

This chapter introduces the technical-treatment components of DEWATS, which correspond to the DEWATS criteria defined in chapter 7.

After a brief overview and comparison of the different technologies, detailed sections on each component explain the specifics of design, applied-treatment processes, and start-up considerations as well as operation and maintenance procedures.

9.1 Overview of DEWATS components

DEWATS is based on four treatment systems:

- sedimentation and primary treatment in sedimentation ponds, septic tanks, fully mixed digesters or Imhoff tanks
- secondary anaerobic treatment in baffled reactors (baffled septic tanks) or fixed-bed filters
- secondary and tertiary aerobic/anaerobic treatment in constructed wetlands (subsurface flow filters)
- secondary and tertiary aerobic/anaerobic treatment in ponds

Components are combined in accordance with the wastewater influent and the required effluent quality. Hybrid systems or a combination of secondary on-site treatment and tertiary co-operative treatment is also possible.

The following treatment components are discussed in further detail in the ensuing chapters:

Grease traps and grit chambers are beneficial for wastewater from canteens and certain industries. Short retention times prevent the settling of biodegradable solids. Grit and grease must be removed frequently.

Septic tanks are the most common form of treatment. The robust system provides a combination of mechanical treatment through sedimentation and biological degradation of settled organic solids. Septic tanks are used for wastewater with a high percentage of settleable solids, typically effluent from domestic sources.

Fully mixed digesters provide anaerobic treatment of wastewater with higher organic load, while serving as a settler in a combined system. In the process, biogas is produced as a useful by-product.

Imhoff tanks are slightly more complicated to construct than septic tanks, but provide a fresher effluent when de-sludged frequently. Imhoff tanks are preferred when post-treatment takes place near residential houses, in open ponds or constructed wetlands of vertical flow type.

Anaerobic baffled reactors or baffled septic tanks function as multi-chamber septic tanks. They increase biological degradation by forcing the wastewater through active sludge beneath chamber-separating baffles. All baffled reactors are suitable for all kinds of wastewater, they are most appropriate for wastewater with a high percentage of non-settleable suspended solids and narrow COD/BOD ratio.

Anaerobic filters combine mechanical solids-removal with digestion of dissolved organics. By providing filter surfaces for biological activity, increased contact between new wastewater and active micro-organisms results in effective digestion. Anaerobic filters are used for wastewater with a low percentage of suspended solids (for example, after primary treatment in septic tanks), and narrow COD/BOD ratio. Upstream Anaerobic Sludge Blanket (UASB) reactors utilise a floating sludge blanket as a biologically active filter medium.

Trickling filters treat wastewater aerobically by letting it trickle over biologically active filter surfaces.

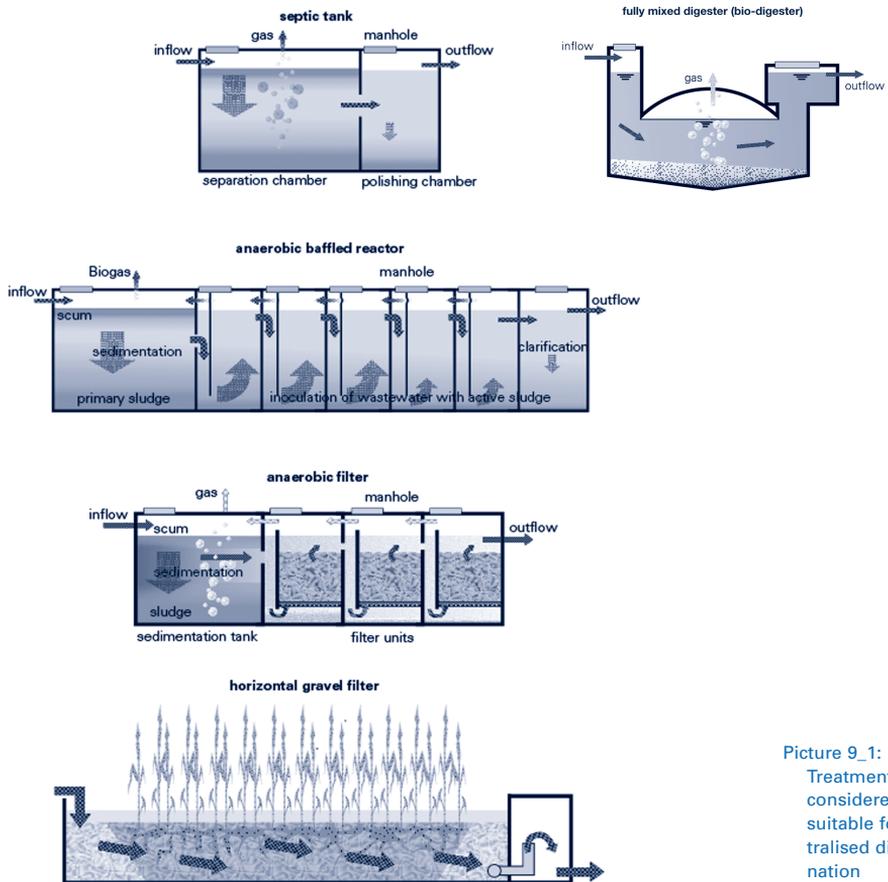
Horizontal gravel filters are sub-surface, flow constructed wetlands, which provide effective, facultative treatment and filtration, while allowing for appealing landscaping. Constructed wetlands are used for wastewater with a low percentage of suspended solids and COD concentrations below 500mg/l.

Pond systems are the ideal form of DEWATS treatment – if the required space is available. Anaerobic ponds are deep and highly loaded with organics. Depending on the retention time, digestion of sludge only or the complete wastewater is possible. Facultative and anaerobic ponds may be charged with strong wastewater, however, bad odour cannot be avoided reliably with high loading rates. Aerobic ponds are large and shallow – they provide oxygen via the pond surface for aerobic treatment. Wastewater for treatment in aerobic ponds should have a BOD₅ content below 300mg/l. Pond systems can be combined with certain types of vegetation, creating aquatic plant systems with additional benefits.

Special provisions are usually required for the treatment of industrial wastewater before standardised DEWATS designs can be applied. These may include open settlers for the daily removal of fruit waste from canning factories, buffer tanks for mixing varying flows from milk-processing plants, or grease traps or neutralisation pits to balance the pH of the influent. In these cases, standard DEWATS components are applicable only after such pre-treatment steps have been taken.

Despite their reliability and impressive treatment performance, such well-known and proven systems as UASB, trickling and vertical filters, rotating discs, etc. are not considered to be DEWATS because they require careful and skilled attendance.

Most treatment processes applied in conventional, large-scale treatment plants do not meet the DEWATS criteria. The activated-sludge process, the fluidised-bed reactor, aerated or chemical flocculation and all kinds of controlled re-circulation of wastewater fall within this category. Regular or continuous re-circulation might be acceptable if the pumps that are used cannot be switched off because they also act as transportation pumps.



Picture 9_1: Treatment systems considered to be suitable for decentralised dissemination

9 Technical components

type	kind of treatment	used for type of wastewater	advantages	disadvantages
septic tank	sedimentation, sludge stabilisation	wastewater with settleable solids, especially domestic	simple, durable, little space because of being underground	low treatment efficiency, effluent not odourless
fully mixed digester	sedimentation, sludge stabilisation	concentrated organic wastewater – e.g. agro-industrial – with settleable solids	access to renewable source of energy (biogas)	less simple than septic tank; special skills needed for gas-tight dome construction
Imhoff tank	sedimentation, sludge stabilisation	wastewater with settleable solids, especially domestic	durable, little space because of being underground, odourless effluent	less simple than septic tank, needs very regular desludging
anaerobic baffled reactor	anaerobic degradation of suspended and dissolved solids	pre-settled domestic and industrial wastewater with narrow COD/BOD ratio, suitable for strong industrial wastewater	simple and durable, high treatment efficiency, little permanent space required because of being underground, hardly any blockage, relatively cheap compared to anaerobic filter	requires larger space for construction, less efficient with weak wastewater, longer start-up phase than anaerobic filter
anaerobic filter	anaerobic degradation of suspended and dissolved solids	pre-settled domestic and industrial wastewater with narrow COD/BOD ratio	simple and fairly durable if well constructed and wastewater has been properly pre-treated, high treatment efficiency, little permanent space required because of being underground	costly to construct because of special filter material, blockage of filter possible, effluent smells slightly despite high treatment efficiency
horizontal gravel filter	aerobic-facultative-anaerobic degradation of dissolved and fine suspended solids, pathogen removal	suitable for domestic and weak industrial wastewater where settleable solids and most suspended solids are already removed by pre-treatment	high treatment efficiency when properly constructed, pleasant landscaping possible, no wastewater above ground, can be cheap to construct if filter material is available at site, no nuisance of odour	high permanent-space requirement, costly if right quality of gravel not available, great knowledge and care required during construction, intensive maintenance and supervision during first 1-2 years
anaerobic pond	sedimentation, anaerobic degradation and sludge stabilisation	strong and medium industrial wastewater	simple in construction, flexible in respect to degree of treatment, little maintenance	wastewater pond occupies open land, there is always some odour, can even be stinky, mosquitoes are difficult to control
aerobic pond	aerobic degradation, pathogen removal	weak, mostly pre-treated wastewater from domestic and industrial sources	simple in construction, reliable in performance if properly dimensioned, high pathogen removal rate, can be used to create an almost natural environment, fish farming possible when large in size and low loaded	large permanent space requirement, mosquitoes and odour can become a nuisance if undersized near residential areas, algae can raise effluent BOD

Table 19:
Pros and Cons of
DEWATS

Admittedly, these self-imposed restraints on DEWATS can, in practice, impact the quality of the effluent. But this need not be the case if there is sufficient space for the plant. Measures to discharge effluent of acceptable quality include:

- provision of sufficient space at the source of pollution
- pre-treatment at source and post treatment where sufficient land is available
- pre-treatment at source and post treatment in co-operation with others
- accepting an effluent with higher pollution load
- restricting wastewater-producing activities at this particular site
- connection to a central treatment plant via a sewage line

The permanent dilution of wastewater or the installation of a highly mechanised, “modern” treatment plant remain theoretical options – experience shows that such processes are chronically afflicted by irregular operation.



Picture 9_2:
One of too many
non-aerating
aerators

Space requirements

Depending on the total volume and the nature of the wastewater and its temperature, the following values may indicate permanent area requirements for setting up a treatment plant:

Septic tank, Imhoff tank:	0.5m ² /m ³ daily flow
Anaerobic baffled reactor, anaerobic filter:	1m ² /m ³ daily flow
Horizontal gravel filter:	30m ² /m ³ daily flow
Anaerobic ponds:	4m ² /m ³ daily flow
Facultative aerobic ponds:	25m ² /m ³ daily flow

These values are approximations for wastewater of typical strength; land requirements increase with wastewater of higher pollution load. Land use can be minimised if closed anaerobic systems are applied, as they are usually constructed underground. The area for sludge-drying beds may require an additional 0.1 to 10m²/m³ daily flow, depending on the wastewater quality and desludging intervals.

Performance

Treatment quality depends on the nature of the influent and boundary conditions like temperature. BOD-removal rates are generally within these ranges:

25 to 50% for septic tanks and Imhoff tanks

70 to 90% for anaerobic baffled reactors and anaerobic filters

70 to 95% for horizontal gravel filter and pond systems

The treatment efficiency of the different components and the required effluent quality decide the choice of treatment system. For example, septic tanks alone are not adequate for direct discharge into surface waters, but may suit treatment on land where the groundwater table is low and odour is not likely to be a nuisance. Assuming a discharge limit of 50mg/l BOD, the anaerobic filter in combination with a septic tank may treat wastewater of 300mg/l BOD without further treatment. Stronger wastewater would require a horizontal gravel filter or pond system for final treatment. Perhaps even long-way open discharge channels are sufficient to provide the necessary additional treatment.

Based on local conditions, many other possibilities for cheaper treatment systems may exist – all options must be considered. Expert knowledge is needed to evaluate such possibilities; wastewater-sample analysis should be compulsory.

Substantial removal of nitrogen requires a mix of aerobic and anaerobic treatment, only provided by constructed wetlands and ponds. In closed anaerobic-tank systems of the DEWATS-type, nitrogen forms to ammonia. The effluent is a good fertiliser but causes algae growth and is toxic to fish if released into surface waters.

Phosphorus is a good fertiliser and, therefore, dangerous in rivers and lakes. Phosphorus removal in DEWATS is limited – as in most treatment plants. Constructed wetlands with filter media containing iron or aluminium compounds present one form of removal. Furthermore phosphorus can be accumulated by sedimentation or fixed in microbial mass, although it can hardly be removed from the sludge or be transformed into a less-harmless state.

Pathogen control

Like all other modern wastewater-treatment plants, DEWATS systems are not focused on pathogen control. Pathogen removal increases with longer retention times, but treatment plants proudly function on short HRTs.

The WHO guidelines and other independent surveys describe the transmission of worm infections as the greatest risk associated with wastewater. Worm eggs or helminths are, for the most part, removed from effluent by sedimentation and accumulate in the bottom sludge. The long retention times in septic tanks and anaerobic filters of 1 to 3 years provide sufficient protection against helminths infection; frequent sludge removal is discouraged due to increased health risks.

Although many bacteria and viruses are destroyed during treatment, the concentrations in the effluent of anaerobic filters and septic tanks are still infectious. Higher pathogen-removal rates are reported from constructed wetlands and shallow aerobic ponds; the effect is attributed to longer retention times, exposure to UV rays in ponds, and various bio-chemical interactions in constructed wetlands. The pathogen-removal rates of these systems are, in fact, higher than in conventional municipal treatment plants.

Chlorination can be used for pathogen control. Simple devices with automatic dosing may be added before final discharge. However, the use of chlorine should be limited to cases of high risk, such as hospital wastewaters during an epidemic. Permanent chlorination should be avoided because it not only kills pathogens but also destroys other bacteria and protozoa, which are responsible for the self-purification effect of receiving waters.

9.2 DEWATS Modules

9.2.1 Grease trap and grit chamber

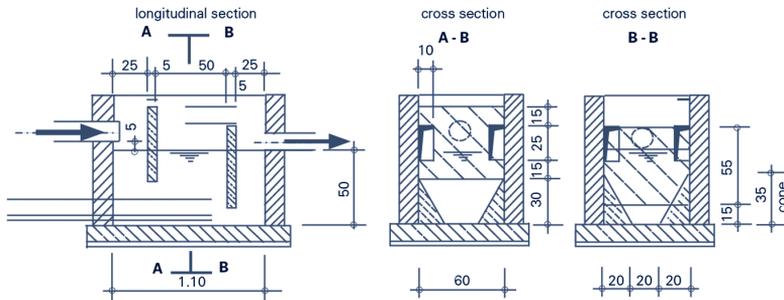
If a septic tank is provided, DEWATS normally do not require grease traps or grit chambers for domestic wastewater. Whenever possible they should be avoided altogether because grease and grit must be removed, at least once a week. However, for canteens or certain industrial wastewaters it may be advisable to separate grit and grease before the septic tank.

The function of grease and grit chambers is comparable to that of septic tanks; light matter should float and heavy matter should sink to the bottom. The difference is that bio-degradable solids should have no time to settle. Retention times for grit chambers are short, therefore, – only about three minutes. The use of masonry structures is not appropriate, especially in the case of minor flows.

A conical trough allows slow flow at a large surface for grease floatation and fast flow at the narrow bottom, which allows only heavy and coarse grit to settle. The water surface is protected from the turbulence of the inflow by a baffle; the outlet is near the bottom.

Picture 9_3:

Design principle of combined grease trap and grit chamber. Accumulating grease, oil and grit should be removed daily, or at least weekly. If this can not be assured, an oversized septic tank is preferable to receive grit and grease

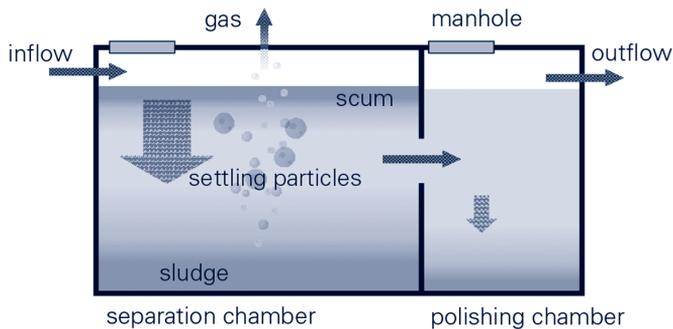


9.2.2 Septic tank

The septic tank is the most common, small scale and decentralised treatment plant, worldwide. It is compact, robust and extremely efficient when compared with the cost of constructing it. It is basically a sedimentation tank in which settled sludge is stabilised by anaerobic digestion. Dissolved and suspended matter leaves the tank more or less untreated.

Two treatment principles, namely the mechanical treatment by sedimentation and the biological treatment by contact between fresh wastewater and active sludge, compete with each other in the septic tank. Optimal sedimentation takes place when the flow is smooth and undisturbed. Biological treatment is optimised by quick and intensive contact between new inflow and old sludge, particularly when the flow is turbulent. How the influent enters and flows through the tank decides which treatment effect predominates.

With smooth and undisturbed flow, the supernatant (the water remaining after settleable solids have separated) leaves the septic tank rather fresh and odourless, implying that degradation has not yet started. With turbulent flow, the degradation of suspended and dissolved solids starts immediately because of the intensive contact between fresh and already active substrate. However, as turbulence hinders sedimentation, more suspended solids are discharged with the effluent, resulting in odours because active solids, which are not completely fermented, leave the tank.

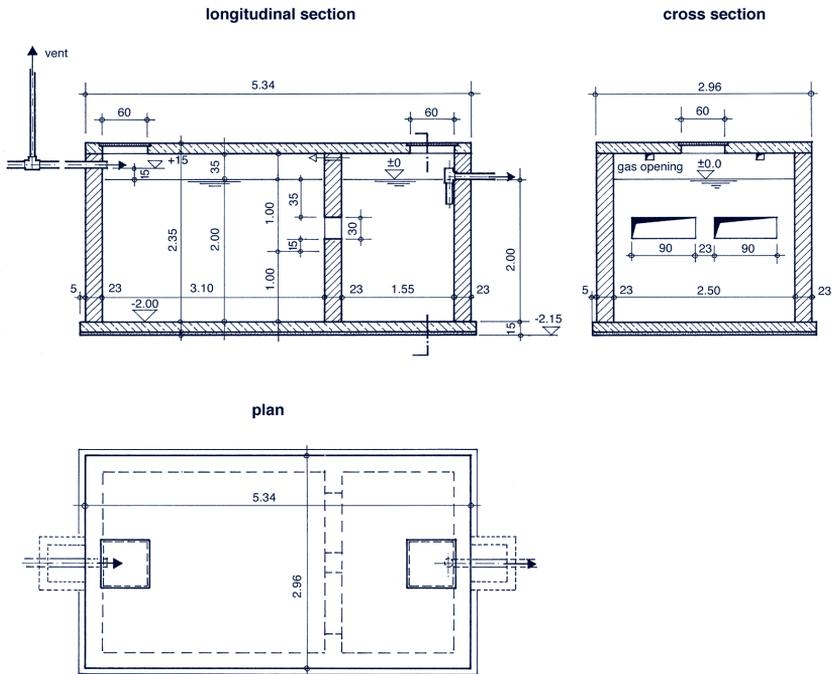


Picture 9_4: Flow principle of the septic tank. Most sludge and scum is retained in the first chamber; the second chamber contains only a little sludge, which allows the water to flow without disturbance from rising gas bubbles

9 Technical components

Domestic wastewater normally forms a heavy scum near the inlet. This consists of matter lighter than water, such as fat, grease, wood-chips, hair or any floating plastics. A larger portion of the floating scum also consists of sludge particles, which are released from the bottom and driven to the top by treatment gases. New sludge from below lifts the older scum particles above the water surface where they dry and become lighter. The accumulated scum must be removed regularly, at least every third year. Scum does not harm the treatment process as such, but it does occupy tank volume.

A septic tank consists of a minimum of two, sometimes three compartments. The compartment walls extend 15cm above the liquid level. They may also be used as bearing walls for the covering slab if some openings for internal gas exchange are provided.



Picture 9_5:

The septic tank. The dimensions have been calculated for 13m³ of domestic wastewater per day

The first compartment occupies about two-thirds of the septic-tank volume, allowing for most of the sludge and scum accumulation. The following chamber(s) are provided to calm the turbulent liquid. They are all the same size and make up the remainder of the volume. All chambers are normally the same depth. The depth from the outlet level to the bottom should be between 1.50m and 2.50m. The first chamber is sometimes deeper.

The size of the first chamber is calculated to be at least twice the accumulating sludge volume. The sludge volume depends on the settleable solids content of the influent and on desludging intervals (see picture 10_5, page 238). Most countries provide a National Standard for tank volume per domestic user.

The SS removal rate drops drastically when accumulated sludge fills more than two-thirds of the tank. This must be avoided, especially in cases where the effluent is treated further in a sand or gravel filter.

“Irregular emptying of septic tanks leads to irreversible clogging of the infiltration bed; rather than renewing the bed, most owners bypass it and divert the tank’s effluent to surface drains.”³³

33 See: Alearts et al, 1990

For domestic sewage, the accumulating sludge volume can be calculated with $0.1l/cap \times d$. When desludging intervals are longer than two years, the sludge volume may be reduced to $0.08l/cap \times d$, as sludge compacts with time (see Picture 10_5).

The inlet may dive down inside the tank, below the assumed lowest level of the scum – or may be above the water level when the inlet pipe is used to evacuate gas. A septic tank is basically a biogas plant, without biogas use. Gas accumulates inside the tank above the liquid, from where it should be able to escape into the air. The ventilation pipe for digester gases should end outside buildings, at an elevation above roof level. Open fire should be avoided when opening the septic tank for cleaning.

The compartments are connected by simple wall openings situated above the highest sludge level and below the lowest level of the scum. For domestic wastewater, the top of the opening should be 30cm below outlet level, its base at least half the water depth above the floor. The openings should be equally distributed across the width of the tank, in order to minimise turbulence. A slot, spanning the full width of the tank, is ideal for reducing velocity and turbulence.

The outlet has a T-joint, the lower arm of which dives 30cm below the water level. With this design, foul gas trapped in the tank enters the sewage line from where it must be ventilated safely. If ventilation cannot be guaranteed, an elbow must be used at the outlet to prevent the gas from entering the outlet pipe. There should be manholes in the cover slab; one each above inlet and outlet and one at each baffle wall, preferably at the inlet of each compartment. The manholes should permit water sampling from each compartment.

Septic tanks were originally designed for domestic wastewater. They are also suitable for other wastewater of similar properties, particularly those that contain a substantial portion of settleable solids.

The treatment efficiency of a septic tank ranges from 25% to 50% COD removal. It serves as rough, primary treatment, prior to secondary or even tertiary treatment. Post-treatment may be provided in ponds or ground filters. In the latter case, regular desludging of septic tanks is mandatory. A septic tank may also be integrated into an anaerobic filter or as the first section of a baffled reactor. Septic tanks are suitable as individual on-site pre-treatment units for community sewer systems because the diameter of sewerage can be smaller when settleable solids have been removed on-site.

Starting phase and maintenance

A septic tank may be used immediately; it does not require special arrangements before usage. However, sludge digestion begins only after several days. Regular desludging is required every one to three years. When removing the sludge, some immature (still-active) sludge should be left inside the tank to enable continuous decomposition of newly settling solids; it is not necessary to remove the liquid. This means, if the sludge is removed by pumping, the pump head should be brought down to the very bottom. Adequate handling and treatment of septic sludge is discussed in detail in section 11.3. The septic tank's surroundings should be kept free of plants to prevent roots from growing in the pipelines and control chambers.

Calculating dimensions

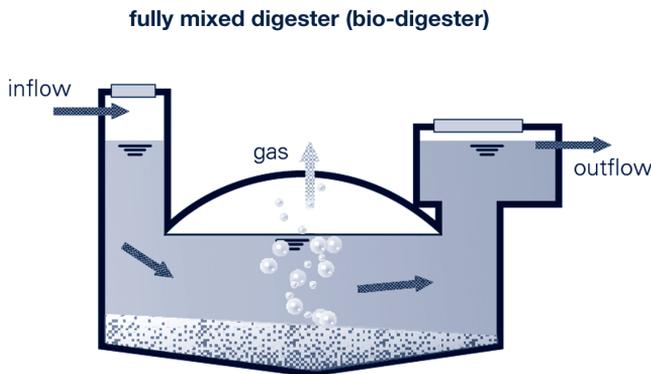
Approximately 80 to 100l should be provided per domestic user. For exact calculation or for wastewater from non-domestic sources, the formula applied in the computer spreadsheet (Table 25, page 240) may be used.

9.2.3 Fully mixed digester

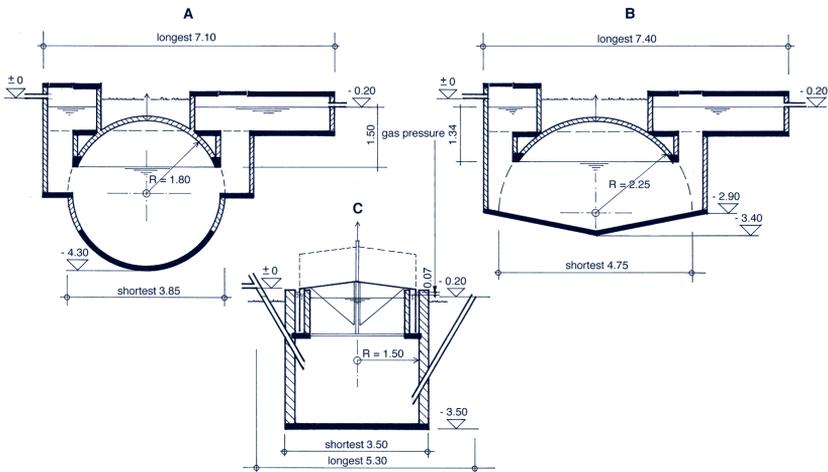
The fully mixed anaerobic digester (also called bio-digester) corresponds to the biogas plants, which are often used by farming families in developing countries. It is suitable for rather “thick” and homogenous substrate like sludge from aerobic-treatment tanks or liquid animal excreta. For economic reasons, it is not suitable for weak-liquid wastewater because the total volume of wastewater must be agitated and kept inside the digester for the full retention time of 15 to 30 days. This results in larger digester volumes and higher construction costs. However, combining different waste sources or blackwater from several toilets can be considered.

Picture 9_6:

Flow principle of the fully mixed anaerobic digester. There is little sedimentation due to viscous substrate. All substrate fractions stay inside the digester for the same period of time. The position of inlet and outlet is less important with homogeneous liquid of high TS content. Small baffles may be provided to avoid short circuiting



“Thick” viscous substrates of more than 6% total solid content do not need stirring. A digester with such a substrate can be operated for many years without desludging because only grit, but hardly any sludge, settles. Moreover, all the incoming substrate leaves the reactor after digestion. Scum formation is still possible with certain substrates. Therefore, if inlet and outlet pipes are used they should be placed at middle height. In fixed-dome digesters, the outlet should be made of a vertical shaft with the opening starting immediately below the zero-line; this will allow some of the scum to discharge.



Picture 9.7: Traditional biogas plants as fully mixed anaerobic digester. A: The ball-shaped fixed dome plant with integrated gas storage and expansion chamber. B: The half-ball-shaped fixed-dome plant. C: The floating drum plant with water seal. All three plants are designed for 600 litres substrate per day of 4% organic dry-matter content, at 25°C and HRT of 25 days. The expected gas production is 8.42 m³/d. A comparison of the space requirements and gas pressure of all three plants indicates that floating drum plants are preferable for high gas-production rates

Since the fully mixed digester is only used for strong substrate, biogas production is high and can be used afterwards. In this case, the gascollector tank and the gas-storage tank must be gas-tight. The immediate gas outlet should be 30cm above substrate level. Smaller units usually use the fixed dome (hydraulic-pressure) system made out of masonry structure, while larger units store the biogas in steel-drums or plastic bags.

The choice of gas-storage system will depend on the pattern of gas utilisation. Ideally, gas production should coincide with gas consumption, in time and volume. For more details, please refer to chapter 6, Biogas utilisation. An abundance of special biogas literature is also available.

Starting phase and maintenance

Starting with some active sludge from a septic tank speeds up digestion and prevents the digester from turning sour. In the rare case of this happening, the loading rate should be reduced until the pH turns neutral. It may be necessary to remove sand and grit after several years.

9 Technical components

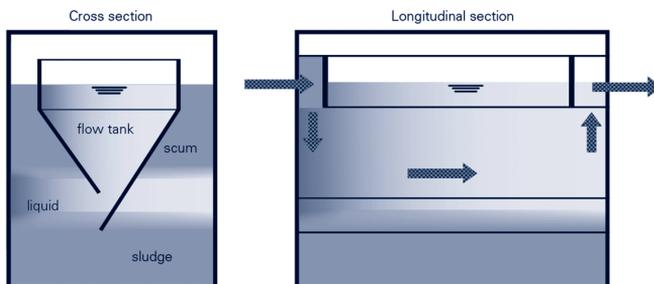
Calculating dimensions

The main parameter is the hydraulic retention time, which should not be less than 15 days in a hot climate and not less than 25 days in a moderately warm climate; a HRT of more than 60 days is required for highly pathogenic substrate. The gas-storage volume depends on daily gas use in relation to daily gas production. The storage capacity of gas for household use should exceed 65% of the daily gas production. Gas production is directly related to the organic fraction of the substrate. In practice, it is calculated as a fraction of the daily substrate that is fed. Experience indicates, for example, that 1kg fresh cattle dung diluted with 1 litre of water produces 40l of biogas. More exact calculations will be obtained by using the formulas applied in the spreadsheet Table 26, page 246.

9.2.4 Imhoff tank

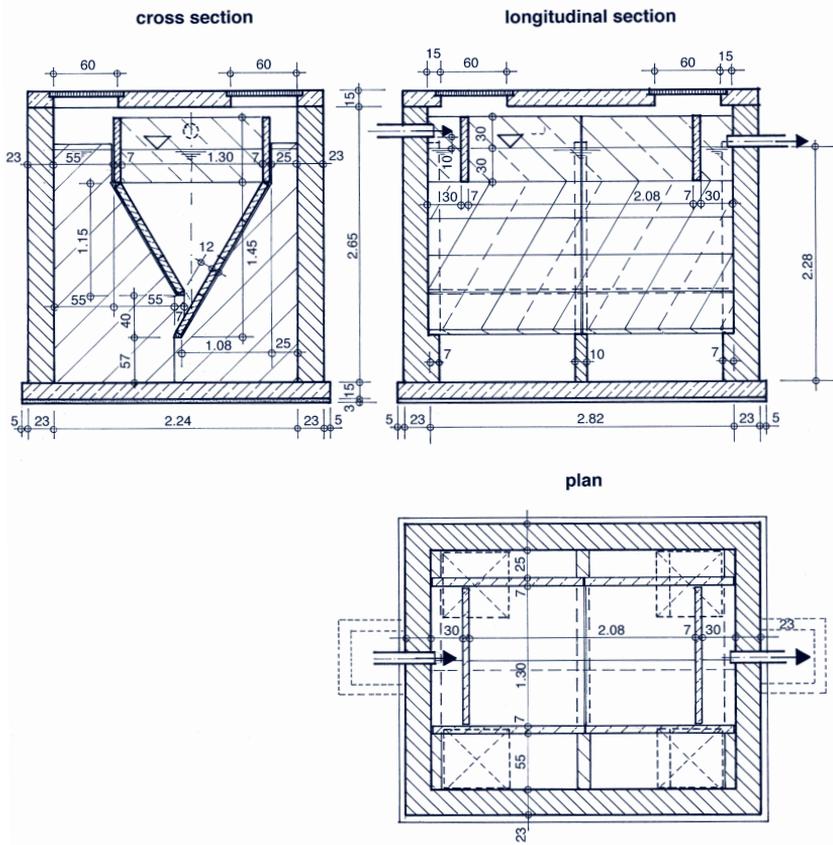
Imhoff or Emscher tanks are typically used for domestic or mixed wastewater flows above 3m³/d when the effluent receives further treatment above the ground and, therefore, should not stink – as may be the case with septic tanks. The Imhoff tank effectively separates fresh influent from bottom sludge.

The tank consists of a settling compartment above the digestion chamber. Funnel-like baffle walls prevent up-flowing foul-sludge particles from mixing with the effluent and causing turbulence. The effluent remains fresh and odourless because the suspended and dissolved solids do not come into contact with the active sludge and turn sour and foul. Retention time should not be much more than 2 hours during peak flow, otherwise this effect is jeopardised.



Picture 9_8:
Flow principle of the Imhoff tank. The water passes quickly through the flow tank, undisturbed by rising gas bubbles; the water does not mix with "ripe" water or sludge

When sludge ferments at the bottom, the sludge particles get attached to foul gas bubbles and start floating upwards. The up-flowing sludge particles assemble outside the conical walls and form an accumulating scum layer, which grows continuously downwards. When the slots – through which settling particles should fall into the lower compartment – are closed, the treatment effect is reduced to that of a undersized septic tank. Sludge and scum, therefore, must be removed at appropriate intervals.



Picture 9_9:
Imhoff tank.
Dimensions have
been calculated for
25m³ of domestic
wastewater per day

The inlet and outlet pipes are the same shape as those in septic tanks. Pipe ventilation must be provided, as Imhoff tanks also produce biogas. Additional baffles to reduce velocity at the inlet – and to retain suspended matter at the outlet – are advantageous. The upper part of the funnel-shaped baffles is vertical for 30cm above and 30cm below the water surface. The shape of an Imhoff tank may be cylindrical; the funnel, however, should always be rectangular, in order to leave adequate space outside the funnel for scum removal. The funnel structure may consist of pre-fabricated ferro-cement. Treatment efficiency lies in the range of 25 to 50% COD reduction.

Starting phase and maintenance

As with septic tanks, no special start-up phase is required. Desludging is necessary at regular intervals. Sludge should be removed from the bottom of the tank by pumping or hydraulic pressure pipes, withdrawing only fully digested substrate and leaving some active sludge behind for maintaining microbial activity. Best practice in the removal, handling and treatment of sludge is discussed in detail in section 11.3.

Scum must be removed before it grows enough to close the slots between the upper and lower compartments. Should this happen, gas bubbles appearing in rows on the water surface above the slots indicate excessive scum accumulation. Scum should be removed before sludge removal; the liquid may remain inside the tank.

Calculating dimensions

The upper compartment, inside the funnel walls, should be designed for 2h HRT at peak flow, and the hydraulic load should be less than $1.5\text{m}^3/\text{h}$ per 1m^2 surface area. The sludge compartment below the slots should be calculated to retain 2.5 litres of sludge per kg BOD reduced per day for short desludging intervals. For longer intervals please refer to the corresponding spreadsheet (Table 27, page 248).

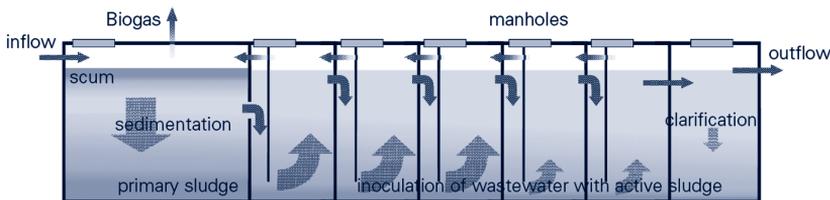
For domestic wastewater and desludging intervals of one year, the upper compartment should have a volume of approximately 50l per user and the sludge compartment below the slots should have a volume of approximately 120 litres per user. This is only a rule of thumb; for more detailed calculations, or for wastewater from non-domestic sources, please refer to the spreadsheet.

9.2.5 Anaerobic baffled reactor

The anaerobic baffled reactor (ABR), also known as the “baffled septic tank”, can be considered as the DEWATS version of the UASB system. It is, in fact, a combination of several anaerobic-process principles: the septic tank, the fluidised bed reactor and the UASB.

The up-flow velocity of the baffled reactor, which should never be more than 1m/h, limits its design. Based on a given hydraulic retention time, the up-flow velocity increases in direct relation to the reactor height. The reactor height, therefore, can not be used as a variable parameter to achieve the required HRT. The limited upstream velocity results in large but shallow tanks, making the system uneconomical for larger plants. This is why baffled reactors are not very well-known or properly researched.

However, the anaerobic baffled reactor is ideal for DEWATS because it is simple to build and simple to operate. Hydraulic and organic shock loads have little effect on treatment efficiency.



Picture 9_10: Flow principle of an ABR. Incoming waste-water is forced to pass through a sludge blanket of active micro-organisms in each compartment. The settler at the front prevents larger solids from entering the baffled section

The main difference to the UASB is that it is not necessary for the sludge blanket to float; it may rest at the bottom. Three-phase separators are also unnecessary because active sludge washed out from one chamber is trapped in the next. Tanks in series also help to digest difficult degradable substances, predominantly in the later chambers after easily degradable matter has been digested in the earlier ones. The anaerobic baffled reactor consists of at least four chambers in series. But practical experience shows that treatment efficiency does not increase with more than six chambers. The last chamber can incorporate a filter in its upper part, in order to retain remaining solid particles; alternatively, a settler for post-treatment can follow the baffled reactor (Picture 9_36).

The DEWATS version of the anaerobic baffled reactor does not have a rack or screen. A settling chamber is used to separate the larger solids before the wastewater continues to a series of up-flow chambers. Between chambers the water flow is directed to the bottom of the next chamber by baffle walls that form a down-shaft, or by down-pipes that are placed on the partition walls. Although down-pipes reduce the total digester length (and the cost) down-shafts are preferable because of better flow distribution.

The wastewater that enters a tank should be distributed over the floor area as evenly as possible. This is facilitated by relatively short compartments (length < 50% to 60% of the height) or, in the case of down-pipes, a distance of less than 75cm between pipes. In larger plants, when longer compartments are required, down-pipe outlets (as well as down-shafts) should reach to the centre of the floor area.

The outlet of each chamber (particularly the last one) should be placed slightly below the water surface to retain possible scum. Although not common practice, baffled reactors can be equipped with three-phase separators – in the form of slanting baffles in the upper third of the tank.

The anaerobic baffled reactor is suitable for treating all kinds of wastewater with BOD above BOD < 150mg/l. Although its efficiency increases with higher organic loading, it is also well-suited for domestic wastewater. There is relatively little experience with baffled reactors because the system is only used in smaller units. As a highly efficient modification of the less-efficient septic tank, baffled reactors combine simple and efficient operation with easy, low-cost construction. Treatment performance is in the range of 65% to 90% COD (70% to 95% BOD) removal. However, three months are required for maturation.

9 Technical components

Starting phase and maintenance

Treatment performance depends on the availability of active microbial mass. Inoculation with old sludge from septic tanks shortens the start-up phase. In principle, it is advantageous to start with only a quarter of the daily flow and with a slightly stronger wastewater. The loading rate should increase slowly over three months. This provides micro-organisms with enough time to multiply before suspended solids are washed out. Starting with the full hydraulic load from the beginning severely delays maturation.

Like regular septic tanks, sludge must be removed at regular intervals, leaving some sludge to ensure continuous treatment efficiency. More sludge accumulates in the front than in the rear compartments. Adequate removal, handling and treatment of sludge is discussed in detail in section 11.3.

Calculating dimensions

The up-flow should not exceed 1.0m/h. This is the most crucial parameter for dimensioning, especially with high hydraulic loading. The organic load should be below $3.0\text{kg COD/m}^3 \times \text{d}$. Higher loading rates are only possible at higher temperatures and for easily degradable substrate. The HRT of the liquid fraction (i.e. above the sludge volume) should not be less than eight hours. Sludge-storage volume should be provided for 4l/m^3 BODinflow to the settler and 1.4l/m^3 BODremoved in the upstream tanks. For exact calculation use the formula applied in the spreadsheet (Table 28, page 252).



Picture 9_12:
Baffled reactor
under construction
at a factory in India

9.2.6 Anaerobic filter

The dominant principle of both the septic and Imhoff tanks is sedimentation combined with sludge digestion. The anaerobic filter, also known as a fixed-bed or fixed-film reactor, is different in that it also includes the treatment of non-settleable and dissolved solids by bringing them into close contact with a surplus of active microbial mass.

“Hungry” micro-organisms digest the dispersed or dissolved organic matter within a short retention time. Most of the micro-organisms are immobile; they attach themselves to solid particles or, for example, the reactor walls. Filter material, such as gravel, rocks, cinder or specially formed plastic shapes, provide additional surface area for them to settle. By forcing the fresh wastewater to flow through this material, intensive contact with active micro-organisms is established; the larger the surface for microbial growth, the quicker the digestion. Good filter material provides 90 to 300m² surface area per m³ of occupied reactor volume. Rough surfaces provide a larger area, at least in the starting phase; the microbial “lawn” or “film” that grows on the filter mass quickly closes the smaller grooves and holes.



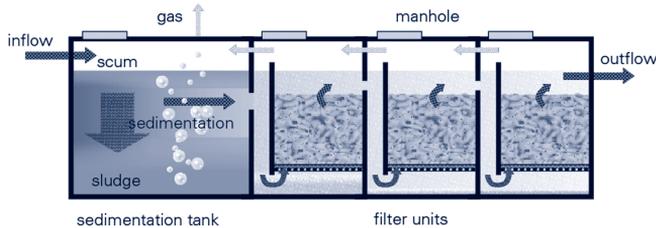
Picture 9_13:
Floating filter balls made of plastic. When the film of micro-organisms becomes too heavy, the balls turn over and discharge their load. The filter medium has successfully been used for tofu wastewater by HRIIE in Zhejiang Province in China.

9 Technical components

Anaerobic filters are very reliable and robust. Experience shows, however, that between 25 to 30% of the total filter mass may be inactive due to clogging. While a cinder or rock filter may not-completely become, reduced treatment blocked efficiency is indicative of clogging in some parts. Sand or gravel filters may block up completely due to smaller pore size.

Clogging happens when wastewater finds a channelled way through just a few open pores; eventually, the lessused voids clog and higher flow velocities occur in the few remaining open. This leads to reduced retention time and active micro-organisms are washed away.

Picture 9_14:
Flow principle of anaerobic up-flow filter. Most suspended solids should be retained in the septic tank. Filter micro-organisms consume dissolved and dispersed solids. Anaerobic filters may also be designed for down-flow



When the microbial film becomes too thick it must be removed. This may be done either by back-washing or by removing the filter mass for cleaning outside the reactor.

The treatment efficiency of well-operated anaerobic filters ranges between 70 to 90% BOD removal. They are suitable for domestic wastewater and all industrial wastewater with low suspended-solids content. Pre-treatment in settlers or septic tanks may be necessary to eliminate larger solids before the wastewater enters the filter.

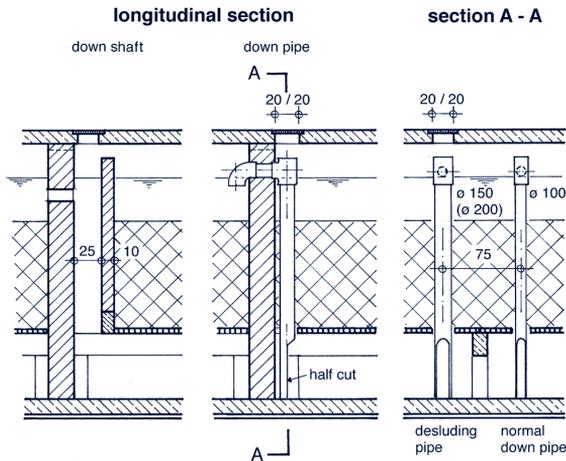
Anaerobic filters may be operated as down-flow or up-flow systems. The up-flow system is normally preferred because there is less risk of washing out active micro-organisms. On the other hand, flushing the filter – or cleaning – is easier in down-flow systems. A combination of up-flow and down-flow chambers is also possible.

9 Technical components

An important design criterion is the equal distribution of wastewater across the filter area. Equal distribution is facilitated by providing adequate free-flow space across the full width before and after the filter. This is why full-width down-flow shafts are preferred to down-flow pipes. The length of the filter chamber should not be greater than the depth of the water.

For smaller and simple structures, the filter mass consists of cinder (5 to 15cm in diameter) or rocks (5 to 10cm in diameter), which are – bedded on perforated-concrete slabs. The filter starts with a layer of large rocks at the bottom. The slabs rests on beams, which are parallel to the direction of flow, approximately 50 to 60cm above the ground slab. Pipes of at least 15cm diameter, or down-shafts over the full width, permit desludging at the bottom with the help of pumps from the top. In case the sludge-drying beds are located directly beside the filter, sludge may also be drawn via hydraulic-pressure pipes. Head losses of 30 to 50cm have to be considered.

Biogas utilisation may be considered in case of BOD concentration > 1,000mg/l; this requires completely gas-tight construction and provisions for collection, storage and use.



Picture 9_16:
Down-shaft and
down-pipes – both
systems may be ap-
plied alternatively
in anaerobic filters
and ABRs

Starting phase and maintenance

Since the treatment process depends on a surplus of active microbial mass, active sludge (for example, from septic tanks) should be sprayed on the filter material before continuous operation is started. If possible, start with only a quarter of the daily flow, and increase the flow slowly over three months. As this might not be possible in practice, treatment is unlikely to be operating at full capacity until approximately six to nine months later.

As with septic tanks, desludging should be done at regular intervals. Where possible, the filter should be back-washed before sludge removal. Adequate removal, handling and treatment of sludge is discussed in detail in section 11.3. The filter should be cleaned when efficiency declines.

Calculating dimensions

Organic-load limits between range 4 to 5kg COD/m³·d. The hydraulic retention time compared to the tank volume should range between one and a half and two days. For exact calculation, please refer to the spreadsheet (Table 29, page 257). For domestic wastewater, constructed gross digester volume (voids plus filter mass) may be estimated at 0.5m³/capita; for smaller units it is closer to 1m³/capita.

9.2.7. Planted soil filters

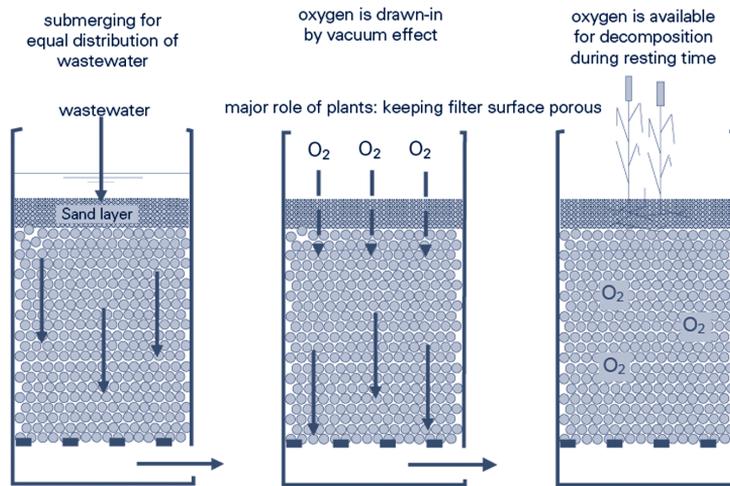
Three basic-treatment systems are referred to as planted soil filters:

- overland-treatment systems
- vertical-flow filters and
- horizontal-flow filters

In overland treatment the water is distributed on carefully contoured land by sprinklers. As the system requires permanent attendance and maintenance is not considered a component of DEWATS.

9 Technical components

In vertical-filter treatment (see picture below) the wastewater is alternately distributed on two or three filter beds with the help of a dosing device (similar to the trickling filter). The treatment functions, predominantly, aerobically. Although vertical filters require only about half the area of their horizontal counterparts and often achieve higher treatment efficiency, the constant operational control, need for a dosing device and strict adherence to charging intervals make vertical filters less suitable for DEWATS.



Picture 9_17:
The principle of
the vertical filter

Horizontal filters comply with DEWATS criteria, as they are simple in principle and require almost no maintenance – if well-designed and constructed. Planted horizontal gravel filters – also referred to as subsurface flow wetlands (SSF) or root zone treatment plants – provide natural treatment for pre-settled wastewater of a maximum COD content of 500mg/l. They are ideal, therefore, as tertiary treatment for wastewater, which has already undergone secondary treatment in units, such as baffled reactors, anaerobic filters or biogas digesters. They are also appropriate for treating pre-settled greywater directly.

Although they don't look complicated – and are quite simple to operate, designing sand and gravel filters requires a solid understanding of the treatment process and good knowledge of the filter medium that is to be used. Before deciding on filter treatment, therefore, one should always consider the alternative: constructing wastewater ponds. Filter treatment, however, has the great advantage of keeping the wastewater below ground, thereby avoiding smells and insect breeding.

9.2.7.1 Horizontal gravel filter

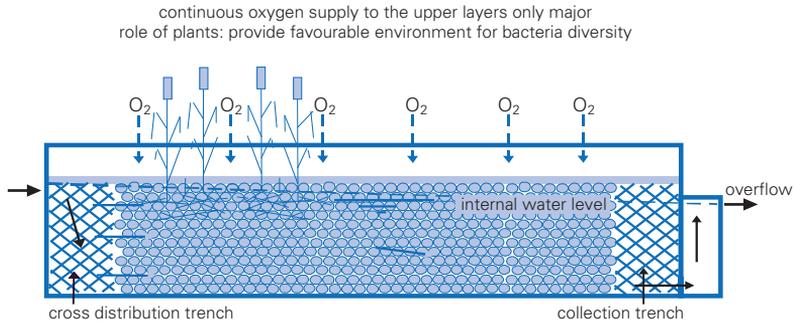
Since clogging is the biggest problem with horizontal gravel filters, the wastewater must be pre-treated so that suspended solids are removed before it enters the treatment unit. When testing wastewater, after 60 minutes in an Imhoff cone the sediment should not be more than 1ml/l, and not more than 100mg SS/l for non-settling industrial wastewater. If the COD-value of settleable solids is less than 40% of the total SS-value, then many of the solids are likely to be fat in colloidal form, which can reduce the hydraulic conductivity of the filter considerably (as may be the case with dairy wastewater).

The treatment process in horizontal ground filters is complex and not yet fully understood. Unlike the vertical filter, the horizontal filter (Picture 9_18) is permanently soaked with water and operates partly aerobic (free oxygen present), partly anoxic (no free oxygen but nitrate – NO_3 – present) and partly anaerobic (no free oxygen and no nitrate present). Combined with physical-filtration processes and the influence of plantation on the biological-treatment process and oxygen intake, the interaction of the separate treatment processes is difficult to predict. There are sophisticated methods for calculating the proper dimensions and treatment characteristics of different filter media, especially in relation to their hydraulic properties. However, such calculations make sense only if the exact required parameters are known, which is hardly ever the case. Rules of thumb, intelligently chosen, are more than sufficient for smaller-sized DEWATS plants. Going beyond these experience-based figures is not advisable without previous tests.

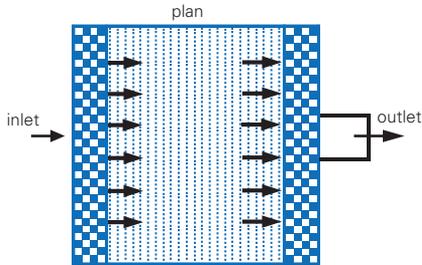
The rules of safe design are:

- large and shallow filter-bed
- wide inlet zone
- reliable distribution of inflow over the full width of the inlet zone
- round, coarse gravel that is nearly the same size as the filter medium

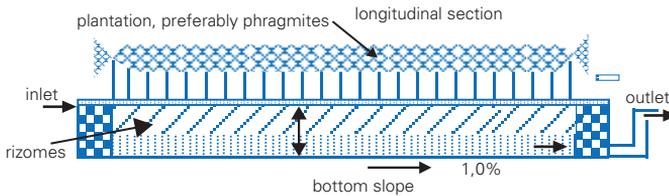
9 Technical components



anaerobic and anoxic conditions in the lower layers



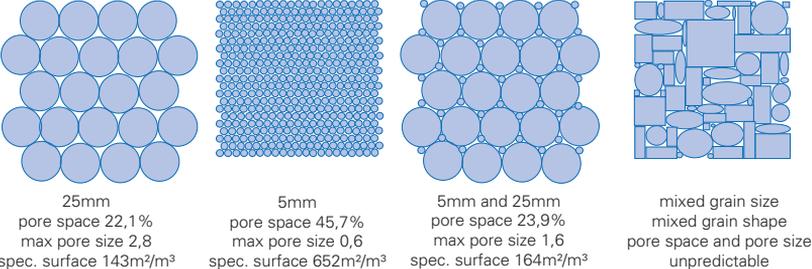
water flow in the horizontal filter



Picture 9_18:
The principle
of the horizontal
filter

Clogging is caused by suspended solids and by biological or mineralised sludge newly formed from the decomposition of organic matter. While large grain sizes with a high percentage of voids prevent clogging, they also reduce treatment performance. In order to utilise the full filter, the front part of the bed must have voids that are small enough to retain some of the SS, while being large enough to allow further SS removal in later parts of the bed. Round, uniform gravel of 6-12mm or 8-16mm is best.

The use of broken-edged stones reduces conductivity by approximately 50% compared to round gravel, due to turbulent flow within irregular pores. So large grains should be chosen when applying flat or mixed grain shapes, such as chippings from broken stones. In the case of mixed grain size, it is advisable to screen the gravel with the help of a coarse sieve: use the larger grains in the front and the smaller grains in the later sections of the filter. Care must be taken when changing from a larger to a smaller grain size because blockages mostly happen at the point of change.



Picture 9_19: Influence of grain size and shape on filter properties

A rather flat slope ($\alpha < 45^\circ$) should join one grain size to the other to ensure a larger connecting area. In particular when grain diameters differ considerably, an intermediate zone consisting of intermediate size may be useful. Mixed-grain sizes do not improve hydraulic conductivity. Removing fine soil from gravel by washing is more important than ensuring the exact grain size.

9 Technical components

If the length of the filter-bed is more than 10m, an intermediate channel for re-distributing cross-flow should be provided. The distribution channel can also serve as a terrace step in the case of steeply sloping topography (Picture 9_21).

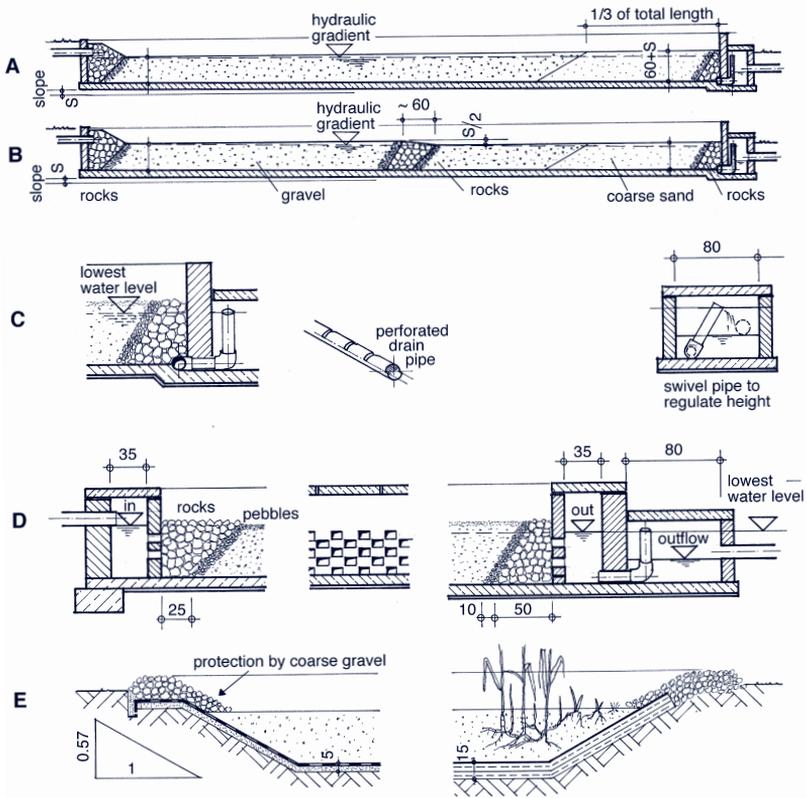
The relation between organic load and oxygen supply reduces with length. This happens because oxygen is supplied evenly over the total surface area, whereas the organic load diminishes during treatment. It is most likely, therefore, that anaerobic conditions prevail in the front part, while aerobic conditions reach to a greater depth in the rear part. However, only the upper 5 to 15cm can really be considered an aerobic zone.

A clogged gravel filter can become useful again if it is not used for periods of several months, because of a process called autolysis; when forced to live without feed, the bacteria live on their own bacterial mass.



Picture 9_20
Horizontal gravel
filter in India

Filter clogging normally results in surface flow of wastewater. This is usually not desired, although it hardly reduces the treatment efficiency if flow on the surface maintains the assumed retention time inside the filter (this could be the case with dense plant coverage). When filters are well-protected and a long way from residential areas, there is no harm in letting some of the wastewater run above the horizontal surface. Such "overland treatment" produces very good results – especially when the water is equally distributed and does not fester in trenches.



Picture 9_21: Horizontal gravel filter (subsurface flow filter). A: Filter basin in masonry and concrete structure, finer gravel is used in the rear portion. B: Long filter bed with additional distribution trench in the middle; the trench is filled with rocks and allows a step in the surface level. C: Detail of collection pipe and swivel pipe to regulate height. D: Details of inlet and outlet structure for improved distribution of flow for wider filter beds. E: Details of filter basins using foils or clay packing for sealing. Sloped side walls are less costly, but plants will not grow near the rim

9 Technical components

Knowledge of the amount of void space within the filter material is essential for calculating the retention time and planning the treatment process. Gravel has 30 to 45% voids, depending on size and shape. (The calculation of HRT in the spreadsheet in table 30 is based on 35% void space; it can be adapted proportional, if the actual void space is greater.) Void space can easily be determined by measuring the water that can be added to a bucket full of gravel (Picture 9_23).

Table 20:

Theoretical properties of gravel and sand as filter material: lower values should be applied for wastewater when designing filter beds

filter medium	diameter of grain mm	pore volume		theoretical conductivity	
		coarse	total	m/s	m/d
gravel	4 - 40	30%	35% - 40%	4.14E - 03	350
sand	0.1 - 4	15%	42%	4.14E - 04	35

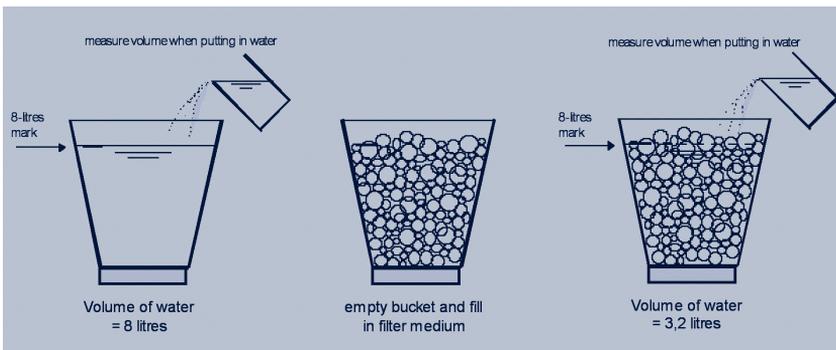
For high conductivity, large pore size is more important than total pore volume. Pre-wetted gravel shall be used when the pore volume is tested, ensuring that pores of only capillary size are “closed” in advance.

34 See: Shilton et al, 1996

In reality, short cuts and volume-reduced by partly clogged areas result in 25% shorter retention times and, consequently, inferior performance³⁴. For this reason, the filter-bed should not be deeper than the depth to which plant roots can grow (30–60cm), as water will tend to flow faster below the dense cushion of roots. However, treatment performance is generally best in the upper 15cm because of oxygen diffusion from the surface. Shallow filters are more effective, therefore, than deeper beds of the same volume.

Picture 9_22:

Determining pore space of filter medium on site. Example: the empty bucket is full after pouring 8 litre of water. The bucket filled with gravel absorbs 3.2 litre of water: Voids space is $3.2/8 = 0.40$ or 40%



Uniform distribution of wastewater throughout the filter requires an equally distributed supply of water at the inlet – and equally distributed reception at the outlet side. Trenches filled with rocks 50 to 100mm in diameter are provided at both ends to serve this purpose. A perforated pipe, which is connected to the outlet pipe, lies below the strip of rocks that form the collection trench. The height of the outlet can be adjusted by a swivel arm, fixed to a flexible elbow. By lifting it until water appears at the surface of the filter near the inlet, the water level in the filter can be adjusted according to hydraulic conductivity. While the top of the filter is kept strictly horizontal to prevent erosion, the bottom slopes down from inlet to outlet ideally at 1%. Site conditions permitting, bigger slope is also possible. To prevent erosion, long filters should have a terraced surface rather than a slope (see picture 9_21 (B)).

The percolation of wastewater into the ground is not desirable so the bottom of the filter must be sealed. While solid-clay packing might be sufficient, heavy plastic foils are more common. A concrete basin with straight, vertical masonry walls allows plants to grow up to the outer rim – not possible with the smooth embankment that plastic foils would require (see picture 9_21 (E)).

In a dry climate, trees search for water and their roots may break the walls and grow into the filter. Whenever possible, trees should not be planted directly beside the filter; this will avoid the structural problems caused by the roots and the unwanted sealing of the filter surface by fallen leaves.

Observation in Europe indicates that the performance of gravel filters diminishes after several years. How long a horizontal filter functions properly depends on several factors: grain size and shape of gravel, the nature and amount of suspended solids in the wastewater, and the temperature and the average loading rate.

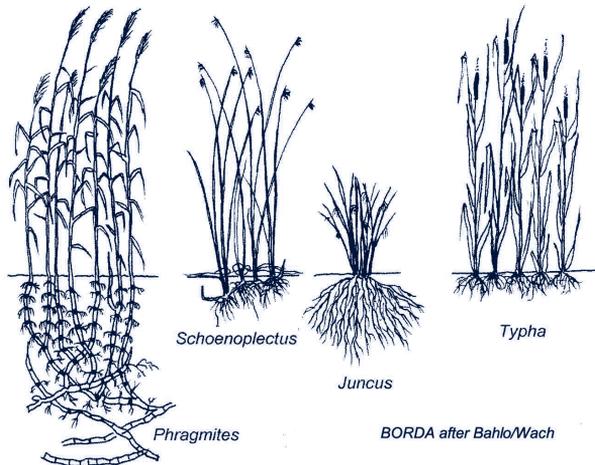
If the filter is drained during resting time, alternate charging can increase the treatment performance of horizontal filters. To allow alternate feeding, the total filter area should be divided into several compartments or beds. Other reports recommend that the filter is changed every eight to 15 years. This timeframe is only a rough estimation and – as stated above – depends on the loading rate and structural details, the impact of which is almost impossible to predict in practice. Weaker wastewater, lower loading rates and larger gravel size generally increase the lifetime of the system.

9 Technical components

Ground filters are covered by suitable plantation – any type of hydro-botanical plant that will grow on wastewater and has deep-reaching and widely spreading roots. The choice of plant influences treatment efficiency; some scientists claim that the micro-environment created inside the filter is responsible for equilibrium between sludge production and sludge “consumption”. Such equilibrium is only likely with low loading rates.

The plants are not normally harvested. *Phragmites australis* (reeds), found almost anywhere, are considered to be ideal because their roots form horizontal rhizomes that guarantee a perfect root-zone filter bed (see picture 9_24). Most swamp and water grasses are also suitable, but not all of them have extending or deep-enough roots. Depending on the type of wastewater, different plants might be preferable: *Typha angustifolia* (cat-tails), together with *Scirpus lacustris* (bull rush), have been to be found the most suitable plants for wastewater from petrol refineries, while the large, red- or orange-flowering iris (sometimes known as “mosquito lily”) is a beautiful plant, which grows well on wastewater but is only suitable for shallow, domestic gravel beds. Forest trees have also been used and are deemed to be only slightly less efficient³⁵. At least two clumps of plants or four sprouted rhizomes should be placed per square metre when planting is started.

35 Kadlec et al, 1996



Picture 9_23:
Plant species common for gravel filter plantation

Within a horizontal filter, plants seem to be “catalysts” rather than “actors” Plants transport oxygen via their roots into the ground. Some scientists claim that this process also supplies surplus oxygen, thereby creating an aerobic environment, while others have shown that plants only transfer as much oxygen as they need to fulfil their own nutrient requirements. For example, Brix and Schierup claim that plants provide $0.02\text{g O}_2/\text{m}^2 \times \text{d}$ to the filter bed, while consuming $2.06\text{g O}_2/\text{m}^2 \times \text{d}$ for themselves. Nonetheless, it is assumed that toxic substances near the roots are eliminated by oxidation. The complex ecosystem that exists in planted gravel filters produces good and reliable treatment results, which in part, must be due to aerobic treatment. This is underlined by reports which claim that COD reduction rates of over 95% can be achieved – which would not be possible under anaerobic conditions alone. The uptake of nutrients by plants is of relatively little importance, especially when plants are not harvested.

Starting phase and maintenance

Young plant seedlings may not grow on wastewater. So it is advisable to start feeding the plant with plenty of fresh water and to let the pollution load grow parallel to plant growth.

When plants are under full load, the outlet level is adjusted according to flow. Water should not stand on the surface near the inlet. If this happens, the swivel arm at the outlet should be lowered. Optimal water distribution at the inlet side is important and must be controlled from time to time. Replacement of the filter media might be necessary when treatment efficiency declines. Since there is no treatment during the time that the filter media is being replaced, it is advantageous to install several, parallel filter-beds.

To prevent clogging of the filter with fine soil, stormwater should neither be mixed with the wastewater before the treatment step, nor should outside stormwater be allowed to overflow the filter bed. Erosion trenches around the filter-bed should always be kept in proper functioning condition.

9 Technical components

Calculating dimensions

If percolation properties – the so called hydraulic conductivity of the filter body – is known, then the required cross-sectional area at the inlet can be calculated using Darcy's Law. To compensate for reduced conductivity with use, only a fraction of the calculated figure for clear water should be used for designing the plant. The conductivity applied in the spreadsheet takes this into consideration. It does not, however, take head of pessimistic statements, which claim that only 4% of the clear-water conductivity should be used. The dimensions of the filter depend on hydraulic and organic loading, temperature and grain size of the filter medium. As a rule of thumb, 5m² of filter should be provided per capita for domestic wastewater. This would mean a hydraulic loading rate of 30l/m² and an organic loading rate of 8g BOD/m² x d. For comprehensive calculation use the formula applied in the computer spread sheet (Table 30, page 264).

Darcy's Law

$$A_c = \frac{Q_s}{k_f \times dH / ds}$$

$$\text{cross-section area of filter-bed (m}^2\text{)} = \frac{\text{flow rate (m}^3\text{/sec)}}{\text{hydraulic conductivity (m/sec) x slope (m height/m length)}}$$

Picture 9_24:
Darcy's law for calculation of hydraulic conductivity



Picture 9_25:
Horizontal gravel filter during construction. Constructed above ground

9.2.7.2 Vertical sand filter

Although the vertical filter is – compared to the horizontal filter – the more efficient and more reliable treatment system from a technical and scientific point of view, it is not suitable for DEWATS because of its permanent operational control, necessity of a dosing device, and strict adherence to charging intervals. Nonetheless, the following section introduces this system to provide a better understanding of related treatment processes.

The vertical filter functions in a similar way to an aerobic trickling filter and, consequently, must be fed at intervals with defined resting times between dosing charges. In addition to the short intervals, which are regulated by dosing devices, longer resting periods of one to two weeks are required. This is only possible if there are at least two alternately fed filter beds.

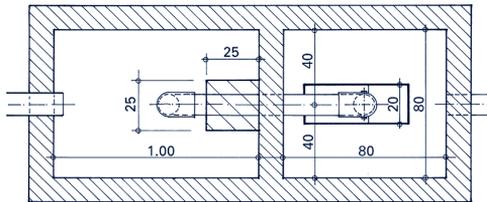
Feeding in doses is necessary for equal water distribution. The resting times are needed so that oxygen can enter the filter after wastewater has percolated (see picture 9_17 on page 196). Doses must be large enough to temporarily flood the complete filter and to distribute the water evenly over the surface, but small enough to allow enough time for oxygen to enter before the next flooding. The filter material, therefore, must be fine enough to cause flooding and porous enough to allow quick percolation. During the short charging times, the wastewater is exposed to the open, which can create a bad odour in the case of anaerobic pre-treatment.

The body of the vertical filter consist of a fine top layer, a medium middle layer and a rough bottom layer. The area below the filter media is a free-flow area, connected to a drainpipe. The free-flow area is also connected to the open via additional vent pipes. The fine top layer guarantees homogeneous flow distribution; the middle layer is the actual treatment zone, while the bottom layer is responsible for providing wide-open pores to reduce the capillary forces, which would otherwise decrease the effective hydraulic gradient.

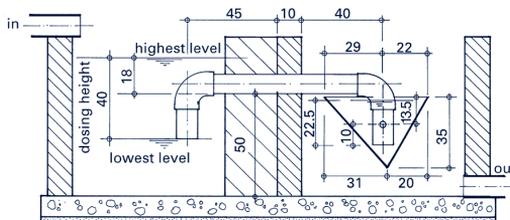
Vertical filters are normally 1m to 1.20m deep. However, if there is enough natural slope and good ventilation, vertical filters can be constructed up to three metres high. Vertical filters may or may not be covered by plantation. In the absence of plantation, the surface must be scratched at the beginning of each resting period, in order to allow enough oxygen to enter; with dense plantation, the stems of the plants ensure sufficient open pores in the filter surface. Several charging points are distributed over the surface to allow quick flooding of the full area. Flooding is the only reliable method of achieving equal distribution of water over the entire filter; charging points spaced across the surface area allow quick submergence. It is not possible to achieve equal distribution by designing supply pipes of different diameters and length, leading to various outlet points. This has been tried often enough; we don't need new failures. Flush distribution is a must.

Dosing of flow can be regulated with self-acting siphons, automatic controlled pumps or tipping-buckets. The latter is most suitable under DEWATS conditions because its determining principle is easily understood and the hardware can be manufactured locally.

section



plan



Picture 9_26:

Dosing chamber with tipping bucket for the controlled operation of a siphon. The bucket closes the siphon until it is filled with water. When losing its equilibrium due to the weight of the water, the bucket turns over and opens the siphon. It falls back into horizontal position to receive new water, which again closes the siphon for the next flush

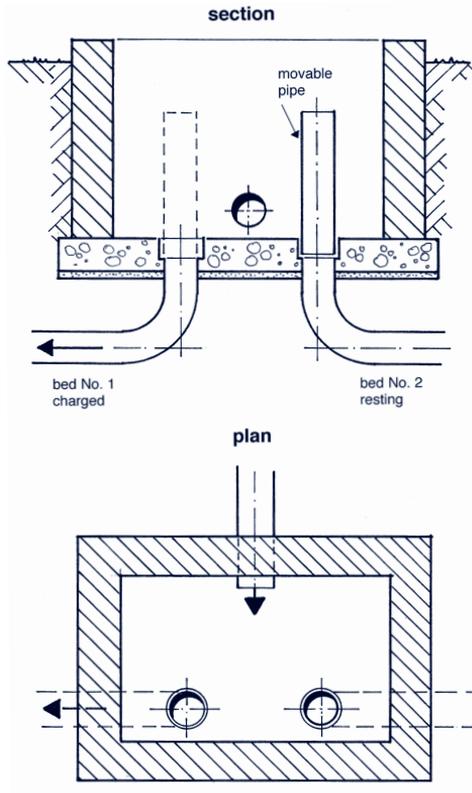
The flow to each bed can be prevented or controlled when necessary with a valve within the inlet pipe. Alternatively, the valve can be replaced by a straight standing piece of pipe in the dosing chamber (see Picture 9_28).

While vertical filters can bear a hydraulic load up to $100\text{l/m}^2 \times d$ ($100\text{mm/m}^2 = 0.1\text{m}$), it is better to restrict loading to $50\text{l/m}^2 \times d$. The organic load may reach up to $20\text{g BOD/m}^3 \times d$; in the case of re-circulation, $40\text{g BOD/m}^3 \times d$ is possible (Metcalf & Eddy). In the case of pre-treated domestic wastewater, the hydraulic load is the deciding factor. Some engineers use these values only for active filter-beds, while others claim that the resting beds must be included within the calculation. If there is any doubt, testing is recommended. However, larger filter areas are always preferable.

Permeability can be calculated with Darcy's Law (on page 206), whereas $dH/ds = 1$. The flow speed ($v = Qs/Ac$), therefore, is equal to the hydraulic conductivity (k).

Starting phase, maintenance and calculating dimensions

The vertical sand filter does not belong to DEWATS. Detailed operational instructions have been deliberately excluded from this handbook to ensure readers don't get the impression that the vertical filter can be constructed and operated under DEWATS conditions.



Picture 9_27:
Distribution chamber for alternate feeding of filter beds. A piece of straight pipe is placed on the outlet, which is to be temporarily closed

9.2.8 Ponds

Ponds (lagoons) are artificial lakes. They provide wastewater treatment through natural processes. Different treatment processes can be utilised; depending on the design of the artificial lake, series of ponds can be used to combine different treatment effects. Ponds are ideal DEWATS and should be given preference over other systems whenever land is available. Ponds are preferable to underground gravel filters, if sympathetic to the surroundings; facultative or anaerobic ponds must be far enough from human settlements to avoid the nuisance caused by bad odours or mosquito breeding. Polishing ponds can be closer, if fish are held within the water body; fish that belong to *gambusia spp.* are commonly used for mosquito control in tropical countries.

Pure pond systems are cheap and need almost no maintenance, even if large.

Ponds may be classified into:

- sedimentation ponds (pre-treatment ponds with anaerobic sludge stabilisation)
- anaerobic ponds (anaerobic stabilisation ponds)
- oxidation ponds (aerobic cum facultative stabilisation ponds)
- polishing ponds (fully-aerobic post-treatment ponds, placed after stabilisation ponds)

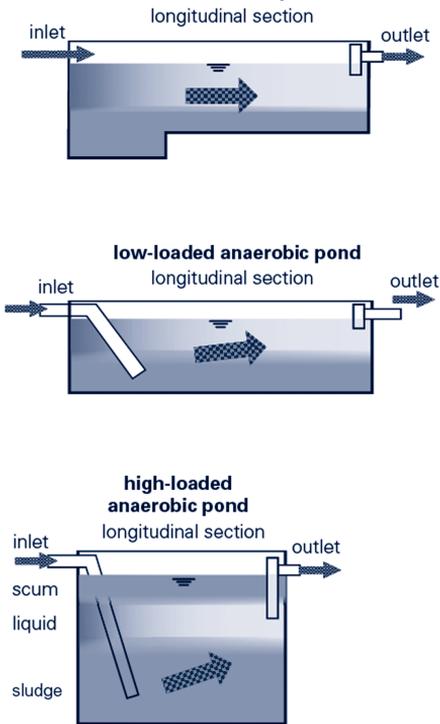
Pond systems intended to provide full treatment normally consist of several ponds serving different purposes. For example, a deep anaerobic sedimentation pond for sedimentation cum anaerobic stabilisation of sludge, two or three shallow aerobic and facultative oxidation ponds with longer retention times for predominantly aerobic degradation of suspended and dissolved matter, and one or several shallow polishing ponds for the final sedimentation of suspended stabilised solids and bacterial mass. Wastewater ponds for fish farming require low organic loading and, in addition, should be diluted by four to five times the amount of river water. Otherwise, the pond must be about 10 times as large as the area calculated in the spreadsheet (see Table 33, page 273).

Artificially aerated ponds are not considered to be DEWATS and, therefore, are not dealt with in this handbook. It may be enough to know that such ponds are 1.5 to 3.5m deep, usually work with a five days hydraulic retention time (HRT) and organic loads of 20 to 30g BOD/m³×d. The energy requirement for aeration is about 1–3W/m³ of pond volume. Only where there is a little scum only the surface of anaerobic ponds may be aerated to reduce the foul smell.

9.2.8.1 Anaerobic ponds

Anaerobic ponds are deep (2 to 6m) and highly loaded (0.1 to 1kg BOD/m³×d). Anaerobic conditions are guaranteed by the depth of the pond, thereby requiring less surface area than aerobic-facultative oxidation ponds.

It is possible to provide separate sludge-settling tanks before the main pond, in order to reduce the organic-sludge load. Such settling tanks should have a HRT of less than one day, with the exact HRT depending on the kind of wastewater. Anaerobic ponds with an organic loading rate of below 300g/m³×d BOD are likely to remain at an almost neutral pH. Consequently, they release little H₂S and, therefore, are almost free from an unpleasant smell. Highly loaded anaerobic ponds omit foul odour, until a heavy layer of scum has been developed.



Picture 9_28:

Principles of anaerobic ponds. Sedimentation ponds have a HRT of about one day, ponds with low loading are supposed to be odourless because of almost neutral pH, highly loaded ponds form a sealing scum layer on top

Before this layer exists, the upper region of the pond will remain aerobic; these ponds are called facultative-anaerobic.

Depending on the properties of the wastewater, the desired treatment effect and possible post-treatment, anaerobic ponds are designed for hydraulic retention times of between one and 30 days. The HRT determines whether only settled sludge or all of the liquid is treated. For domestic wastewater the anaerobic pond may function as an open septic tank. It should be small, in order to develop a sealing scum layer; in this case, treatment efficiency is only in the range of 50 to 70% BOD removal.

“Wrong” retention times result in stinky effluent. If the retention time is longer than one day, not only bottom sludge but also the liquid portion begins to ferment. On the other hand, if the retention time is too short for the liquid to stabilise substantially, the effluent remains at a low pH and stinks of H₂S. Too-short retention times have the same effect as too-high organic loading rates.

pollutant	dimension	inflow	outflow	removal rate
suspended solids	mg/l	431	139	68%
COD mg/l	mg/l	1189*	505	58%
BOD ₅	mg/l	374	190	49%
Nkjel	mg N/l	116	99	15%
P total	mg/l	26	24.5	6%
fecal coli	No/100ml	6,156,000	496,000	92%
fecal strepto	No/100ml	20,900,000	1,603,000	92%
nematode ova	No	139	32	77%
cestode ova	No	75	18	76%
helminth ova	No	214	47	78%
*the high COD/BOD ratio is caused by mineral of pollution which is also the reason for the COD-removal rate being higher than that of the BOD ₅				

Table 21:
An example of the high performance of a simple settling pond
Source: Drioeche et al, 1997

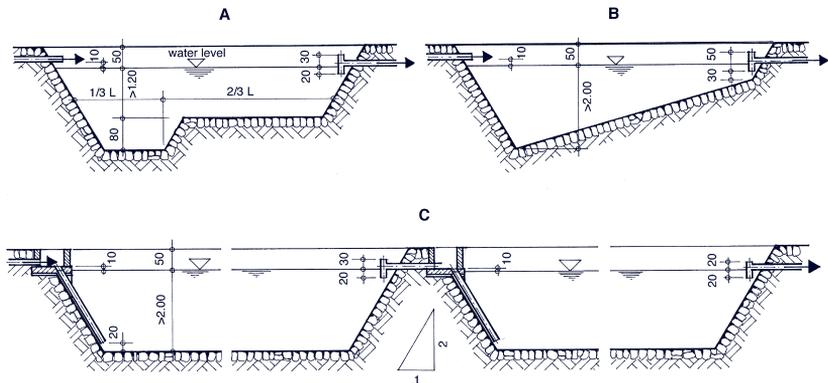
In industries, such as sugar plants or distilleries, anaerobic ponds are often used as the first treatment unit, followed by oxidation ponds. The treatment efficiency of high-loaded ponds with long retention times ranges from 70 to 95% BOD removal (CODrem. 65 to 90%), depending on the biodegradability of the wastewater. Several ponds in series are recommended for long retention times.

Anaerobic ponds are not very efficient in treating wastewater with a wide COD/BOD ratio (> 3:1). For this type of wastewater, sedimentation ponds with very short retention times, followed by aerobic/facultative stabilisation ponds are recommended.

ambient temperature °C	org. load BOD g/m ³ *d	efficiency BOD rem. %
10	100	40
15	200	50
20	300	60
23	330	66
25	350	70
28	380	70
30	400	70
33	430	70

Table 22:
Design parameters for low-loaded anaerobic ponds in relation to ambient temperature
Source: Mara 1997

Picture 9_29:
Cross-sections of anaerobic ponds constructed from rocks, with cement-mortar pointing. A and B: A deeper inlet section accumulates most of the sludge within a limited surface area. C: Two anaerobic ponds in series. The first pond may be highly loaded (scum sealed), while the second pond may be low loaded (neutral pH)



Pond size is also determined by the long-term sludge-storage volume. Anaerobic ponds with sufficient, integrated sludge storage make sludge-removal intervals of over 10 years possible.

Starting phase and maintenance

Start-up does not require any special arrangements. But one must be aware of the fact that a heavily loaded pond will release bad odour until a layer of scum seals the surface. Inlet and outlet structures should be monitored during operation. A drop in the effluent quality is a warning that the sludge must be removed. If this is neglected, the receiving waters or the ensuing treatment units will suffer the consequences.

Calculating dimensions

Retention time and volumetric organic load are the two design parameters for anaerobic ponds. A non-smelling pond loaded with $300\text{g BOD/m}^3\text{d}$, for a short HRT of one day, requires approximately 0.2m^3 per capita for domestic wastewater. Anaerobic stabilisation of the liquid fraction requires longer retention times, the calculation of which depends on temperature, desired treatment quality and organic load. The organic loading rate should not exceed $1\text{kg BOD/m}^3\text{d}$. For exact calculation please refer to the formula in the spreadsheet (Table 31 and 32, pages 268 and 269).



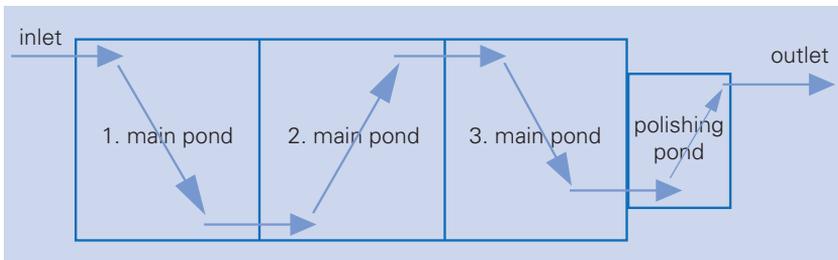
Picture 9_30:
Anaerobic pond
in Namibia

9.2.8.2 Aerobic ponds

Aerobic ponds receive most of their oxygen via the water surface. For loading rates below $4\text{g BOD}/\text{m}^2 \times \text{d}$, surface oxygen can meet the full oxygen demand. Oxygen intake increases at lower temperatures and with surface turbulence caused by wind and rain. Oxygen intake also depends on the actual oxygen deficit up to saturation point so may vary at 20°C between $40\text{g O}_2/\text{m}^2 \times \text{d}$ for fully anaerobic conditions and $10\text{g O}_2/\text{m}^2 \times \text{d}$ in the case of 75% oxygen saturation.³⁶ (Mudrak&Kunst, after Ottmann 1977).

³⁶ See Mudrake et al, 1997

The secondary source of oxygen comes from algae via photosynthesis. However, in general, overly intensive growth of algae and highly turbid water prevents sunlight from reaching the lower strata of the pond. Oxygen “production” is then reduced because photosynthesis cannot take place. The result is a foul smell because anaerobic facultative conditions prevail. Algae are important and positive for the treatment process, but are a negative factor when it comes to effluent quality. Consequently, algae growth is allowed and wanted in the beginning of treatment, but not desired when it comes to the point of discharge because algae increase the BOD of the effluent. Algae in the effluent can be reduced by a small final pond with a maximum one-day retention time. Larger pond areas – low loading rates with reduced nutrient supply for algae - are the most secure, but also the most expensive measure.

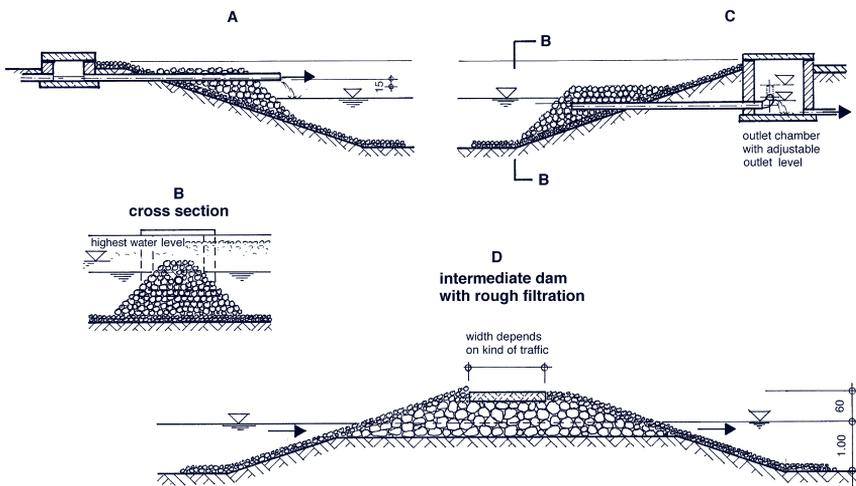


Picture 9_31:
Flow pattern of
aerobic-facultative
ponds in series

The laboratory results of effluent wastewater often give a false impression of insufficient treatment. As nearly 90% of the effluent BOD comes from algae, many countries allow higher BOD loads in the effluent from ponds, as compared to other treatment systems. Baffles or rock bedding before the outlet of each of the ponds have a remarkable effect of algae retention. Intelligent structural details increase the treatment quality considerably at hardly any additional cost – and may be seen as being as important as adequate pond size.

Treatment efficiency increases with longer retention times. The number of ponds is of only relative influence. With the same total surface, splitting one pond into two ponds increases efficiency by approximately 10%. Having three instead of two ponds adds about 4% and from three to four ponds having increases efficiency by another 2%.

This shows that having more than three ponds is not justifiable from an economic point of view because the same effect can be achieved by just enlarging the surface area. Instead of constructing the dams and banks of an additional pond, the required land should be used as additional water area.



Picture 9_32: Section through a large aerobic-facultative stabilization pond. Banks should be protected against erosion by waves. A: Inlet; banks should also be protected against erosion by influent. B: Cross-section B-B (front view of C). C: Outlet structure with swivel arm to adjust height of pond according to seasonal fluctuation of water volume.

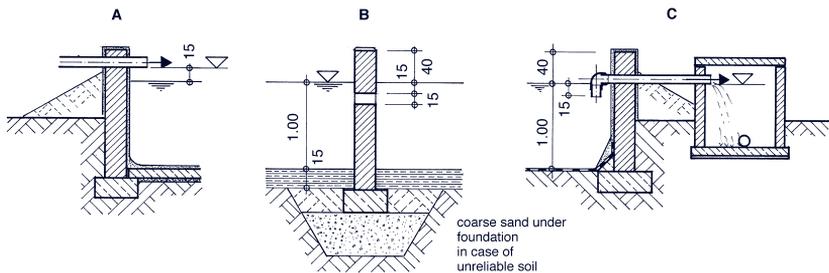
9 Technical components

The first pond may be as much as twice the size of the others, if there are several inlet points. In principle, having several inlet points – to distribute the pollution load more equally and to create a larger area for sedimentation – is an advantage. On the other hand, it might be advisable to provide a slightly separated inlet zone to avoid bulky, floating matter littering the total pond surface.

The inlet points should be as far away from the outlet as possible. The outlet should be below the water surface to retain floating solids, including algae. Gravel beds acting as roughing filters are advisable between ponds in series and before the final outlet.

The erosion of banks by waves could be a problem with larger ponds. Therefore, the slope should be 1 (vertical) to 3 (horizontal) and covered with rocks or large bits of gravel. This also helps to keep the soil embankments from slipping. Banks and dams can be protected by planting macrophytes, such as cat-tail, or phragmites. Dams between ponds should be paved and wide enough to facilitate maintenance.

Picture 9_33:
Details of aerobic-stabilisation ponds (basins) of smaller size. A: Inlet structure, concrete flooring, B: Baffle wall, compacted clay flooring, C: Outlet structure, foil flooring (protection against misuse may be advisable)



Aerobic stabilisation ponds must be shallow enough to permit adequate oxygen intake but deep enough to prevent weed growth at the bottom of the pond. A depth of 90cm to 1m in a warm climate and up to 1.2m in cold-climate zones (due to frost) is suitable. Deeper ponds become facultative or even anaerobic in the lower strata.

Smaller volumes of wastewater, such as from schools, hospitals or residential houses are better pre-treated in Imhoff tanks, septic tanks, baffled reactors or, at the least, sedimentation pits, before reaching the aerobic stabilisation pond. Properly operated Imhoff tanks, which have odourless effluent are preferable. A septic tank with smelly effluent is to be preferred if regular desludging of the Imhoff tank cannot be guaranteed. If pre-treatment is not provided, the pond must have a deeper sedimentation zone near the inlet; bad odour is to be expected. It might be wiser, therefore, to construct a small sedimentation pond, on which a sealing scum layer will develop. Should the scum layer reach a thickness of more than 10cm, papyrus can be grown on it to make it look more attractive.

Starting phase and maintenance

The pond matures much faster if it is filled with river water *before* the first wastewater enters. With the exception of controlling the inlet and outlet structures regularly, no permanent attendance is required. But the performance of the pond should be monitored and any disturbance of the water quality investigated. Sludge must be removed at defined intervals, to avoid a decline in treatment quality. Adequate sludge removal, handling and treatment is discussed in detail in section 11.3.

Calculating dimensions

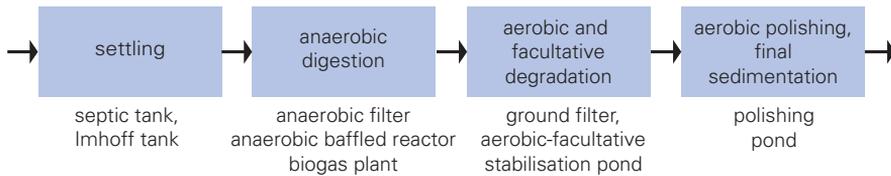
Organic surface load and hydraulic retention time are the two decisive design parameters. While the minimum hydraulic retention time ranges from five to 20 days, the maximum organic load depends on the ambient temperature (see Table 23 on this page). The amount of sunshine hours is important, as UV radiation is effective at destroying pathogens. Although this consideration is not included in the calculation, ponds should be slightly oversized in areas with permanent cloud cover. Organic loading should be less than $20\text{g BOD/m}^2 \times \text{d}$. For domestic wastewater, a pond surface of between 2.5 and 10m^2 may be estimated per capita. All values depend on the type of pre-treatment, the surrounding temperature, and health objectives. For more exact calculation, please refer to the formula applied in the computer spreadsheet (see Table 33, page 273).

5 days HRT	
ambient temperature °C	organic load BOD g/m ² *d
10	7.0
15	11.7
20	17.7
23	21.8
25	24.5
28	28.4
30	30.8
33	33.8

Table 23:
Organic surface loading for aerobic-facultative ponds
Source: Mara, 1997

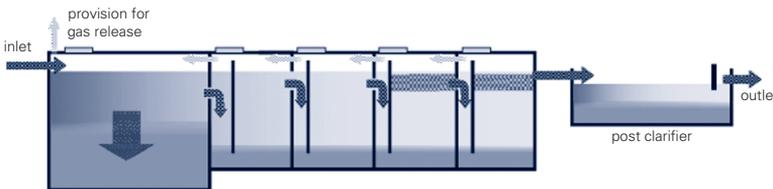
9.2.9 Hybrid and combined systems

Each technology has its strengths and weaknesses. It makes sense, therefore, to combine different treatment units into a more efficient modular, treatment system. An example of such a combined system could be sedimentation in a settler or septic tank followed by anaerobic decomposition of non-settleable suspended solids in anaerobic filters or baffled reactors. Further treatment in ponds or ground filters provides aerobic conditions. Deciding which technologies are most appropriate for combining depends on treatment requirements and boundary-site conditions.



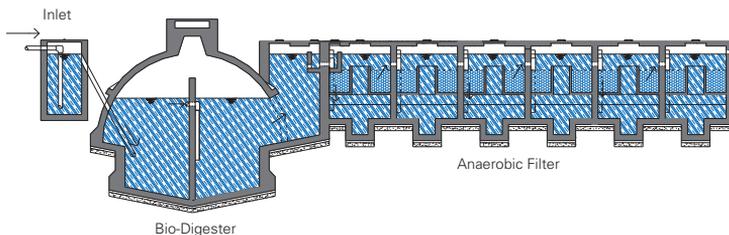
Picture 9_34: The complete treatment chain of DEWATS-technology

Apart from applying different DEWATS modules in series, hybrid systems can also combine different technologies within one treatment unit. One can, for example, combine the anaerobic baffled reactor with the anaerobic filter by adding filters in the last chambers (see picture 9_36); alternatively, if a floating-filter medium is available, one may provide a thin filter layer at the top of each baffled chamber. In practice, the combination of six baffled chambers with two filter chambers has performed reliably and well.

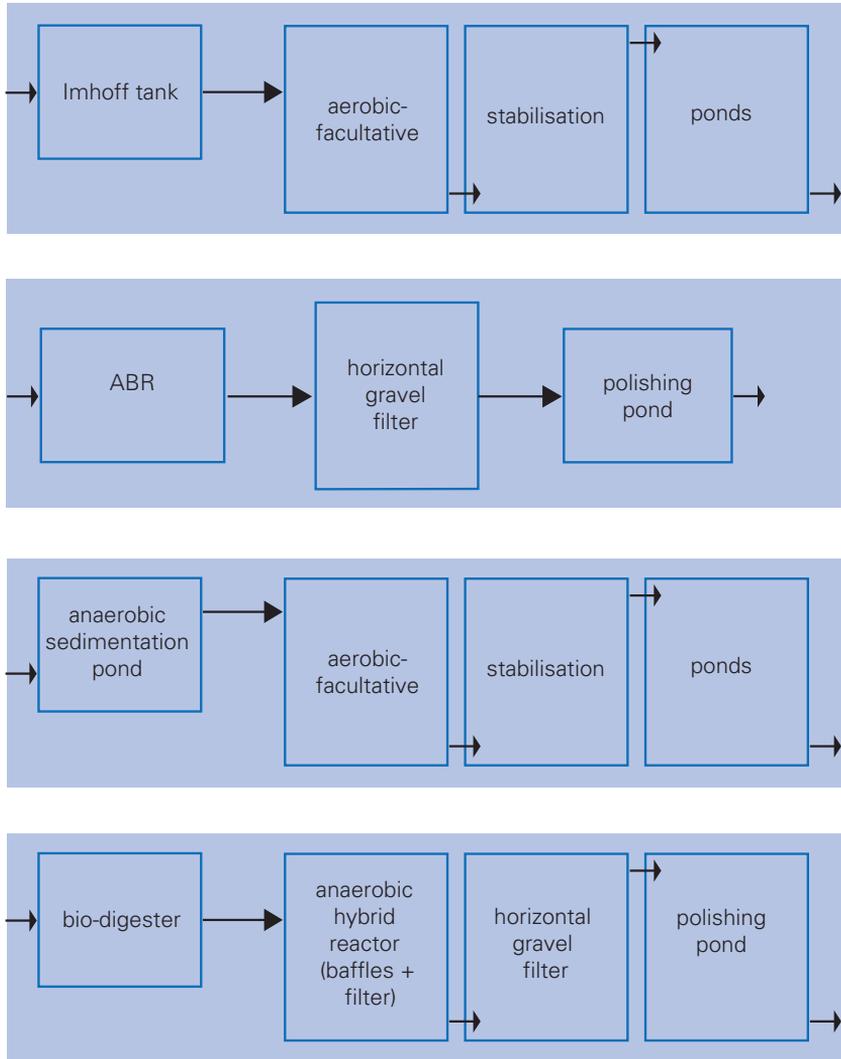


hybrid system with settler, anaerobic baffles and filter units

Picture 9_35: Examples of a hybrid and a combined system



9 Technical components



Picture 9_36:
Typical combinations for full treatment with DEWATS-modules

9.3 Non-DEWATS technologies

DEWATS commands low maintenance. This implies that technologies which cannot be “switched on and off” as one likes, is integral to the DEWATS concept. DEWATS are intended to function every day with the efficiency envisaged. Systems, which are highly efficient but require a great deal of regular care to function at an acceptable level, do not suit the concept of decentralised wastewater treatment. To avoid any misunderstanding: The technologies which are regarded here as non-DEWATS are by no means inferior treatment systems. They may even be used in a decentralised concept. However, not without highly qualified operational staff which is closely supervised by an experienced management.

9.3.1 UASB

The UASB system is not considered a DEWATS technology. However, an understanding of the principle on which it functions may improve one’s understanding of the anaerobic baffled reactor.

In a UASB reactor (Upstream Anaerobic Sludge Blanket reactor) the upstream velocity and settling speed of the sludge is in equilibrium and forms a locally rather stable, suspended sludge blanket in the lower part of the digester. This sludge blanket of suspended active sludge acts as a filter medium. After some weeks of maturation, granular sludge forms and improves the physical stability and filter capacity of the sludge blanket.

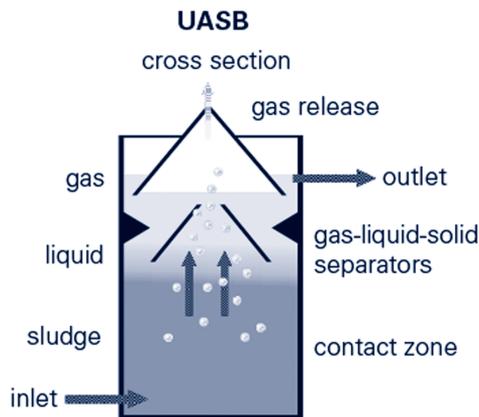
To keep the blanket in its proper position, the hydraulic load must correspond with the upstream velocity and with the organic load. The latter is responsible for the development of new sludge. So the flow rate must be controlled and regulated in accordance with fluctuations of the organic load. Generally, the fluctuation of inflow is high in smaller units and regulating wastewater flow is not possible. Furthermore, it is not possible to stabilise the process by increasing the hydraulic retention time without lowering the upstream velocity. Although the system is simple to build, these operational difficulties render it unsuitable for DEWATS, particularly for relatively weak, domestic wastewater.

Fully controlled UASBs are used for relatively strong industrial wastewater. Slanting baffles (similar to the Imhoff tank) help to separate gas bubbles from solids, whereby solids are also separated from the up-streaming liquid. These baffles are called 3-phase separators. Biogas can be collected and used.

UASB reactors require several months to mature – to develop sufficient granular sludge to provide treatment. Granular sludge looks like big flocs of dust; microbial slime forms chains, which coagulate into flocs or granules. High organic loading, in connection with lower hydraulic loading, speeds up the granulation process in the starting phase. Since higher velocities are required to lift sludge granules compared to single sludge particles, the sludge blanket remains relatively stable.

Starting phase, maintenance and calculating dimensions

The UASB does not belong to DEWATS. Details of how to operate it and calculate its dimensions are deliberately omitted from this handbook so that readers don't gain the impression that the UASB can be built and operated under DEWATS conditions.



Picture 9_37:
Flow principle of UASB reactors. Up-streaming water and gas-driven sludge particles hit baffles, which cause to separate gas, solids and liquid

9.3.2 Trickling filter

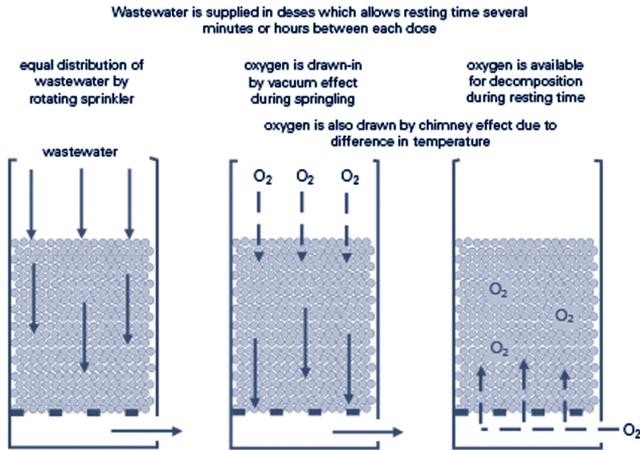
The trickling filter is not thought of as a DEWATS solution. But some understanding of how it works will improve one's understanding of the principle of aerobic-wastewater treatment.

The trickling filter follows the same principle as the anaerobic filter, in the sense that it provides a large surface for bacteria to settle. The main difference between the two systems lies in the fact that the trickling filter works under aerobic conditions. This implies that the bacteria, which are immobilised at the filter medium, must have equal access to air and wastewater. So wastewater is dosed at intervals, providing time for air to enter the reactor during the breaks. An equal distribution of wastewater over the full surface area will utilise the filter mass most efficiently.

A trickling filter consists of:

- a dosing device
- a rotating sprinkler
- a filter body, which is ventilated both from the top and the bottom

9 Technical components



Picture 9_38:
The principle of the trickling filter

Rocks with a diameter of between 3 and 8cm in are used as the filter medium. The outside of the filter body is closed to prevent sludge flies from escaping into the open. The filter rests above ground to allow ventilation. The bottom slab is sloped so that sludge and water inses away. The bacterial film must be flushed away regularly to remove dead sludge and to prevent clogging. High hydraulic-loading rates ($> 0.8\text{m}^3/\text{m}^2 \times \text{h}$) have a self-flushing effect. With organic-loading rates of $1\text{kg BOD}/\text{m}^3 \times \text{d}$, 80% BOD removal is possible. Higher loading rates reduce efficiency.

In a 2m-high trickling filter with a wastewater of $500\text{mgBOD}/\text{l}$, the organic-loading rate comes to:

$$0.8 \times 24\text{h} \times 0.5\text{kgBOD}/\text{m}^3/2\text{m height} = 4.8\text{kg BOD}/\text{m}^3 \times \text{d}$$

At such a high organic load, a removal rate of only 60% BOD may be expected. The simple calculation shows that wastewater would have to be recycled nearly five times to get the expected treatment quality and self-flushing effect. However, the trickling filter could be operated with lower hydraulic-loading rates if regular flushing is done.

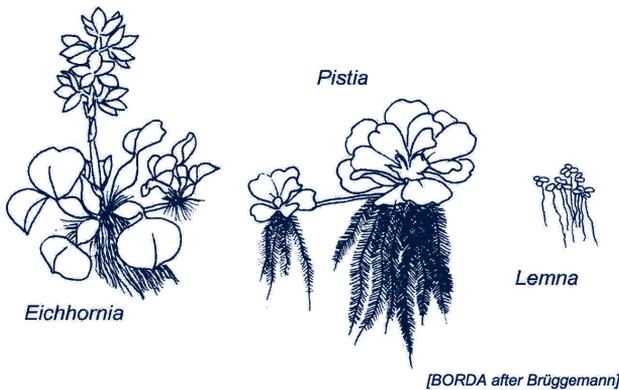
The self-flushing (high-rate) trickling filter is a reliable system, despite fluctuations in the flow of wastewater. Nonetheless – as it requires a rotating sprinkler and pump for operation – the system is not a suitable DEWATS solution.

Starting phase, maintenance and calculating of dimensions

Details for calculation and instructions for operation are not included in this handbook as the trickling filter cannot be built and operated under DEWATS conditions.

9.3.3 Aquatic-plant systems

Water hyacinth, duckweed, water cabbage and other aquatic plants can improve the treatment capacity of pond systems. The heavy metals that accumulate in water hyacinths are removed when the plants are harvested. Duckweed is a good substitute for algae; if not confined within fixed frames, duckweed is blown by the wind to the lee-side of the pond. If it is retained in a surface baffle, it leaves a cleaner effluent. Improved treatment efficiency however, is only guaranteed by regular attendance and harvesting. Special design features for harvesting increase the total area requirement of the treatment system. The evaporation rate of aquatic-plant systems is four times higher than that of open ponds (in the range of 40l/m²×d in hot climates).



Picture 9_39:
Aquatic plants,
commonly used
for wastewater
treatment

The area required for a pond is almost the same, regardless of aquatic plants. If the organic-loading rate is low, plants provide protect mosquito-controlling fish from birds. However, some plants such as water hyacinth, are disadvantageous, as they hide mosquito larva from fish and provide shelter for snakes. High organic loading rates – where additional treatment by aquatic plants is most beneficial – do not allow the survival of fish for mosquito control.

As aquatic-plant systems become a nuisance if they are not maintained properly, they are not considered as DEWATS. However, aquatic plants make sense if utilised in conjunction with wastewater farming for intensive and controlled nutrient recycling, or to improve the appearance of residential areas.

Starting phase and maintenance

Operation and maintenance is mainly an agricultural-management issue rather than a wastewater-treatment issue. The pond should start off with fresh, river water and the pollution load should be slowly increased, as plant cover increases. Plants must be harvested regularly to prevent bottom sludge forming from dead plants. Duckweed, in particular, should be kept within frames. Inlet and outlet structures should be controlled regularly.

Calculating dimensions

For practical reasons, please refer to the same formula as for unplanted oxidation ponds (see Table 33, page 273).



Picture 9_40:
Aerobic pond for
post-treatment of
a DEWATS system
at Aravind-Eye-
Hospital in
Pondicherry, India