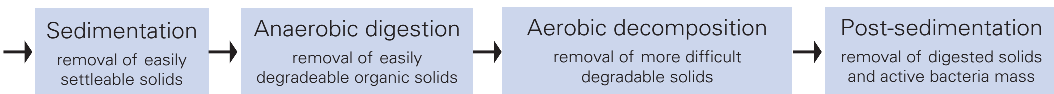
8 Treatment in DEWATS

DEWATS make use of the natural biological- and physical-treatment processes discussed above to reduce and remove pollutants from wastewater. External energy supply, dosing of chemicals and movable parts are avoided to minimise both possible flaws in operation and maintenance.

As the various natural-treatment processes require different boundary conditions to function efficiently, DEWATS are comprised of a series of treatment units, each providing an ideal environment for the removal of certain groups of pollutants. Stability of the treatment system is ensured, as each treatment step only removes the “easy part” of the pollution load, sending the leftovers to the following step.



Picture 8_1: Several steps are required for full treatment

The term “phase separation” has a double meaning. On the one hand it is used for the separation of gas, liquid and solids in anaerobic reactors; on the other hand it is used to describe the technical separation of different stages of the treatment process, either in different locations or in sequences of time intervals. The latter kind of phase separation becomes necessary when suitable nutrients cannot be provided simultaneously to micro-organisms, which have differing growth rates and prefer different feeds. Some micro-organisms grow at a slower rate than others. As not all the enzymes required for degradation are initially found in all substrates, the micro-organisms take time to produce adequate amounts of the missing enzymes. As disscussed previously, enzymes act as the “key which opens the lock of the food box for micro-organisms”.

Substrates, for which enzymes are immediately available, can be readily degraded; substrates, which first require the microbial production of specific enzymes, are degraded much more slowly. In an environment which hosts substances that are both easy and difficult to degrade, the microbial population responsible for easy degradation tends to predominate.

To protect the "weaker" (slower) micro-organisms, it is advisable to artificially separate microbial populations in phases by providing each with its own favourable environment. The characteristics of the wastewater and the desired treatment results must be identified, before the dimensions of the treatment vessels for the different phases can be designed.

In the case of DEWATS, it is often easiest to provide longer retention times, so that the "slow" micro-organisms find their food after the "fast" ones have satisfied their demand. This process is easier to manage and, in the case of smaller plants, it is cheaper to design certain units this way. In other units, like the baffled reactor, the efficiency of the treatment in subsequent chambers justifies its higher cost; processes, which require sequencing batch operation involving technical equipment and process control, are thereby avoided.

Phase separation becomes unavoidable if different phases require either anaerobic or aerobic conditions. In the case of nitrogen removal, longer retention times alone do not provide adequate treatment conditions because the nitrifying phase needs an aerobic environment, while denitrification requires an anoxic environment. Anoxic means that nitrate (NO_3) oxygen is available, but free oxygen is not. Anaerobic means that neither free oxygen nor nitrate-oxygen is available. Nevertheless, the aerobic phase can only lead to nitrification if the retention time is long enough for the "slow" nitrifying bacterium to act, as compared to the "fast" carbon oxidisers.

In the case of the addition of plant material to an anaerobic digester, pre-composting of plant residues before anaerobic digestion is another example of simple phase separation. As lignin cannot be digested anaerobically (it requires peroxidase enzymes usually produced by fungi), it is decomposed aerobically. Afterwards, anaerobic micro-organisms can reach the inner parts of the plant material in the digester.

8.1 Parameters for wastewater-treatment design

Treatment must remove or reduce pollutants within the wastewater sufficiently to prevent harm to the environment and humans. Before deciding, what kind of treatment is necessary and the dimensions of each unit, planners and designers must identify the following:

- quality and quantity of the raw wastewater
- local conditions and their influence on treatment processes
- standards to be fulfilled in final use or discharge

Laboratory analysis is used to determine the quantity and quality of the pollution load, the feasibility of treatment, the environmental impact under local conditions – and whether a particular wastewater is suitable for biogas production. Some parameters can even be seen and understood by experienced observation.

As the quality of wastewater changes according to the time of day and from season to season, the analysis of data is never absolute. It is far more important that the designer understands the significance of each parameter and its "normal" range than to know the exact figures. Ordinarily, an accuracy of ±10% is more than sufficient.

This chapter gives a concise overview, introducing:

- control parameters, essential for characterising wastewater and
- dimensioning parameters, utilised in DEWATS design

Textbooks on the analysis of wastewater should be consulted for laboratory techniques or comprehensive handbooks on wastewater, such as Metcalf and Eddy's *"Wastewater Engineering"*.

8.1.1 Control parameters

Volume

The daily volume or the flow rate of wastewater determines the required size of the building structure – on which the feasibility or suitability of the treatment technology is decided. It is essential not to underestimate the peak flow.

Surprisingly, the determination of flow rate is often rather complicated, due to the fact that flow rates change throughout the day or with the season, and that volumes have to be measured in "full size". It is not possible to take a representative sample. In the case of DEWATS, it is often easier and more practical to measure or enquire about the water consumption (per capita consumption of water from taps and/or wells) rather than try to measure the wastewater production. The flow of wastewater is not directly equal to water consumption, since not all the water that is consumed ends up in the drain (for example, water for gardening), and because wastewater might be a mix of used water and stormwater. If possible, stormwater should be segregated from the treatment system, especially if it is likely to carry substantial amounts of silt or rubbish. Rainwater drains should never be connected to the treatment plant, however, ponds and planted gravel filters will be exposed to rain (and evaporation). The volume of water in itself is normally not a problem as hydraulic loading rates are not likely to be doubled and a certain flushing effect might even be advantageous. Soil clogging (silting) could become a problem, however, if stormwater reaches the planted gravel filter after eroding the surrounding area.

For high-rate reactors, like anaerobic filters, anaerobic baffled reactors and UASB, the flow rate could be a crucial design parameter. If exact flow data are not available, the hours of the day, which account for most of the flow, should be determined and used. Hydraulic retention-time calculations should take into account the flow rate fluctuation.

The flow rate is calculated by collecting and measuring volumes per time period. Possible measurement techniques include monitoring the rise in level of a canal that is closed for a period of time, or the number of buckets filled during a given period. Another good indicator of the actual flow rate is the time it takes, during initial filling for the first tank of a treatment plant to overflow.

In larger plants the flow rates are normally measured with measuring flumes (for example, the Parshall flume) where a rise in level across the flume is related to the flow.

Solids

Total solids (TS) or dry matter (DM) include all matter, which is not water. Organic total solids (OTS) or volatile solids (VS) are the organic fraction of the total solids. TS is found by drying the sample. The inorganic fraction is found by burning the dry matter and weighing the ash. TS minus ash is OTS or VS. Solids may be measured in mg/l or as a percentage of the total volume.

The parameter "suspended solids" (SS) is the amount of organic or inorganic matter that is not dissolved in water. Suspended solids include settleable solids and non-settleable or suspended solids. Settleable solids sink to the bottom within a short time. They can be measured with a standardised procedure in an Imhoff-cone, usually for a defined settling period of 30 minutes, one hour, two hours or one day. Measurement of settleable solids is the easiest method of wastewater analysis because solids are directly visible in any transparent vessel. For collecting initial on-site information, any transparent vessel will do (for example, water bottles, which should be destroyed for hygienic safety after use).

Table 13: Domestic wastewater derives from various sources. Composition of wastewater depends largely on standard of living and domestic culture. Source: Metcalf&Eddy, 1996

range source	min g/cap*d	max g/cap*d
faeces (solids, 23%)	32	68
ground food wastes	32	82
wash waters	59	100
toilet (incl. paper)	14	27
urine (solids, 3.7%)	41	68

Non-settleable suspended solids consist of particles which are too small to sink to the bottom within a reasonable time (with regard to the design parameters of the treatment processes). SS is determined by sample filtration. Suspended solids are an important parameter because they cause turbidity in the water and may cause physical clogging of pipes, filters, valves and pumps.

Colloids are very fine suspended solids (< 0.1ηm) which pass laboratory filter paper, but are not dissolved in water (dissolved solids are solutes (molecules or ions) that disperse through out the water molecules). A high proportion of fatty colloids can create large problems in fine-sand filters.

In domestic wastewater, the BOD derives to approximately one third (33%) from settleable solids, to half (50%) from dissolved solids, while one sixth (17%) of the BOD derives from non-settleable SS (see Table 17, page 165).

Fat, grease and oil

Fat and grease are organic matter that is biodegradable. However, since they float on water and have a sticky consistency their physical properties are a problem in the treatment process and in nature. It is best to separate fat and grease before biological treatment and dispose to sludge treatment facilities (see section 11.3) or other specific recycling plants (e.g. soap production).

The amount of fat that remains in treated domestic wastewater is normally small. A fat content of approximately 15 to 60mg/l is allowed in the effluent of slaughter-houses or meat-processing plants for discharge into surface waters. Mineral grease and mineral oils – such as petrol or diesel – although they may also be treated biologically, should be kept away from the treatment system. Their elimination is not within the scope of DEWATS.

Turbidity, colour and odour

Most wastewaters are turbid because the solids suspended in them scatter and disperse light. So highly turbid fluid indicates a high content of suspended solids. Metcalf and Eddy define the relationship between turbidity and suspended solids in the following equation:

SS [mg/l] = 2,35 × turbidity (NTU), or

turbidity (NTU) = SS [mg/l] / 2,35[32]

32 Metcalf & Eddy, 1996; page 257

NTU is the standardised degree of turbidity. Its value can be determined with the help of a turbiditimeter or by standardised methods, which measure the depth of water at which it is no longer possible to see a black cross or a circle against a white background. Turbidity may prevent algae in surface waters from producing oxygen during daytime, as would otherwise be the case.

The colour is not only indicative of the source of wastewater, but also of the state of degradation. Fresh domestic wastewater is grey, while aerobically degraded water tends to be yellow-brown, and water after anaerobic digestion turns blackish. Turbid, black water may be easily settleable because suspended solids sink to the bottom after digestion when given enough undisturbed time to form flocs.
A brownish colour indicates incomplete aerobic or facultative fermentation.

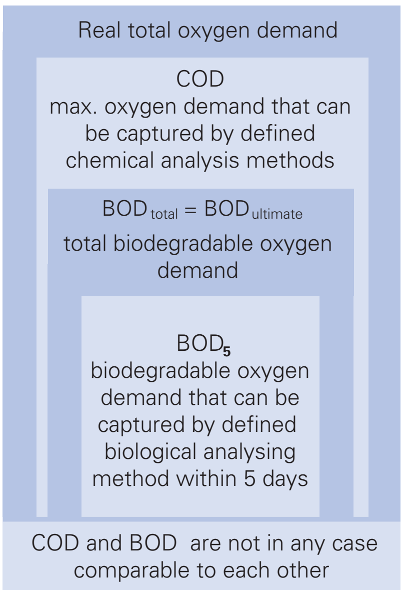
Wastewater that does not smell probably contains enough free oxygen to restrict anaerobic digestion – or the organic matter has long since been degraded. A foul smell ("like rotten eggs") comes from H_2S (hydrogen sulphide), which is produced during anaerobic digestion, especially at a low pH. A foul smell, therefore indicates that free oxygen is not available and that anaerobic digestion is still underway. Vice versa, whenever there is substantial anaerobic digestion there will always be a foul smell.
Fresh wastewaters from various sources have characteristic smells. Experience is the best basis for drawing conclusions: dairy wastewater will smell like dairy wastewater, distillery wastewater will smell like distillery wastewater, etc. "smelling the performance" of treatment plants is an important skill. An alert wastewater engineer should remember the different odours and their causes, to build up a repertoire of experience for future occasions.

COD and BOD

COD (Chemical Oxygen Demand) is the most common parameter for measuring organic pollution. It describes the amount of oxygen required to oxidise all organic and inorganic matter found in the water. The BOD (Biochemical Oxygen Demand) is always smaller than the COD. It describes the amount of oxygen required for the oxidisation of matter, which can be oxidised by the biological organisms in a body of water. It approximates the organic fraction of the COD. Under standardised laboratory conditions at 20°C, it takes about 20 days to activate the total carbonaceous BOD (=$BOD_{ultimate}$, BOD_{total}). In order to save time, BOD-analysis determines the biological oxygen demand after five days. The result is called BOD_{5}, which in practice, is commonly referred to simply as BOD.

The BOD_5 is a certain fraction (approximately 65 to 70%) of the ultimate BOD. This fraction is different for each wastewater, depending (for example) on the proportions of organic matter in soluble and suspended form. The ratio of BOD_{total} to BOD_5 is larger for refractory or difficult degradable wastewater and, thus, it is also larger for partly treated wastewater.

COD and BOD are the results of standardised laboratory-analysis methods. They do not fully reflect the bio-chemical truth, but are reliable indicators for practical use.



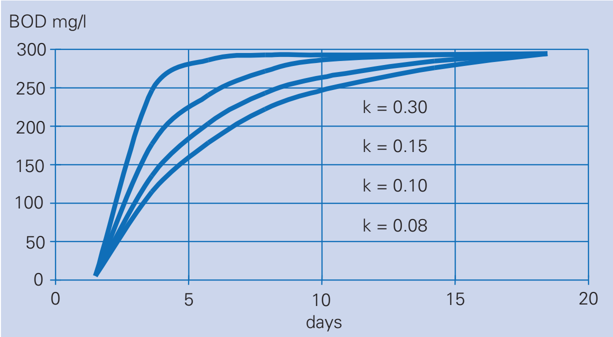
Picture 8_2: Definition of oxygen demand. The BOD_5 is a part of the total BOD; the total BOD may be understood as part of the COD; and the COD is part of the absolute real oxygen demand. The total BOD may be equal to the COD; the COD may be equal to the real oxygen demand

Biological oxygen demand describes the portion of the wastewater which can be digested easily, for example, anaerobically. The COD/BOD_{total} approximates the relation of total oxidisable matter to organic matter, which is degraded first by the most common micro-organisms. For example, if a substrate is toxic to micro-organisms, the BOD is zero; the COD nonetheless may be high, as would be the case with chlorinated water. In general, if the COD is much higher than the BOD (>3 times) one should check the wastewater for toxic or non-biodegradable substances.

In practice, the quickest way to determine toxic substances is to have a look at the shopping list of the institution which produces the wastewater.
The kinds of detergent bought by a hospital may be more revealing than a wastewater sample taken at random. It is important to know that the COD in a laboratory test shows the oxygen donated by the test-substance, which is normally $K_2Cr_2O_7$ (potassium dichromate). The tested substrate is heated to initiate the chemical reaction (combustion). Occasionally, $KMnO_4$ (potassium permanganate) is used for quick on-site tests – also known as the permanganate value (PV) or oxygen adsorbed from permanganate (OA). The COD_{Cr} is approximately twice as much as the COD_{Mn}; however, the two values do not have a fixed relation, which is valid for all wastewaters.

Easily degradable wastewater has a COD/BOD relation of about 2. The COD/BOD ratio widens after biological, especially anaerobic treatment because biological degradation has already taken place. COD and BOD concentrations are measured in mg/l or in g/m³. Absolute values are measured in g or kg. A weak wastewater from domestic sources, for example, may have a COD below 500mg/l while a strong industrial wastewater may have a value of up to 80,000mg/l BOD.

When too much BOD or COD is discharged into surface waters, the oxygen



Picture 8_3: BOD-removal rates are expressed by rate constants (k) which depend on wastewater properties, temperature and treatment-plant characteristics. The curve shows the BOD-removal rates at 20°C. The value after 5 days is known as BOD_5

present in that water is consumed for the decomposition of the pollutants and, thus, is no longer available to support aquatic life. Effluent standards for discharge into receiving waters may tolerate 30 to 70mg/l BOD and 100 to 200mg/l COD.

Wastewater analysis sometimes states the total organic carbon (TOC). This indicates how much of the COD can be attributed to carbon only. In designing DEWATS, knowledge of BOD or COD is sufficient; TOC is of no practical concern.

toxic metal	concentration mg/l
Cr	28–200
Ni	50–200
Cu	5–100
Zn	3–100
Cd	70
Pb	8–30
Na	5,000–14,000
K	2,500–5,000
Ca	2,500–7,000
Mg	1,000–1,500

Table 14: Concentration of toxic substances which inhibit anaerobic digestion. Source: Mudrak/Kunst, 1991

Nitrogen (N)

Most of the nitrogen in human excreta is contained in water-soluble urea. The types of nitrogen compounds found in wastewater are good indicators for which treatment steps are currently happening or have happened. Nitrogen is a major component of proteins (albumen). A high percentage of albuminoid nitrogen indicates fresh wastewater. During decomposition, when large protein molecules are broken up into smaller molecules, nitrogen is found in the form of free ammonia (NH_3, toxic for fish). However, ammonia dissolves in water and forms ammonium ions (NH_4^+) at low pH levels. At a pH level above 7, NH_4^+ transforms to NH_3. There is always a mass balance between NH_3 and NH_4. NH_3 evaporates into the atmosphere, which leads to unwanted nitrogen losses, if the treated wastewater is intended for irrigation (see section 7.1.5, page 141). Ammonium further oxidises to nitrite (NO_2^-, toxic) and finally to nitrate (NO_3^-, not toxic for fish).

From the chemical symbol, it is evident that ammonia (or ammonium) will consume oxygen to form nitrate, the most stable end-product. The albuminoid and the ammonia nitrogen together form the organic nitrogen, also called Kjeldahl-N (N_{kjel}). The total nitrogen (N_{total}) is composed of N_{kjel} (not oxidised N) and nitrate-N (oxidised N).

Pure nitrogen (N_2) is formed when oxygen is separated from NO_3 ions to oxidise organic matter. Since pure nitrogen hardly dissolves in water, it is released immediately into the atmosphere, an attribute used to remove nitrogen from wastewater in the process of denitrification. Nitrification (under aerobic conditions) followed by denitrification (under anoxic conditions) is the usual process of removing nitrogen from wastewater.

For optimum growth of micro-organisms, untreated wastewater should have a BOD/N relation of 15 to 30. Nitrogen is normally not monitored in the effluent of smaller plants. Discharge standards for the effluent of larger plants permit 10 to 20 mg/l of N_{kjel}-N.

Phosphorus (P)

Phosphorus (P) is an important parameter for planning the treatment of unknown wastewater, especially in relation to BOD, nitrogen or sulphur. Microbial growth demands approximate ratios of BOD/P and N/P of 100 and 5, respectively. Insufficient amounts of phosphorus lead to lower microbial activity and, therefore poorer removal of COD (BOD).

High phosphorus content in the effluent leads to water pollution by algae growth. However, since very little phosphorus is removed in DEWATS it is the least important parameter to the designing engineer. Discharge standards for larger plants allow P in the range of 1 to 5 mg/l.

Temperature

Temperature is an important parameter, as warmer conditions promote microbial growth. Anaerobic digestion requires minimal temperatures of 10°C; temperatures between 18 and 25°C are good, 25 to 35°C are ideal. Anaerobic processes are more sensitive to low temperatures than aerobic ones because the micro-organisms achieve lower energy gains for themselves, through the production of biogas, as an oxidiseable, energy-rich end-product. The ambient temperatures in tropical and subtropical zones are ideal for anaerobic treatment which is the basis for DEWATS.

Higher temperatures are also favourable for the growth of aerobic bacteria, but disadvantageous for oxygen transfer (Picture 7_8). A warmer environment reduces the capability of water to absorb oxygen from the air. This is the reason why ponds may become anaerobic at the height of summer.

pH-value

The pH-value indicates whether a liquid is acidic or alkaline. The scientific definition of the pH is rather complicated and of no interest to practical engineering (it indicates the H-ion concentration). Pure water has a pH of 7, which is considered to be neutral. An effluent of neutral pH indicates optimal treatment performance. Wastewater with a pH below 4 to 5 (acidic) and above 9 (alkaline) is difficult to treat; mixing tanks may be required to buffer or balance the pH level. In the case of a high pH, ammonia-N dominates, whereas ammonium-N is prevalent at low pH-values.

Volatile fatty acids

Volatile fatty acids (VFA) are used as a parameter to check the state of the digestion process. A high concentration of VFA always coincides with a low pH. Fatty acids are produced at an early stage of digestion. Too high a concentration of fatty acids indicates that the second stage of digestion, which breaks up the fatty acids, is not keeping pace with acidification. This indicates that the retention time is either too short or that the organic pollution load on the treatment system is too high. Values of VFA concentrations inside the digester in the range of BOD inflow concentration values indicate a stable anaerobic process.

Dissolved oxygen

Dissolved oxygen (DO) describes the concentration of oxygen gas that is dissolved in water. The parameter indicates the potential for aerobic treatment and is usually applied to assess the quality of surface waters. DO is vital to support aquatic life: most species of fish require a minimum of 4 to 5 mg/l DO for survival and breeding.

Pathogens

The World Health Organisation (WHO) distinguishes between high-risk transmission of intestinal parasites (helminths eggs), and lower-risk transmission of diseases caused by pathogenic bacteria. Indicators for these risks are the number of helminths eggs and the number of faecal coliforms per volume of effluent, respectively. For uncontrolled irrigation less than 10,000 e-coli per litre and less than 1 helminth egg per litre is permitted by the WHO standard. E-coli bacteria are not pathogenic, but are a good indicator of faecal bacteria. Regardless of the number of ova, bacteria or viruses, wastewater is generally unsafe to humans.

Organism	Disease/symptoms
	Virus (lowest frequency of infection)
polio virus	poliomyelitis
coxsackie virus	meningitis, pneumonia, hepatitis, fever, common colds, etc.
echo virus	meningitis, paralysis, encephalitis, fever, common colds, diarrhoea, etc.
hepatitis A virus	infectious hepatitis
rota virus	acute gastroenteritis with severe diarrhoea
norwalk agents	epidemic gastroenteritis with severe diarrhoea
reo virus	respiratory infections, gastroenteritis
	Bacteria (low frequency of infection)
salmonella spp.	salmonellosis (food poisoning), typhoid fever
shigella spp.	bacillary dysentry
yersinia spp.	acute gastroenteritis, diarrhoea, abdominal pain
vibro cholerae	cholera
campylobacter jejuni	gastroenteritis
escherichia coli	gastroenteritis
	Helminth worms (high frequency of infection)
ascari lumbrocoides	digestive disturbance, abdominal pain, vomiting, restlessness
ascaris suum	coughing, chest pain, fever
trichuris trichiura	abdominal pain, diarrhea, anaemia, weight loss
toxocara canis	fever, abdominal discomfort, muscle aches, neurological symptoms
taenia saginata	nervousness, insomnia, anorexia, abdominal pain, digestive distrubance
taenia solium	nervousness, insomnia, anorexia, abdominal pain, digestive distrubance
necator americanus	hookworm disease
hymenolepsis nana	taeniasis
	Protozoa (mixed frequency of infection)
cryptosporidium	gastroenteritis
entmoeba histolytica	acute enteritis
giardia lamblia	giardiasis, diarrhoea, abdominal cramps, weight loss
balantidium coli	diarrhea, dysentery
toxoplasma gondii	toxoplasmosis

Table 15: Wastewater transmitted diseases and their symptoms

Exact pathogen counts are of limited importance for DEWATS design. Bacterial or helminth counts are important when wastewater is discharged into surface waters, which are used for bathing, washing, or irrigation.

Domestic wastewater and effluents from meat-processing plants and slaughter-houses, which carry the risk of transmitting blood-borne diseases, such as hepatitis, are particularly dangerous. The handling and discharge of such effluents may demand special precautions.

8.1.2 Dimensioning parameters

Hydraulic load

The hydraulic load is the most common parameter for calculating reactor volumes. It describes the volume of wastewater to be applied per volume of reactor, or per surface area of filter, within a given time. The usual dimension for the hydraulic load of reactors is $m^3/(m^3 \times d)$, meaning that $1m^3$ of wastewater is applied per $1m^3$ of reactor volume per day. The reciprocal value denotes the hydraulic retention time (HRT). For example, $1m^3/d$ wastewater on $3m^3$ of reactor volume results in a hydraulic load of $0.33m^3/(m^3 \times d)$, which is equal to a hydraulic retention time of three days ($3m^3$ volume/$1m^3$ of water per day).

The hydraulic retention time (HRT) gives a relation of volumes of feed in an empty reactor. It does not, for example, distinguish between sludge and liquid. The hydraulic retention time of a septic tank states nothing about the fraction of wastewater, which stays inside the tank for longer, nor does it say anything about the time that the bottom sludge has for digestion. In the case of vessels filled with filter media, the actual hydraulic retention time depends on the pore space of the media. For example, certain gravel consists of 60% stones and 40% pore space between the stones. A retention time of 24h per gross reactor volume is thereby reduced to 40%, which gives a net HRT of 9.6h.

For groundfilters and ponds, the hydraulic loading rates may be expressed in $m^3/(ha \times d)$, $m^3/(m^2 \times d)$ or $l/(m^2 \times d)$. Alternatively, the value may be stated in cm or m height of water cover on a horizontal surface. For example, 150 litres of water applied per square meter of land is equal to $0.15m^3/m^2$, which in turn is equal to 0.15m or 15cm hydraulic load.

Hydraulic loading rates are also responsible for the flow rate (velocity) inside the reactor. This is of particular interest in the case of up-flow reactors, like UASB or baffled reactors, where the up-flow velocity of liquid must be lower than the settling velocity of sludge particles. In such cases, the daily flow must be divided by the hours of actual flow (peak-hour flow rate). For calculating the velocity in an up-flow reactor, the wastewater flow per hour is divided by the surface area of the respective chamber (v = Q/A; velocity of flow equals flow divided by area). When splitting one large reactor into several chambers in series, it must be considered that the up-flow velocity in each chamber is greater than in the original large reactor. This is due to the fact that the flow rate per hour remains the same, while the area through which the flow passes is reduced to individual chambers. The necessity to keep velocity low, therefore, can lead to relatively large digester volumes, especially in anaerobic baffled reactor.

Organic load

For strong wastewater, the organic loading rate – and not the hydraulic loading rate – becomes the determining design parameter. In the case of tanks and deep anaerobic ponds, the calculation is done in grams or kilograms of BOD_5 (or COD) per m^3 digester volume per day. For shallow aerobic ponds, organic loading is related to the surface area using the dimensions grams or kilograms of BOD_5 (or COD) per m^2 or ha per day.

Table 16: Organic-loading rates and removal efficiencies of various treatment systems. Sources: mixed

typical values	aerobic pond	maturation pond	water hyacinth pond	anaerobic pond	anaerobic filter	baffled reactor
BOD_5 kg/m³*d	0.11	0.01	0.07	0.3-1.2	4.00	6.00
BOD_5 removal	85%	70%	85%	70%	85%	85%
temperature optimum	20°C	20°C	20°C	30°C	30°C	30°C

The permitted organic loading rate is influenced by the time needed by the various kinds of micro-organisms for their specific metabolism under the given conditions (often expressed as rate constant k). This, in turn is, influenced by the kind of reactor, the reactor temperature and the kind of wastewater. Easy-to-degrade substrate can be fed at higher loading rates because the micro-organisms involved multiply fast and consume organic matter quickly. For difficult-to-degrade substrate, some of the micro-organisms require longer contact times.

Excessive loading rates can lead to "poisoning" and the process collapsing because end-products from one step of fermentation cannot be consumed by the ensuing group of micro-organisms. In anaerobic digestion, for example, overloading leads to acidification of the substrate, preventing final methanisation.

At very low loading rates, almost no sludge is produced because the micro-organisms "eat each other" for want of feed (autolysis). Consequently, incoming wastewater is not met by sufficient micro-organisms for decomposition. Although low organic loading rates do not destabilise the process, they do reduce overall treatment efficiency.

Sludge volume

The volume of sludge is an important parameter for designing sedimentation tanks and digesters. This is because the accumulating sludge occupies tank volume that must be added to the required reactor volume. The amount of biological sludge production is directly related to the amount of BOD removed which, however, depends on the decomposition process. Aerobic digestion produces more sludge than anaerobic fermentation. In addition to the biological sludge, primary sludge consists partly of settled solids, which are already mineralised.

	mineral dry matter		organic dry matter		total dry matter		BOD_5	
	g/cap.*d	g/m³	g/cap*d	g/m³	g/cap.*d	g/m³	g/cap.*d	g/m³
settleable solids	20	100	30	150	50	250	20	100
suspended solids	5	25	10	50	15	75	10	50
dissolved solids	75	375	50	250	125	625	30	150
Total	100	500	90	450	190	950	60	300

Table 17:
Average distribution of solids in domestic wastewater in Germany.
Source: Imhoff, 1990

Large, conventional sewage-treatment works remove sludge continuously and often under water – producing a very liquid sludge with a low, total solid content of between 1 and 5%. In DEWATS, the sludge remains inside the tank for at least one year, where it decomposes under anaerobic conditions and undergoes further volume reduction, as it compacts under its own weight with time.

Although the literature varies widely, it can be assumed that approximately 0.005 litres of sludge per gram BODremoved accumulate in the primary treatment step of DEWATS, including a certain percentage of mineral settleable particles. There is sludge accumulation in secondary treatment as not all digested organic matter accumulates as settleable sludge, and mineral particles have already been removed. A sludge value of 0.0075 litres per gram BODremoved can be assumed for oxidation ponds, taking additional sludge from algae into account. The above figures are estimates for "modern" domestic wastewater as described in Table 18. True sludge production is influenced by the wastewater's settling properties, ratio of organic and mineral matter content and physical boundary conditions. Further details on sludge handling and treatment can be found in section 11.3.

Table 18: Properties of primary sludge Source: Metcalf&Eddy, 1996

Properties of sludge from primary sedimentation		
specific grafity of solids kg/l	specific grafity of sludge kg/l	dry solids g/m³
1.4	1.02	150.6

Additional benefits of wastewater treatment

The possible additional benefits of wastewater treatment should be considered at an early stage of planning so that it can be incorporated into the design.

Where and how the treated effluent is disposed or used affects the form of treatment that is required. While the removal of nutrients may be beneficial for the discharge into open water bodies or groundwater, it is counterproductive for reuse in agricultural irrigation. Reuse in agriculture, on the other hand, results in higher hygienic-treatment demand. More extensive treatment or dilution with fresh river-water might also be necessary to allow fish farming.

Other possible benefits from wastewater treatment, like biogas production, also restrict the choice of treatment methods, and influence investment and maintenance costs as well as amortisation.

Picture 8_4: Sludge from a septic tank in India – the black colour of the sludge indicates anaerobic condition