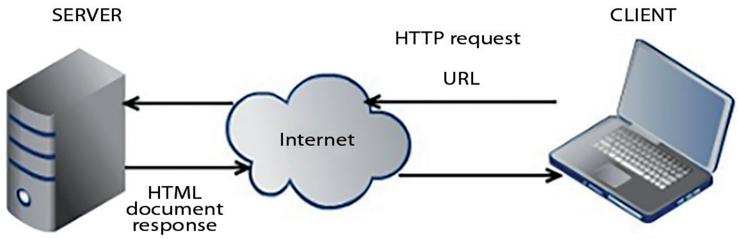

Figure 3
Client–Server connection [2]

HTML, a hypertext-descriptive, mark-up language that is used most often to create websites. Fast, platform-independent, support for multimedia devices,.htm or.html extension. Hypertext means that each file can be easily linked. The text language can be set not only in content but also in form. The text description determines the placement and references of the data to be displayed on the website. The task of the web browser is to interpret and execute these instructions. HTML uses the ASCII code table, a text file. There are several types of data types in HTML:

- text: allows any number and type of characters
- number: specifically, specify size or area mark
- date/time
- content: embeds in document
- link
- medium descriptor: e.g. screen: screen, projection: projector

Hyperlinks are now an essential part of the webpage, allowing us to switch between content and parts of the document. You can place the link anywhere on the page, refer to another part of the document, to a different point on the webpage, but also to a point outside that website. The link is designed to point to another file. Two categories of links can be distinguished: the absolute and relative link.

Absolute link: The full path of the target file must be specified, not the reference page.

Relative Link: Enter the path from the referral page.

A basic element of decision support systems is that the user can enter data. We can do this with forms. After entering the data, it is possible for the software on the server to process it or to use another non-HTML program on the website. To create a decision support system, you should know the parts of the HTML forms and the steps to develop them.

We expect our form to request, store, process and send the result to the user by email. In case of data entry, if you make a mistake, you are expected to report it to the user.

To embed the forms, the commands <form> or <form>should be written to… The form attribute is the action, which is a reference to the form processing program. This can usually be activated by pressing a button. For example, by inserting an Enter or a separate button. To send the result, you must provide an email address: mailto: xy@z.hu.

You need to specify how you want the data to be sent (method). In order to do this, the GET and POST are available. It is recommended to use POST, as there is no limit on size and passwords are encoded. There are several versions that can be used for encoding (enctype).

The data we enter may belong to several types:

- text: 20-character-long field, but you can type texts of any length
- password: is a text that replaces the input data with *
- checkbox/radio button: selection option except that more can be selected from checkboxes, only one at the radio button
- file: upload files from your computer
- submit: sends the data
- reset: delete the entered data, reset it

The text has several available attributes:

- name: controller name
- size: field width
- maxlength: maximum text length that can be entered
- value: initial value
- readonly: read-only field
- disabled: unauthorised field (e.g. not relevant based on answers to previous questions)

If you have to choose the right one from many items, you can use the drop-down list instead of the radio buttons. Such a list <select> or <select> should be placed between… and then the list items <option> or <option> are listed…

Querying the sent data

An object that processes HTTP requests and can generate HTTP responses can be used to process the sent data in a Java environment. This allows us to create a dynamic web page. Java calls this object servlet, so the servlet must be written in Java. The servlet container manages all of the servlets on their webserver, their lifecycle and URL assignment.

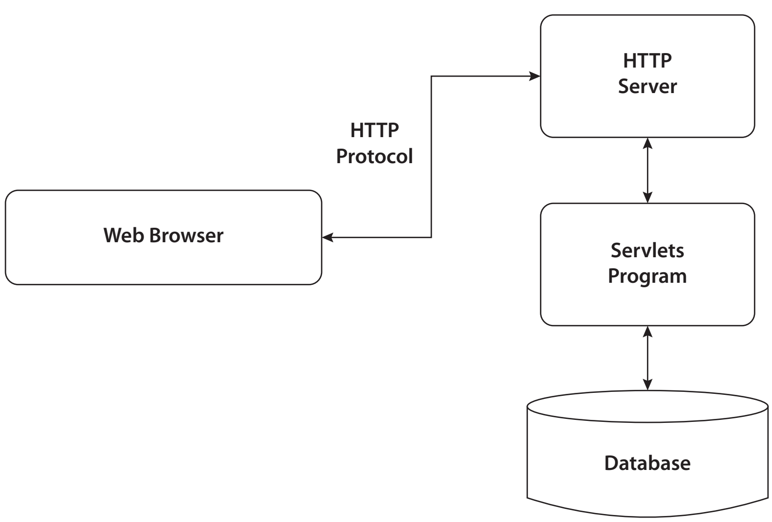

Figure 4
Fundamentals of server operation (compiled by the author)

The servlet's life cycle consists of:

a) The servlet container creates the servlet object.
b) The container initialises the servlet, i.e. assigns an initial value.
c) Servlet servicing the client.
d) The container invites you to delete the method and delete the servlet.
e) With the exception of Step 3, one of the above steps takes place only once in the life of the servlet.

We need to know three types of servlets related to the forms:

- *HttpServletRequest:* Incoming request data, information collection.
- *HttpServletResponse:* After data processing, it provides the client with a response.
- *HTTPServletContext:* It influences the servlet environment, it works continuously, it is "loaded" at initialisation.

HTTPServletRequest Methods

Query request:

- public String getProtocoll (): return value is the name and version number of the protocol used by the request
- public String getMethod (): return value of the command given in the request

Retrieving contact information:

- public String getRemoteHost (): specifies the IP address of the computer
- public String getLocalName (): the IP address of the server serving the request
- public int getLocalPort (): the local port number of the computer connection

Querying parameters sent by Form:

- public String getQueryString (): parameter string sent as part of the URL •

Access to a single parameter:

- public String getParameter (String name): returns the value of the parameter with the specified name if the entered data is text type
- public String [] getParameterValues (String name): returns values for a parameter with the specified name
- public Enumeration getParameterNames (): the list contains the names of all parameters sent by the browser

Access to the data sent:

- public String getCharacterEncoding (): returns the character encoding mode used by the client to send master data
- public int getContentLength (): returns the length of data sent

HTTPServletResponse Methods

Set the answer type:

- public void setContentLength (int len): determines the length of the response
- public void setCharacterEncoding (String charset): defines the character encoding mode used to send the response

Options for sending a reply:

- public ServletOutputStream getOutputStream () throws IOException: channel for returning Byte data, such as images
- public PrintWriter getWriter () throws IOException: returns text data

Send a redirect request:

- public void sendRedirect (String location) throws IOException: redirects the browser to a specific address

It should be mentioned that many interfaces have been created for the development of smart web pages, to facilitate the application of the above processes and logic. There are quite a number of solutions on the market where the web page editor no longer meets the code, but you can only design your website through a graphical interface.

These editing interfaces are based on the fact that webpages or forms within it have permanent elements (images, texts, files) and can thus provide a frame. However, there is a limit to editing, if we want to choose unique solutions, we will not find a pre-programmed solution. However, if it is a simple task (data entry, scan, run algorithm, send response), we can use it safely.

We have seen how the decision support system is built, how its background simulations run and how the web application is built. Applying these techniques requires the expertise of process engineers and IT experts, but it should be emphasised that the responsibility is always on the decision-maker. The expert/decision support system only suggests opportunities for the user, but the consequences are always taken by the decision-maker.

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Questions

1. What decision rules do you know?
2. How decision support systems could be defined?
3. Compare leadership management systems with decision support systems!
4. Which three layers can a decision support system be divided into? What is the role of each layer?
5. What are the features of OLAP?
6. What are the different types of decision support systems for which applications to run?
7. Describe the simplex method!
8. How is it possible to embed a GPS-X simulation environment based on mass balance modelling into a decision support system?
9. What can you say about the decision support system database?
10. What is the decision algorithm based on?
11. Outline a client-server connection!
12. What types of data can be in HTML?
13. What is an HTML Form?
14. What is Servlet?
15. What HTTP Servlet Request Methods do you know?

Tamás Papp

Annex

Examples for Individual Wastewater Treatment Units

Nowadays, the investment in the self-built modern on-site wastewater facilities are common as well as the local community organised, EU founded municipal wastewater management projects. One of the main principles of the law is that there should be adequate regulations for the implementation of advanced individual initiatives until the development of professional, on-site wastewater treatment solutions, developed by the local government, with the assistance of a specialist service provider.

The regulatory principle remains that developments and related environmental authority tasks of household wastewater treatment maximum of 500 m^3/year capacity on a property-by-property basis fall within the competence of local self-government notaries, in particular to relieve the National Inspectorates for Environment, Nature and Water. The involvement of the Inspectorates in case of individual initiatives can be done through professional assistance. In contrast, at municipal-level specialised wastewater treatment development and public services are implemented within the framework of a new legal institution, the Urban Wastewater Management Program, where the participation of the Inspectorate in the opinion of the UWMP can ensure the representation of environmental interests.

Program "B" advises three distinct alternatives for settlements or part of settlements, where the connection to the public sewage system is not economically sound:

– modern individual wastewater treatment (on-site sewage facilities)
– use of small wastewater treatment units
– closed tanks, storage tanks (septage)

These are the legal definitions of these under the Government Decree on Program "B":

Individual wastewater treatment: the use of individual wastewater treatment facilities, which includes the treatment and/or final disposal or temporary collection and storage of municipal wastewater with 1 to 25 population equivalent. Depending on the environmental and water management aspects and the building density, these may include: on-site sewage facilities, individual small wastewater treatment units and closed wastewater storages. Disposal and handling of liquid, sludge and construction waste from individual wastewater treatment facilities must be carried out in accordance with a separate legislation.

On-site sewage facility: A facility that reduces the environmental load of the municipal wastewater non-accessing to the public sewage system and disposal, but able to ensure the same degree of treatment as the large-scale wastewater treatment systems. The on-site sewage treatment facility is able to treat the wastewater without energy input. Elements: septic tank, gravel/sandstone(s), which, on the whole, allow the utilisation of the residual nutrient content of the treated wastewater for the vegetation and soil biota in case of final release into the geological medium or harmless placement in surface waters.

Small wastewater treatment unit: an installation that serves for the non-utility drainage and disposal of municipal wastewater, and provides an environmental solution equivalent to the municipal wastewater drainage and treatment. The individual wastewater treatment plant carrying out the treatment of the sewage by means of energy input shall ensure the removal of the pollutants of the wastewater according to a separate legislation; the recipient can be surface water or soil.

Closed wastewater storage: an installation consisting of one or more closed and watertight tanks; for the non-hazardous collection of wastewater and for the temporary storage of municipal liquid waste; the non-hazardous disposal of municipal waste collected in this area is provided after regular disposal and further treatment in accordance with specific waste management legislation.

It is regrettable that the use of on-site sewage facilities, as well as the use of small wastewater treatment units, is still not common even among professionals and manufacturers. It is necessary to pay special attention to the fact that this method, which is very different in the design, operation and last but not least, in the treatment efficiency, as well as the cost of wastewater treatment, i.e. in the public sewage system, should be distinguished in practice.

In the area of settlements with no sewage network, less than 2,000 PE, the operation of the small wastewater treatment unit is justified in the recreation area. In such cases, wastewater can be treated locally.

It is important to know the quality certificate of the small wastewater treatment unit intended for installation, since today in Hungary only the units can be on sale and operated, which is CE certified and was issued according to the standard MSZ EN 12566-3. If the load exceeds 2,000 PE, connection to the public sewage system is required.

Table 1
Effects of waste on small wastewater treatment units (compiled by the author)

Solid or liquid substances not to flush in the toilet	What they cause	Where to place
Ashes	Does not decompose	Bin
Chemicals	Poison the wastewater	Collection site
Disinfectants	Kills bacteria	Collection site
Dyes	Poison the wastewater	Collection site
Frying fat	Dumps in the tubes, causing a plug	Bin
Sticking plaster	Plugging in the tubes	Bin
Medicine	Poison the wastewater	Collection station, pharmacy
Motor oil	Poison the wastewater	Collection station, gas station
Pesticides	Poison the wastewater	Collection site
Razor blade	Can cause injury in the wastewater treatment plant	Bin
Drain cleaner	Smashes pipes and seals, poisoning sewage	Collection site
Powder insecticide	Poison the wastewater	Collection site
Sanitary pads	Cause damage to the environment	Bin
Diluent	Poison the wastewater	Collection site
Cotton bud	Deposited in the units	Bin
Diaper	Plugging	Bin

If the load is even, an anaerobic small wastewater treatment unit is enough, but if the load is uneven, e.g. in the resort area, aeration is inevitable in order to achieve proper treatment efficiency.

Nowadays, many companies design, manufacture, construct, install and commission small sewage treatment units. Manufacturers classify their product in three types of equipment capacity.

- small
- medium
- large

These classifications differ from company to company, because they use different PE limits based on PE: keeping in mind the areas of use that can be:

- single-family buildings
- social houses
- resort areas
- nurseries
- vessels
- motorway rest areas

Polydox treatment unit

In December 1992 Polyduct Zrt., as the first open joint-stock company in Hajdú-Bihar County, it was formed from the plastics plant of KITE (Corn and Industrial Plant Production Cooperation). As a quality supplier of gas and wastewater investments, they have been present in the Hungarian public utilities for about 20 years. Thanks to continuous improvements, Polyduct Zrt. has an extensive product range in water industry now and offers a comprehensive solution for the modern equipment and units required.

Figure 1
Polydox 6 and 12 biological wastewater treatment unit [1]

Recognising its importance, the company is a founding member of the Individual Wastewater Treatment Task Group. The Task Group maintains close contact with the Ministry of Rural Development (formerly the Ministry of Environment and Water) and is involved in shaping the legal background of individual wastewater treatment solutions. As a domestic producer of individual wastewater treatment equipment, the company is committed to spreading their products as widely as possible.

Specifications for the Polydox 6 and 12 wastewater treatment plants (for CE marking, according to EN 12566-3).

Table 2
Technical data of the Polydox 6 and 12 wastewater treatment unit

	Polydox 6	**Polydox 12**
Capacity	1–8 PE (population equivalent)	8–12 PE (population equivalent)
Hydraulic daily load	0.9 m^3/day	1.8 m^3/day
Material	Polyethylene	Polyethylene
Size	Ø1500 × 2300 mm	Ø1700 × 1920 mm
Weight	150 kg	180 kg
Height	2,300 mm	1,920 mm
Volume	2.4 m^3	3 m^3
Electric connection	230 V	230 V
Effective connector size	DN110 PVC pipe	DN110 PVC pipe
Effluent connection size	DN110 PVC pipe	DN110 PVC pipe
Energy use	1 kWh/day	1 kWh/day
Field of application	retail	retail
Treatment efficiency	COD: 90% BOD_5: 90% Total suspended solid: 90%	COD: 90% BOD_5: 90% Total suspended solid: 90%
Disposal of treated wastewater	infiltration release into surface water	infiltration release into surface water

The structure of the Polydox 6 and 12 wastewater treatment unit

Primary clarifier: Coarse mechanical treatment part. Its function is to mechanically remove large size pollutants from municipal wastewater and to store excess sludge from biological processes.

Aerobic tank: Here, complete biodegradation and complete nitrification take place.

Secondary clarifier: It filters out settable materials and sludge. The settled sewage sludge is returned to the aerobic space by the mammoth pump placed here, where it is reintroduced into the treatment process.

Operation of the Polydox 6 and 12 wastewater treatment unit

The wastewater flows among the separate volumes by gravity. This process includes the installation of a mammoth pump controlled by electronics. Finally, the treated wastewater flows out of the unit by gravity. Dissolved oxygen is provided by compressed air required for oxidation. This is produced by a membrane compressor located in the control cabinet with the control unit. The compressed air passes through the air diffuser into the aerobic volume.

The air supply of the wastewater treatment plant and the operation of the mammoth pumps at appropriate intervals are provided by the control system. This system can be operated manually or automatically. In automatic operation, pumps and aeration units operate according to a predetermined program in the control unit as follows:

– the mammoth pump delivers wastewater from the primary clarifier to the aerobic volume
– the aeration unit has an on/off control in automatic mode
– the mammoth pump is switched on by the sludge recirculation at every second hour

Stabilisation of sludge takes place under anaerobic conditions in the sludge storage. Depending on the PE, the sludge zone provides a residence time of 10–14 months. This stabilises the sludge. The approximately 500 l of stabilised sludge thus formed must be removed from the pre-settling zone by suction, and the pre-settling room must be filled with clean water.

Treated wastewater flows to an infiltration zone or may be discharged into surface water. The sizing of the infiltration zone is the task of the designer.

The installation of the equipment is underground, for inspection and maintenance of the Polydox 6 type 1, and for the Polydox 12 type there are two trap doors.

Regulation (EC) No 28/2004 of the European Parliament and of the Council on limit values for pollutants and certain rules for their application (XII.25.) and according to the Hungarian KvVM Decree, the quality of the effluent discharged from the equipment complies with the limit values defined in Area Categories 2, 3 and 4 for direct introduction into the recipient. If phosphorus removal is also required in case of introduction into the recipient, an additional chemical dosage should be installed.

Sludge stabilisation in the sludge storage tank occurs under anaerobic conditions. Depending on the PE, the sludge residence time is about 1–1.5 years. The stability of the sludge is then the most favourable. Finally, the stabilised sludge can be removed by septage truck. Treated wastewater during the process can be drained through an infiltration zone.

Selecting the location of the small wastewater treatment unit

The unit can receive max. 60 cm deep sewage without lifting:

– A free space of at least 3 m in diameter should be provided to accommodate the reservoir so that the pit can be made free of obstructions.
– Keep a minimum distance of 1 m between the tank and the nearest building. If the depth of the pit exceeds the depth of the foundation, this distance should be increased to 3 metres. Do not build above the tank!
– Avoid installing the tank in the groundwater area. If this is unavoidable, the tank may need to be anchored and ask for assistance from a specialist.
– The tank can be placed under a traffic route exposed to pedestrians, but can only be built on a separate technical design for the area exposed to motor traffic!
– In the vicinity of trees and plants, the tank should not be closer than 2 m to the tree trunk. Plants can be planted above and below the tank only in case their roots will not be in the way of the tank or the root of the container will not push the container wall.

In case of slopes, a specialist should be inspected to determine if a support wall is needed within the 5 m range of the tank.

Placement of a sewage treatment tank

To create a foundation pit

Create a foundation pit with a flat base with a diameter of 0.3 metres in all directions for the maximum diameter of the tank (ø 1.6 m) due to the need for work and the space needed for filling/re-filling and compacting the bedding material.

To avoid the risk of collapse, the wall around the excavation should be expanded at an angle of 35 to 80 degrees.

When determining the depth of the pit, you must take into account the need for a minimum depth of 20 cm, and the tank can receive max. 60 cm deep water.

After lifting the ground, at the bottom of the foundation pit – preferably from gravel – form the bottom bed, which must be sufficiently compacted (3-fold machine ramming or equivalent manual compaction) and then levelled. There can be no sharp stones or protrusions in the bedding.

Placing the tank

Carefully lower the tank (using straps) into the pit and check the level. The lifting tabs on the tank can only be used when the tank is empty (weight is approximately 150 kg).

Fill the tank with water half.

Put the manhole cover so that no gravel or sand gets into the tank during the top recharge.

Fill the tank around the filler – sand and sand-aggregate mixture (grain size is in the range of 0.8–0.32) evenly over the tank at –0.2 metres. Tighten all layers with a manual machine compression tool evenly. Machine compaction near the tank wall is forbidden. It is forbidden to return the soil to the immediate vicinity of the tank.

If filling the side bed has reached the height of the water in the tank, the tank must be filled with water up to the level of the spaces.

You can then continue – as described above – to develop the side bed.

Connect the inlet and outlet pipelines without voltage, observing the correct slopes.

You can use the soil out of the pit to fill the last 20 cm layer, but it cannot contain sharp stones.

Installation of the electrical control cabinet of the unit

Following the above, a pre-assembled cabinet with the support stand must be placed at the dedicated connection point of the wastewater treatment plant and secured to the equipment with the supplied screws. You need to install the electric wire that comes in the ground through the protective tube through the 3X1.5 MT cable into the switch cabinet. At the end of the electrical cable, an IP 54 plastic connection box should be installed 6. A. with fixed connection with terminal block. The colour-coded stumps of the air valve in the control cabinet must be connected to the air outlets protruding from the tank in accordance with the colours.

The unit can be operated from a 230 V protective earthing network. The operator is responsible for eliminating any major voltage fluctuations. When installing the equipment, a contact protection test must be carried out and the report drawn up by the operator of the equipment must be kept. Work on the machine only in the power-off state.

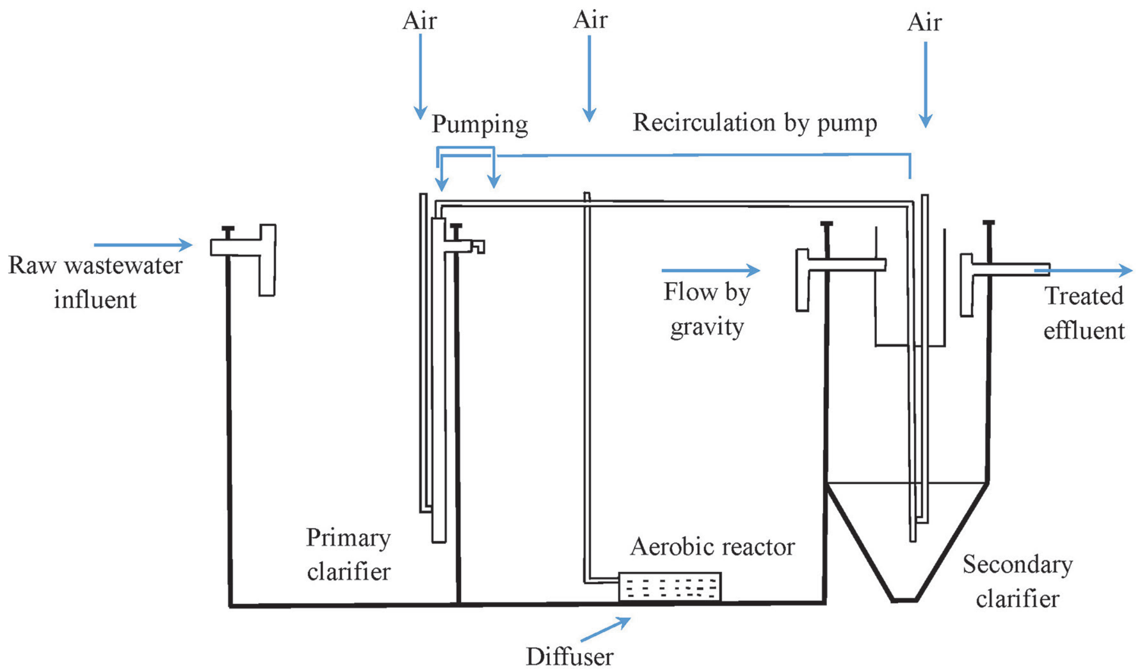

Figure 2
Polydox 6 and Polydox 12 operating principles [2]

Operational conditions

Wastewater is treated by bacteria that break down, use up the wastewater constituents during their metabolism. Bacteria are very sensitive to antibiotics and disinfectants because they destroy them in great quantities. The following rules must be observed for the survival and reproduction of degrading bacteria:

- use up to 1 dl daily of chlorine-based cleaning and disinfecting agents (e.g. Hypo, FloraSept, Domestos, Clorox, Bref Duo Active, Devil, Tiret Professional, Cillit Duo); we can keep our home with natural tools and environmentally friendly cleaners
- avoid using acids and alkali (e.g. drain cleaners)
- up to 2 washing machine programs per day are recommended
- dangerous, therefore, it is forbidden to pour toxic or flammable substances into the drain: thinners, paints, pesticides, motor oil, etc.
- do not throw away any non-degradable materials, e.g. cigarette butts, paper diapers, wipes, cleaners, office paper, packaging materials, foils, etc.
- do not pour the cooking oil, food residue, fruit or vegetable residue used in the wastewater treatment plant, do not use food waste grinder
- do not let water from swimming pools or boilers into the unit
- wastewater from animal husbandry is forbidden to mix with household wastewater
- rainwater is not wastewater, do not discharge into the unit; it is advisable to collect in a separate closed rainwater collection tank, which could be used for irrigation

Maintenance instructions

A Polydox biological wastewater treatment unit does not require continuous monitoring, dedicated safety equipment such as conventional sludge biological systems, but periodic inspection is also required for these types. It is necessary to check and possibly replace the aeration elements every 5–6 years. No hazardous gases can be formed in the reactor space; no special protection requirements are needed. If the unit is not placed in an enclosed area, it must be surrounded by a fence to prevent unauthorised intrusion.

In case of settlement-level operation, a responsible person in charge of the equipment must be appointed and the operation must be solved in an organised manner. It is the responsibility of the operator to carry out the necessary checks, treatments, work and to keep the operation log up-to-date. The inspection should also cover the connecting structures outside the equipment.

Table 3
Inspection frequency of a small equipment by the owner of the residential property (compiled by the author)

Name of activity	Frequency
Visual inspection of equipment	Weekly
Checking of flows	Monthly
Checking the quality of treated wastewater	Monthly
Supply of electricity	Ongoing
Providing access to equipment	As needed

Table 4
Inspection frequency of the unit by the operator (compiled by the author)

Name of activity	Frequency
Measuring sludge blanket level in sludge storage	Monthly
Checking the turbidity of the settling tank, removing the floating materials	Every 3 weeks
Sampling and determine the quality of the influent and effluent	With the frequency specified by the inspectorates
Excess sludge removal	Annually
Correcting possible operational errors	As needed

Polydox 30 and 50 biological wastewater treatment unit

Polydox 30 and 50 wastewater treatment units are larger than the types discussed above, both in size and capacity. The manufacturer recommends it to smaller schools and pensions, but it can also be installed in small industrial plants.

It is enough to install a 2.5 × 2.5 m work pit, which should be placed above the groundwater level at least one meter from the building. When choosing the location of the installation, it should also be noted that the 2.5 m area should be woodless because the roots can push the side of the tank, which can lead to damage.

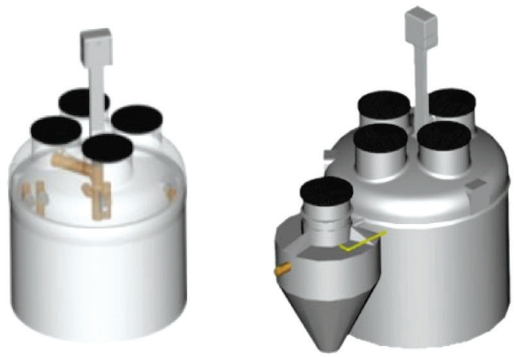

Figure 3
Polydox 30 and 50 wastewater treatment unit [2]

Table 5
Specifications for the Polydox 30 and 50 wastewater treatment unit (compiled by the author)

	Polydox 30	**Polydox 50**
Capacity	30 PE (population equivalent)	50 PE (population equivalent)
Hydraulic daily load	4 m^3/day	6 m^3/day
Material	Polyethylene	Polyethylene
Size	2,500 mm	2,400 × 3,550 mm
Height	2,000 mm	2,000
Volume	7 m^3	8.4 m^3
Electric connection	230V	230 V
Effective connector size	DN160 PVC pipe	DN160 PVC pipe
Effluent connection size	DN110 PVC pipe	DN110 PVC pipe
Energy use	6 kWh/day	7.596 kWh/day
Field of application	retail	retail
Treatment efficiency	COD: 90% BOD_5: 90% Total suspended solid: 90%	COD: 90% BOD_5: 90% Total suspended solid: 90%
Disposal of treated wastewater	infiltration release into surface water	infiltration release into surface water

The structure of the Polydox 30 and 50 wastewater treatment equipment

Primary clarifier: It is responsible for mechanical treatment; removing solids and store excess sludge from biodegradation.

Anaerobic tanks: Here, the hydrolysis of biodegradation takes place, transforming the slowly degradable organic materials into readily degradable organic materials. The homogeniser (mixer) placed in the anaerobic space promotes denitrification and some nitrification can begin.

Aerobic tanks: The two volumes of the same size and design are in series, where the complete biodegradation is realised and the complete nitrification process takes place. Flow through aerobic volume is via fixed contact elements. The biofilm carrier, PVC-bonded multi-cell module is installed in cast polyethylene cylinders, fixed as a stand-alone cartridge to the bottom of the treatment unit. Air bubbles captured in the "cartridge" in the aerobic space, through the mammoth pump effect, continuously flow upstream of the wastewater. This circular flow provides the nutrient and oxygen supply to the biological membrane adhered to the surface of the contact elements. The aged, mineralised part of the biofilm is constantly detached and flows into the secondary clarifiers with the biologically treated sewage.

Secondary clarifier: Its task is to separate settleable materials and sludge. Recirculation of the settled sludge is provided by the mammoth pump placed in the secondary clarifier. The recirculating sludge enters the anaerobic space. The excess sludge is transferred to primary clarifiers for stabilisation through the recirculation.

Operation of the Polydox 30 and 50 wastewater treatment equipment

The wastewater is transported between the tanks by gravity. Treated wastewater also flows out of the system by gravity. Compressed air is provided to fulfil the requirement of dissolved oxygen. The compressed air is provided by a membrane compressor, which is housed in a common box with the electrical control unit. The supply of compressed air under fixed battery cartridges is performed on a round, elastic membrane with fine bubble aeration elements. The device control system provides air supply and control of the mammoth pump.

The system can also operate in manual and automatic mode. In automatic mode, the aeration unit, the homogenising pump and the sludge pump are operated by the pre-programmed controller as follows:

- switches the aeration unit on/off
- operates the homogenizing pump
- switches sludge circulation pump on/off

The stabilisation of sludge (raw, primary sludge, excess sludge) occurs under anaerobic conditions at the bottom zone of the primary clarifier. Depending on the PE, the sludge zone provides a residence time of 10–12 months. This stabilises the sludge. The stabilised sludge is transported by a suction tank vehicle. Treated wastewater flows to an infiltration zone or may be discharged into surface water. The sizing of the infiltration zone is the task of the designer.

The placement of the equipment is underground, the number of openings for inspection and maintenance is 4 for Polydox 30 and 5 for Polydox 50.

Regulation (EC) No 28/2004 of the European Parliament and of the Council on limit values for pollutants and certain rules for their application (XII.25.) and according to the Hungarian KvVM Decree, the quality of the effluent discharged from the equipment complies with the limit values defined in Area Categories 2, 3 and 4 for direct introduction into the recipient.

If phosphorus removal is also required in case of introduction into the recipient, an additional chemical dosage should be installed.

Selecting the location of the small wastewater treatment unit

A free space of at least 3.5 m in diameter should be provided to accommodate the reservoir so that the pit can be made free of obstructions.

It is recommended to keep a minimum clearance of 1 m between the tank and the nearest building. If the depth of the pit exceeds the depth of the foundation, this distance should be increased to 3–6 metres. Do not build above the tank!

Avoid installing the tank in the groundwater area. If this is unavoidable, the tank may need to be anchored and ask for assistance from a specialist.

The tank can be placed under a traffic route exposed to pedestrian traffic, but cannot be installed in the area exposed to motor traffic, and should be completely excluded!

In the vicinity of trees and plants, the tank should not be closer than 2.5 m to the tree trunk. Plants can be planted above and below the tank only in case their roots will not be in the way of the tank or the root of the container will not push the container wall.

In case of slopes, a specialist should be inspected to determine if a support wall is needed within the 5 m range of the tank.

Placement of a sewage treatment tank

To create a foundation pit

Create a foundation pit with a flat base with a diameter of 0.3 metres in all directions for the maximum diameter of the tank (ø 2.5 m) due to the need for work and the space needed for filling/backfilling and compacting the bedding material.

To avoid the risk of collapse, the wall around the excavation should be expanded at an angle of 35 to 80 degrees.

When determining the depth of the work pit, it must be taken into account that a minimum flat concrete bed of 20 cm is required and that the tank can be loaded with a maximum of 30 cm of ground cover.

After lifting the ground, lower the bottom min. 20 cm flat concrete bedding.

Placing the tank

Carefully lower the tank (using straps) into the pit and check the level. The lifting tabs on the tank can only be used when the tank is empty (mass is approximately 400 kg).

Fill the tank with water half.

Place the manhole covers so that no gravel or sand gets into the tank during top recharging.

Fill the tank around the filler – sand and sand-aggregate mixture (in the range of 0.8–0.32) evenly over the tank at –0.2 metres. Tighten all layers manually and evenly. Machine compression is prohibited! It is forbidden to return the soil to the immediate vicinity of the tank.

If filling the side bed has reached the height of the water in the tank, the tank must be fully filled with water after the tank's inlet and outlet pipes are connected and then closed.

You can then continue – as described above – to develop the side bed.

Check the connected pipes. These must be securely fastened.

You can use the soil out of the pit to fill the last 20 cm layer, but it cannot contain sharp stones.

Installation of the electrical control cabinet of the unit

Then place the control cabinet at max. distance of 5 m of the unit, electrical connection shall be provided by connecting the 3 × 0.75 MTK ground cable to the control cabinet. The electrical power supply must be fixed. This operation should only be carried out by a qualified electrician. The numbered stubs of the air valve in the control cabinet must be connected to the numbered air connectors on the tank. The unit can be operated from a 230 V protective earthing network. The operator is responsible for eliminating any major voltage fluctuations. When installing the equipment, a contact protection test must be carried out and the report drawn up by the operator of the equipment must be kept. Work on the machine only in the power-off state.

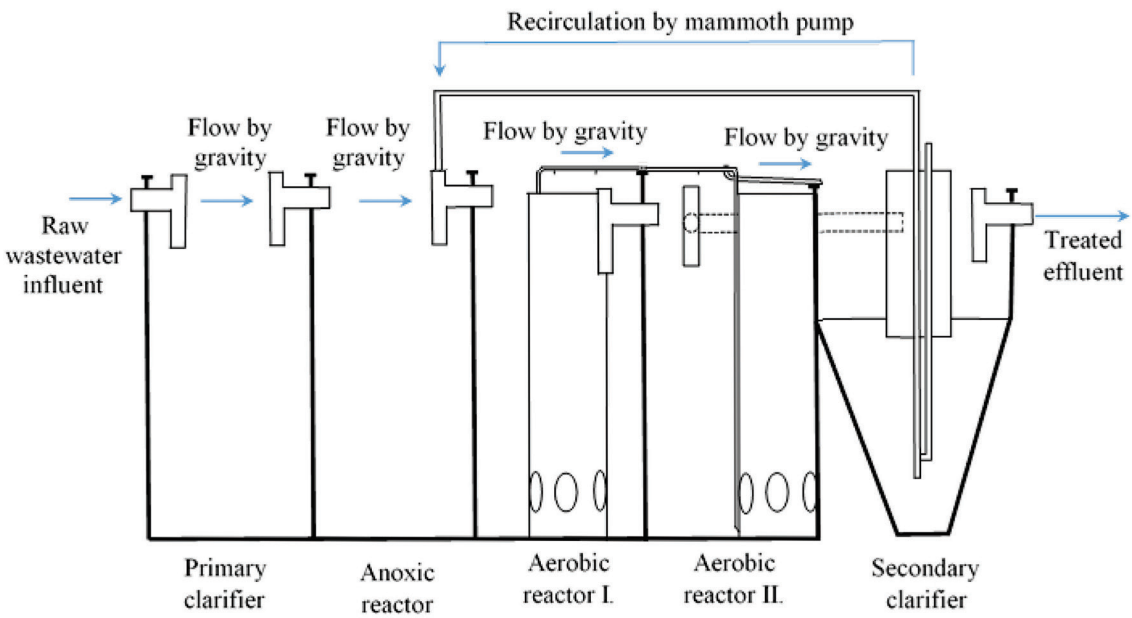

Figure 4
Operation principle of Polydox 30 and Polydox 50 [2]

Operational conditions

Wastewater is treated by bacteria that break down, "eat" the wastewater constituents during their metabolism. Bacteria are very sensitive to antibiotics and disinfectants because they destroy them in greater quantities. The following rules must be observed for the survival and reproduction of degrading bacteria:

- use up to 1 dl daily of chlorine-based cleaning and disinfecting agents (e.g. Hypo, FloraSept, Domestos, Clorox, Bref Duo Active, Devil, Tiret Professional, Cillit Duo); we could use our naturally degradable and environmentally friendly cleaners
- avoid using acids and alkalis (e.g. drain cleaners)
- up to 2 washing machine programs per day are recommended

– dangerous, therefore, it is forbidden to pour toxic or flammable substances into the drain: thinners, paints, pesticides, motor oil, etc.
– do not throw away any non-degradable materials, e.g. cigarette butts, paper diapers, wipes, cleaners, office paper, packaging materials, foils, etc.
– do not pour the cooking oil, food residue, fruit or vegetable residue used in the wastewater treatment plant, do not use food waste grinder
– do not let water from swimming pools or boilers into the unit
– wastewater from animal husbandry is forbidden to mix with household wastewater
– rainwater is not wastewater, do not discharge into the unit; it is advisable to collect in a separate closed rainwater collection tank, which could be used for irrigation

Maintenance instructions

A Polydox biological wastewater treatment unit does not require continuous monitoring, dedicated safety equipment such as conventional sludge biological systems, but periodic inspection is also required for these types. It is necessary to check and possibly replace the aeration elements every 5–6 years. No hazardous gases can be formed in the reactor space, no special protection requirements are needed. If the unit is not placed in an enclosed area, it must be surrounded by a fence to prevent unauthorised intrusion.

In case of settlement-level operation, a responsible person in charge of the equipment must be appointed and the operation must be solved in an organised manner. It is the responsibility of the operator to carry out the necessary checks, treatments, work and to keep the operation log up-to-date. The inspection should also cover the connecting structures outside the equipment.

Table 6
Inspection frequency of a small equipment by the owner of the residential property (compiled by the author)

Name of activity	Frequency
Visual inspection of equipment	Weekly
Checking of flows	Monthly
Checking the quality of treated wastewater	Monthly
Supply of electricity	Ongoing
Providing access to equipment	As needed

Table 7
Inspection frequency of the unit by the operator (compiled by the author)

Name of activity	Frequency
Measuring sludge blanket level in sludge storage	Monthly
Checking the turbidity of the settling tank, removing the floating materials	Every 3 weeks
Sampling and determine the quality of the influent and effluent	With the frequency specified by the inspectorates
Excess sludge removal	Annually
Correcting possible operational errors	As needed

In case of faulty operation of the equipment, the fault must be eliminated, the sampling must be repeated and the smooth operation must be verified by inspection.

Basic operations and machines for operating the equipment:

– air blower, whose air supply can be controlled by a blower valve
– control-operated homogeniser
– recirculating mammoth pump; operated according to the specified time program

Removed stabilised sludge does not pose an environmental hazard if disposed of in accordance with legal regulations.

Öko Tech Home Kft.

Figure 5
A.B. Clear wastewater treatment unit [3]

The company Öko Tech Home Kft. has been dealing with biological wastewater treatment since 2004. It has a pioneering role in promoting and spreading small size wastewater treatment units in Hungary. The installation and commissioning of the wastewater treatment units also belong to the company's profile; therefore, in this area considerable experience has been accumulated over the years. After several years of practical experience, a self-developed biological wastewater treatment equipment has been created. Using the operational and maintenance experience of the installed wastewater treatment units, an equipment has been developed which, with high treatment efficiency, has a minimum maintenance requirement. Efforts have been made to minimise the possibility of failure and the wastewater treatment plant does not contain wear parts. The product also has a CE conformity certificate. It is important that using a small biological wastewater treatment unit, the chemicals dosed in the household should be precisely selected. Also, citizens who have not previously favoured environmentally friendly detergents now have to switch to biodegradable products. This will help to save energy and protect the environment at the same time.

A.B. Clear biological wastewater treatment specification

The following data are from a report prepared by VITUKI (Water Science Research Institute in Hungary). Based on these, A.B. Clear biological wastewater treatment plants comply with 28/2004 (XII.25.) KvVM Decree (Annex 2, Category 3), which applies to intermittent watercourse.

Table 8
Treatment efficiency of A.B. Clear 6–8 and 10 wastewater treatment unit (compiled by the author)

Treatment efficiency	COD	BOD_5	Total suspended solid	$N\text{-}NH_4$	TN	TP
A.B. Clear treatment efficiency (%)	95	95	95	92	87	67
A.B. Clear effluent quality parameters (mg/l)	55	20	18	10	20	8

Table 9
Technical data of A.B. Clear 6–8 and 10 wastewater treatment unit (compiled by the author)

Technical data	A.B. Clear 6	A.B. Clear 8	A.B. Clear 10
Daily capacity (m^3)	0.78	1	1.3
Diameter (mm)	1,330	1,330	1,500
Height (mm)	1,900	2,200	2,530
Inlet pipe height (mm)	1,380	1,680	1,715
Outlet pipe height (mm)	1,220	1,520	1,555
Diameter of inlet and outlet pipe (mm)	110/110	110/110	110/110
Air blower pressure (Δp in mbar)	230	230	230
Air supply capacity (l/min)	30	37	52
Microbubble aeration unit (ø63 mm) length (mm)	0.3	0.36	0.5
Air power supply (W)	60	60	80

Field of uses recommended by the manufacturer

Detached houses

In case of family houses, it is easiest to implement self-sufficient biological wastewater treatment. Water can also be recycled easily and cheaply, and the garden can be watered with the treated effluent. If effluent water is used to rinse the toilet, drinking water consumption can be reduced by 30–40%. The device tolerates load fluctuations within wide limits, so neither a few days, a week's holiday, nor a larger visitor number can be a problem, they can be bridged by the introduction of a microprocessor control unit. The minimum space required for equipment and accessories such as artificial grass covers make the equipment almost invisible in any garden.

Holiday homes, weekend and hunting houses

The fluctuation of load in these properties is often significant in many cases. The holiday home is almost continuously used from spring to autumn, but in winter it is seldom visited. In this case, the microprocessor control unit is recommended for bridging smaller, few-day, weekly fluctuations. In this case, the wastewater treatment plant must be prepared for winter, drained and then filled with clean water. The device must be restarted upon re-use.

Pensions, motels

Biological wastewater treatment is also a good investment in the service sector, whether we look at wastewater drainage or savings from recycling. Due to their nature, these facilities may also be subject to strong load fluctuations, and many facilities have a seasonal variation. In such cases, the installation of two small wastewater treatment units could be a solution. Thus, in a low-load period, only one of the units is running, and at higher loads, the other equipment can be started, so the capacity of the system can be varied within wide limits. In addition, individual biological wastewater treatment for those who wish to provide ecotourism is also a good choice.

Apartments

Similarly to family houses, biological wastewater treatment units can be used for condominiums, and in this case, even the load fluctuations are lower.

Industries, offices

Treated water can be recycled: rinsing the toilets as well as irrigation of the green area around the site could be an option. However, it is important to note that the unit is suitable for treating household wastewater, so if any other industrial, technological wastewater is disposed of, it is necessary to agree with the service provider on possible pretreatment and other solutions.

Farms

For farms far away from central sewer networks, cesspools are currently widespread but individual wastewater treatment units could be an inexpensive and environmentally friendly solution. Treated water can also be used for irrigation. The power requirement of the equipment is minimal; therefore, it can be easily gained from solar, wind or other alternative systems. In case of farms, tendering opportunities are often published.

With our biological wastewater treatment, municipal wastewater can be reused for many purposes after the treatment. The best way for reuse is irrigation to plant root zone. After post treatment, the biologically treated wastewater can also be used for toilet flushing or car wash.

For example, in a four-person household, toilet flushing accounts for 35–40% of the water consumption. This can be saved by using treated water; where an existing cesspit is replaced, it can be used as a treated wastewater storage, making water management easier. If the water is not reused, it can drain into the gravel bed or be released into surface water if water permit allows it.

One of the easiest ways is to drain the rainwater or the treated wastewater. Water is drained into the soil through an underground pipe system. On the one hand, the system can be applied at the overflow of the storage tank, and on the other hand, it can ensure the root zone irrigation of the garden plants.

The main part of the drainage system is a pipe of at least 10 metres (perforated PVC pipe), one end of which is connected to the outlet pipe of the rainwater collecting tank and terminated in the ground, going down with a small slope at the end of the system above the ground with a vertical pipe. For better drainage efficiency, a large, washed (pebble) gravel should be wrapped around the pipe. It is recommended to make a 40 cm wide, 60 cm thick bed under the drainpipe. The drainage trench must be covered with geotextile over the pebbles and the drainage pipe to avoid spillage. The remainder can then be retracted with the originally extracted soil to provide a pedestrian or vehicle-accessible surface.

Incoming rainwater pipe is under the frost limit. The overflow must be below the inlet, at least with 2 cm. The pipe thus goes under the frost limit. Its minimum incline is equivalent to the sewer tubes, i.e. half a centimetre per meter. It is advisable to dig the trench required for laying the leaking pipe with a grab so that it is even, as its bottom should be completely horizontal. The drainage system can only be built on soils that have not been agitated or have been sufficiently compacted over the years.

Material requirements for drainage system, ideal for soil conditions at 10 metres:

- 10 m drainpipe, 100 mm in diameter
- geotextile, 10 metres long, 50 cm wide for covering the ditch
- 2 m^3 of gravel

For a soil with good water absorption, such as sand, a 10 m long drainpipe is sufficient. However, if the soil is clayey and water is difficult to drain, then a system of 20 or even 30 metres may be needed.

It is important that drainage can only be solved on your own site.

If treated wastewater is drained, the residual organic matter could feed the plants.

These wastewater treatment units use a unique technology to treat the sludge. The essence of the innovation is a structure that dewaters the excess sludge and collects it in a bag that is easy to handle, inside the container. This eliminates the need for sludge removal, and the collected sludge can be composted and utilised as a plant nutrient even in the home. Another advantage of this technology is that it automatically maintains the sludge amount in the system, so that in case of regular emptying of the sludge bag, neither the excessive sludge of the sewage treatment plant nor low sludge level is possible.

Operational principle of A.B. Clear 6–8 and 10 wastewater treatment unit

The technology used in the biological wastewater treatment unit is based on activated sludge technology. The wastewater coming from the household (kitchen, bathroom) discharges to the treatment unit, where the constituents are decomposed with the help of activated sludge under anaerobic and aerobic conditions.

The units apply total oxidation similarly to large urban wastewater treatment plants. All processes take place inside a tank, separate chambers correspond to different wastewater treatment processes. The decomposition is carried out by microorganisms. Where aeration is necessary, an air pump is installed.

The entering wastewater first flows through a coarse filter located in the anaerobic tank and retains the large solid particles. The soluble materials are fragmented here due to the water movement and along with the wastewater through the filter and through the chamber into the anoxic space. Here pollutants degrade without air.

Thereafter, the fluid enters the aerobic zone, which is aerated. Here, a microbubble aeration tube supplies the bacteria with oxygen; due to these processes, the device does not have an unpleasant odour. The wastewater enters the secondary clarifier after this last degradation process. Here the treated water and sludge are separated, water flows out at the upper part, sludge is taken out at the bottom of the chamber. Treated water that meets environmental standards and limits outflows through an outlet pipe.

The purpose of the mammoth pumps is to circulate the produced sludge within the tank and to remove excess sludge. Excess sludge is dewatered and stored until emptying. Treated water can also be placed directly in the final disposal (e.g. drainage) or stored in a cistern for subsequent recycling.

In A.B. Clear units, all processes are operated by air pumps. There are no other moving parts in these units. The electrical components are as follows:

- diaphragm air pump (factory part): low power, quiet, 230V power supply; it is constantly running with standard equipment; clean your air filter quarterly, every 50,000 operating hours replace the membrane
- AC motor (factory part): the air pump is normally supplied to the wastewater treatment unit, but directs all air to the mammoth pump of the sludge bag at pre-set times (default value is once a week), removing and dewatering excess sludge
- microprocessor controller (optional): it is recommended to use when the unit is underloaded or the load is fluctuating; it operates as a three-position timer; the modes must be set by the user on request

Advantages of A.B. Clear 6–8 and 10 wastewater treatment unit.

- The units provide an environmental solution equivalent to centralised wastewater treatment.
- Easy to install and operate. Installation takes only a few hours and anyone can learn how to operate it.
- Low investment and maintenance costs, the production and commissioning of the wastewater treatment unit do not exceed the average cost of connection to a central channel.
- Minimal dry solid – stabilised sludge – is produced during the decomposition of wastewater, e.g. about 0.5 m^3 per year for four people.
- The operation of the wastewater treatment plant is quiet, so it can be installed inside the building, no separate sound insulation is required.

- In addition to being easy to install due to the polypropylene plastic material, the biological wastewater treatment unit is highly resistant to environmental impacts and has a long service life.
- There is little chance of failure.
- The unit does not contain any substances harmful to the environment and operates without the use of additives.
- Low operating costs. The energy consumption of the household version of the unit is about 14–16 kWh/month.
- Biologically treated water can be re-used for root zone irrigation or for other purposes, and there is no channel fee, so the investment will pay off in one or two years.
- Minimal maintenance requirement.

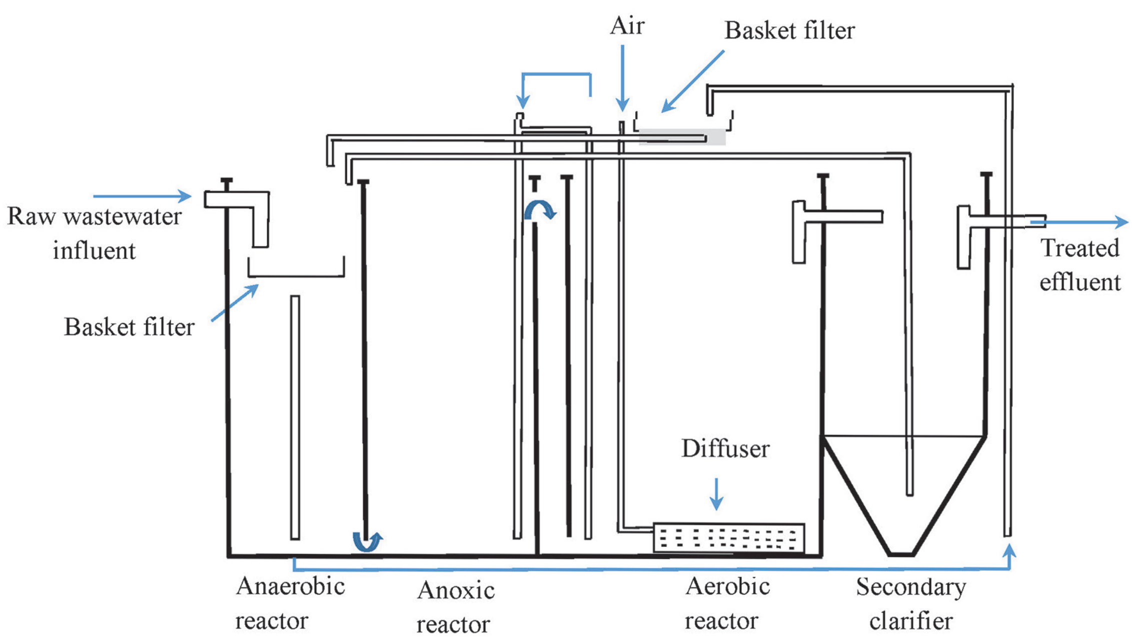

Figure 6
Operating principle of A.B. Clear units [4]

Inspection and maintenance of the sewage treatment unit

During operation, the equipment must be inspected visually at least weekly. The things to check are:

Odour

If there is no unpleasant smell at all when the equipment is opened, there is a biological equilibrium in the equipment. In case of strong odour (channel odour), the biological equilibrium is likely to be overturned, in which case please check the efficiency of the aeration, do the sludge probe.

Aeration

Aeration is one of the most important operating conditions for equipment. The air from the air diffuser is distributed by the valves to the chambers, so each component is monitored and checked. The microbubble air inlet is located at the bottom of the right and left semi-circular portions of the aerobic chamber. Normally, a large number of small bubbles will rise to the surface, and the water surface will be "bubbly". If there is no aeration at all, you need to make sure that the power supply is on, if there is voltage, then the valves need to be adjusted. If, instead of the many small bubbles, some large ones rise to the water surface, it means that the air intake element has been damaged so that it must be replaced.

Mammoth pump

Pumps without moving parts (Ø D 50 PVC thinner grey tubes) circulate the sludge inside the unit, as well as breaking up solid water-soluble wastes and sludge collection. They must operate continuously as they are set up during installation, but they need to be checked and adjusted if necessary. If the sludge concentration reaches 600–700 ml/l, it may cause blockage, which can be eliminated in several ways. The easiest solution is to temporarily open the appropriate valve. The mammoth pumps operate with significantly less air than the microbubble aeration, but in case of plugging, the tube can be blown through the complete closure of the other valves and full opening of the clogged pump valve. If this is done, remember to reset the valves as required. If the purging is not successful, you can also prevent a defect by pigging or pushing the hose inside.

Basket filter

This is a flange-shaped perforated sheet directly below the inlet pipe. This captures the large solids from the wastewater entering the sewer, its soluble components are largely fragmented due to air mixing from below. The insoluble wastes are retained and have to be removed from time to time. The cleaning cycle of the basket filter is determined by the amount of material that comes from the household, but it is generally recommended to clean it once a week. The filter can simply be removed from the tank. If there is not enough fluid in the filter due to plugging, the overflow will allow the water to flow, but this can lead to further blockages.

Water level

The unit is in continuous operation, therefore the water level can be considered constant. At higher loads, the water level in the chambers may rise slightly, which is normal. On the other hand, if we find that the walls separating the chambers are all under water, a coherent water surface has been created in the system, there is a blockage at the inlet or outlet. (This is usually the drainage system.) The obstruction in the unit is caused by the blockage outflow section, which can be removed with a Ø 10–12 mm rod. The blockage of the drainage system can be detected by looking through the aeration pipe on the system.

Foaming

It is necessary to distinguish between two types of foaming; one is white foam, which refers to the state of sludge deficiency (a phenomenon characteristic of post-inoculation, which disappears within one month after adaptation), while the other is brown foaming, which occurs if the sludge concentration is above 400–500 ml/l or the aeration is not sufficient. While detergents may cause excessive foaming due to the fluid flow, this does not cause any problem. If there is a thick, hard foam on top of the secondary clarifier, it must be removed and broken with a water jet and, if possible, eliminated. (This may be due to low or high aeration.)

Air valves

If we find that any aeration system components (grinders, mammoths R1 and R2, braking outflow and suction mammoths) are not working properly, for example, fine-bubble aeration is hardly working, or the mammoth pumps are not working enough, the valves in the unit will not work properly. Based on the user manual, all valves can be adjusted in the correct way. For other reasons, the valves shall not be adjusted: the process control cannot be solved by adjusting the valves.

Excess sludge

If we find a sludge ratio above 50%, it is worth removing the excess sludge with the help of a specialist (septage removal). If this is done, the aeration allowing the settling process to work has to be stopped. This takes half an hour or so in the same way as in sludge probes. In this case, the upper part of the fluid is almost completely clear in all the chambers, and the settled sludge is clearly visible at the bottom. The suction tube must be squeezed to the bottom of the chambers to remove the large part of the sludge. In this case, the fittings, pipes and connectors at the bottom of the chambers have to be handled with care to avoid damaging them during work. Sludge should not be completely pumped out because it contains the largest number of bacteria, which are responsible for biodegradation. The septage removal should be performed resulting that the water level is reduced by 40–50 cm in each chamber. It is important to move progressively during the emptying of the chambers; it should not be possible to have a difference of more than 30 cm between the water levels of each chamber, as this can damage the walls due to excessive pressure. The same applies to pumping and filling. The unit has 3 “chamber pairs” that are connected at the bottom, resulting in the fact that the pumping in one chamber has effect on the other chamber’s water level.

After removing the sludge, the water level in the unit must be restored. The easiest way to do this is by opening a garden hose or by opening the taps in the house or flushing the toilet. With the normal water level reset, the valve settings, aeration, mammoth pumps, etc. must be checked again according to the above-mentioned aspects. If we found everything right, the aeration should be restarted and the cover of the equipment returned.

Depending on the loading rate, sludge must be removed 1–3 times a year.

GRAF wastewater treatment unit

For over 50 years, the GRAF brand represents high quality plastic products. Established in 1962 and originally selling agricultural plastic boxes, it became the European market leader in rainwater harvesting. The GRAF Group currently employs a workforce of over 500 employees. It employs 310 people in Germany and has a turnover of over EUR 105 million. GRAF products are exported to more than 70 countries across the globe. They have been manufacturing and distributing small sewage treatment equipment since 2001.

Figure 7
One2Clean wastewater treatment unit [5]

Table 10
Technical data of the One2Clean wastewater treatment plant (compiled by the author)

Technical data	One2Clean 1-3 EW	One2Clean 4-5 EW
Maximum capacity	3 PE	5 PE
Maximum daily BOD_5 load	0.18 kg	0.30 kg
Maximum daily hydraulic capacity	0.45 m³	0.75 m³
Q_{hmax}	0.03 m³	0.05 m³
Maximum daily energy consumption	0.6 kWh	1 kWh
Line voltage	230 V	230 V
Installed power	42 W	48 W
Capacity built	450 l/d	750 l/d

Field of application of the One2Clean wastewater treatment unit

One2Clean wastewater treatment unit is a compact and easy-to-use biological wastewater treatment equipment that is suitable for the biological treatment of household wastewater between 1 and 50 inhabitants. One2Clean biological wastewater treatment units are ideal for treating communal wastewater from family homes, holiday resorts, restaurants, hotels, other service industry, public institutions (kindergartens, schools). It can be used under any circumstances, intermittently, with variable loads.

The One2Clean wastewater treatment unit complies with the requirements of MSZ-EN 12566-3 and has a CE Declaration of Conformity. This equipment provides an excellent environmental solution and does not have any harmful effects on the environment; it is quiet, odourless, with minimal external electrical energy input. The parts of the equipment are easy to install on the site and require no special expertise. It does not require continuous supervision during the operation, and the inspections and maintenance work can also be carried out by the owner of the property. The maintenance task consists primarily of the annual septage removal collected in the storage tank and the control of the aeration system.

System benefits:

– can be used under any circumstances
– programmable max. 90-day break (e.g. for weekend houses)
– operates with minimal external electricity input
– in the event of a break of more than 90 days, the system does not need to be drained
– CE certifications according to ISO 9001 and MSZ-EN 12566-3
– 5 years extended operating warranty
– excellent cleaning efficiency
– low operating and maintenance costs

Installation of the sewage treatment unit

The equipment must not be connected to the electricity network during the installation period. The equipment and the wastewater connection system must be protected from frost and must therefore be installed with a minimum of 50 cm of ground cover; if this cannot be ensured, a suitable insulating material has to be applied.

The installation of the equipment's electrical units must always be carried out by a specialist. All joints must be completely sealed, because leakage from the unit could contaminate the environment and adversely affect the performance of the equipment. Avoid excessive effort when tightening screws, as this may cause damage. When making connections, make sure that weight, vibrations, or stresses do not fall on the unit.

Connection to the wastewater inflow

Connection to the wastewater network is only possible after the entire system has been installed and after a successful operation test. Connector pipe size: NA 110 mm. The connection wire must always be sloped. When raw wastewater is discharged, the slope can be 1:100, and for treated wastewater the slope is 1:200. Avoid 90° bends, if necessary, install cleaning element or use 45° fittings. The connection pipe material can be KG-PVC or KPE. When using a pump, the recommended pipe diameter DK 32, material KPE, pressure class 6 bar.

Electrical connections

The power cord of the equipment must only be installed by an electrician. When installing the connection cable, it is necessary to provide the appropriate contact protection (FI relay and circuit breaker). The power cord can be permanently attached to the power cord. Never use the cable to pull the plug out of the socket. Protect the plug and the power cord from hot surfaces, oil pan and sharp edges.

The values given in the technical data must correspond to the mains voltage at the installation site. During installation, the person in charge must check whether the electrical connection has a grounding that meets the standard. Network connection can only be extended with the standard extension cable. The power plug and connections must be designed to protect against splashing water.

Installation and commissioning of the sewage treatment unit

The winter months should be avoided as far as possible during the commissioning of the equipment (December, January, February). The installation of the appliance must be carried out as described in the manual, otherwise the installation may cause malfunction. Nobody may remain in the container(s) and shaft(s) while operating the equipment. The appliance may only be used in a power range specified in the guarantee leaflet. Commissioning may only be carried out by trained persons aged 18 and over. The basic safety and health regulations must be adhered to during installation. Wash hands with disinfectant after contact with all sewage and sludge. It is important that the load capacity of the tanks and shaft covers is max. 70 kg, so it is forbidden to drive on the cover.

It is forbidden for the installer to consume alcohol before and during work.

Organic matter of wastewater is decomposed by cultured microorganisms in activated sludge. Starting the system needs to fill the unit with clean water. Water filling must also be carried out in the connecting pipes. Filling can be accelerated so that raw wastewater can be fed into the system, but it should not exceed 50% of the daily load. If it is only filled with clean water, 50% of the total amount of planned wastewater must be fed into the unit. If the total amount of wastewater arriving is not more than half of the planned value, of course the whole quantity can be discharged.

The introduction of wastewater into the aerobic zone begins the formation of activated sludge. This will increase to 3–4 weeks in summer and 6 to 8 weeks in winter to ensure maximum treatment efficiency, but within 10 days you can achieve an acceptable efficiency. Switch on the aeration unit after the raw wastewater has been discharged. The aeration unit is not in continuous operation and is switched on (programmed) by the controller. Hold in case of a power failure (no wastewater is generated for more than ten days), the program has to be switched to “holiday” operation.

Operation of the One2Clean wastewater treatment unit

Due to their low weight, small sewage treatment systems made of plastic can be installed without heavy equipment. This means that it is easy to transport and install in places that are difficult to access. Plastic wastewater tanks also have smooth internal surfaces that make treatment easy. What is more, plastic containers are 100% waterproof.

These systems are based on the idea that purification processes take place naturally if we provide the right conditions for operation. Oxygen is essential. If there is an oxygen deficiency in the system, the "good bacteria" that are needed for proper treatment are "replaced" by "bad bacteria" that grow in low oxygen conditions. These bacteria produce a black, sticky sludge that will gradually clog the system. Therefore, good oxygen supply of the system is absolutely necessary to prevent clogging.

The wastewater from the property is used for biological treatment and for storing the sewage sludge in the treatment tank. Biological treatment of wastewater is carried out by bacteria. An important part of the operation of the equipment is the creation of the proper aeration to ensure that the bacteria in the activated sludge have sufficient air (oxygen). The supply of a sufficient amount of fresh air (oxygen) is provided by a programmed control unit controlled by a compressor and a fine bubble aeration unit. The sampling point for the effluent wastewater quality is in the control cabinet.

The One2Clean wastewater treatment unit is based on the SBR principle (Sequencing Batch Reactor) and it has a batch operation. The equipment consists essentially of an aerobic unit (control cabinet). This unit is divided by a baffle wall and is divided into an activated sludge zone that is in contact with the lower part of the container, so that in this process the total amount of wastewater is directly controlled by an aerobic wastewater treatment. The whole equipment is aerated by a fine bubble aeration, and the bacteria that grow up in the activated sludge treat the wastewater biologically.

Wastewater treatment in the One2Clean is done without pretreatment; therefore, no anaerobic processes can develop. The operation of the wastewater treatment plant is controlled by a microprocessor control unit that controls the compressor and the air distribution.

SBR technology is a series of different phases that follow each other and run at least once a day.

Phase 1. Aeration: The incoming raw wastewater flows directly to the biological zone. There is no lifting, delay, the aerobic microorganisms immediately start wastewater biodegradation. Aeration is performed by a compressor that uses the ambient air. Aeration is a batch process that allows controlled wastewater treatment. Thus, the equipment can be adapted to different environmental conditions and loads.

Phase 2. Sedimentation: There is no aeration in the second stage. The activated sludge and other sedimentation materials settle by gravity. In the upper part, there is a clear water zone and the sludge is at the bottom. Possible floating sludge is above the clean water zone.

Phase 3. Removal of treated wastewater: At this stage, the biologically treated wastewater is discharged from the SBR tank. This pumping process is performed with compressed air according to the "mammoth pump principle". The device is designed not to absorb any floating sludge that may be formed at the top. The device provides the minimum water level without a separate structural element.

After Phase 3 is completed, Phase 1 starts again with the biological treatment. It runs 2 cycles a day. The individual selection of switching times can be set by the operator–maintenance personnel.

When using the biological sewage treatment unit, the followings should be considered:

- for bacteria, the optimum pH is between 6.5 and 7.5; detergents from households increase the pH, therefore, a maximum of 2 to 3 washing machine programs per day is allowed
- large amounts of concentrated acids and alkalis (> 0.5 l/day) should not be used, e.g. channel and drain cleaners; drainage of condensation and other heating boiler water and water used

in heating pipes; high concentrate organic pollutants, e.g. milk and dairy products, scraps of food, fruit and vegetable residues
- it is forbidden to introduce rainwater, swimming pool and Jacuzzi water, wastewater from animal husbandry and animal slurry, toxic substances: thinner, flammable substances, pesticides and motor oil into the sewer
- dispersal of non-degradable materials into sewers e.g. paper napkins, office paper, sanitary napkins, packaging material, foils, tomato shells, sunflower shells is not allowed
- limit the release of cooking fats and edible oils into the sewer (max. 2–3 dl/day); on the one hand, they can block the sewer system and, on the other hand, it is very unfavourable for microorganisms if they get into the sewage treatment unit; it is recommended collecting and composting them

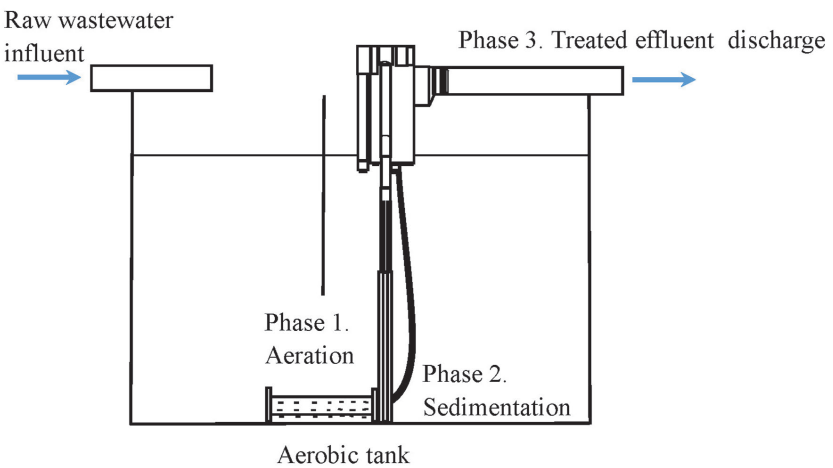

Figure 8
Operation principle of the One2Clean wastewater treatment unit (compiled by the author)

Monitoring and inspection frequency of the wastewater treatment unit

One2Clean does not require continuous monitoring, but periodic inspections are required for these types of equipment. These controls are partly carried out by the owner of the residential property (if any). No special safety equipment is required for general inspection and maintenance, but dangerous gases can be generated in the tanks and manholes, so it is forbidden to enter them. If maintenance or repairs are required in the tank or manhole, they may only be entered wearing suitable protective equipment after draining and adequate ventilation.

It is advisable to thoroughly inspect the entire system every 5 years. If the operator responsible for operating the equipment is designated, the operator is responsible for carrying out the necessary checks, treatments and other work.

The inspection should also cover the connecting structures outside the equipment. Winter operations and controls are similar to those in summer. Make sure that plastic products at low temperatures usually reduce their resistance to impact and mechanical forces.

The equipment must always be switched on. The operator's duty is to operate the equipment without error. Almost all malfunctions lead to a reduction in the treatment capacity of the equipment.

Therefore, errors should be recognised in time and corrected immediately or repaired by a qualified service technician. The periodic inspection shall be carried out as follows:

Daily checks: Daily check that the unit is operating properly. This is true even if the operating light is green and there is no audible alarm.

Monthly checks: Visual inspection of the sludge, there should be no turbidity or discoloration in the effluent. Checking the clogging of the influent/effluent (visual inspection). Read the air compressor operating hours (all hours of operation), aeration and drain valve, and record it in the event log.

Table 11
Inspection frequency of the unit by the operator (compiled by the author)

Name of activity	**Frequency**
Visual inspection of the unit and the control	Daily
Checking of flows	Every 6 months
Check sludge blanket level	Every 6 months
Sludge removal	Annually
Checking the aeration system	Every 6 months
On-site inspection, maintenance for all equipment	Every 6 months

Maintenance of the wastewater treatment unit

Wastewater treatment systems can operate in an active and passive manner depending on the installation. These wastewater treatment systems are reliable, robust, withstand extreme loads and load fluctuations, are durable and significantly reduce pollutants in raw wastewater. Their operation is simple; the maintenance covers the checking and fixing the errors in the tanks and in the aeration system.

However, the system may fail if there is clogging, and sewage could leak from the tank and raw wastewater may reach the infiltration area, but this malfunctioning is easily detectable. This phenomenon can be avoided by regular maintenance and inspection.

Control cabinet

From the supplied property, the wastewater flows directly into the treatment unit, where biological treatment takes place, and suspended solids and excess sludge collects. From the top of the manhole, it should be checked visually that the water level in the tank is adequate, there are no deposits around the openings and there is no hard layer on top of the wastewater. Visually, we need to make sure that there are no greasy or accumulated floating sludge at the inlet and outlet and around the water lift. If the lower level of the floating sludge approaches the upper end of the ending of the water lift, the floating sludge should be removed immediately. Other deposits should be removed with a long-edge brush or high-pressure washer. Check sludge levels at least twice a year. Excess sludge should be removed once a year. The tank should be filled with water after the sludge removal.

Dangerous gases can be generated in the unit; therefore, it is forbidden to enter. If maintenance or repair is needed, it can be entered wearing protective equipment after draining and adequate ventilation.

Lift station and pump

Visually determine that there are no deposits in the shaft and on the pump, check that the level switch is working properly. It is advisable to remove any deposits on the pump and pump shaft annually, making sure that any solids that may fall out of the pump do not enter the system. It is a common mistake that the level switch does not switch properly due to the deposited solids, and thus the water level in the shaft will rise, which will swell the system and the oxygen supply will be insufficient. The pump may remain permanently switched on due to deposits, resulting in damage to the pump.

Infiltration zone

Visually, in the area around the infiltration zone, the earth's surface must be dry and free of precipitates and should be odourless. If water appears on the surface of the infiltration zone, and the sampling shaft is filled with water, this indicates that the drainage area is blocked, overloaded, or the groundwater level has risen. In case of clogging, the infiltration zone must be flushed with a high-pressure washer through the cleaning opening at the end of the zone. If there is no visible result, the infiltration zone must be dismantled and clogging must be stopped; if this is not possible, the clogged pipes or gravel layer must be replaced. If the elevated groundwater level or the system is permanently overloaded, a new zone must be used. If there is a wastewater smell in the area, it indicates that the ventilation system is blocked.

In order to determine whether there is a need to remove excess sludge from the wastewater treatment unit, a sedimentation test should be carried out according to the maintenance interval. The SV30 must be determined for the sedimentation test. SV30 is the amount of sludge that can be measured after 30 minutes of sedimentation of 1,000 ml of sludge. The amount of sludge in the wastewater treatment plant can be determined on the basis of SV30. The SV30 is measured in a 1,000 ml stationary cylinder.

The following steps must be followed when measuring:

1. Switch on aeration – if not active – and let the sludge mix briefly.
2. Immerse the sampling vessel in the container and take a sample of the activated sludge.
3. Fill the sludge sample into the stationary cylinder to the 1,000 ml mark.
4. Allow the sample to settle in the stationary cylinder for 30 minutes without agitation.
5. Read the sludge height. If the level is > 900 ml/l, then the excess sludge should be removed.

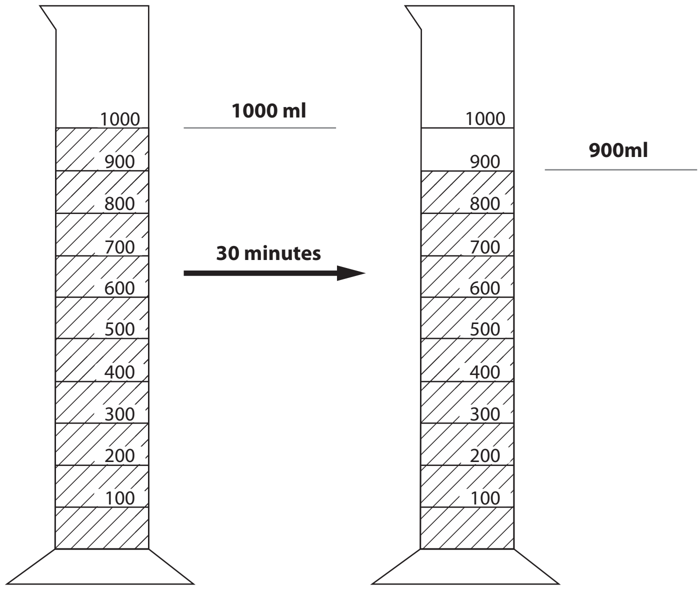

Figure 9
Sludge settling test (compiled by the author)

ASIO AS-VARIOcomp wastewater treatment units

ASIO Hungária Kft. is present on the domestic market as a member of the ASIOGROUP group of companies, which has nearly 20 years of professional experience and significant international background. Their main profile is the distribution and production of polypropylene wastewater treatment equipment. Their activities range from the preparation of licensing and implementation plans, through production, to commissioning, but they can also help with long-term, reliable operation with the maintenance service. The technologies distributed are becoming more widespread; these have been used worldwide in many places.

In addition to their wastewater products (grease, oil separator, industrial and communal wastewater treatment units), the company deals with conventional storage and buffer tanks, as well as rainwater recycling systems, which can be customised according to the needs of the customers. As opposed to expensive regional systems, AS-VARIOcomp is the perfect solution for small settlements, as well as for the private and public sectors where there is no public sewer connection or a central sewage collection system. At these locations, the AS-VARIOcomp biological wastewater treatment plant operates as a classical utility replacement, providing a technically and environmentally sound background for cost-effective treatment of wastewater treatment.

Figure 10
AS-VARIOcomp K [6]

Table 12
Technical specifications of AS-VARIOcomp K (compiled by the author)

Type	Population Equivalent (PE)	Q (m^3/day)	BOD_5 (kg/day)	Size (diameter × height) (mm)	Weight (kg)	Energy demand (W)
5K	3–5	0.6	0.24	1,320 × 2,020	160	60
8K	6–10	1.2	0.48	1,480 × 2,020	260	80
15K	11–17	2.25	0.9	1,700 × 2,800	450	110
20K	18–24	3	1.2	1,945 × 2,810	700	120
5K ULTRA	3–5	0.6	0.24	1,320 × 2,020	195	150
8K ULTRA	6–10	1.2	0.48	1,480 × 2,020	275	170
15K ULTAR	11–17	2.25	0.9	1,700 × 2,800	480	390
20K ULTRA	18–24	3	1.2	1,945 × 2,810	730	400

Table 13
Process guarantee on effluent – AS-VARIOcomp K and K ULTRA (compiled by the author)

Parameter	AS-VARIOcomp K	AS-VARIOcomp K ULTRA
BOD_5 (mg/l)	25	5
COD (mg/l)	90	40
Suspended solids (mg/l)	30	3
P_{total} (mg/l)	2	2

Application of AS-VARIOcomp K

There are many ways of application of AS-VARIOcompK treatment unit such as:
- single-family houses
- motels
- restaurants
- smaller industrial facilities

Can be used in residential areas that are only temporarily occupied – e.g. holiday and weekend houses, ranches, hunting houses – where there is no continuous wastewater load.

Figure 11
AS-VARIOcomp unit [6]

Table 14
Technical specifications – AS-VARIOcomp

Type	Population Equivalent (PE)	Q (m^3/d)	BOD_5 (kg/d)	Size (LxWxH) (mm)	Weight (kg)		Energy demand (kW)	
					N	N/PUMP	N	N/PUMP
30N	25–33	3.75–4.95	1.62	2,000 × 2,160 × 2,830	1,250	1,320	0.33	1.2
40N	34–44	5.1–6.6	2.28	3,000 × 2,160 × 2,830	1,400	1,470	0.33	1.2
50N	45–55	6.75–8.25	3	4,000 × 2,160 × 2,830	1,750	1,820	0.75	1.4
60N	56–70	8.4–10.5	3.6	4,000 × 2,160 × 2,870	1,900	1,970	0.75	1.6
80N	71–90	10.65–13.5	4.8	5,000 × 2,160 × 2,870	2,200	2,270	0.75	1.6
100N	91–110	13.65–16.5	6	6,000 × 2,160 × 2,870	2,450	2,520	1.5	2
125N	111–135	16.65–20.25	7.5	7,000 × 2,160 × 2,870	2,700	2,770	1.5	2
150N	136–155	20.4–23.25	9	8,000 × 2,160 × 2,870	2,950	3,020	1.5	2

For AS-VARIOcomp N/P and AS-VARIOcomp N/P/PUMP equipment, the phosphorus concentration of the effluent treated water must not exceed 2 mg/l.

Table 15
Process guarantee on effluent – AS-VARIOcomp

Parameter	Effluent
BOD_5 (mg/l)	25
COD (mg/l)	100
Suspended solid (mg/l)	25

Installation of the AS-VARIOcomp wastewater treatment unit

The equipment may not be installed in a location where the integrity of the equipment is endangered, such as territory with earthquake hazards and floodplains.

The installation must be carried out in accordance with the approved design or construction plan. Deviations from the licensing or export plan may only be made with the written permission of the designer.

In case of installation, the depth of the foundation pit shall be determined so that the sandstone gravel levelling layer and the reinforced concrete substrate determined by the designer are located. Under the reinforced concrete min. 10.0 cm thick sandy gravel (grain size: 2–10 mm) shall be placed for balancing purpose. The construction of the concrete slab can be a ±1 mm flat (±1–3‰ slope) surface. The surface of the reinforced concrete is determined by the designer depending on the surface and weight of the unit.

The level of the reinforced concrete for the stability of the equipment must be determined.

The perimeter of the pit is approximately 50 cm greater than the perimeter of the equipment to be installed.

In case of high groundwater level, the installation must be concreted around. The height of the concreting is determined by the designer based on the maximum groundwater level.

Installation steps:

1. The dimensions of the pit and the buoyancy force must be determined by the designer taking into account the groundwater level.
2. There must be no water in the work pit. Otherwise, its level should be lowered to the base level.
3. After preparing the concrete foundation, check the unevenness of the concrete foundation (tolerance ±1 mm) and record the result of the measurement. In case the unevenness does not correspond to the allowed tolerance, the installation should not be continued. Provision must be made for adequate tolerance.
4. Prior to insertion, the condition of the equipment should be checked, especially for welds. In case of potential damage, do not proceed with installation and contact the manufacturer/distributor. Damages must be repaired before being placed in the work pit.
5. Make sure there is no foreign material or rainwater in the unit. The foreign objects must be removed; the rainwater must be pumped out.
6. Make sure that there are no objects, stones, earth, etc. on the concrete. These should be removed if necessary. If this "dirt" cannot be removed from the concrete base, the installation should not be continued.
7. The release of the unit onto the concrete slab should be carried out evenly and slowly.

8. After the tank has been placed, the surfaces must be cleaned of dirt by mechanical means.
9. Then the piping – the inlet and outlet pipes – must be connected to the tank. The connection seals must be made with silicone oil.
10. The equipment consists of one compressor, installation or connection (electrical and air pipe connections) by the designer based on the design documentation. For larger equipment, the machine consists of several units (compressors, pumps, control panel). They must be installed by the customer, but their connection is always undertaken by the manufacturer/distributor and will be carried out at an agreed time after completion. The manufacturer/distributor makes a first setting on the control panel after wiring the electrical equipment. However, during the subsequent operation, the operator must be provided by the manufacturer/distributor for the maintenance or servicing of electrical equipment.
11. The electrical connection must be carried out by a qualified technician using the original connection cable. During concreting, the tank must be stiffened from the inside against the pressure of the concrete. The need for stiffening is determined by the designer. Prior to concreting, the tank must be filled with water up to a height of 1 m and then the height of the water level must be raised continuously along with the rate of concreting so that the water level above the concreting level should be at least 30 cm.
12. When recharging with the ground, the tank must be filled with water up to a height of 1 m and then the height of the water level must be raised continuously, along with the rate of discharge, so that the water level above the concreting level should be at least 30 cm. Compression of individual layers max. 30 cm layers – the compactness (Trφ) specified in the design – can only be done with a light compacting machine (e.g. cart), making sure that the packing machine does not touch the container. When compacting the ground, make sure that the pipe connections are not damaged. If the pipe end of the unit is damaged or broken during the earthwork, the manufacturer/distributor is not able to carry out warranty repairs, and the manufacturer/distributor will correct the defect for a fee.
13. In case of concreting or backfilling with earth, the tanks above the discharge height must be stiffened from the inside. It is recommended to place the supports at a height of 0.5 m, horizontally, at 1.0 m.
14. If the slab is concreted, it must be supported by the slab to prevent the tank from falling.
15. After installation, the MSZ 172-1: 1989 contact and ground resistance test must be performed.
16. The installation, touch protection and grounding protocols must be retained by the operator.

Commissioning of the AS-VARIOcomp wastewater treatment unit

Installation must always be carried out by the manufacturer/distributor before putting the equipment into operation. In the commissioning, customers (operators) are trained by the distributer.

The commissioning consists of:

- full control
- checking the base
- staff training
- giving the original documentation

The commissioning report is prepared, which contains the data and signatures of the trained persons.

- proposal for commissioning
- operational log book

The waterproofness of the container must be checked by a seal test. The water tightness test is carried out by the manufacturer/distributor during manufacture, and the water tightness of the equipment is covered by the warranty.

The operation of the unit starts with the initiation of biological processes. To start the aeration, the cable of the air compressor is to be connected to the electricity grid. The appropriate connector is selected during the installation of the wastewater treatment plant.

In the event of any damage of the power cord, unplug the air compressor immediately from the connector and ensure that it is properly replaced. Once the air compressor is switched on and the tank is filled with clean water, it is possible to start the equipment.

The air pump must be kept permanently switched on, otherwise the required efficiency cannot be achieved.

The treatment efficiency gradually increases and reaches maximum efficiency in about 4–8 weeks. The time can be reduced by applying activated sludge from an external source. It is advisable to obtain sludge from a well-functioning plant for inoculation. In this case, contact the manufacturer/distributor.

Purpose and tasks of the testing period

Purposes

The test operation is a definite period of time prior to the final commissioning of the equipment. The purpose of the test operation is to drive the equipment, to set the parameters of the treatment technology, to prove the performance of the equipment in practice, and to develop the optimal operation of the entire system.

Tasks and responsibilities

During the test operation, professional supervision must be ensured. The task of the operator in test mode is to carry out measurements and tests necessary to achieve the specified objective, to evaluate the system and to prepare the final handling and maintenance instructions based on the set parameters.

Test run conditions

The proper installation of the equipment is a prerequisite for starting the test period. The operation must be checked in advance with tests, where the designer, the constructor, the investor, the actual operator, the future operator and the representative of the administration must be present. During the operational tests, the durability of the performance shall be verified.

Operation of the AS-VARIOcomp wastewater treatment unit

Parts of the equipment:

Primary clarifier: The incoming settable solids are retained. The sediment from the sewage and the activated sludge are stored here. Mineralisation takes place here; the high molecular substances are broken down.

Biological tank: Mixture of microorganisms, called activated sludge, are "fed" from organic and inorganic substances, using the oxygen of the air. The more the amount of the activated sludge increases, the more the content of organic matter in the wastewater decreases.

Secondary clarifier: Settling process separates the activated sludge from the treated wastewater. In reality, this is a relatively complicated biochemical-technological process that works when an optimal amount of air is introduced into the system, optimal concentration and sludge age is maintained.

The processes of the wastewater treatment plant are integrated into a tank. In order to improve the treatment efficiency, a biomass carrier can be placed in the biological volume, which is a solid grid that retains and grows microorganisms that feed on the substrate (nutrient) in the wastewater like the activated sludge. For pumping, mammoth pumps (a tube with air at the lower end that goes up and takes up the fluid to be pumped) are used.

The wastewater flows into the pre-settler where the mechanical, floating and settable materials are removed. The primary effluent flows to the biological zone, where activated sludge and attached biomass are responsible for biological treatment. The activated sludge flocs consist of bacteria (autotrophs, heterotrophs, within that nitrifiers, denitrifisers: Pseudomonas, Nitrozomonas, Nitrobacter). The mixture of fluid and activated sludge flows from the biological reactor to the secondary clarifier, where the treated water is separated from the activated sludge by sedimentation. Treated water is transferred to the outflow tank by means of the mammoth pump, from which it leaves the sewage treatment plant. The majority of the settled sludge is recirculated to the biological zone. The excess, aerobically stabilised sludge is reverted back to the primary clarifier.

The equipment is able to equalise the diurnal flow fluctuations. The air used by the aerator is provided by the air compressor. The air from the aeration is used to drive the mammoth pumps.

Temporarily, when the unit is underloaded (during holidays), instead of letting out the treated water, the flow is reverted back to the clarifier.

AS-VARIOcomp wastewater treatment units in series

If two units with 100 PE are in series, the first one is highly loaded, the second one receives less load. In this case, each stage has its own sludge recirculation, so at the end of the technological process, the sludge age could be increased by 2/3 of the original sludge age resulting in better efficiency.

It is worth to use an anaerobic pre-selector zone, where the recirculated sludge could be introduced. This results in more efficient phosphorus removal. In the first stage, aeration has a higher intensity and the sludge age is lower compared to the second stage. The biological processes are identical compared to the one stage system.

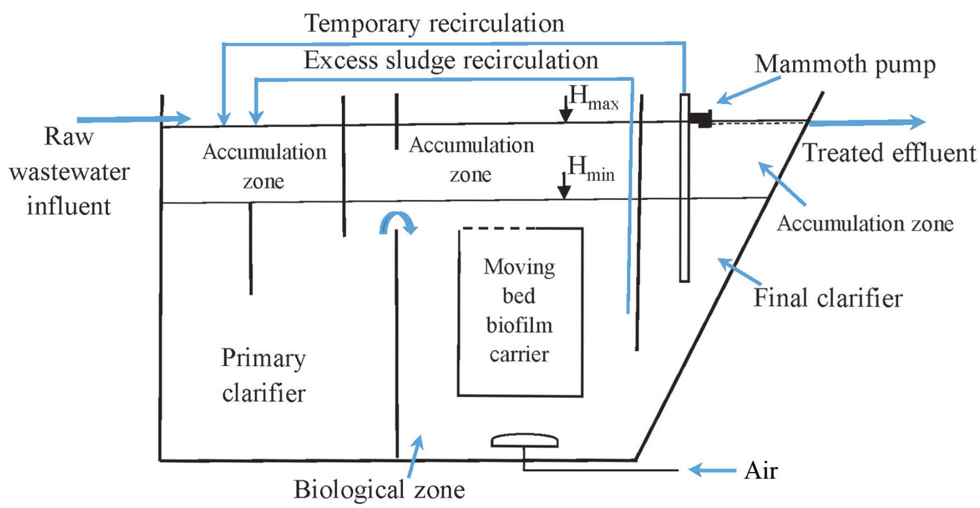

Figure 12
Operation of the AS-VARIOcomp (compiled by the author)

Processes in the AS-VARIOcomp

The composition of the household wastewater depends on the lifestyle of the people living in the area, but in general it can be stated that raw wastewater discharge is not allowed into surface water. In most cases, combinations of physicochemical and biological processes should be used to treat the wastewater. Non-soluble, floating or coarse matter should be filtered with screens, sand settled in grit chambers, prior to further treatment. Aerobic biological processes produce excess sludge, which must also be separated from the aqueous phase by mechanical means.

Depending on the sensitivity of the recipient, treatment should always be done in a controlled manner, which should be provided by a combination of the above methods. Removal of nitrogen compounds means spatial or temporal alternation of aerobic and anoxic conditions. Under these conditions, the sludge recirculation from oxic to anaerobic zones can significantly increase the phosphorus removal without chemical addition. Municipal wastewater treatment is a complex system in which all the nutrients necessary for microbial growth are available.

There are few products in the human activity, the quantity of which is close to the amount of wastewater and simultaneously, continuously generated and processed. In dry weather, household wastewater actually contains only the wastes removed by the population together with liquid. This comes from toilet use, bathing, hand washing and washing.

Treatment stages of the AS-VARIOcomp wastewater treatment plant

Mechanical pretreatment: Its purpose is to protect the equipment from larger solids. This is usually solved with a screen installed in front of the unit. This screen has to be cleaned from time to time; screening is a hazardous waste due to its microbiological activity.

Clarification: Its purpose is to remove suspended materials and related adsorbed pollutants, thereby reducing the load on the biological unit. The load of the equipment is, of course, dependent on the length of the sewer system; we do not include it in the evaluation and analysis, since in this case there is no sewage transport. In large wastewater treatment plants, it is a huge problem that wastewater travels for half a day or even longer, before it arrives to the wastewater treatment plant, causing unpleasant anaerobic processes. For a 10-km-long gravitational public sewer, it will take 3 to 6 hours for the wastewater to get to the sewage treatment plant. This is not the case here, because the channel is very short.

Biological treatment: Its purpose is to remove inorganic and organic pollutants in the wastewater by microbiological processes, using oxygen. The products of the processes are carbon dioxide, sludge (inorganic and organic matter containing nitrogen and phosphorus, cells of dead microbes), nitrogen gas, nitrite, nitrate and sulphate compounds.

Secondary sedimentation: Its purpose is to separate the sludge from the treated wastewater. Sludge is a mixture of water and solid particles with varying dispersions and shapes, which are expressed in dry matter, approximately 2–9%.

The effluent from the primary clarifier flows to the aeration unit. Organic matter is removed in the aerated zone. The process is performed by autotrophic and heterotrophic microorganisms. Air is injected with an atomiser and the purpose of aeration is twofold, one is aeration, another purpose is to mix the sludge so that it does not settle in the equipment and there is no digesting process in the anaerobic anoxic micro-environment at the bottom of the tank.

The removal of ammonia is carried out by Nitrosomonas europeae, the product of the process is nitrite ion, which is converted into nitrate by the Nitrobacter winogradsky. Phosphorus is in the form of phosphate, inorganic polyphosphate, organic phosphate (ATP, ADP, AMP). With lime, aluminium salts can be precipitated, or pre-precipitated in the system, but in the latter case, the amount of sludge should be increased.

Conversely, phosphorus may be present in critical quantities, which can be a problem for treated wastewater as phosphorus causes eutrophication (nutrient enrichment) in surface water.

The treatment process is carried out by the biomass, i.e. sludge, composed of microorganisms. These are autotrophic or heterotrophic bacteria, including anaerobic, aerobic or facultative anaerobic microbes in the biomass. This is a microorganism community in the sludge, each of which depends on the other: the nitrifiers and denitrifiers live in symbiosis. Activated sludge develops spontaneously; if we inoculate our system with sludge from a well-functioning plant, this process can be significantly accelerated.

The critical operating condition is the amount of substrate, i.e. the material to be removed from the wastewater and temperature. Obviously, the processes are faster when the temperature is high, but of course, the temperature of the water does not need to be continuously measured with a thermometer, as the temperature depends on the time of day and weather. (Warm water used for washing and bathing is likely to heat the water to a satisfactory temperature). Most of the microbes feel mesophilic at 20–40°C and can reproduce and function.

We have already mentioned the load on the equipment as an important parameter for large plants. We can also talk about the load here, but in the present case, the key factor is not the easily biodegradable organic matter, but the flow fluctuations.

During the day, most people are not at home, they go to work. If we look at the overall use of water, we can see that in the morning when we are preparing, there is much greater water use than at noon when only young and older people in the inactive age are at home. The other peak is in the evening: we arrive home, wash, bathe, cook. At weekends, cleaning is responsible for the high water consumption. We should consider these fluctuations in the wastewater treatment unit as well. When the waterflow is low, water stops in the equipment, as there is no pumping. The other case is when suddenly the amount of water flowing in increases putting a higher load on the substrate: it is advisable to set the aeration to a higher degree.

An additional advantage of the aeration is to prevent sludge bulking. This phenomenon occurs when a low amount of nutrients is found in microorganisms. In nutrient-deficient media, microbes are long; they grow like yarns to reach the nutrient. This prevents flocculation and the filtering of flocculated sludge.

If the aeration intensity is low, it is not possible to apply high sludge load (nutrient-rich sludge), because it may cause sludge bulking. To prevent sludge bulking, two separate zones have to be ensured, one is nutrient rich, the other one has low nutrient concentration. This means in practice to have an anoxic zone prior to the aerobic zone.

The sludge will be starved in an anoxic system since the aerobic microorganisms could only gain oxygen from nitrate.

It is important to remember that raw wastewater does not contain nitrate since human activity produces ammonium ion. Nitrates are produced during the operation of microorganisms in wastewater.

The result of the wastewater treatment is the effluent water, carbon dioxide and other gases. Another product is the sludge. From the biological unit the water flows to the secondary clarifier, where phase separation occurs. The essence of this is that the solids settle down and the clear water is discharged at the top. It can happen that biological processes occur in the secondary clarifier. Anaerobic conditions may develop, where methane and other gases are produced and the sludge rises.

Such a problem cannot occur if the sludge comes from a well-aerated system. It is recommended that sludge be removed twice a year and transported. The volume of excess sludge is high, its infectibility and pollutant content are varied.

In order to ensure the smooth operation of the equipment and the effluent quality, the following materials should be avoided in the household:

- infectious and toxic substances
- paint, solvents and chemical sprays
- non-dissolved acids and alkalis
- other chemicals such as chemical developers, adhesives

Take care of disinfectants: Sanitary hygiene disinfectants should be used very carefully. Not only viruses and bacteria in the household are destroyed, but also bacteria in the wastewater treatment equipment that perform the treatment.

Care should be taken to avoid excessive washing: The treatment process in the wastewater treatment unit is adversely affected by the sudden waterflow containing large amounts of detergents and surfactants.

Take care of fats and grease: In addition to chemical factors, large amounts of animal fats and vegetable oils also pose a threat to the performance of the treatment process. During the decomposition of fats and grease, the environment becomes acidic, deteriorating the treatment efficiency.

Take care of the water discharged from pools: Large amount of clear water discharge, even if it has no pollutants, could cause “microorganism wash-out”.

It is advisable to separate the rainwater from the wastewater network, because it increases the fluid volume and dilutes the wastewater causing nutrient-poor zones.

In nutrient-poor zones, filamentous bacteria may develop with low settleability. Water from swimming pools should not be allowed to discharge.

The operating and maintenance instructions of the equipment must cover the maintenance of each technological equipment and components. Sludge management shall be also addressed.

The operation of the equipment shall follow technology, safety and public health regulations and the conditions for the operation shall be specified in a separate manual.

The operating rules must include regulations on:

– daily operation
– technological processes
– periodic inspections and checks, record and evaluation of operating data
– personal conditions
– security, rules for emergency and health protection, preliminary and periodic medical examinations

The operator must have:

– equipment documentation
– labour protection and protection against physical contact documents
– technical documentation and commissioning protocol

Implementation of the operating instructions must be recorded in an operational log. The log is managed by the operator recording sampling and other events. After power-up, regular checks and activities specified below should be performed.

Table 16

Maintenance frequency (compiled by the author)

Name of operation	Time interval
Checking air compressor operation	Daily
Visual inspection of the unit	Weekly
Check and adjust sediment cycle	Monthly
Sludge removal	Every 6 months
Air filter cleaning	Every 3 months
Dewatering the aerator	Every 3 months
Cleaning of interior parts of the unit	As needed
Removal of spilled sludge	As needed
Sampling	As needed

Check air compressor: It must be verified, whether the air compressor is working. Unusual noise could be a sign of failure.

Visual inspection: Visual check has a high importance in the successful operation.

After opening the lid, the followings should be checked:

Mammoth pump: The mammoth pump is a submerged pipe, having air at the bottom responsible for sludge recirculation and the treated water effluent. In case of proper operation, the water flows continuously through the respective outlets. In case of trouble-free operation, the outlet openings must not be fed. If any malfunction is suspected, the mammoth pump must be cleaned.

Aeration operation: For proper functioning of the aerator, the basin surface contains a layer with fine bubbles. If this layer is not formed, the air compressor operation shall be checked (clogging the filter, electrical connector cable).

Checking the outlet pipe: No sludge or solids should be present at the outlet. This may be due to high aeration intensity, high flowrate, small amount of biomass. If it occurs, it needs to be cleaned. The presence of water in the outlet manifold indicates that the effluent pipe is blocked. If this happens, it needs to be cleaned.

Checking the level of secondary clarifier: The sediment precipitated on the surface of the clarifier may occur. If this phenomenon occurs often, this could be a sign of the excess sludge in the clarifier. In this case, the sludge level should be checked and provide sludge removal. In addition, the floating sediment may also refer to anaerobic condition. The gases produced could lift the sludge to the surface of the clarifier. In this case, the sludge recirculation should be increased or an anaerobic zone should be created.

Check and set sludge recirculation: The wastewater treatment process requires an optimum amount of activated sludge. Activated sludge is made up of microorganisms and the excess biomass should be removed. Removal of excess sludge is done by the mammoth pump. Removal of the floating sludge is achieved by means of a dipping device.

The amount of sludge in the biological tank should be checked:

- using a ladle attached to a handle, water should be removed from the unit and the sample should be poured into an Imhoff cone or 1 l cylinder
- the full Imhoff cone (or measuring cylinder) should be set to level ground and left for approximately 30 minutes to settle

The sludge blanket level should be checked. The result of the observation provides information on the concentration of activated sludge.

Optimal concentration of activated sludge: The volume of settled sludge is 1/3 to 1/2 of the volume of the Imhoff cone, which means that about the same amount of sludge is removed than produced.

Low concentration of activated sludge: The volume of settled sludge is smaller than 1/3 of the volume of the Imhoff cone, which means that more sludge is removed than produced. Therefore, sludge removal should be reduced.

High concentration of activated sludge: The volume of settled sludge is larger than half of the volume of the Imhoff cone, which means that less sludge is removed than produced. Therefore, the amount of excess sludge should be increased.

No activated sludge developed: There is no exact sludge blanket. This means that no activated sludge has been formed. This could happen in the commissioning period. Or, it had been formed, but washed out (for example, a larger amount of detergent discharged). In both cases, another week is needed to observe whether the situation develops or not.

The activated sludge did not settle after 30 minutes: There is no exact sludge blanket level because the sludge is found in the full volume of the cone. The sludge has poor sedation capabilities. It will improve during the operation of the wastewater treatment unit.

The poor settling ability of the sludge can also result from improper loading of the equipment (for example, by introducing sweet water).

Sludge removal: Wastewater and related products are hazardous waste and the treatment should be in accordance with legal requirements. Sludge removal can be done only by a licensed company. Sludge removal is done by a septage truck. The suction basket is placed at the bottom of the unit.

The sedimentation volume becomes available after opening the odour-closing lid. To properly remove the sludge, the upper hard cover of the sludge layer must be broken and the contents of the clarifier must be mixed and then can be the sludge removal performed. Switch off the air pump before inserting the suction basket.

Care should be taken so that the suction basket is carefully placed in the clarifier not to puncture the bottom of the container or the baffles.

Sludge removal shall not exceed 60–70% of the sludge; the rest 30–40% is needed for recirculation. After the sludge removal, fill the sedimentation area immediately with clean water and switch on the air pump. No fluid from other compartments should be removed.

Air filter cleaning: The air compressor can be damaged by dust accumulated on the air filter. This can be prevented by blow out or sucking off dust.

Dewatering the aerator: Condensed water from the aerator shall be removed. Carefully open the screw on the aeration valve and leave to make all water flow out. In that moment when only air is leaving the pipeline the screw must be pulled back firmly again. The air pump unit must operate during decompression.

During winter operation, the containers should be closely monitored and when icing is visible, the ice must be broken.

Cleaning of interior parts of the unit: Clean the walls of the tank; dirt and settled solids should be removed by brush and by rinsing the surface.

Cleaning mammoth pumps: The deposited solids on the openings can be removed with a brush. The individual parts should also be rinsed with clean water. The outflow “elbow tube” of the mammoth pump must be turned upwards in the outlet tank before cleaning.

Removal of spilled sludge: For example, sediment from the level of the filling zone can be drained with a ladle and this sediment shall be returned to the primary sedimentation.

BV-I wastewater treatment unit

The BV-I individual wastewater treatment unit is a reliable solution where connection to the sewage collection system is not economically sound. Domestic wastewater is treated locally at such a degree that the effluent could be used for irrigation or could be emitted into a suitable recipient. Due to its simple structure and low operating costs, this equipment is widely used. BV-I achieves 95–98% organic matter removal and its operation is highly reliable.

Its structural design ensures the quantitative and qualitative equalisation of the wastewater; the aeration-mixing equipment maintains the necessary oxygen content and keeps the sludge suspended; sludge recirculation does not require sludge pump.

The hydraulic capacity of the BV-I is 1.3 m^3/day; therefore, it is suitable for treating communal wastewater of family houses, small condominiums, pensions, hotels, plants, offices.

Its function is odourless and not noisy; it fits into the overall picture of the garden, so it can be placed in the immediate vicinity of the apartment buildings.

Sludge removal is enough once a year in order to remove the inorganic pollutants as well as the floating grease and fat. The BV-I treated effluent can be further used by root zone irrigation as per the current legislation. BV-I consists of a pre-fabricated concrete basin and a technological unit built on it. Due to the prefabrication, no installation is carried out at the place of installation, only the placement of the reinforced concrete structure and the technological installation.

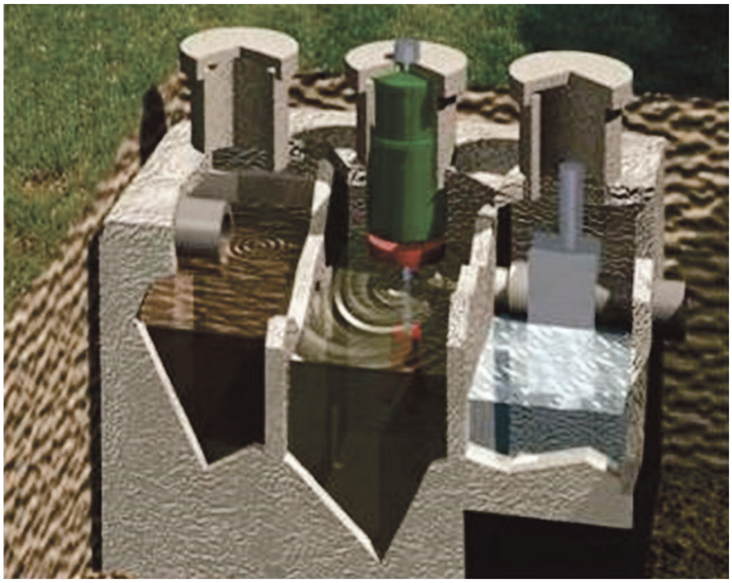

Figure 13
BV-I wastewater treatment unit [7]

Table 17
Technical specifications of BV-I (compiled by the author)

Size	2,800 × 1,680 × 1,800 mm
Performance	180 W
Electric connection	230 V
Inlet size	DN110 PVC pipe
Outlet size	DN110 PVC pipe
Energy use	1 kWh/day
Hydraulic capacity	1.3 m^3/day
Treatment efficiency	COD: 90% BOD_5: 90% Total suspended solid: 90%
Disposal of treated wastewater	Draining Root zone irrigation

BV-I treatment process

The BV-I domestic wastewater treatment unit applies activated sludge. The deep aeration system and mixer stabilisation of the sludge provides an optimum living space for the microorganisms performing the treatment. Its base unit is a prefabricated reinforced concrete tank equipped with an aerator–mixer and a clarifier.

Wastewater discharges to the first tank, where the flow equalises and anaerobic processes happen. Here phase separation of inorganic matters and grease also occurs.

The pre-treated wastewater passes through a "T" tube and flows into the aeration tank. The lower part of the through-pipe ensures that the further flow is from the most homogeneous layer, and its upper branch is used to eliminate any clogging.

In the aerobic chamber, the aeration mixer provides the necessary oxygen content and keeps the sludge in suspension.

The amount of oxygen supplied is 3 g/h based on the research of the National Institute of Public Health.

The aeration mixer with 180 W power ensures constant mixing and air intake. Its structure is extremely simple, it does not contain wear parts (valves, pistons), and it is particularly corrosion resistant. Its operation does not require automatic constant treatment.

Sludge settles down to the inclined bottom surface, where it slopes back to the aeration basin through an opening with a 300 × 150 mm dimension. This design ensures constant sludge recirculation without the use of separate equipment (sludge pump).

The treated wastewater flows upwards and goes out of the system through a post-filter. The post-filter removes the remaining suspended solids.

Options to accommodate the treated water:

- root zone irrigation
- infiltration

Technical specifications of the BV-I

The BV-I base unit is a prefabricated concrete basin delivered to the installation site.

Dimensions: 2.8 × 1.68 × 1.8 m.

For prefabrication, the reinforced concrete basin is divided horizontally from the lower plane to 1.15 m. The lower tank element is 1.15 m, and the upper pool element is 0.65 m high.

There are various technological openings on the upper basin element, and domes and cover plates for handling are connected to it.

The material of the basin elements is C16-12/k.VZ. concrete, 150 mm × 150 mm, single-core welded mesh with 6 mm thickness. The corners are reinforced with a 12 mm concrete core.

The material of domes and dome covers is of the same concrete quality with the tank, but does not contain reinforcement.

Blast openings are provided for the introduction of wastewater in such a manner that the wastewater treatment plant can be placed parallel to or along the longitudinal axis of the sewer. The outlet(s) required for use will break out at the application site.

Between the anaerobic and aerobic chambers, a hole of 110 mm diameter for the positioning and fixing of the "T" lead-through tube is located at the top of the wall in the upper basin.

At the top of the anaerobic chamber there is a 300 mm diameter opening for the service of the unit. The dome is placed when the equipment is installed. For fixing, the part of the dome that contacts the pelvic element is covered with cement mortar. The cover does not require a separate fixation.

There is enough space for the periodic cleaning of the suction tube next to the T-shaped transfer tube. The useful volume of the anaerobic chamber is 1.8 m^3.

In the upper plane of the aerobic chamber, a dome is provided in the upper plane of the anaerobic chamber to provide the location of the aeration mixer, the upper planes of which are provided for holding the nests and the groove for introducing the electric cable.

An aperture 300 mm × 150 mm is provided on the lower plane of the wall between the aerobic and clarifier chambers to provide sludge backflow. The useful volume of the aerobic chamber is 2.5 m^3.

The top filter is built into the upper part, which is used to collect the floating sludge. For the clarifier placement, a plastic element of 110 mm in diameter is embedded in the product.

At the top of the clarifier, there is an aperture of 300 mm in diameter, where the dome is placed. The dome is fixed in the same manner with the anaerobic chamber.

The useful volume of the clarifier is 0.8 m^3.

The total useful volume of the BV-I is 5.1 m^3.

The outer diameter of the dome is 460 mm, the inner diameter is 300 mm, their height is 400 mm. Its material is the same quality of concrete as the basin elements without reinforcement.

Dome covers are 520 mm in diameter and 80 mm in thickness. The ventilation line of the air inlet is concreted in the axial line of the lid of the dome lid supporting the aeration mixer.

The BV-I wastewater treatment plant is placed in the ground. Choosing a field level of 0.0, the main level data is:

- bucket bottom level: –2.35 m
- gravel bed top plane: –2.20 m
- treated wastewater outlet level: –0.80 m
- sewage influent bottom level: –0.70 m
- reinforced concrete basin upper plane: –0.40 m
- top plane of dome covers: +0.08 m

If the depth of the sewer is not 0.70 m, the above level data should be corrected with the difference.

Installation of the BV-I wastewater treatment unit

The BV-I domestic wastewater treatment plant is suitable for the treatment of communal wastewater from existing or new buildings, family houses, boarding houses, offices and industries. For wastewater exceeding 1.3 m^3/day, it is also possible to install multiple units in parallel.

Choose your installation location so that only passenger transport is possible later on.

Raw wastewater and treated water pipes must be laid in a ditch.

The unit can normally be connected to a 0.7 m deep sewage pipeline. In case of a deeper sewage line, the equipment must also be placed deeper so that the connecting sewage pipeline meets the inlet of the equipment. At this point, the machine's dome must be extended to the field level.

The dimensions are shown in the installation diagram in the appendix. In case of unfavourable soil conditions, the protection of sidewalls should be ensured.

The foundation of the equipment is a 15 cm thick gravel bed with a horizontal surface under normal ground conditions. In case of unfavourable soil conditions, the necessary foundation is determined by the adaptive designer.

The reinforced concrete structure arrives at the truck from the prefabrication plant and places the crane in the work pit.

The order of installation of the reinforced concrete works is as follows:

- location of the bottom element and checking the horizontal position
- cleaning the lower element from any material that may have fallen
- wetting surfaces and placing sealant
- attaching the upper element and checking the fittings
- attaching the dome and covers
- wiring and sealing of wastewater and treated water pipes
- attaching and electrical connection of the aeration-mixer
- soil refill, compression
- electric supply
- BV-I power supply is provided from the normal 230 V network; the connection to the network is made through a standard grounded socket
- the BV-I; the intermittent operation of the aeration-mixer motor of the wastewater treatment plant is provided by the control unit; the control unit is connected to the mains with a plug
- the control unit and the mixing-aeration device are connected by a 3 × 1.5 mm cross-section cable; it is advisable to place the cable in the duct workpiece
- the electric motor of the mixing-aeration device has a rated voltage of 220 V, an output of 180 W, a speed of 2,800 rpm, an IP 55 protection class, and an insulation class
- the rated motor current is 0.8 A

Start-up

Tasks of the builder:

- adaptation of the type design by an authorised person
- construction of sewage pipeline
- preparation of the work pit
- the foundation
- preparation of structures for the treated wastewater
- land reclamation and landscaping
- provide an electrical connection for positioning the control unit

Tasks of the supplier:

- transportation of equipment to the site
- positioning in the pit
- electrical wiring, commissioning

Buildings related to the treatment and disposal of wastewater are subject to a building permit in accordance with the legislation in force. Accordingly, the builder must submit a building permit application to the competent construction authority.

The appendix to the application is the licensing plan documentation prepared by the adaptation designer. This Type Approval Plan contains the data needed to conduct the building permit process.

Tasks of the adaptive designer:

- establishment of the site layout and additional technical description
- developing a foundation plan
- the requirement of the builder and the design of treated water according to the requirements of the authorities

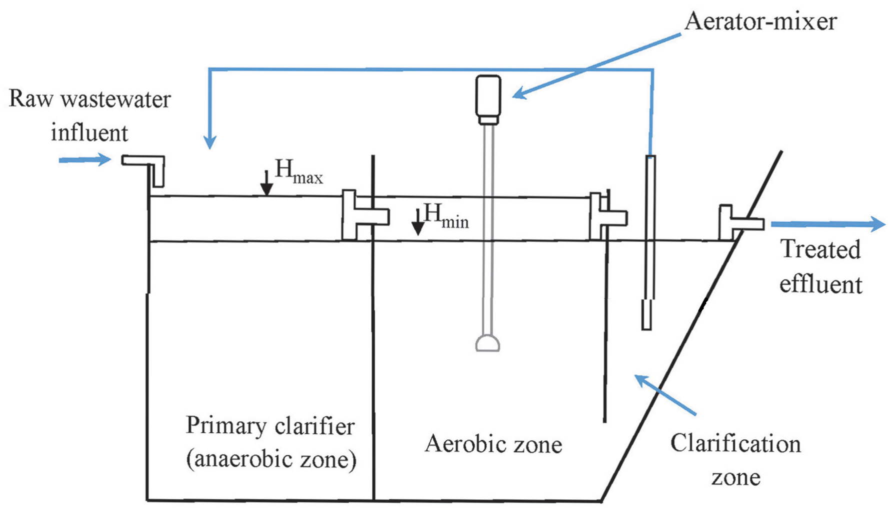

Figure 14
Operation principle of the BV-1

Operating and maintenance instructions

The BV-I unit for domestic wastewater treatment. In order to function properly and to be able to use its properties, the operator and the user must comply with this chapter.

Wastewater regulations: The BV-I is only suitable for domestic wastewater treatment. Proper operation cannot be guaranteed if it is contaminated by any industrial activity.

It can also deteriorate the treatment efficiency if aggressive household chemicals (bleach, hydrochloric acid, descaler, etc.) are used in large quantities at the same time.

It reduces the efficiency of the equipment when solid waste is deposited in large quantities (e.g. kitchen towel) into the wastewater. Protect the environment by placing the remainder of the grease used in baking into the solid waste.

Toxic substances (e.g. chemicals used in amateur photography) that can damage the living sludge or pass through the wastewater treatment plant should not be allowed to enter sewage.

The equipment works with the following wastewater quality parameters as required:

COD: 450 mg/l
BOD_5: 225 mg/l
Total suspended solid (mg/l)

The wastewater treatment plant requires automatic, periodic interventions/maintenance. It is necessary to check the state of the clarifier once a month. If the level of the water surrounding the clarifier is higher than the water level inside, then the filter is clogged:

- lift the dome cover of the clarifier and place it on the ground
- insert a hose into the inside of the filter and wash it with a strong jet of water for at least 10 minutes
- replace the dome cover

With this, the filter cleaning is complete, the unit will operate again.

It is necessary to remove the sludge once a year. This is done as follows:

- defuse the system
- lift the lid of the centre engine mount dome
- disconnect the cable connector
- lift the aeration-mixer and raise it to the ground with the aeration shaft and clean the aeration shaft from the dirt that has been deposited; the four-way nozzle at the end of the aeration shaft can be unscrewed and the hollow shaft hole can be checked; if the hole is blocked, it must be cleaned by compressed air blowing or by pulling the wire
- lift the dome cover of the pre-settling chamber
- remove the wastewater from the chamber; make sure that grease collected on the surface is removed
- similarly, remove the contents of the aeration chamber; due to the lower connection it also eliminates the contents of the clarifier
- replace the aeration-mixer, making sure that bottom parts are returned to the trays designed for this purpose, and then connect the cable
- check that the aeration system is not clogged, if yes, use a water jet
- replace the dome covers
- plug the mains plug into the socket to restart the unit

Other requirements:

- keep children away from the unit while removing dome covers
- the wastewater treatment plant and its 2 m area are only suitable for passenger transport
- work on the equipment requires thorough cleaning

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Wastewater generated in settlements without sewerage must be treated in order to relieve the burden on the receiving water body and to avoid risks to public health. The design methodology of individual wastewater treatment and the contexts related to the operation have been known for a long time; however, the application is not widespread. The aim of the textbook entitled *Individual Wastewater Treatment Technologies* is to acquaint the reader with the issue of individual wastewater treatment and its specialties. General wastewater treatment concepts and operations, the legal background of decentralised wastewater treatment is presented, followed by a wide range of technologies from a wide and colourful offer of individual wastewater treatment units. An insight into the numerical modelling is also presented. We hope that not only students but also practitioners from design and operation engineers, those interested in wastewater treatment could find useful information.