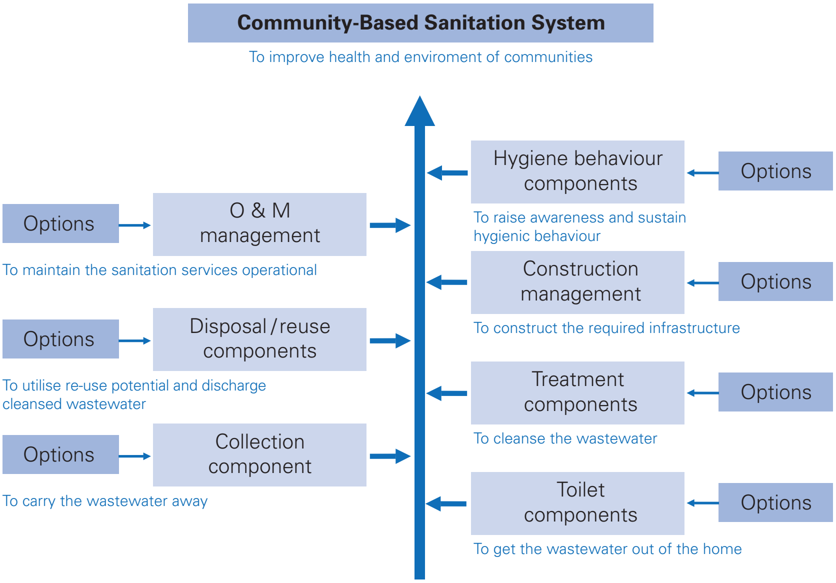
11 Project components: sanitation and wastewater treatment – technical options

The other components of DEWATS and DEWATS/CBS systems along the sanitation chain before and after the wastewater treatment are:

- toilets
- collection systems
- reuse and disposal systems, including sludge treatment and biogas applications
- construction management
- management of operation & maintenance
- health and hygiene behaviour



Picture 11_1 Community-Based Sanitation System: technical options along the sanitation chain

Each component presents a wide range of possible technical options. To select the most appropriate solution for a location, the options must be assessed with the help of various criteria, such as capacity, costs, self-help compatibility, operation & maintenance, replication potential, reliability, convenience and efficiency.
While operational and process related issues are dealt with in chapters 5 and 6, this chapter presents technical options for toilets, collection systems, sludge accumulation and treatment, the reuse of wastewater and sludge as well as biogas utilisation.

11.1 Toilets

When communities use hygiene and sanitation methods that fit their real needs and abilities, they will enjoy better health. In most cases, the toilet component is the users' prime concern. There are many reasons why users might prefer one sanitation option over another, beside, health, better water supplies or improved hygiene:

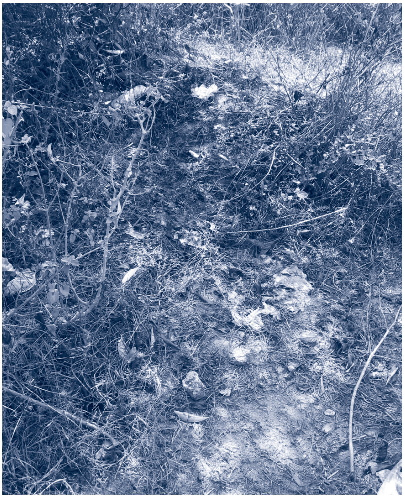
- Privacy – the need for privacy makes it important for a toilet to have a good shelter. Providing a door or enclosed entrance, or constructing it away from busy locations, makes the toilet nicer to use
- Safety – a poorly constructed toilet can be dangerous to use. If it is far from the home, women may be in danger of sexual violence. A toilet must be well-built and in a safe location
- Comfort – people prefer to use a toilet with a comfortable place to sit or squat, and a shelter large enough to stand up and move around in. Children, the elderly or people with disabilities have special needs to permit comfortable use
- Cleanliness – no one wants to use a dirty and smelly toilet. Toilet areas should be well-lit and ventilated. Easy-to-clean surfaces and cleary defined of cleaning responsibilities help to ensure that toilets are well-kept
- Respect – a well-kept toilet brings status and respect to its owner; this may be an important reason for people to spend money and effort to build one

The following section describes a selection of possible toilets – from common, hazardous models to recommended options. No one toilet design is right for every community or household. It is important, therefore, to understand the benefits and risks of each and to adapt designs to suit local conditions and cultural preferences.

11.1.1 Common practices to be discouraged

Open defecation

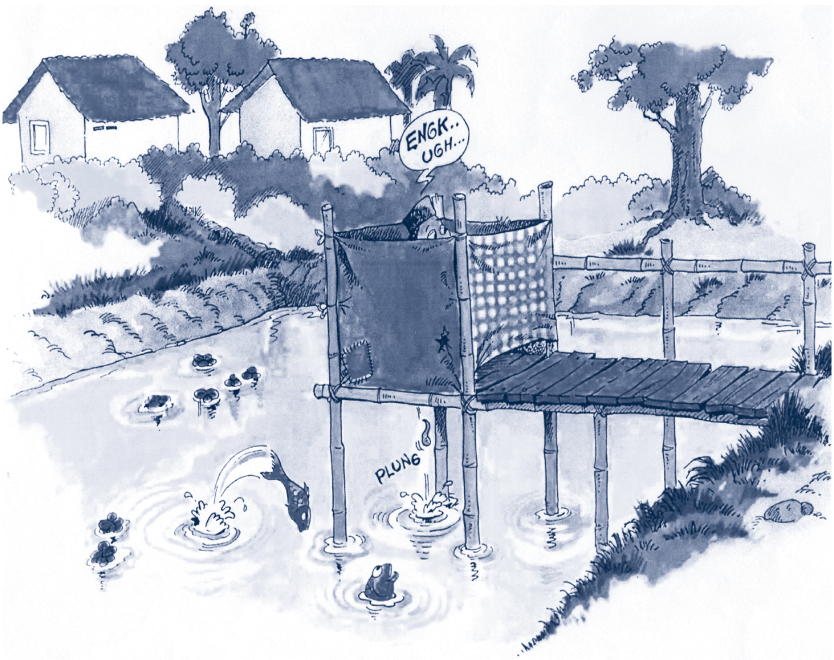
The lacking of sanitation facilities forces large parts of the world's population to defecate openly. Depending on the location, refuge is sought in the forest, jungle, lakes, rivers or the ocean. Apart from lacking privacy and the obvious associated hygienic-health risks, open defecation places humans in a vulnerable situation. Women and children can easily become targets of sexual abuse or violence. In many cases, parents also worry about the safety of their children, because of poisonous snakes or other potential dangers in the bush or jungle.



Picture 11_2 and 11_3: Residents returning from distant open-defecation areas; a bush toilet

Overhang latrine

Overhung latrines are usually built from bamboo or wood and sited above the surface of water bodies (such as rivers, ponds or lakes). Excreta fall directly into the water, where they are decomposed. Usually it is a public facility, which serves an entire or part of a community. This type of latrine pollutes the receiving water body, which can no longer be used as a fresh-water source (exceptions may include very rural settings with large or fast-moving water bodies). Furthermore, the system is usually inconvenient, as it is located away from settlements. The exposed location affords users with little privacy.



Picture 11_4: Overhang latrine

11.1.2 Closed pit toilets

Closed pit toilets are very common in developing countries and are always located outside the house.

They consist of a deep pit, which is covered by a platform with a shelter. The platform has a hole in it and a lid to cover the hole when it is not in use. The platform can be made of wood, concrete, or logs covered with earth. Concrete platforms help to keep water out of the pit and are very durable. A closed pit toilet should have a lining or concrete-ring beam to prevent the platform or the pit itself from collapsing. The average pit depth of 3m is usually limited by the groundwater table or rocky underground. The underground of the latrine should be water pervious. Dry anal cleansing is advantageous to minimise water content. No sullage treatment is included.

The latrine can be used until it is filled up to half a metre below the top; its lifetime depends on the number of users and pit size. At that point, space is required for emptying for the pit – which is to be discouraged for hygienic reasons – or relocation of the toilet.

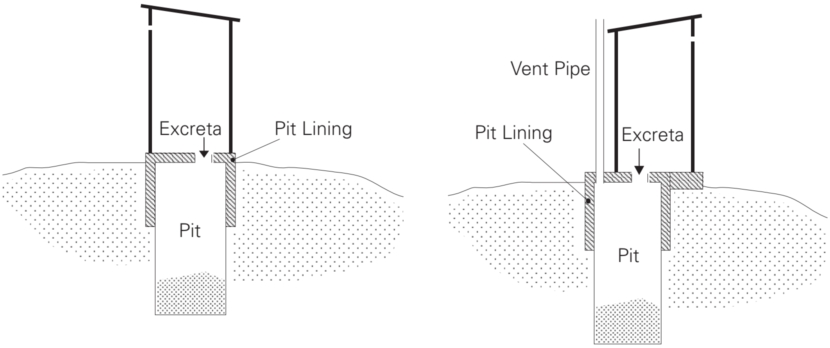
To prevent groundwater pollution and increased health risks, pit toilets are only suitable in flood-free areas, where the highest seasonal groundwater table lies well below the floor of the pit. The system has a large potential for odour, insects and hygiene hazards, especially if not cleaned regularly.

Ventilated improved pit toilets (VIP)

The VIP toilet is a kind of closed pit toilet that reduces smells and flies. The design and applicability is the same as for a normal pit latrine – made of a latrine superstructure, a pit-cover slab and a lid-covered hole for defecation. The only difference is the ventilation pipe, provided with a durable fly-screen on the top and reaching high above neighbouring roof-tops. A dark-coloured ventilation pipe should be chosen, to promote convection, or upwards air-flow within the pipe. A disadvantage of VIP latrines is that the toilet room must be kept relatively dark to encourage flies to travel towards the light at the end of the ventilation pipe, where they are trapped and die at the fly-screen. Good maintenance of the screen is important to ensure convenience and healthy conditions. Dry anal cleansing is advantageous to minimise water content. No sullage treatment is included. It is common to relocation the latrine after the pit is full.

Shallow (composting) pit toilets for tree planting

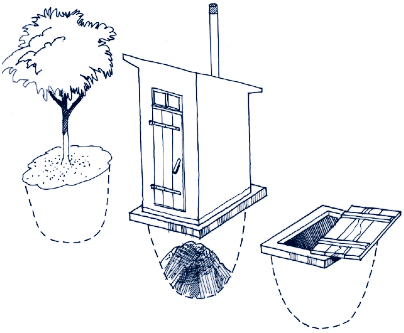
The design is similar to that of a VIP latrine – made of a latrine superstructure, a pit cover slab with ventilation pipe and a lid-covered hole for defecation. The system is better at reducing the risk of groundwater pollution when compared to other closed pit toilets because the pit is very shallow (maximum depth of 0.5 to 1m). It thereby ensures that the faecal matter is contained within the biologically active upper soil zone, where it can be decomposed.



Picture 11_5: Standard pit and VIP latrine

When the pit fills, the toilet house, including the concrete slab, is moved to a neighbouring location and a tree is planted on the site of the first pit. Shallow pit toilets are most appropriate where there is space and people want to plant trees. They can be constructed in locations where rocky underground prevents the digging of deeper pits.

The design can be improved by installing a urine separation pan with a collection container, in sandy-soil conditions, to avoid nitrogen infiltration. The system is not suitable in areas with a rocky surface, extremely high groundwater or flooding.



Picture 11_6 to 11_9: Shallow (composting) pit toilets for tree planting. Source: Stockholm Environment Institute, 2004

11.1.3 Composting toilets

Composting toilets retain faeces and urine and turn them into soil conditioner and fertiliser. Sitting or squatting models are available.

The composting latrine consists of a squatting plate, which is placed over a watertight vault usually constructed above the soil. The vault is ventilated through a pipe, which extends above the surrounding rooftops and has a fly-screen at the top. To support the composting process it is necessary to add dry organic material, such as straw, leaves, sawdust, soil or vegetable waste, at daily intervals. This reduces smells and helps the waste to break down. Different techniques can be applied to reduce the water content, thus guaranteeing optimal aerobic conditions. Under the right conditions, the mix will heat up, thereby killing most germs, including roundworm eggs (the hardest to kill). After sufficient treatment time (usually one year), the composted material is removed for use as a fertiliser. To be safe, it is best to mix it into a compost pile, where it will break down more. Then it can be mixed into the soil for planting.

Due to the importance of the moisture content in the chamber, composting latrines are only suitable for communities using dry cleansing material or with separate wash-water drainage and treatment. Since the water content within the vault must be monitored, the users must fully understand and appreciate the process to ensure proper operation of the system without odour or insect nuisance.
The toilet is normally located outside the house and can be used for many years, if operated properly. The system is convenient in rural areas where composting is traditionally practised. No sullage treatment is included.

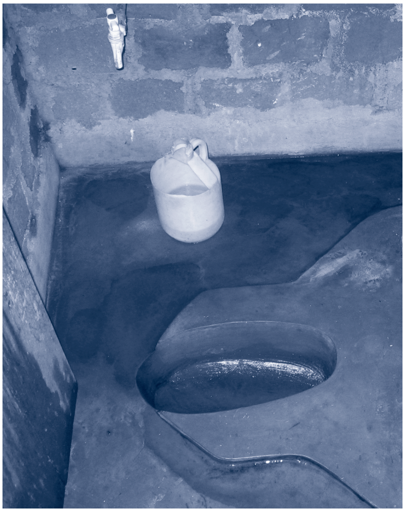
A variation of the system includes two vaults, which are alternately in use. While one vault is being used, the content of the other is topped up with 30cm of soil and covered with a concrete slab. With time, the contents are dehydrated through evaporation and decomposed by micro-organisms. When the second pit is full, the odourless and partially disinfected compost can be removed from the first pit. If it is still wet and smells, further composting or storage in a dry place is advised. Wear gloves, and wash hands after handling the fresh fertiliser.

11.1.4 Dry, urine-diversion toilets

Dry, urine-diversion toilets combine toilet house and treatment facility into one above-ground structure. They can be located inside the house, attached to it or left as a free-standing unit in the yard. Urine and faeces are collected separately by special toilet models of various designs. Sitting and squatting models are available.

The super-structure is elevated to create sufficiently sized faeces-storage volume below the cover slab. These storage chambers are waterproofed to ensure dry conditions, even in the case of heavy rain or flooding.

The key to successful operation is the fast dehydration of the faeces. Laying bamboo, cornstalks, branches or other dry plant matter on the floor of the chamber before initial use facilitates the drying process. Furthermore, a handful of ashes, sawdust or dry soil sprinkled over the faeces after defecation will to absorb moisture and avoid fly breeding.



Picture 11_10 and 11_11: Selection of urine-diversion and, squatting toilet models

A ventilation pipe, which extends above the surrounding rooftops and has a fly-screen at the top, causes a constant draft into the toilet, thereby drying the faeces and avoiding smell. Ventilation is increased by using black chamber-access doors facing the sun.

From the separation toilets, urine can be led to collection containers. If collected, it should be treated by air-tight storage for three to six months before being diluted 10 to 1 with water and used as a liquid fertiliser rich in phosphorous and nitrogen. Alternatively, urine – together with water used for anal cleansing – can be led into an evapo-transpiration reed-bed next to the toilet house. Its plants are cut back periodically, chopped into small pieces and added to the processing vault after drying. Good experiences with the system have been reported in South India, even in humid conditions. The traditional Vietnamese double-vault toilet works in the same way but only in combination with dry anal cleansing and urine utilisation for agriculture purposes.

Picture 11_12 and 11_13: Selection of urine-diversion and, squatting toilet models

Faecal storage and treatment can be practised with two possible systems:

a) Two-chamber system: the compartment below the toilet is divided into two chambers. When one chamber is full, it is closed and the second one is used. When the second is full, the first is emptied. The toilet model either has two faecal openings (one leading to each chamber), or the toilet bowl can be removed and turned around to use the other chamber.
b) Storage receptacles: the compartment below the toilet contains several containers. Plastic bins or locally produced reed-baskets can be used. When one of the containers fills, the chamber is accessed and the full container is replaced with an empty one. The full container remains in the compartment. When all storage capacity has been exhausted, the full container with the longest storage time is removed and emptied. Reed-baskets are perfect if further composting is desired.

Access to the faeces chamber can be through a water-tight door, a concrete slab or a temporary hole (weak mortar brickwork) in the chamber wall.

The system is suitable for all geographical conditions – particularly in regions with water scarcity, high groundwater table, flooding or rocky soil. Implementation requires the users to have intensive training. It is not recommended for public or communal toilets, as there is a high risk of misuse.

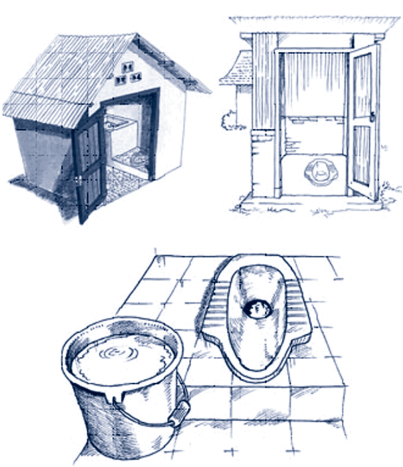
11.1.5 Pour-flush toilets

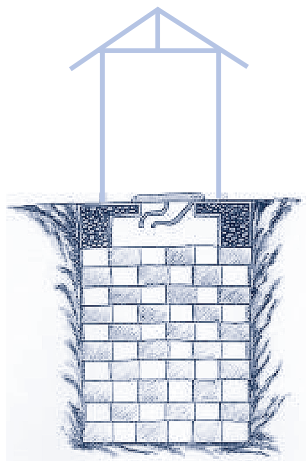
Pour-flush toilets are very common; sitting and squatting models are available. Excreta are washed away with approximately 0.5 to 2 litres of water poured into the pan with a scoop. These toilets should only be applied,therefore, where adequate amounts of flush water are available. Since they have a water seal against odours and insects, pour flush-toilets can be located within the house, if desired. Where water is required for anal cleansing, pour-flush toilets are particularly suitable because the same water can be used for flushing. As no complex mechanical devices are needed for operation, the toilets are robust and rarely require repair. Since water is available near and in the toilet, cleaning is very easy.

Pour-flush toilets use a plastic, fibreglass, or cement bowl or squatting pan set into a concrete platform. The concrete platform can either be placed directly over a pit, or it can be connected by pipe to one or two pits. Alternatively, the pipes can feed into a wastewater-collection system or directly into other treatment units (i.e. septic tank).

Pour-flush toilets with one leach pit

Single leach pits are made of a latrine superstructure and a WC pan with a water seal. A collection pipe, 100mm in diameter, is laid at a gradient of at least 1 in 20, if the pit is off-set. The wastewater is discharged into a pit lined with water-pervious brick or stone work. Pits should be covered with reinforced-concrete slabs, stone slabs or wooden planks, secured against mischief by children.





Picture 11_14: Pour-flush toilet

Picture 11_15: Pour-flush toilet with one leach pit

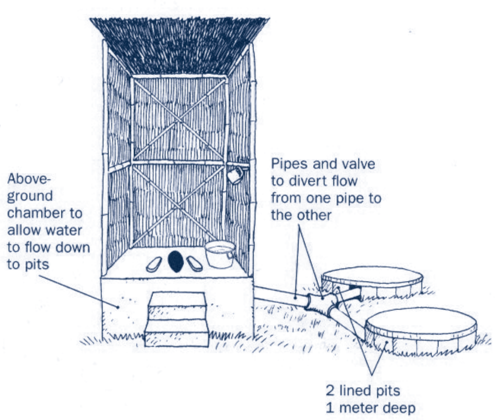
Pour-flush toilet with single leach pit

One-pit pour flush toilets can only be used until it the pit is full. A five-headed family will fill a lined pit of two metre depth and 1 meter diameter in approximately 5 years and emptying is required before continued use is possible. Desludging should be provided by professional service providers to minimise health risks. It is easier if the pit is off-set and not directly under the superstructure. Pour flush pit toilets should be applied only in flood-free areas, where the highest seasonal groundwater table lies at least 3m below ground level.

Pour-flush toilet with two leach pits

When there are two pits, a valve directs the wastewater to the pit currently in use. The first pit is used until it is nearly full. Then waste is diverted into the second pit. Soil is added to the first pit and its contents are left to settle for at least two years, then it can be emptied without any great risk of illness from germs.

For a family of five, two pits measuring one metre deep and one metre in diameter would need alternating approximately every three years. The distance between the pits should be at least the same as the depth of the pits. Pour-flush pit toilets are only appropriate in flood-free areas, where the highest seasonal groundwater table is more than 3m below ground level.



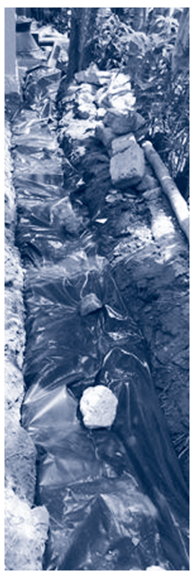
Picture 11_16: Pour flush toilet with two leach pits (toilet house shown without door)

Pour-flush toilet with individual septic tank and French-drain gravel filter

Pour-flush toilets can also lead the wastewater into a small on-site treatment facility. Septic tanks are watertight containers, which provide primary treatment by separating, retaining and partially digesting settleable and floatable solids in wastewater. Septic-tank effluent must receive proper secondary treatment before being discharged to the groundwater or surface water bodies. Directly ensuing soakage pits should not be applied, if the vertical distance from the bottom of the soakage pit to the highest seasonal groundwater is less than 1.5 metres. In these cases, septic tanks can be combined with French-drain filters or equivalent treatment. Septic tanks accumulate sludge which must be emptied after approximately five years and treated separately.

French-drain filters are simplified horizontal, gravel filters for on-site sanitation where there are space constraints and a high groundwater table. They provide simple filtration and anaerobic treatment, where high groundwater tables prevent direct septic-tank effluent infiltration. At the end of the French-drain filter, water is infiltrated to the soil though a plant-bed.






Picture 11_17 to 11_20: Construction of a French-drain filter, connecting a plastic septic tank with a plant-bed

Pour-flush toilet attached to wastewater-collection system

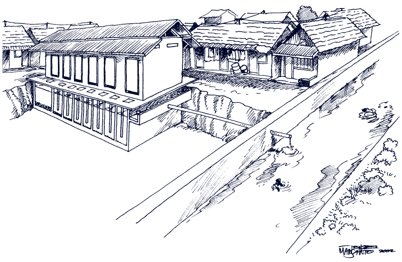
Since pour-flush toilets operate with water, the waste can be washed into a local wastewater-collection system, which transfers the excreta to a centralised or decentralised-treatment facility. For more details on wastewater-collection systems, please refer to section 11.2.

11.1.6 Community toilet blocks

Community toilet blocks usually consist of a number of toilet compartments. A large variety of available superstructure options can also include bathrooms, public water-points and laundry facilities.

Each toilet should not be shared by more than six households or 25 people. Integrated concepts can include treatment options such as septic tanks or baffled reactors. Community toilets are a suitable CBS option in settlements where the majority of the households don't have toilets. For convenience, communal toilet blocks should be no further than 50 metres walk.

Past experience has shown that maintaining and operating community toilets properly is a major obstacle for their sustainability. User fees are a "must" to finance routine operation and maintenance services, which ought to be carried out by permanent or part-time O & M staff employed by community groups or private-service providers.



Picture 11_21 and 11_22: Community toilet blocks

11.2 Collection systems

11.2.1 Rainwater drains

Systems with open ditches for discharging rainwater are quite common in the urban areas of developing countries. The ditches usually drain rainwater into rivers or, sometimes, into agricultural-irrigation canals. The unauthorised discharge of domestic waste or drainage of sullage through such a system is a health hazard and should be discouraged.

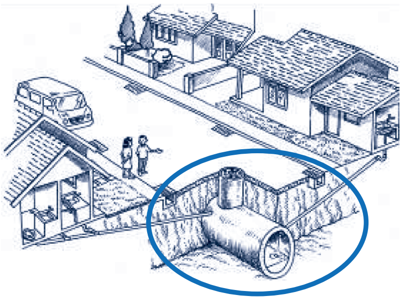
Covered rainwater drains

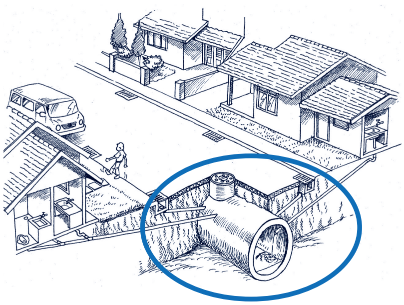
Covered rainwater drains are often used to collect wastewater in areas which lack conventional sewerage systems. Drains are covered by concrete slabs to stop them being blocked up by litter and to prevent people from coming in contact with their contents. So that rainwater can enter the system, periodic inlets in the drain covers are required. Theoretically, connected treatment plants would have to be designed for the purification of combined flows – rainwater and domestic wastewater – which requires a very high treatment capacity and investment. Such systems present a temporary solution, where no other system of waste-water collection is available, but it should be replaced by an improved system as soon as possible. The system smells, promotes insect breeding – and remains a health hazard.

Picture 11_23: Open and closed rainwater drains

11.2.2 Conventional gravity sewerage

In conventional gravity sewerage, domestic wastewater flows to a treatment facility via a system of concrete pipes. The system consists of house connections, which lead to a reticulation sewer line, normally laid beneath the main roads. There are inspection manholes every 70m along the route.





Picture 11_24 and 11_25: Conventional gravity sewerage systems: 11_24: no stormwater connection to main sewer 11_25: stormwater connected to (bigger) main sewer

So that the system can be cleaned, the minimum diameter is usually 200mm (D). To avoid solids deposit, minimum velocity of 0.5m/s is required. The maximum velocity should not exceed 6 to 8m/s. The necessary gradient of the pipes is, in part influenced by their diameter. In preliminary design, the gradient (I_S) can be estimated through the equation $I_S=1/D$. In flat areas, conventional sewer systems can demand very deep and expensive excavation. To avoid excessively deep sewers in large systems, it is necessary to use either a flushing tank or construct a pumping station. In Europe, pipes are usually laid at a minimum depth of 1.5 to 2.0m to guarantee load rating suitable for normal traffic as well as frost protection.

The maintenance of the reticulation system plus the operation and maintenance of possible pumping stations make up the operating costs.

Combined gravity sewerage

In combined gravity sewerage, domestic wastewater flows to a treatment facility together with collected rain- or stormwater, in a similar system to the conventional gravity sewerage. However, since the system must be designed to handle peak flow, much bigger pipe diameters are required for the mixed flow; diameters in the range of 300 to 1,200mm are common. Furthermore, inlets for rainwater from roof and street run-off are necessary.

Just because such gravity systems are currently considered the standard solution in most developed countries, does not mean that the conventional or the combined sewerage system is the optimal solution under all conditions. Engineers should compare all feasible options on an economic and technical basis.

Seperated gravity sewerage

As shown in Picture 11_24, stormwater is not collected together with domestic wastewater but drained seperately. This is today's preferred solution. Wastewater-treatment systems are prevented from stormwater shock loads. The advantages are twofold:

- the biology of the treatment system will be kept stable and does not have to adapt to different concentrations of wastewater (dilution)
- the wastewater-treatment system does not have to be oversized in terms of treatment volume (due to hydraulic peak loads)

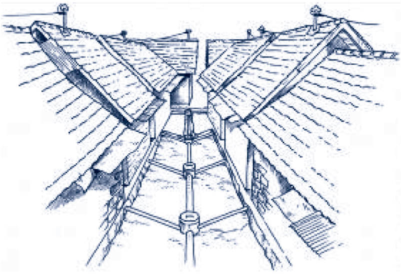
11.2.3 Simplified gravity sewerage

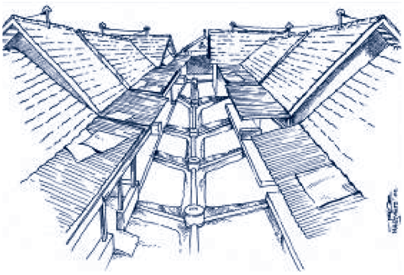
Simplified gravity-sewerage systems function like their conventional, larger counterparts. But the design criteria for construction have been simplified so that they just comply with minimum hydraulic requirements. As a result, the pipes made from plastic or concrete have smaller diameters and are usually laid at a flatter gradient and a shallower depth. The system can also cope with fewer inspection manholes. Although the costs are reduced, there is an increased probability of malfunction, resulting in more intensive operation and maintenance work.

Condominial gravity sewerage

Condominial sewerage is usually based on a PVC-piping system with a minimum diameter of 100mm, leading wastewater towards a nearby treatment facility or towards another sewer network. Pipes are laid at a flat gradient and routed through private land, such as frontyards, backyards (in-block) or pavements. So the required tyre-load capacity is considerably less than for in-road systems. Consequently, it is possible to lay the pipes at a shallow depth. Backyard and frontyard systems require a minimum cover of 20cm, while cover under pavement should be 40cm. Another advantage of backyard sewers is the reduced piping length, resulting in reduced costs. Furthermore, shallow condominial sewerage systems do not require large, expensive manholes.

Simple inspection chambers (located every 20m) and junction boxes at sewer connection points are usually sufficient. As with all systems, who's responsible for maintenance should be clearly defined.



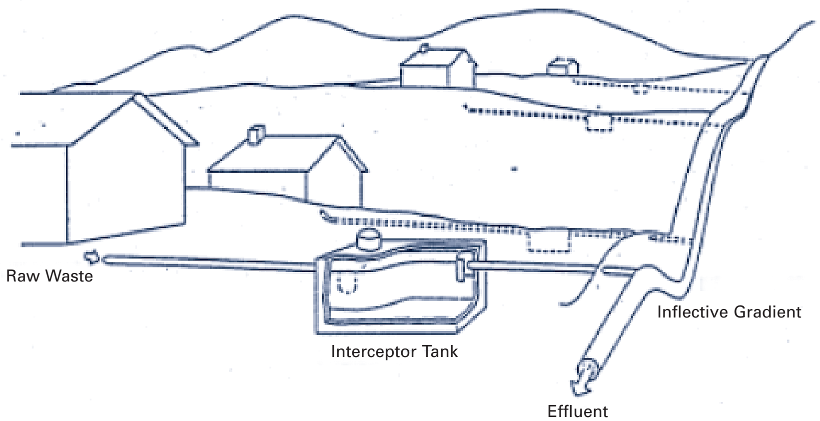


Picture 11_26 and 11_27: Backyard and front-yard condominial gravity sewerage

Small-bore sewerage

Small-bore systems, also called “solid-free sewers”, “common effluent drains” or “settled sewerage”, receive the effluent from individual or shared household septic tanks. Hence, coarse solids are removed and only the liquid part of sewage enters the sewerage system. Unlike conventional gravity systems, no self-cleansing flow-velocity is required. As a result, small-bore sewers can be operated with less water, allowing the connection of (low) flush toilets (including pour-flush) from households served by a standpipe or yard tap. The pipes have smaller diameters. Flow is driven by the elevation difference between inlet and outlet, and, therefore, can be installed very close to the surface in all types of terrain and even allow inflective gradients.

Simplified sewerage systems, the clogging and blocking of pipes is very unlikely, because of the pre-treatment in septic tanks. This effectively reduces the amount of maintenance needed on the piping system, although regular septic-tank emptying is essential.



Picture 11_28: Small-bore sewerage system

A 100mm-diameter pipe at a slope of at least 1:60 is required to connect the toilet to the septic tank. The level of the tank should not be deeper than necessary, so that the maximum potential energy (arising from its elevation) is available for the flow in the main sewer. At the least the first two metres of the connecting pipe from the septic tank to the plot boundary should have a diameter slightly smaller (50mm diameter) than the sewer main. This reduces the risk of blockage in the main sewer. Any misuse of the tank would then result in the plot-owner being inconvenienced rather than the whole neighbourhood.

The small-bore sewer mains should consist of plastic pipe with a minimum diameter of 100mm, installed at a depth of at least 300mm on plots, 1m on public lands or roads, and 1.2m when crossing roads. Clean-out points should be located at the upstream ends of the system, at the intersection of sewer lines, at major changes of direction, high points, and intervals of 150 to 200m in long, flat sections. These provide access to the sewer inspection and flushing during sewer cleaning. Manholes are not required.

Unlike conventional gravity sewers, small-bore sewers can alternate between open channel and pressure flow, taking maximum advantage of the elevation difference between the upstream and downstream ends of the sewer. Care must be taken that the hydraulic grade line during peak flow does not rise above the invert of the septic-tank outlets. If this is assured, the sewer may have low points or dips and can curve to avoid objects. High points of the sewer should be ventilated. As the sewer is not intended to carry solids, it is designed on hydraulic considerations only.

Pumping stations are only required where elevation differences do not permit gravity flow. If this is the case, permanent electricity supply and professional maintenance services are required for sustainable operation.

Because of the nature of the effluent from the septic tanks, the effluent of small-bore sewers is highly corrosive and odorous. If required, pumps and pump wells should be protected against corrosion and odour emission.

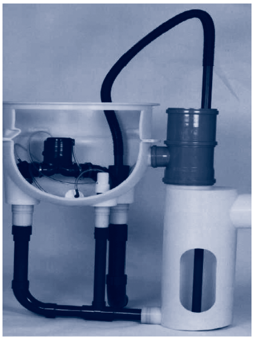
11.2.4 Vacuum sewerage

Vacuum wastewater-collection systems save water by using air as the main transport medium within the pipelines, by maintaining a low pressure of 0.6bar within the sewer network with vacuum pumps. The sewerage lines can be installed very close to the surface in all types of terrain – and can even transport wastewater around obstacles and up-hill. They require a power supply at one centralised location. The system consists of three basic elements: collection chambers, sewer network and a vacuum station.

Any type of (low-)flush toilet (including pour-flush) can be used. The wastewater drains from the household to a collection chamber by gravity. These chambers are not mechanised and can be located on or near the plot, and can receive wastewater streams from several neighbouring households. When the wastewater in the collection chamber reaches a certain level, an interface valve is triggered and opens automatically without an external power supply. This valve connects the collection chamber to the low-pressure sewer network. Together with the wastewater, about six times more air will be sucked into the system. The air is used as a transport medium for the wastewater, reaching transport velocities of 4 to 6m/s on the way to the vacuum vessel or pump sump in the vacuum station. When the collection chamber is emptied, the interface valve closes again. The pump sump is connected to a treatment facility.

Collection chambers must be made of watertight, smooth, corrosion-resistant material and big enough to take 25% of the average daily flow. The pipe network is made of PE-HD (polyethylene, high density) or PVC (polyvinyl chloride); both can be electro-welded or solvent-welded (cemented). Only the short gravity sewer from the house to the collection chamber must have a minimum diameter of 100mm and be laid at 1:60 or steeper.

The minimum size of the vacuum sewer grid should be 90mm diameter. Pipelines should be designed to withstand the internal suction pressure and temperature. The minimum pressure rating of selected pipes should be 9bar.
The minimum cover of the main vacuum pipeline under roads should be only 1m and 1.2m. The vacuum sewer mains and branch connections should have isolation valves ever 500m and 200m respectively.


Picture 11_29 to 11_31: PE-HD vacuum Pipe with individual connection (left), collection chamber (centre), waste-water collection, water supply and stormwater-drainage pipes in one trench (right)

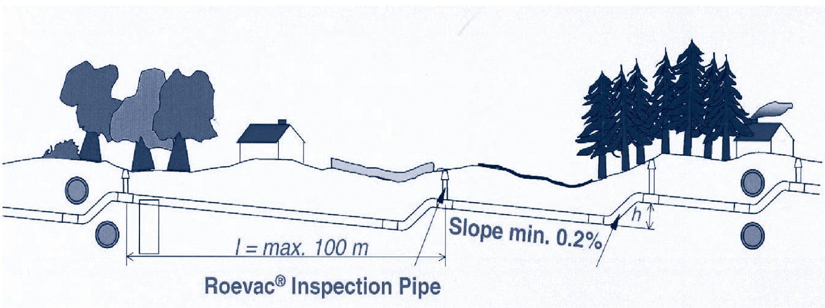
Since the flushing velocity is provided by the suction pressure, the pipelines do not require a downward slope, although they should have a minimum gradient of 1 in 500; however, the pipes can even be laid uphill. Lifts – or short, upward sections of pipe – can be used to ensure that the pipes do not have to be laid at excessive depths or to avoid objects. It is recommended that the pipe should be laid with a saw-tooth profile.

Since the whole system is watertight, it can be installed directly in the groundwater table, in flood areas or in the same trench as water-supply lines. Unlike gravity or small-bore sewer systems, vacuum sewer-pump capacities do not have to meet the peak wet-weather flow. There is no infiltration, no exfiltration and no groundwater contamination.

Routine maintenance checks of the network are not necessary, as a change in system pressure will indicate problems. Inspection pipes, installed at distances of approximately 100m permit the insertion of inflatable balls and precise location of the problem. The vacuum station should be inspected every week, collection chambers and vacuum vessel every year and the valve diaphragm in the collection chamber needs to be changed every five years.

Because of these technical maintenance requirements and energy-supply demands, the system is not appropriate in all locations. But it can have advantages where other systems are too costly or not feasible:

- flat topography – avoiding extensive installation excavation or lifting stations
- rock layers, running sand or a high groundwater table
- areas short of water supply or poor communities that cannot afford the amount of water necessary for operating of gravity systems at scour velocities
- ecologically sensitive locations or flooding zones
- areas with obstacles to a gravity sewer route
- installation of new fresh-water network and sewerage pipes in the same trench



Picture 11_32: Design of vacuum sewer layout (saw-tooth profile). Credit: RoeVac® Manual, Roediger Vacuum GmbH, Germany

11.3 Sludge accumulation and treatment

All organic-degradation processes produce certain amounts of biomass or sludge, which gather at the bottom of treatment units. Sludge changes its properties with time, due to the activity of micro-organisms and the degradation of organic components. When organic degradation has been completed and all bio-chemical reactions stop, the sludge has been "stabilised". Stabilised sludge is less odorous and easier to dewater and treat.

The speed of sludge production, and the sludge's characteristics depend on the wastewater quality, sludge-retention time and other treatment parameters. Under certain conditions, there is no accumulation of sludge. A state of equilibrium between sludge production and degradation is possible in an anaerobic environment with high temperatures, adequate microbial feed within the sludge and long sludge-retention times. Under such conditions, 80% of the organic matter is converted into biogas, while the remaining organic matter is pushed out in dissolved form as effluent. Experience at existing DEWATS facilities in tropical regions, like Indonesia, shows that well-designed and constructed anaerobic units avoid the necessity of sludge removal.

In most locations, however, such boundary conditions cannot be guaranteed and even well-designed DEWATS will accumulate sludge with time. This can be caused by cooler temperatures (particularly below 15°C) or wastewater with higher mineral content. Under aerobic processes, due to the higher yield of bacteria, about 50% of the COD is transformed into biomass. Under anaerobic conditions, only about 5% of the COD is transformed into biomass, i.e. 90% less sludge (from biomass) is produced. The transformation of COD is not rate related, but yield or energy extraction related (stoichiometry, not kinetics).

The total mass of sludge is the sum of two components: non-biodegradable material in the influent and biomass produced. Sludge originating from components in the influent that can not be degraded will not be different in an aerobic or anaerobic process.

Sludge accumulation leads to a reduction of capacity and retention time within a treatment facility, ultimately resulting in inefficient treatment and the discharge of hazardous wastewater. Neglect of regular sludge removal can lead to the sludge mineralising at the bottom of the unit, until it reaches a consistency, which makes removal impossible without an operational halt and total emptying of the facility. To ensure adequate treatment and continuous operation, therefore, sludge must be removed at appropriate intervals.[37]

37 Sludge should remain within the facility as long as possible, since stabilised sludge is easier to handle and dewater. At the same time, the sludge storage capacity must not be exceeded to ensure continuous treatment efficiency. Sludge removal intervals depend on the wastewater, type of treatment and storage capacity of the facility. Conventional tank design requires sludge removal every half to three years; ponds must be emptied every one to twenty years.

Sludge from domestic and husbandry wastewater is highly contaminated by worm eggs and cysts. Practices like illegal sludge-dumping into rivers, lakes or malfunctioning treatment plants pose a risk to human health and the environment. Ensuring an infrastructure for safe removal, handling and treatment, therefore, should be an integral part of town or city planning and management. It must be considered in the planning and construction of any wastewater-treatment facility.

Sludge removal, drying, treatment, selling, reuse or disposal can either be practised directly by the operator of the wastewater-treatment facility or by a service provider.

11.3.1 Sludge removal

Sludge removal should only be practised by trained personnel, as both the sludge and the gases within the facility present dangers. Particularly in anaerobic processes, methane and H_2S are produced, creating a risk of suffocation. Ventilation must be provided and open fire should be prohibited at the facility. Sludge settles in layers. The top layers contain active micro-organisms, which provide treatment by feeding on the wastewater, while the lower layers stabilise and become inactive with time. The goal of desludging is to remove only the older, bottom sludge; 30 to 50cm of active sludge should remain to ensure continuous treatment efficiency.

Desludging can be done with buckets, by pumping or by hydraulic pressure.

- Bucket removal is discouraged because it is impossible to withdraw only the lower sludge layers. Handling poses health risks to the operators. If practised, the workers should wear protective clothing by over their mouth, hands and feet.
- For pumping, free-flow rotary pumps are recommended to prevent clogging. The pump head is lowered to the chamber floor to remove only the oldest sludge. The pumped effluent should be visible; when the sludge becomes too light in colour, pumping should be halted to give the sludge time to flow to the mouth of the pump. Only black, stabilised sludge should be removed.
- Hydraulic desludging is practised through installed pipes at the bottom of the chamber with a diameter of at least 100 to 150mm diameter. The ductile consistency of settled and compacted sludge requires the outlet of a 2.5m-long pipe to be 0.35 to 0.50m below the normal wastewater outlet, to overcome the hydraulic loss of 15 to 20%. Sludge flow is regulated with a gate valve, which has a free opening of the full diameter, or by flexible pipes, which are lowered to initiate desludging. When not in use, these flexible pipes should be closed and locked to protect against smell and insects, while valves handles should be removed to prevent children getting up to mischief.

11.3.2 Sludge treatment

The goals of sludge treatment are:
- stabilisation
- dewatering/dehydration and volume reduction
- wastewater treatment of leachate or liquids
- pathogen destruction
- agricultural reuse or environmentally safe and hygienic disposal

Unstabilised sludge should not be dried or treated openly anywhere near where people live because of bad odour and the nuisance from flies. The origin and properties of sludge, therefore, determine which treatment should be applied: sludge from grease traps, settlers or septic tanks – also called septage – contains relatively fresh waste and has a solid content below 1%. These substances should be transported to nearby centralised treatment facilities for further stabilisation before final sludge treatment. Organic industry sludge must be removed quite frequently. Treatment in anaerobic digesters is recommended, due to its high organic content and biogas potential.

Domestic DEWATS units produce small amounts of well-stabilised sludge with good dewatering properties. In urban areas, the sludge shaved be transported to an existing centralised treatment plant. Where this is not possible, two sustainable treatment and disposal options have been identified:

- Small-scale application: the stabilised sludge can be dried on sand-beds – either directly next to the DEWATS or at a more appropriate location – and eventually the sludge can be composted and turned into agriculturally valuable humus
- Large-scale application: the construction of a decentralised sludge-treatment facility with DEWATS components. This option is only financially viable, if there are enough DEWATS or on-site treatment plants in the area to provide sufficient amounts of sludge or septage for continuous operation. In many locations, such a concept is highly beneficial, as it addresses the existing problem of septage treatment from on-site systems in the area – a very common deficiency

11.3.2.1 Small-scale application – drying and composting

The sludge from most DEWATS units is a thick liquid of approximately 3 to 5% solid content. However, the loss of a large amount of water cannot be avoided as large amounts of water are withdrawn with it, the solid content of removed sludge is closer to 2%. These large liquid volumes are difficult and expensive to transport.

For small DEWATS, therefore, stabilised sludge can be spread directly on flower-beds as fertiliser. A thin layer of sludge dries almost immediately and the slight foul smell once a year will be acceptable in most locations.

Where larger amounts of sludge cannot be transported to a more suitable drying place, drying sand-beds can be installed directly next to the treatment facility. By locating the bed approximately 40cm below the water level of the plant, hydraulic pressure can be used to distribute the sludge in a 20cm thick-layer. The bed is made up of coarse aggregate (>50mm diameter) and covered with 10 to 15cm of coarse sand.

Picture 11_33: Sludge-drying bed and well-stabilised, small sludge cluster.

The process comprises steps:

- dewatering – filtration of water through a sand-bed. Process efficiency is a function of the filter area and depth, filter material, sludge loading and sludge properties. Total Solids (TS) can be raised from 1-5% to 15-25%
- drying wind and sun assist in natural evaporation of moisture. Process efficiency is a function of sun and wind intensity, humidity, air temperature, precipitation, sludge properties and loading depth. TS can be raised to 80%

The bottom of the drying bed should be sealed, to prevent groundwater contamination, and a slight slope should lead to drainage pipes for dewatering. In hot and dry climates, a bed can be loaded perhaps five times per year. In the case of moderate temperatures, frequent rain or high humidity, special considerations – like roofs, enclosing structures or longer drying times – are required. Banana plants can be planted in the sludge bed to make the most of moisture and nutrients.

Composting is a natural, aerobic-decomposition process, in which useful microorganisms break down organic matter and produce carbon dioxide, water, humus and heat. Properly heaped compost reaches a temperature of up to 70°C over several weeks of maturation, thereby killing pathogens, including helminths and ova. It requires no special mechanical equipment and produces a final product, humus, which has a value as fertiliser and soil conditioner.

Parameter	Description/Comment
50% moisture content	A handful of squeezed compost should feel moist and retain its form without water dripping from it. If it is too wet, dry organic material must be added. If it is too dry, it must be watered. Protection against rain or solar radiation might be advisable.
Density of 0.6 to 0.8 (promoting aeration)	Use of stiff bulking agents or bedding promotes natural aeration. Compost pile should be turned at least once to move outside material to the inside, ensuring heat treatment of all material.
C:N ratio of 30:1	Different bulking agents can be used to adjust the ratio.
pH value of 5 to 9	Verified with litmus paper; low pH can be raised with lime or other amorphous alkaline substances.

Table 37: Requirements for a successful composting process

The largest problem with economic sludge composting is the high water content of sludge. Where large amounts of dry organic matter are available, it can be mixed with dewatered sludge (of at least 25% Total Solids) to achieve the desired Total Solids (TS) and consistency.

A successful composting process requires:

Composting can be practised within permeable boxes or elongated piles called windrows.

- If boxes are used, they must have a door for loading and removal. The walls of the box must either contain openings for oxygen supply from all sides of the compost – or the compost must be turned frequently
- If windrows are used, they should not be more than 1.2 to 1.5m high with approximately double the width and a natural slope

Since composting demands a solid understanding of the process, some experts argue that it should only be applied for greater amounts of sludge and if a composting facility already exists. Where local knowledge of the process there is with farmers or within solid waste management schemes, sludge composting can be a successful approach.

Picture 11_34 to 11_36: Box composting (left), windrow composting (middle), compost (right)

Humus, the stabilised and sanitised product of composting, is an excellent soil improver, rich in nutrients and with good moisture-retention qualities. The desludging and composting process can be planned in accordance with agricultural cycles to provide the maximum benefit to farmers.

However, premature desludging should be discouraged, as longer desludging intervals produce a safer sludge. Agreements between sludge-treatment plant operators, local farmers or organic-fertiliser producers should be encouraged. Marketing of the final product demands control mechanisms to ensure a high-quality product and might require awareness-raising activities and advertisement campaigns to promote its benefits. Alternatively, sludge compost can be used to cover landfills, or as a raw material for making items such as flower-pots, drainage trays or bricks.

If composting is not possible but sludge is to be used fresh on agricultural land, then the sludge must be put into trenches which are covered by 25cm of soil, at least. It's not suitable in areas of high ground water.

11.3.2.2 Large-scale application – sludge and septage-treatment facility

Some DEWATS, particularly those treating animal husbandry or organic industrial wastewater, produce greater amounts of sludge. If there is no sludge-treatment facility nearby, the construction of one should be considered. In most cases, such a facility will offer great benefits to the greater local community – if it is designed to also treat septage from local on-site septic tanks and pit latrines. The following example introduces such a treatment facility.

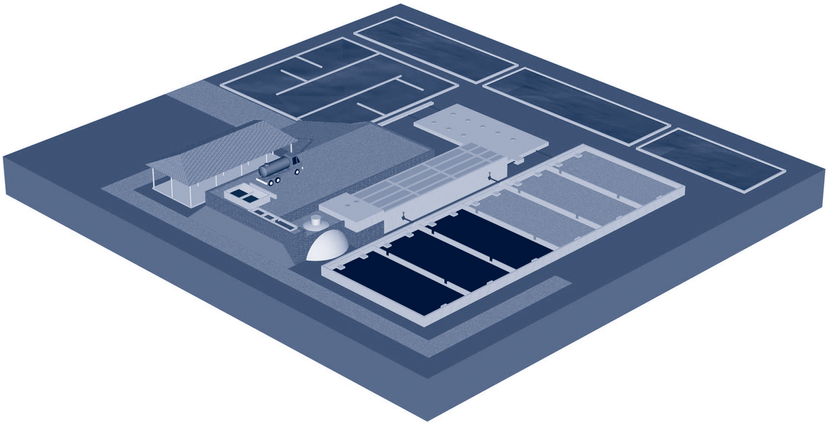
Municipal sludge treatment plant (IPLT) in Mojokerto, East Java, Indonesia

Mojokerto is a town in East Java with a population of approximately 150,000. As 60 to 80% of its wastewater is treated in on-site sanitation plants (septic tanks, latrines, and grease traps) there is great septage accumulation. The emptying of the septic tanks used to be carried out by a private company, which used three to four trucks to transport and dispose of the untreated septage into a river.

In March 2005, the Municipality of Mojokerto partnered with BEST Surabaya and BORDA to initiate a septage-management and recycling project. BORDA and BEST planned the septage-disposal service and treatment facility (IPLT). The municipality is responsible for construction, while operation will be carried out by BEST in the first year and then handed over to the municipality.

Picture 11_37 and 11_38: Septage-disposal truck, polluted river – misused as a dumpsite

To ensure that the collected septage actually ends up in the treatment plant, the municipality will be using an innovative financing model. The municipality sells "chips" to the community. When a septic tank is emptied, a chip is passed to the driver of the collection truck, who takes it to the treatment facility. The treatment plant is later paid according to the amount of chips it returns to the municipality.



Picture 11_39 to 11_41: IPLT under construction

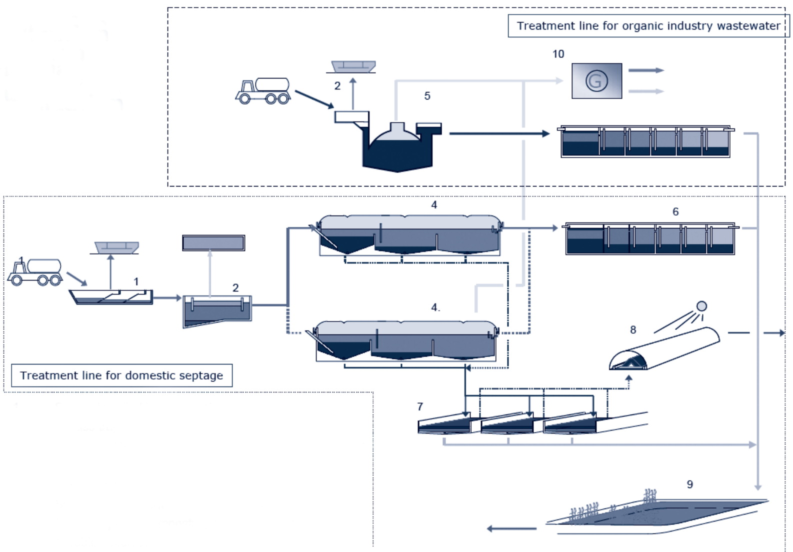
The facility is designed to handle 32m³ of septage per day. Its modules are similar to those of DEWATS and its closed components prevent odour pollution. Pre-treatment ensures that the plant is low maintenances. It includes:

- 20 and 10mm screens to avoid blockage
- a grease trap to prevent fatty accumulating sludge in pipes and reactors
- grit chambers to avoid sand accumulating in channels, pipes and reactors

A stabilisation reactor combines liquid/solid separation with anaerobic treatment. It reduces odour, oTS, COD and BOD, while improving dewaterability and drying. Biogas is produced, collected, and used/burned. The reactor consists of three chambers:

- chamber 1: mixed reactor with siphon feed to mix the sludge and promote biological activity; theoretical hydraulic retention time 1-3 days
- chamber 2: up-flow sludge bed
- chamber 3: sludge sedimentation

Design for biogas utilisation



1 Sc
2 Gr
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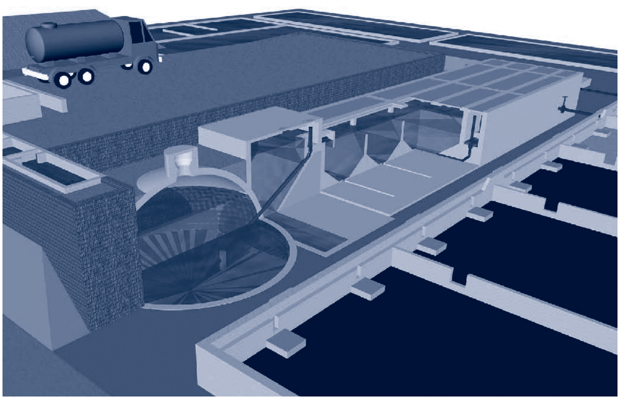
w
5 Do
6 Ba
7 Sa
8 Tunnel dryer for composting and disinfection
9 Aerobic maturation for the liquid phase
10 Biogas utilisation for producing heat or electricity

Picture 11_42: Treatment scheme of IPLT, Mojokerto

The installation of two reactors enables alternate operation with a defined retention time for the charged sludge. The suggested sludge retention time is 15 to 20 days. A stripping column oxidises NH_4 and removes NH_3 to prevent inhibition of the anaerobic liquid treatment.

Six sand-filter beds dewater and dry the stabilised sludge. Dewatering performance ranges from 40 to 55% TS during the rainy season and from 50 to 70% TS during the dry season. Separated sludge water is drained. The sludge is composted in tunnel dryers – these consist of a simple floor with a removable greenhouse roof for storm protection. The windrows are aerated with timber air channels; the sludge is composted for 30 to 50 days. The sludge water or the liquid fraction of the sludge is treated in a baffled reactor and horizontal gravel filter.

Picture 11_43 and 11_44: Timber aeration channels; leachate treatment in a horizontal gravel filter



Picture 11_45: The technical concept of IPLT Mojokerto

11.4. Reuse of wastewater and sludge

11.4.1 Risks

Wastewater is never hygienically safe. Proper handling of wastewater and sludge is the only successful preventive health method. The farmer who uses wastewater for irrigation must consider the risk to his own health and to the health of those who consume the crops grown by him. He must therefore check whether the wastewater he uses for irrigation is suitable to the crops or pasture ground he intends to water.

Fresh, untreated domestic and agricultural wastewater contains over one million bacteria per millilitre, thousands of which are pathogens - both bacteria and viruses. Eggs of worms are found in the range of 1000 per litre. Epidemical statistics reveal that helminthic (intestinal worm's) infection presents the most common risk from irrigation with untreated wastewater. The risk of bacterial infection comes followed by the risk of virus infection, which is the lowest. Although the removal rates in anaerobic systems are usually over 95%, many pathogens remain even after treatment. The effluent from oxidation ponds is less pathogenic.

pathogenes	in sludge and water		in soil	on plant
	10-15° C < days	< days	20-30° C[1)] < days	< days
virus	100	20	20	15
bacteria				
salmonella cholera fecal coli	100 30 150	30 5 50	20 10 20	15 2 15
protozoe				
amoebae cyst	30	15	10	2
worms				
ascari ova tape worm ova	700 360	360 180	180 180	30 30

[1)]not exposed to direct sun light

Table 38: Survival of pathogens Source: EAWAG

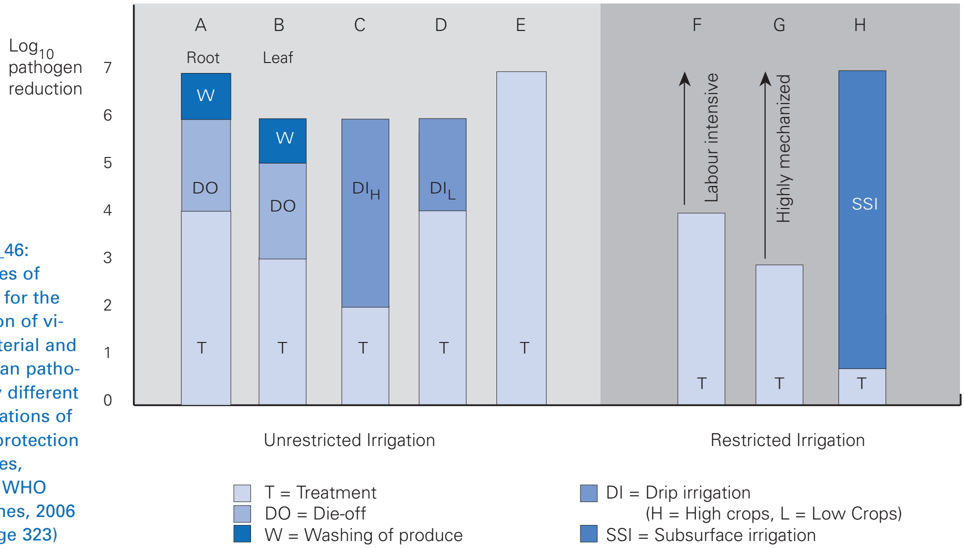
The World Health Organisation (WHO) recommends that treated wastewater for unrestricted irrigation should contain less than 10,000 fecal coliforms per litre (1000/100ml), and less than 1 helminth egg per litre. This limit should be observed strictly since the risk of transmitting parasites is relatively high.

Pathogenic bacteria and viruses are not greatly effected in anaerobic filters or septic tanks because they remain in the treatment plant for only a few hours before they are expelled together with the liquid that exits the plant. Post treatment in a shallow pond that ensures exposure to the sun reduces the number of bacteria considerably.
Those farmers who use sewage water for farming or sludge as a fertiliser are exposed to certain permanent health risks. These health risks are controlled within organised and specialised wastewater farming or within commercial horticulture, because of certain protective measures that are taken, such as the use of boots and gloves by the workers and the transportation of the wastewater in piped systems. However, such precautions are very unlikely in small-scale farming. Plants are either watered individually with the help of buckets or trench irrigation is used. The flow of water is usually controlled by small dykes which are put together by bare hand or bare foot making direct contact with pathogens unavoidable.

A shallow storage pond to keep water standing for a day or more before it is used may minimise the number of pathogens, but would hardly reduce the indirect health risk. It is also likely that children will play here, ducks will come to swim and animals may start to drink. Fencing may help. A more foolproof preventive measure may be an establish health-education programme that reminds users of the dangers – and the precaution they need to take.

Consumers of crops grown by such means and animals that graze on pastures that are irrigated with wastewater are also endangered. Since bacteria and viruses are killed by a few hours, or at most a few days of exposure to air, wastewater should not be spread on plants which are eaten raw (e.g. lettuce) for at least two weeks prior to harvesting. India has prohibited the use of wastewater irrigation for crops that are likely to be consumed uncooked.

Since bacteria and viruses stay alive much longer when wastewater percolates into the ground, root crops like potatoes or carrots except for seeds or seedlings should not be irrigated with wastewater.



Picture 11_46: Examples of options for the reduction of viral, bacterial and protozoan pathogens by different combinations of health protection measures, source: WHO Guidelines, 2006 (see page 323)

Table 39: Verification monitoring of wastewater treatment for the various levels of wastewater treatment in Options A–G in picture 11_46, source: WHO Guidelines, 2006

Type of irrigation	Option (Picture 11_46)	Required pathogen reduction by treatment (log units)	Verification monitoring level (E.coli per 100ml)	Notes
Un-restricted	A	4	≤ 10^3	Root crops
	B	3	≤ 10^4	Leaf crops
	C	2	≤ 10^5	Drip irrigation of high-growing crops
	D	4	≤ 10^3	Drip irrigation of low-growing crops
	E	6 or 7	≤ 10^1 or ≤ 10^0	Verification level depends on the requirements of the local regulatory agency
Restricted	F	4	≤ 10^4	Labour-intensive agriculture (protective of adults and children under 15)
	G	3	≤ 10^5	Highly mechanized agriculture
	H	0.5	≤ 10^6	Pathogen removal in a septic tank

* For example, for secondary treatment, filtration and disinfection: five-day biochemical oxygen demand, <10 mg/l; turbidity, <2 nephelometric turbidity units; chlorine residual, 1 mg/l; pH, 6-9; and faecal coliforms, not detectable in 100 ml.

11.4.2. Groundwater recharge

Recharge of groundwater is probably the best way to reuse wastewater particularly since the groundwater table tends to lower almost everywhere. Wastewater had been freshwater, and freshwater drawn from wells has been groundwater before. Sustainable development is directly related to the availability of water from the ground. Thus, recharging of this source becomes absolutely vital to human civilisation. The main question is how far the wastewater needs treatment before it may be discharged to the ground. Due to the high risk of groundwater pollution, this topic is very delicate and needs to be handeld with highest precaution.

11.4.3 Fishponds

Wastewater is full of nutrients which, when directly used by algae, water plants and lower animals could become fish feed. But fish need also oxygen to breathe, which must be dissolved in water in the pure form of O_2 (4mg/l for carp species, > 6mg/l for trout species). Because free oxygen is needed for degradation of the organic matter present in wastewater, it cannot be expected to be in sufficient supply for the survival of fish. Therefore, pre-treated wastewater must be mixed with freshwater from rivers or lakes, otherwise wastewater ponds must become so large that oxygen supply via pond surface overrules the oxygen demand of the organic load.

The organic load on fishponds should be below 5g BOD/$m^2 \times d$ before 5 times dilution with freshwater. This implies that if the chances of dilution are non-existent, the organic load may be 1g BOD/$m^2 \times d$.
If possible, there should be several inlet points in order to distribute organic matter more equally where it comes into contact with oxygen quickly. As mentioned before a turbulent surface increases the oxygen intake, and cooler temperatures increase waters ability to store free oxygen. However, it is not worthwhile trying to increase oxygen intake by specialy shaped inlet structures or similar measures. At a stage where oxygen deficiency can only be little, oxygen absorption is also little.

The pH should be 7 to 8. Fish culture is not possible if wastewater may be toxic or polluted by mineral oils, temporarily or permanently.

Wastewater should not be mixed with freshwater before the fishpond. Otherwise wastewater nutrients would initiate the heavy growth of fungi, algae and other species without being consumed by fish. When a fishpond is started, it should be filled with fresh water, wastewater is added later.

When using natural lakes for wastewater-based fishery it should be known, whether the lake is legally considered to be part of the treatment system or already part of the environment in which wastewater is discharged. In other words, it must be clear whether discharge standards must be observed at the inlet or whether the effluent of the lake will do.

The type and condition of fish are an indicator of water quality. Carp can live in water with a lower oxygen content and are the most common species in wastewater-based fish culture. Tilapia has become the most common "Development Project Fish" and is also growing well in wastewater ponds. Tench species often have difficulty surviving, because they take feed from the ground and run into get problems with anaerobic bottom sludge. It is advisable to empty the ponds once a year to remove sludge or at least expose the bottom sludge to oxygen for stabilisation.

Fishponds are normally more turbid than other ponds, because fish swirl up sludge from the ground. Trout species survive surprisingly well, despite higher turbidity, when the oxygen content is sufficient. However, it should be clear that more specialised knowledge of fish species, fish production and marketing is needed than can be contained in this chapter. More information is available from the regional offices of fishery departments and should be obtained before starting a wastewater fish-farming system.

Fishponds have a hydraulic retention time of 3 to 10 days and a depth of 0.5 to 0.8m. Net fish production is in the range of 500kg/ha (50g /m^2), 900 to 1,200kg/ha are said to be harvested from Calcutta's municipality fish farm. There is also the possibility of raising fish in 2.5 to 3m deep ponds where different kinds of fish live in different strata. An almost unbelievable 12,000kg/ha are claimed to have been harvested in Brazil in such ponds every year. A higher fish population produces more sludge which reduces the amount of free oxygen. Whether wastewater-based fishery becomes a viable business depends on the market price of fish and fishery operating costs. Fingerlings must be kept separate because fish, when set free, should weight 350g in order to be too heavy for fishing birds.

Losses can reach 50% when fishponds become an ecological niche which attracts fish-hunting birds.

Fish lose the foul taste of wastewater if they are kept for a few days in fresh water before consumption. This also reduces the risk of pathogen transfer. Fishermen need to be aware that the wastewater always bears a certain, albeit small, health risk.

11.4.4 Irrigation

Treated domestic or mixed community wastewater is ideal for irrigating parks and flower gardens. Irrigation normally takes place in the evening or early morning so that people won't be bothered by the slightly foul smell of anaerobic effluent. Nonetheless, the irrigation of public parks is often forbidden by law.

In order to provide updated and reliable orientation, the World Health Organisation has published in 2006 four volumes of "Guidelines for the safe use of wastewater, excreta and greywater":
Volume 1 - Policy and regulatory aspects
Volume 2 - Wastewater use in agriculture
Volume 3 - Wastewater and excreta use in aquaculture
Volume 4 - Excreta and greywater us in agriculture
These documents are widely recognised and can be downloaded from the WHO website free of charge.

A few facts to bear in mind:
For an irrigation rate of 2m per year (20,000m³/ha) – the normal requirement in semi-arid areas – even welltreated wastewater with concentrations as low 15mg/l of total nitrogen and 3mg/l total phosphorus provides 300kg N and 60kg P per ha via irrigation without additional cost; at the same time the respective amount of groundwater is saved.

In areas where there is plenty of rain, less water is needed for irrigation. So pre-settled but otherwise fresh wastewater may be more appropriate with respect to fertiliser. With 0.1m per year (1,000m³/ha) of fresh wastewater for irrigation, some 60kg nitrogen, 15kg phosphorus and a similar amount of potassium could be applied per ha. However, domestic wastewater in modern households sometimes lacks the potassium which might need to be added to mobilise nitrogen and phosphorus.

As this book deals with wastewater, it does not provide detailed information on either general or specific local questions of agriculture or the nutrient requirements of different crops. Each farmer has to find out his or her own preferred method and his or her own way of using efficient and safe quantities of water. The practical farmer knows which nutrients are needed for which crop and a trained agriculturist would also know – from wastewater analysis – whether the composition of nutrients and trace elements suits the proposed plantating. He or she will also know, from that analysis, whether too many of toxic elements remain in the water (toxic elements might play a role if the COD is much higher than the BOD). Such tests are advisable when using treated industrial or hospital wastewater for the first time. The person responsible for the wastewater source is obliged to inform farmers about toxic or otherwise dangerous substances in the effluent, for example, radioactive elements from x-ray laboratories.

Original saline water will remain saline even after intensive treatment. Copper and other metals, especially heavy metals, accumulate in the soil. Long-term application of such water will spoil the soil forever.

11.4.5 Reuse for process and domestic purposes

Pathogenic wastewater – from domestic sources, slaughterhouses or animal stables should not be reused for any purpose, except irrigation. Partly treated organic wastewater (this is more or less all wastewater from DEWATS treatment) should not be reused directly as process water in industries or as flushing water in toilets. Reusing wastewater will always mean that some traces of organic matter or toxic substances remain or accumulate. Reuse also means longer retention times in a closed system which might facilitate anaerobic processes within pipes and tanks which will cause corrosion. There is also a theoretical risk of biogas explosion.

To suppress organic decay one may have to add lime, which might form limestone inside the system or other inhibiting substances which would make appropriate final wastewater treatment costly. For example, even the first washing water in a fruit-processing plant or a potato-chip plant might already contain too much organic matter for any reuse without lime being added to suppress fermentation.

The chance of re-circulating parts of the water to serve the production process is limited, especially when the wastewater engineer and the production engineer don't have the necessary knowledge. The pollution content and level of treatment needed, as well as the amount of water required for consumption – and the wastewater flow over a given period of one day (or one season) – must be investigated. It might be necessary to build intermediate water stores and install additional pumps. Wastewater reuse is an option that deserves close consideration in the context of sustainable development. But, for process and domestic purposes, the accompanying problems mean it can't be recommended.

Reusing industrial wastewater which is only slightly polluted and perhaps not organically polluted, is a completely different matter. For example, press water in a soap factory may be reused for mixing the next load of soap paste. All water-consuming modern industries have reduced their water consumption considerably in the last few years. In most countries, including India and China, water-consumption limits are obligatory for many industrial processes, such as sugar refining, brewing, canning, etc.: Saving water in the process is always better than reusing water which has been carelessly wasted and polluted.

11.5 Biogas utilisation

11.5.1 Biogas

All anaerobic systems produce biogas. 55 to 75% of methane (CH_4), 25 to 45% of carbohydrate (CO_2) plus traces of H_2S, H, NH_3 go to form biogas. The mild but typical foul smell of biogas is due to the hydro-sulphur, and after which transforming into H_2SO_3, is also responsible for the corrosive nature of biogas. The composition rate of biogas depends on the properties of wastewater and on the design of the reactor – the retention time. Theoretically, the rate of methane production is 350l per kg removed BOD_{total}. In practice however, methane production should be compared to 1kg removed COD of where values are closer to the removed BOD_{total} than to the removed BOD_5. By doing so, one assumes that during anaerobic digestion only biodegradable COD is removed, which is involved in the production of methane. In reality, the gas production rates are lower than this because a part of the biogas dissolves in water and cannot be collected in gaseous form. It is also the norm to relate biogas production to organic dry matter (DM) in case of very strong viscous substrate, 300 to 450l biogas per kg DM can be expected.

The calorific value of methane is 35.8MJ/m³ (9.94kwh/m³). The calorific value of biogas depends on the methane content. Hydrogen has practically no role. As a rule of thumb, 1m³ biogas can substitute 5kg of firewood or 0.6l of diesel fuel.

industry	COD per product kg/to	COD removal %	relative gas production m^3 CH_4/COD_{in}	methane content %
beet sugar	6-8	70-90	0.24-0.32	65-85
starch – potato	30-40	75-85	0.26-0.30	75-85
starch – wheat	100-120	80-95	0.28-0.33	55-65
starch – maize	8-17	80-90	0.28-0.32	65-75
molasses	180-250	60-75	0.21-0.26	60-70
distillery – potato	50-70	55-65	0.19-0.23	65-70
distillery – corn	180-200	55-65	0.19-0.23	65-70
pectine		75-80	0.26-0.28	50-60
potato processing	15-25	70-90	0.24-0.32	70-80
sour pickles	15-20	80-90	0.28-0.28	70-75
fruit juice	2-6	70-85	0.24-0.30	70-80
milk processing	1-6	70-80	0.24-0.28	65-75
breweries	5-10	70-85	0.24-0.33	75-85
animal slaughter	5-10	75-90	0.26-0.32	80-85
cellulose	110-125	75-90	0.26-0.33	70-75
paper/board	4-30	60-80	0.21-0.28	70-80

Table 40: Potential biogas production from some selected industrial processes. Source: ATV, BDE, VKS

11.5.2 Scope of use

As pointed out above, biogas may be used in burners for cooking or in combustion engines to generate power. Its use will depend on whether enough can be supplied regularly to meet the minimum requirement of a particular use. If biogas cannot be utilised, it should be released in the air via safe ventilation or flaring. It is pointless to collect, store and distribute biogas when there is no real demand.

It is not essential to extract carbohydrate (CO_2) before biogas is used. But it might be advisable to remove an unusually high H_2S content with the help of iron oxide: Biogas flows through a drum or pipe filled with iron oxide (e.g. rusted iron borings or swarf). The oxygen reacts with the hydrogen to form water, while sulphur and iron (or sulphide of iron) remain. The iron may be reused if it becomes rusty again from exposure to air.

The minimum amount of biogas for a household kitchen requires is approximately $2m^3/d$. Approximately 20 to $30m^3$ of domestic wastewater is required daily to produce the minimum amount of gas. From an economic point of view, biogas utilisation from wastewater becomes meaningful if the strength of the wastewater is at least 1,500mg/l COD and the regular daily flow is $20m^3$.

The best use of biogas is for heat production. Biogas burners are simple in principle and can be made from converted LPG-burners. Biogas can be used for cooking in the home and canteens, or for drying and heating as part of industrial processes. The very best use of biogas would be as fuel for the same process that produces the wastewater.

Biogas can also be used in gas lamps. But the light from a biogas lamp cannot compete with an electric light.

Biogas can be used as fuel in diesel and petrol engines. As the ignition point of biogas is rather high, it will not explode under the pressure of a normal diesel engine. So, around 20% of diesel must be used for ignition, together with biogas. Diesel engines are the most suitable because they don't have to rely on a regular supply of biogas. Also, the slow flame speed of biogas is better suited to the slowly revolving diesel engine than to petrol engines. Biogas would not have enough time to burn completely with engines that run with more than 2,000 revolutions per minute.

11.5.3. Gas collection and storage

Biogas is produced within wastewater and sludge, from which it rises in bubbles to the surface. The gas must be collected above the surface and stored until it is ready for use. Even when gas production is regular, the accumulation of useable gas is irregular. Gas bubbles cause turbulence which leads to the explosive release of gas in a chain reaction. Stirring substrate, especially stirring sludge, has a similar effect. As a result of this, gas production fluctuates by plus/minus 25% from one day to the next. The volume of gas storage must provide for this fluctuation.

The volume of gas in stock changes according to gas production and the pattern of gas consumption. With rigid structures, the volume of the storage tank either changes as the volume of gas present changes, or the gas pressure increases along with the stored volume. In fixed-dome plants, and with flexible material such as plastic foils, both the volume and the pressure fluctuate.

There are two main systems for rigid materials:
- the floating drum and
- the fixed dome

For flexible material there are two variants, as well:
- the balloon, and
- the tent above water

The **floating drum** (see Pictures 9_7-C, page 183 and 11_47) is a tank that floats on water, the bottom of which is open. The actual storage volume changes depending on the amount of gas available and the drum rises above the water according to gas volume. The drum is normally made out of steel. To avoid corrosion, materials such as ferro-cement, high-density polyethylene (HDPE), butyl rubber, ethylene propylene diene monomer rubber (EPDM) and fibreglass have also been tried. As a rule, only very experienced workshops have been successful with these materials. Most find leakage a problem. The gas pressure is created by the weight of the drum (the weight is divided by the occupied surface area to calculate the pressure). A safety valve is not required as surplus gas is released under the rim when the drum rises beyond a certain point.

The **fixed dome** principle (see Picture 9_7–A+B, page 183) has been developed for biogas digesters for rural households as an alternative to the floating drum with its corrosion problem. The fixed-dome plant follows the principle of displacing liquid substrate through gas pressure. The gas pressure is created by the difference in liquid level between the inside and outside of the closed vessel. If there is very high gas pressure, the outlet pipe functions as a safety valve. The inner level of the outlet pipe, therefore, must be lower than that of the inlet.

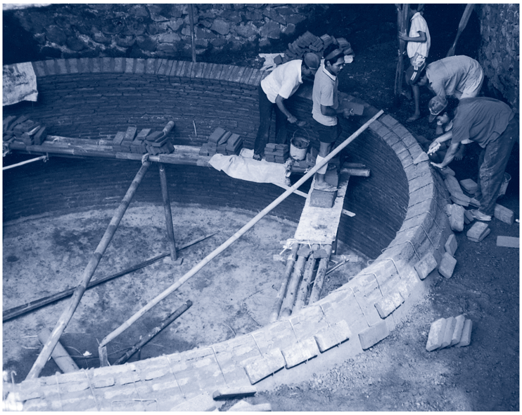
Picture 11_47: Floating drum plant. The drums are being lifted for re-painting which allows a view of the double-ring wall of the water jacket. Constructed by LPTP and BORDA for a slaughter-house in Java/ Indonesia.

In biogas plants that have a relatively high gas production compared to the volume of substrate, an expansion chamber is needed to sustain gas pressure during use. In the case of wastewater, where the volume of water is relatively large compared to the volume of gas production, an expansion chamber may not be required because the in-flowing wastewater replaces the wastewater, which has been pushed out by the gas. For this reason, gas consumption must correspond with intensive wastewater inflow. An expansion chamber is required when there is little to no wastewater flow during gas consumption. It is not when the simultaneous volume of consumed gas is less than the volume of waste-water inflow.
The surface area of an anaerobic treatment tank is relatively large compared to the amount of biogas produced. Consequently, fluctuation in liquid levels as a result of variation in gas volumes in the upper part of the reactor are relatively small. All the same, it may influence the design, especially the level of baffles needed to retain floating solids.

Biogas is an end-product of decomposition and, therefore, has very fine molecules that can pass through the smallest crack and the finest hole. So its storage must be as gas-tight as a bicycle tube. The usual-quality concrete and masonry is not sufficiently gas-tight – bricks are porous and concrete has cracks. So, bricks and concrete must be well plastered by applying several layers and adding special compounds to the mortar to minimise shrinking rates. Several layers of plaster help to cover the cracks on one layer with the next layer of plastering, in the hope that the cracks in different layers do not appear at the same spot.

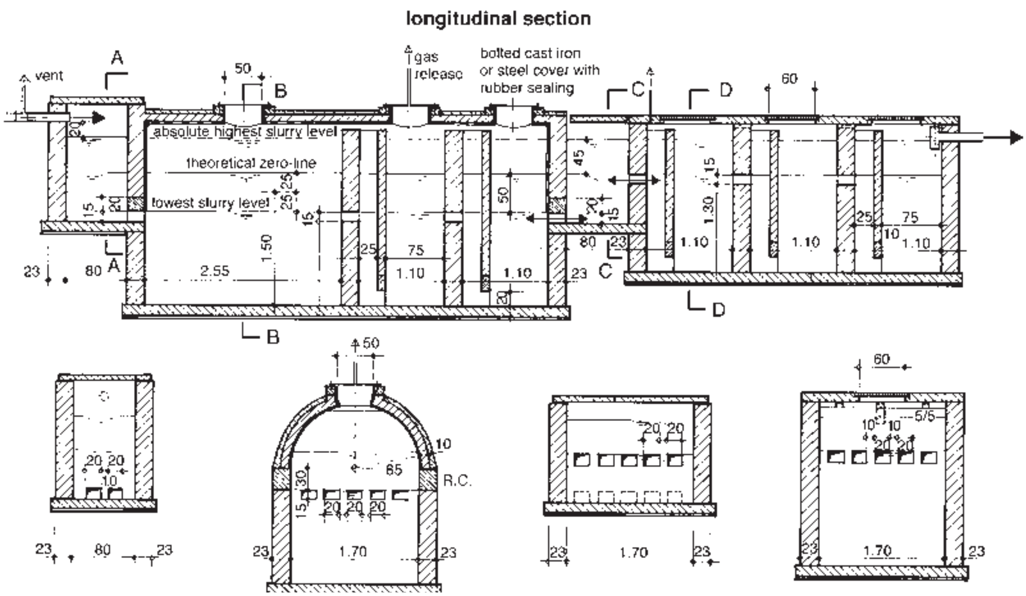
Table 41: Typical prescription for gas-tight plaster in fixed-dome biogas plants. The method was developed by CAMARTEC/GTZ in Arusha, Tanzania and has been successfully applied in many countries since 1989. Source: Camartec, BORDA

1st layer	cement–water brushing
2nd layer	cement plaster 1:2.5
3rd layer	cement–water brushing
4th layer	cement plaster 1:2.5 with water–proof compound
5th layer	cement–water brushing with water proof compound
6th layer	cement plaster 1:2.5 with water–proof compound
7th layer	cement–water finish with water–proof compound



Picture 11_48: Fixed-dome biogas plant for cattle dung, under construction by CYSD and BORDA at a farm in Orissa, India

A structure under pressure cannot develop cracks, therefore the structure of the gas storage should be under pressure whenever possible. This is the reason why anaerobic reactors should have arched ceilings, So that a heavy-soil covering creates the required pressure. Normally, baffled reactors and anaerobic filters are rectangular. As it is difficult and expensive to make these structures gas-tight, and considering the fact that gas production is greatest in the first part of the reactor, it may be reasonable to collect gas from the first chambers only. These chambers must be completely gas-tight; rear chambers must be ventilated separately.



Picture 11_49:
Baffled septic tank with biogas utilisation. Only biogas from the settler and the first two baffled chambers is used. They are arched in order to guarantee a gas-tight structure. The tanks which store biogas are separated from the three chambers at the rear of which biogas is not collected. The design is based on 25m³ daily wastewater flow, 4,000mg/l COD and a necessary gas storage volume of 8m³.

Tent systems are mostly used with anaerobic ponds. Balloons may be connected to any anaerobic-tank reactor. Balloons and tent systems require the same material. These materials must be gas-tight, UV-resistant, flexible and strong. PVC is not suitable. The weakest points are the seams and in particular the connections between the foil and the pipes. To secure gas tightness, foils of tent plants are fixed to the solid structure below the liquid level. Foil covering may also be fixed to frames floating on the wastewater. Balloons should be laid on a sand bedding or hung on belts or girdles. It may be necessary to protect them against damage by rodents. The gas pressure must be kept under control to match the permissible stress of the material, especially at joints. Fitting a safety valve, which functions as a water seal on gas pressure, should solve this problem.
Balloon and tent systems, unless securely fenced and protected against stones or rubbish thrown by children, are not suitable for domestic plants.

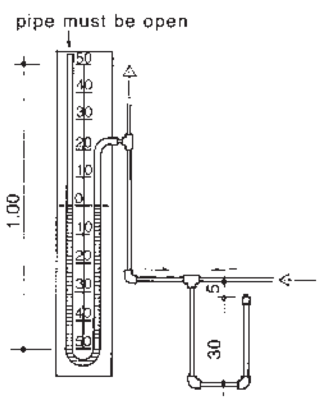
Picture 11_50: Tent gas storage above a liquid manure tank. Biogas plant constructed by SODEPRA and GTZ at a cattle park in Ferkessedougou, Ivory Coast.

11.5.4 Distribution of biogas

Normal water-pipe installation technology may also be used for biogas distribution in DEWATS. But ball valves should replace gate valves. All parts should be reasonably resistant against corrosion by sulphuric acid. The joints in galvanised-steel pipes should be sealed with hemp and grease or with special sealing tape. Joints of PVC pipes must be glued; the glue must be spread around the total circumference of the pipe.

Biogas always contains a certain amount of water vapour, which condenses to water when the gas cools down. This water must be drained; otherwise it may block the gas flow. Drain valves or automatic water traps to avoid blockages must be provided at the lowest point of each pipe section. Pipes must be laid in a continuous slope towards the drain points; straight horizontal pipes should not sag.

Gas pressure drops as the pipe gets longer, and more so with smaller pipe diameters. The pipe diameter must be larger when the point of consumption is far off. Long distances are generally not a problem, but should be kept as short as possible for economic reasons. Connecting stoves or lamps with a piece of flexible hose to the main distribution pipe means that equipment can be moved without disconnecting the pipe. It also allows for condensed water to be drained. In the case of fixed-dome plants, where it is difficult to see the amount of gas available, a U-shaped gas-pressure meter (manometer) could be installed near the point of consumption.

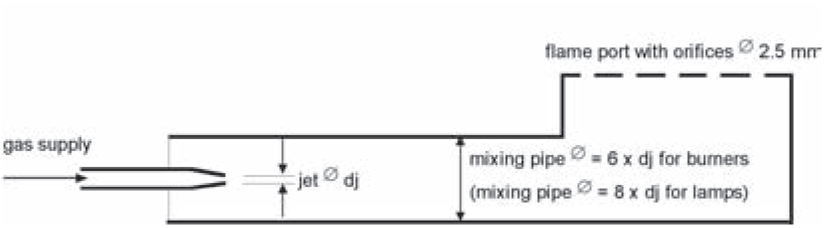


Picture 11_51: Pressure gauge out of transparent flexible pipes and water trap to collect condensed vapour which develops in gas pipes due to changing temperature. Water must be drawn from the trap when gas-flames start to flicker.

11.5.5. Gas appliances

In principle, biogas can be used in the same way as any other gaseous fuel, for example in refrigerators, incubators, or water heaters. But it's most commonly used in stoves, lamps and diesel engines.

Biogas needs a certain amount of air to burn – on average, one cubic metre of gas requires 5.7m³ of air for complete combustion, a quarter of what LPG would need. So, LPG burners have smaller jets; consequently the relative air intake compared to biogas burners is greater. The air intake needed for combustion is regulated by the difference of jet diameter to mixing-pipe diameter. For open burners, which draw primary air at the jet and some secondary air at the flame port, the ratio between jet diameter and mixing-pipe diameter may be taken as 1:6. For lamps, where secondary air supply is lower, this figure may be 1:8.



Picture 11_52: Principle design parameters for biogas appliances. The relation between jet diameter and mixing-pipe diameter is important for good performance and efficiency, irrespective of gas pressure. Other parameters are less crucial or can be found by trial and error, for example, the number and diameter of orifices or the length of mixing pipe.

When converting LPG equipment to biogas, the jet must be widened, to around one-sixth of the diameter of the mixing pipe of a burner. These ratios are the same for all gas pressures. There is no need to regulate the air intake when gas pressure changes. However, air requirement is greater when methane content is higher. The difference is too small to be of practical importance. Since the flame speed of biogas is relatively low, biogas flames tend to be blown off when gas pressure is high. It may be advisable to increase the number or size of orifices at the flame port in order to reduce the speed. It is also possible to reduce the flow by placing an obstacle at the flame outlet; for example, a pot set on the burner.

It is trickier to regulate the air-gas mixture in lamps that use textile mantles, because the hottest part of the flame must be directed at the mantle so that the mineral particles glow. If the flame burns inside the mantle, the pressure might be too low and the primary air may be too much. If, on the other hand, the flame burns outside the mantle, there would not be enough primary air and the pressure might be too high. As the composition of biogas also has a role to play, it is not easy to give general recommendations for lamp design. Practical testing is the only solution.

Diesel engines always have a surplus of air and proper mixing is not required. The gas is connected to the air – supply pipe after the air filter. The mixing of air and gas is improved when gas enters the air pipe by cross flow. Dual fuel engines are started with 100% diesel; biogas is added slowly when the engine is hot and under load. The amount of biogas is regulated by hand. The engine usually starts to splutter when there is too much gas. When the engine runs smoothly, it is regulated like a pure diesel engine with the help of the throttle. For generating 1kwh electricity, approximately 1.5m^3 biogas and 0.14l diesel are required.