Catalogue of Technologies for Integrated Urban Water Management

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Global Water Partnership

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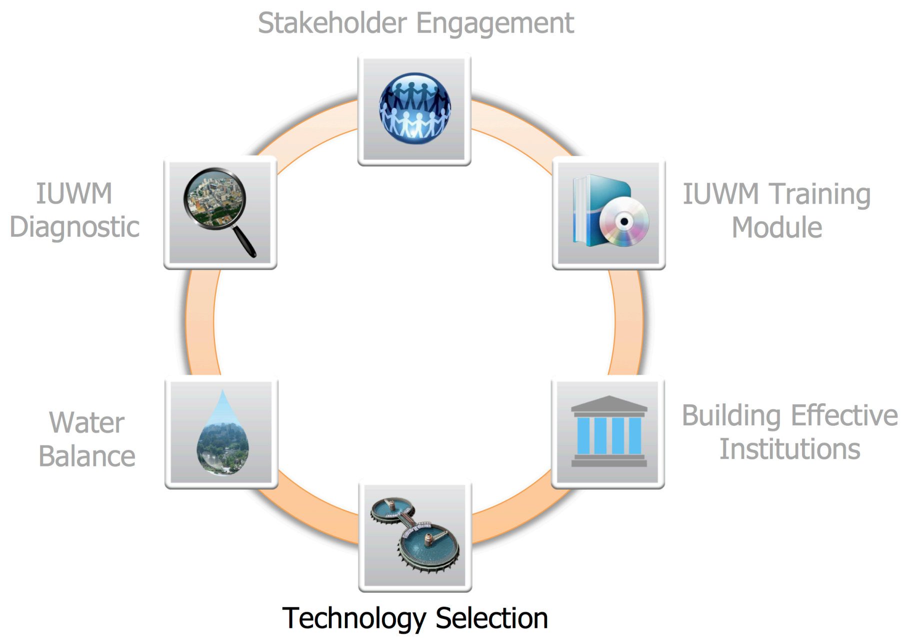

Prepared for the Global Water Partnership

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December 2014

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Global Water Partnership

TECHNOLOGY

Biosand Filter

SOURCE Freshwater

SCALE Household

Description

The biosand filter (BSF) is a modification of traditional slow sand filter for household level water treatment. A BSF consists of a concrete or plastic container filled with sand and gravel. It is design to work intermittently due to the fact that there is always a standing layer of water above the filter bed. The biological layer at the top of the sand layer plays a major role in the removal of most of the pathogens, turbidity and other contaminants. Physical straining also contributes to the purification process The filter is simple to use and can be produced locally.

Design Criteria

The filter container is usually made of concrete or plastic or any other water-proof, rust-proof and non-toxic material. The dimensions of the container are approximately 0.9 m to 1 m height and with a surface area of 0.3 m^2. The concrete filter box is cast from a steel mould or made with a pre-fabricated pipe. The container is filled with layers of sieved and washed sand and gravel. The filter is designed to have a standing water layer above the filter media, which is maintained by ensuring that the height of the outlet pipe is about 5 cm above the sand layer. This design feature allows the formation of a biological layer and distinguishes the BSF from slow sand filter and allows for intermittent operation.

Applications

BSF is suitable for the treatment of water at household level. BFS is recommended not to use water with turbidity more than 50 NTU and dissolved chemicals (e.g., organic pesticides or arsenic) are not removed.

Chlorinated water should not be used as chlorine kills microorganisms presented in biofilm resulting reduction of performance in pathogen removal. The water can be chlorinated after filtration in order to enhance the water quality.

Components

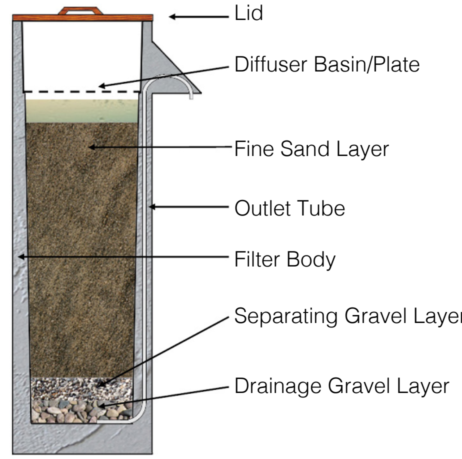
Concrete or plastic container, filter media, clean water collector.

Capacity

Generally depends on the size of the family. Mostly 10- 20 liters capacity for the ease of handling and treating.

Costs

Generally low-cost; depending on availability of materials. Capital cost about US $ 12-40, Cost/liter treated about US $0.01.



Operating Principles

Water is poured on to the diffuser plate and will flow through the filter media. Filtered water is collected through the outlet pipe and stored in a clean water container.

Major four steps in the treatment processes include mechanical trapping, predation, adsorption, and natural death.

- Mechanical trapping and sieving: Suspended solids and pathogens are physically trapped in the spaces between the sand grains.
- Adsorption and attachment: dissolved and suspended particles may get attached to the filter media.
- Predation: Pathogens are consumed by other microorganisms in the biological layer. This biological layer matures over one to three weeks, depending on volume of water filtered, the amount of nutrients and availability of micro-organisms in the water.
- Natural death: Pathogens finish their life cycle or die because there is not enough food or oxygen for them to survive, particularly deep in the filter media layer.

Typical Bio-filter designed for a household level

Utility & Efficiency

BSF removes pathogens such as bacteria, protozoa and helminthes. BSF is also effective for the removal of virus. Other contaminants such as turbidity and particulate iron are also removed in the process. However, dissolved chemicals, such as organic, pesticides or arsenic are not effectively removed.

The table below shows the biosand filter treatment efficiency in removing pathogens, turbidity and iron (CAWST 2009).

	Turbidity	Bacteria	Viruses	Protozoa	Iron
Lab	95%	Up to 96.5%	70-99%	>99.9%	NA
Field	87.5-98.50%	NA	NA	85%	90-95%

Reliability

Reliable for the removal of suspended solids and microorganisms.

Replication Potential

Standardized designs are available.

Regulatory/Institutional Issues

A BSF should be constructed only by trained technicians. Materials are generally locally available and the construction by trained local staff may create opportunities for local business.

Operation and Maintenance

- For turbidity levels greater than 50 NTU, the water should first be strained through a cloth or settling before using the BSF.
- The flow rate through the filter will slow down over time as the pore openings between the sand grains become clogged. When the flow rate drops to a level that is inadequate for the household use the filter needs to be cleaned.
- The need for cleaning depends on the amount and quality of water being put through the filter. If the water is relatively clean (turbidity less than 30 NTU), the filter may likely run for several months without this maintenance procedure.
- Cleaning is done by a simple 'swirl and dump' procedure performed on the top of the sand, and only takes a few minutes. It consists of agitating the surface sand, thereby suspending captured material in the standing layer of the water. The dirty water is scooped out. The cleaning process can be repeated as many times as necessary to regain the desired flow rate.
- When a BSF is used for the first time, there is no biofilm yet. The biological layer typically takes 20 to 30 days to develop to maturity in a new filter depending on inlet water quality and usage. Removal efficiency and the subsequent effectiveness of the filter increase throughout this period. During this period, users will need to disinfect or boil the water or use an alternative supply.

Advantages

1. Removes effectively pathogens, turbidity, color, odor and iron.
2. Relatively high flow-rates (over 30 L per hour) can be achieved.
3. One-time installation with few maintenance requirements and negligible operation costs.
4. Long life and can be manufactured from locally available materials generating an opportunity for local businesses.
5. Easy to operate and maintain.

Disadvantages

1. Biological layer takes 20 to 30 days to develop to maturity.
2. Low rate of virus inactivation.
3. High turbidity (> 50 NTU) will cause filter to clog quickly and requires more maintenance.
4. Investment cost could be higher for low income families
5. Cannot remove dissolved compounds.
6. For concrete BSF, its heavy weight can make transporting it difficult.

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TECHNOLOGY

Ceramic Pot Filter

SOURCE Freshwater

SCALE Household

Description

Ceramic filters are simple devices made out of clay and used to filter drinking water in order to remove turbidity, suspended materials, and pathogens. Removal takes place by physical process such as mechanical trapping and adsorption on the ceramic micro-scale pores. The filters are often locally manufactured, easy to assemble and require no energy to operate.

Design Criteria

Ceramic filter is made from a mix of local terra-cotta clay and sawdust or other combustibles, such as rice husks. It is a low-cost, and has a bucket-shaped (11” diameter and 10” deep). The filters are prepared by using a simple press, and then fired in a kiln. A colloidal silver solution is then applied to the surfaces of the fired clay as a bactericide, after which it is set for use in a plastic receptacle tank with a lid and a spigot.

Applications

Ceramic filtration is most appropriate in areas where there is capacity for quality ceramic filter production, a distribution network for replacement of broken parts, and user training on how to correctly maintain and use the filter.

Components

Ceramic filter, clear water containers, lid and tap.

Capacity

Generally variable but limited to portable capacity. It can treat 8-10 litres of water in one charge.

Costs

Pricing for ready-to-use filter units, including the receptacle, is determined by local production costs and is usually between US$15 to $25. Replacement clay filters will cost US $4 to $6.

Operating Principles

The filter is flowerpot shaped, holds about 8-10 liters of water, and sits inside a plastic or ceramic receptacle. Water flows through the pores of the ceramic filter into a storage receptacle. The suspended solids and pathogens are physically trapped in the spaces between the fine grains. The treated water is then accessed via a spigot embedded within the water storage receptacle.

Utility & Efficiency

Laboratory testing has shown that although the majority of the bacteria are removed mechanically through the filter’s small (0.6–3.0 microns) pores, colloidal silver is necessary to inactivate 100 percent of the bacteria. The filter removes 99.99 percent protozoa by mechanical processes. However, the effectiveness of ceramic filter in inactivating or removing viruses is unknown.

Reliability

Variable treatment performance particularly for virus removal.

Replication Potential

Standardized designs are available. Potters for Peace is a United States and Nicaragua based non-governmental organization (NGO) that promotes the flower-pot ceramic filter design by providing technical assistance to organizations interested in establishing a filter factory.

Regulatory/Institutional Issues

Requires expert supervision but can be constructed with locally available material.

Operation and Maintenance

Raw water is poured into the ceramic pot. The water slowly passes through the pores and is collected in the lower container. The treated water is stored in a clean water storage container to protect it from recontamination.

For turbidity levels greater than 50 NTU, the water should be first strained through a cloth or settled prior to using the ceramic pot filter.

The filter pot should be regularly cleaned using a cloth or soft brush to remove any accumulated material. The life time of the filter is up to 5 years; however, it is recommended that the filter pot be replaced every 1-2 years. This is in part to avoid poor performance due to fine invisible cracks which may have developed over time. Any cracks will reduce the effectiveness since water can short-circuit without being filtered through the ceramic pores.

Advantages

1. Removes pathogens, turbidity and suspended solids; partially effective for the removal of viruses and iron
2. Keeps water cold and safe, improves taste and odor of water.
3. Relatively low cost and simple to use and clean.
4. Can be constructed with locally available material.
5. Except for clay pot, it's durable, easy to move and transport.

Disadvantages

1. Does not remove all pathogens.
2. Does not remove chemical contaminants and color.
3. Highly turbid or iron containing water plugs pores of the ceramic pot.
4. Variable quality control for locally produced filters.
5. Filters can break over time - need for spare parts.
6. A low flow rate of 1-3 liters per hour for non-turbid waters.

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TECHNOLOGY

SOURCE Freshwater

SCALE Household

Gravity-Driven Membrane (GDM) Technology

Description

Gravity-driven membrane (GDM) technology works without any back flushing or cleaning. Pressure required to press water through the membranes is generated by gravity produced by differing water levels between two storage tanks. As a feed, natural water (river, spring, well or rainwater) can be used without pre- or post-treatment. Although turbid waters can be used, a pre-treatment is required if the water is extremely turbid. GDM technology has a high potential for implementation for drinking water treatment in households or for communities.

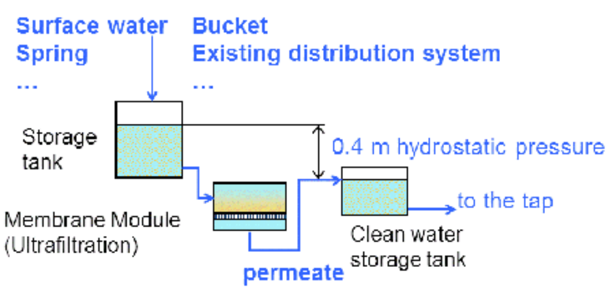
Design Criteria

GDM consists of two water tanks arranged on top of each other. The upper tank contains the UF-membranes and the lower tank stores filtered water. Optionally, a smaller tank with a sieving cloth can be placed on top of the upper tank to remove coarse solids such as branches and sand. The clean water tank is dimensioned for a total volume of about 10 liters whilst the membrane tank is dimensioned for about 20 liters.

When operating the unit, feed water is poured in to the membrane tank and driven through the membrane sheets by its own pressure. Water is then led to the clean water tank through a silicon tube connected to a permeate removal pipe, located at the center of the ultrafiltration membranes sheets. The central location of the permeate removal pipe keeps water levels in the membrane tank at a minimum volume of 10 liters, which keeps the membranes from drying out and the clean water tank from over flowing.

Applications

Most ultrafiltration membranes have pores that are smaller than the size of bacteria and viruses. Thus, water filtered through these membranes is microbiologically safe.
As a feed, natural water (river, spring, well or rainwater) can be used without pre- or post-treatment. If turbid waters are used, a pre-treatment will required (in the form of cloth filter).



Gravity-driven membrane treatment unit

Components

Different components as shown in the design step (see figure above).

Capacity

Generally variable from 10 to 20 liters for household uses.

Costs

The lifespan of a household filter is estimated to be about 5 years and the production cost is calculated at about US $40–50.

Operating Principles

The operating principle of GDM is based on the idea of operating ultrafiltration membranes in a dead end mode using gravity as only driving force. This implies that all water has to go through the ultrafiltration membrane since there is no other outlet. Through this process, a high removal of bacteria and viruses can be obtained and the use of external energy sources can be avoided.

The system runs without any backwashing leading to a fouling layer on the membrane surface. An increased fouling layer decreases the flux through the membranes. However, underlying research has shown that flux values do not necessarily decrease with time but stabilize around a constant value. Furthermore it has been shown that a heterogeneous fouling layer containing high bacteriological activity and predation has a positive effect on the flux values through the membrane. Thus, in order to preserve activity in the fouling layer, no chemicals are used for disinfection.

Utility & Efficiency

Very high efficient in removing pathogenic bacteria and other suspended solids.

Reliability

Reliable in achieving the desired water quality but performances will also depend on the local conditions.

Replication Potential

Standardized designs are available.

Regulatory/Institutional Issues

Requires expert design, cannot be constructed with locally available material.

Operation and Maintenance

Water is collected from a source and then transported to the household where it is stored or immediately poured into the filtering unit. Because of the small pore size of the ultrafiltration membranes, a wide variety of micro-organisms can be removed. Maintenance of the filter unit comprises of regular cleaning of the tap in order to avoid recontamination. Also, a regular surveillance of the clean water tank is needed in order to avoid overflow.

Advantages

1. Suitable for drinking water treatment in households or for communities.
2. Produces microbiologically safe drinking water.
3. No back flushing or cleaning is required.
4. Effective performance in removing different contaminants including micro-organisms.
5. Does not require energy input unlike other membrane technologies

Disadvantages

1. This is not suitable for highly turbid water.
2. Requires skilled technician to install.
3. Relatively costlier than bio sand and ceramic filter.
4. Not applicable for rural areas where advanced technology is not possible.

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Life Straw Technology

SOURCE Freshwater

SCALE Household

Description

LifeStraw is a point-of-use water intervention that can be used at home or at the sources of water. It comes in two different designs as personal lifestraw and Family lifestraw. The family LifeStraw is a modification of the personal lifestraw redesigned into a gravity-bladder filtration system which purifies larger volume enough for a family. The LifeStraw personal water filter enables users to drink water safely from contaminated water sources where users suck on one end of the filter to apply the needed pressure.

Design Criteria

LifeStraw is a cylindrical plastic tube that contains a hollow fiber membrane of 0.2 microns pore sizes. It uses only physical filtration methods and no chemicals.

Applications

LifeStraw is ideal for homeowners during emergencies where water supplied at home is not safe. It is also ideal for campers and hikers who may be drinking from rivers or lakes and are not certain of the water safety. It filters a maximum of 1000 litres of water.

LifStraw Family is used for the family of five or more. It filters a maximum of 18,000 liters of water.

Components

Different components as shown in the design step.

Capacity

Generally variable from 10 to 20 liters for the household uses.

Lifestraw allows someone to drink water directly from source

Place LifeStraw® in water and sip through the mouthpiece

Regularly blow through LifeStraw® after drinking to keep the filters clean and to prevent them from clogging

To clean, wipe your LifeStraw® with a soft cloth

Costs

Costs vary according to the location. In the USA the costs of a LifeStraw is about US $ 20-25/pc.

Operating Principles

In Lifestraw Family, water is poured into the feed water bucket where the profiler removes coarse particles larger than 80µm. Gravity pushes the water with particles finer than 80µm down the plastic hose towards the purification cartridge. At the time of first use, opening the exit valve removes all the air trapped inside the hollow-fiber membrane and moistens the membrane surface, allowing an optimal filtration of the untreated water. The exit valve must be closed after 3 seconds.

The purification cartridge (hollow-fiber membrane) filters out particles larger than 0.2 microns by size exclusion (turbidity and microbes including protozoan parasites, bacteria and viruses). The required filtration pressure comes from the elevated tank that generates about 0.1 bar pressure.

Purified water can be collected from the blue tap. When the cleaning bulb is squeezed, trapped particles on the retenate are flushed out through the exit valve by backpressure applied when the cleaning red bulb is squeezed.

The purified water complies with the USEPA requirements of 6/4/3 log reductions of bacteria, viruses and protozoa, respectively. The 0.1 bar pressure allows a flow-rate of 12-15L/hour.

The LifeStraw® Family filter also contains a chlorine chamber located below the top container. This chamber elutes low amounts of active chlorine, which protect the ultrafiltration membrane from fouling. The active chlorine slows down biofilm formation and protects the ultrafiltration cartridge leading to an extended lifetime of the LifeStraw® Family water purifier.

Utility & Efficiency

LifeStraw is the most advanced personal water filter available today. LifeStraw fulfils the rigorous standards for water filtration and surpasses EPA guidelines for E. coli, Giardia, and Cryptosporidium oocysts,.

Reliability

Reliable in achieving good water quality as designed but performances will also depend on the local conditions.

Replication Potential

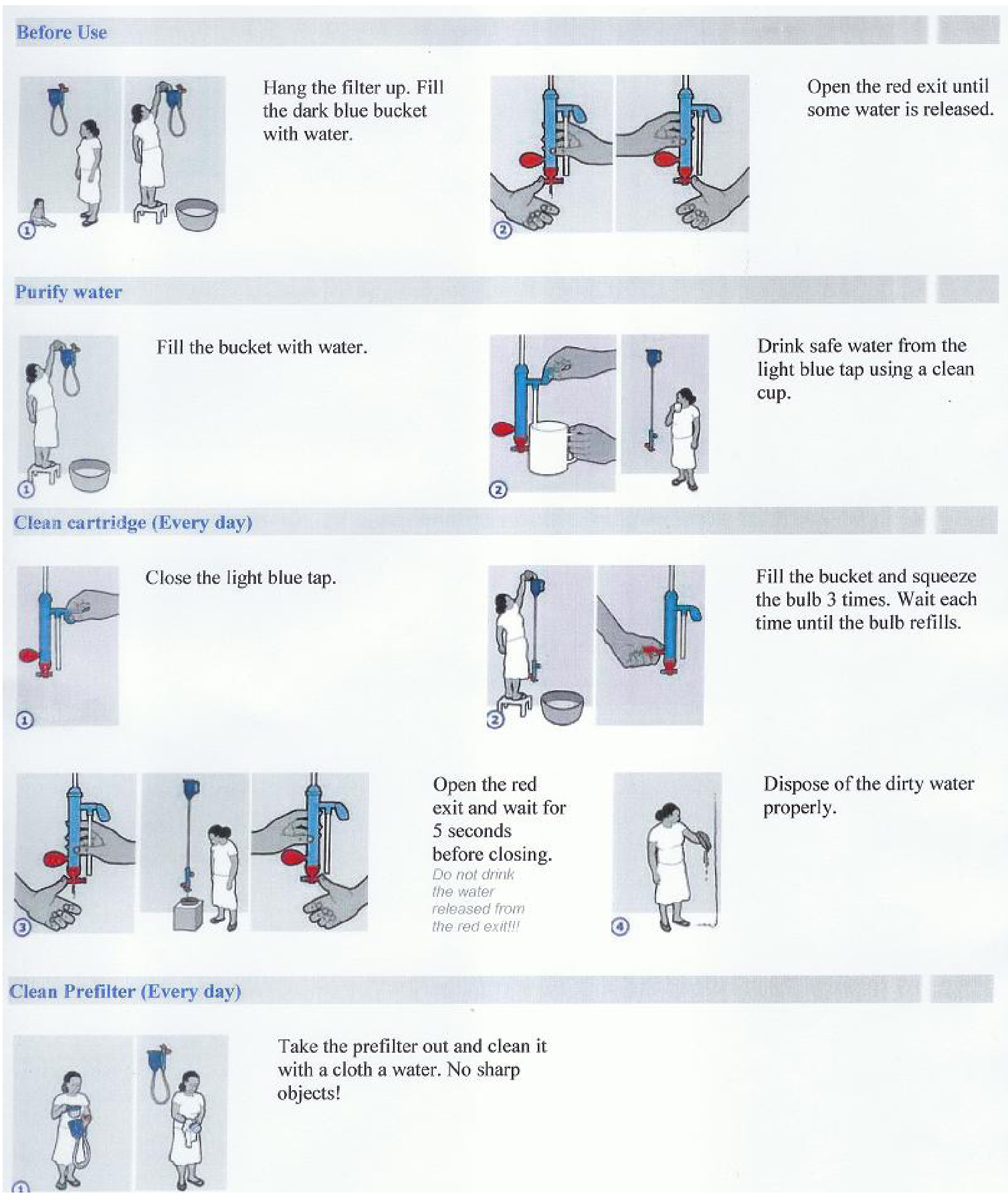
Standardized designs are available and applicable for different family sizes.

Regulatory/Institutional Issues

Requires expert design, cannot be constructed with locally available material.

Operation and Maintenance

Pre-filter should be cleaned daily by removing pre-filter from container, wash and replace. Purification cartridge should be cleaned daily. Cartridge is cleaned by squeezing the red bulb, waiting 30 seconds, and repeating this twice. Open the red valve and allow water to flow out of the red outlet for 30 seconds. The figure below describes operation and maintenance procedures.



Advantages

1. Lifestraw filters up to 1,000 liters of water.
2. Removes 99.99% of waterborne bacteria, 99.9% of waterborne protozoan parasites.
3. Reduces turbidity, filtering down to 0.2 microns
4. Ultralight: weighs only 2oz.
5. Does not use iodine or iodized resin.
6. Contains no chemicals, uses no energy, has no moving parts.
7. Very high flow rate; easy to clean.

Disadvantages

1. Cannot be fabricated using local materials.
2. Risks of cross contamination and improper operation.
3. Relatively costlier than biosand and ceramic filter.
4. Needs regular backwash to ensure the required level of the quality.

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TECHNOLOGY

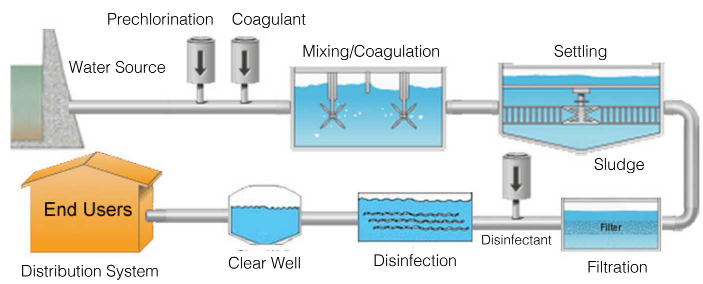
Coagulation-Flocculation

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Coagulation-flocculation is a chemical water treatment technique typically applied prior to sedimentation and filtration (e.g. rapid sand filtration) to enhance the ability of a treatment process to remove particles. Such particle may include suspended, dissolved organic and/or inorganic matter as well as several biological organisms, such as bacteria, algae or viruses. Those material has to be removed, as it causes deterioration of water quality by reducing the clarity (e.g. causing turbidity or color), and eventually carrying pathogenic organisms or toxic compounds adsorbed on their surfaces. Coagulation is the destabilization of colloidal particles brought about by the addition of a chemical reagent called as coagulant. Flocculation is the agglomeration of destabilized particles into microfilm and after into bulky flocculation which can be settled called floc. The addition of another reagent called flocculation aid may promote the formation of the floc. Coagulation-Flocculation is also a common process to treat industrial and domestic wastewater in order to remove suspended particles from the water.



Coagulation-Flocculation in a drinking water system

Injection of coagulant chemicals

Design Criteria

Selection of coagulants and flocculants and their dose is important steps in coagulants-flocculants process. However selection of physical size and capacity of the tanks will be based on the water quality and quantity to be treated in a system.

The commonly used metal coagulants are either based on aluminum or iron. The aluminum coagulants include aluminum sulfate, aluminum chloride and sodium aluminate. The iron coagulants include ferric sulfate, ferrous sulfate, ferric chloride and ferric chloride sulfate. Other chemicals used as coagulants include hydrated lime and magnesium carbonate. The effectiveness of aluminum and iron coagulants arises principally from their ability to form multi-charged polynuclear complexes with enhanced adsorption characteristics. When metal coagulants are added to water the metal ions (Al and Fe) hydrolyze rapidly but in a somewhat uncontrolled manner, forming a series of metal hydrolysis species. The efficiency of rapid mixing, the pH, and the coagulant dosage determine which hydrolysis species is effective for treatment.

There has been considerable development of pre-hydrolyzed inorganic coagulants, based on both aluminum and iron to produce the correct hydrolysis species regardless of the process conditions during treatment. These include aluminum chlorohydrate, polyaluminum chloride, polyaluminum sulfate chloride, polyaluminum silicate chloride and forms of polyaluminum chloride with organic polymers. Iron forms include polyferric sulfate and ferric salts with polymers. There are also polymerized aluminum-iron blends.

The principal advantages of pre-polymerized inorganic coagulants are that they are able to function efficiently over wide ranges of pH and raw water temperatures. They are less sensitive to low water temperatures; lower dosages are required to achieve water treatment goals; less chemical residuals are produced; and lower chloride or sulfate residuals are produced. They also produce lower metal residuals.

The degree or extent of flocculation is governed by both applied velocity gradients and time of flocculation. These two parameters influence the rate and extent of particle aggregation and the rate and extent of breakup of these aggregates. In this process, primary particles are induced to approach close enough together, make contact and progressively form larger agglomerates, or flocs.

Applications

Coagulation-flocculation is a conventional pre-treatment method typically used in combination with sedimentation and rapid sand filtration to separate the suspended and dissolved compounds from the water in centralized drinking water treatment plants. Mostly coagulation-flocculation is combined with sedimentation and rapid sand filtration. Coagulation-flocculation is also often used to remove suspended solids in domestic and industrial wastewater treatment plants.

Components

Coagulants mixers, flocculants mixers, flocculants tank linked to the sludge collector.

Capacity

It depends on the total water demand and water supply source. The size is decided based on the design.

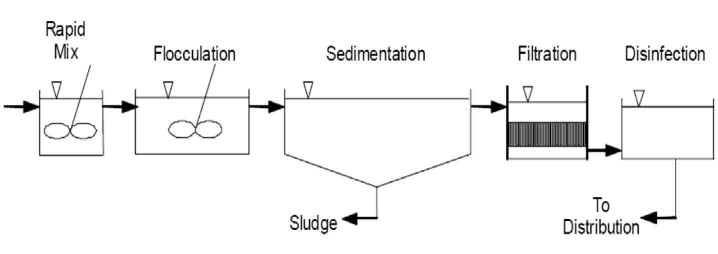
Costs

This is high-tech and requires external energy to mix and chemicals for the coagulation-flocculation process. Thus, this is costlier process.

Operating Principles

Coagulants such as mineral and/or organic coagulants typically iron and aluminum salt, organic polymers with charges opposite to those of the suspended solids are added to the water to neutralize the negative charges on dispersed non-settable solids such as clay and organic substances. Coagulation destabilizes the particles' charges. Once the charge is neutralized, the small-suspended particles stick together. The slightly larger particles formed through this process are called microflocs and which are too small to be visible to the naked eye. A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation and formation of the microflocs. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete.

Conventional Surface Water Treatment for Drinking Water



Following coagulation, flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles. The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added (flocculation additives may be activated silica, talcum, activated carbon, anionic or cationic flocculants and pH control reagents such as acids or bases). High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the separation process (sedimentation, floatation or filtration). Design contact times for flocculation range from 15 or 20 minutes to an hour or more.

Utility & Efficiency

The efficiency of the coagulation-flocculation process is dependent on many variables, including type of coagulant used; coagulant dosage; final pH; coagulant feed concentration; type and dosage of chemical additives other than primary coagulant (e.g. polymers); sequence of chemical addition and time lag between dosing points; intensity and duration of mixing at rapid mix stage; Type of rapid mix device; velocity gradients applied during flocculation stage; flocculator retention time; type of stirring device used; flocculator geometry.

Reliability

System is highly reliable, however, operation and monitoring plays a most important role.

Replication Potential

Needs detailed technical feasibility study, and experts supports before installation.

Regulatory/Institutional Issues

Requires standard design, expert services and supervision.

Operation and Maintenance

Operation and Maintenance of coagulators - flocculators include:

- Chemical stock: There should be a good stock at least sufficient for one month of operation.
- Dosing control: Correct dosing of coagulant chemicals is very important for efficient and effective removal of suspended solids. Samples of raw water should be taken regularly, and tested with a range of coagulant concentrations to determine the optimum dose rate of coagulant. The results should be used to adjust the coagulant dose.
- Rapid mixing of the water and coagulant chemicals at the

point where the chemicals are added is essential.

- Flocculation should be achieved by gentle mixing so as to maximize the number of collisions between suspended particles and flocs, without breaking the flocs up through rapid mixing.
- Plant layout: The flocculator and clarifiers should be located close to one another and water should flow slowly between them so as to not break up the flocs.
- Sludge management: During the coagulation-flocculation treatment process, a substantial amount of sludge is generated. This sludge can be reused as fertilizer for agriculture when no toxic compounds are present. In the presence of toxic sludge the solid waste has to be treated or disposed of in an environmentally proper manner.

Advantages

1. Low cost and simple technology that can also reduce costs for subsequent treatment.
2. Separates most of the suspended and colloidal particles from water.
3. It improves efficiency of filtration process.
4. It requires low cost and easily available chemicals.

Disadvantages

1. It requires chemicals for coagulants and flocculants.
2. Qualified personnel required for design (e.g. construction of chambers and dosage of chemicals), operation (chemical dose selection) and system maintenance.
3. Transfer of toxic compounds into solid phase and developed sludge has to be treated with care.
4. Needs regular energy supply for the mixers.

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TECHNOLOGY

Bank Filtration

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Bank Filtration (BF) has been common practice in many European cities for more than 100 years. Bank filtration is a natural process of water treatment which avoids the use of chemicals and when properly designed and operated produces water of acceptable quality. It was originally intended to remove pathogens and suspended solids from increasingly polluted surface waters. However it is now being used to remove trace organics and other contaminants. It utilizes the physical, chemical, and biological processes in the soil and aquifer for purification of surface water during its passage to production wells. In the context of developing countries, BF has been considered as one of the best technologies to contribute for a more sustainable water cycle by recharging stressed groundwater bodies with filtered surface water.

Example of Bank Filtration site

Design Criteria

The design of BF systems usually requires a detailed hydro-geological investigation, knowledge about the characteristics of the catchment.

The quality of water (e.g. salinity), geologic formation of the site (e.g. amount and solubility of arsenic content, redox conditions), soil characteristics (texture) and hydraulic characteristics of the soil (porosity, permeability) are factors to be assessed prior to planning for BF for water abstraction.

Pollutants in soil of geogenic (e.g., arsenic) or anthropogenic origin (e.g. heavy metals from an industrial site, nitrate from agriculture) may render BF unsuitable. For effective BF, the soil texture should have good filtration properties. Limestone and dolomite bedrocks, for instance, are rich in fissures that have very high hydraulic conductivity. They are therefore unsuitable for the removal of water contaminants.

Suitable soil textures for BF are sand and gravel aquifers with hydraulic conductivity greater than 0.0001 m/s, a minimal thickness of 5 m and a good hydraulic connection to the adjacent surface water.

Applications

BF is applicable when there is need to improve the quality of abstracted water from surface water sources and to reduce cost of water treatment. Operation of a BF system is suitable where groundwater level in the surroundings of the BF well will not decline below an ecologically and economically justifiable threshold value due to operation.

Components

Abstraction wells, connection systems, surface water source, ground water source

Capacity

Its size vary widely based on local conditions and level of treatment capacity. The performances will vary according to the local hydrogeology and river hydrology.

Costs

Generally low-cost but variable to the local conditions.

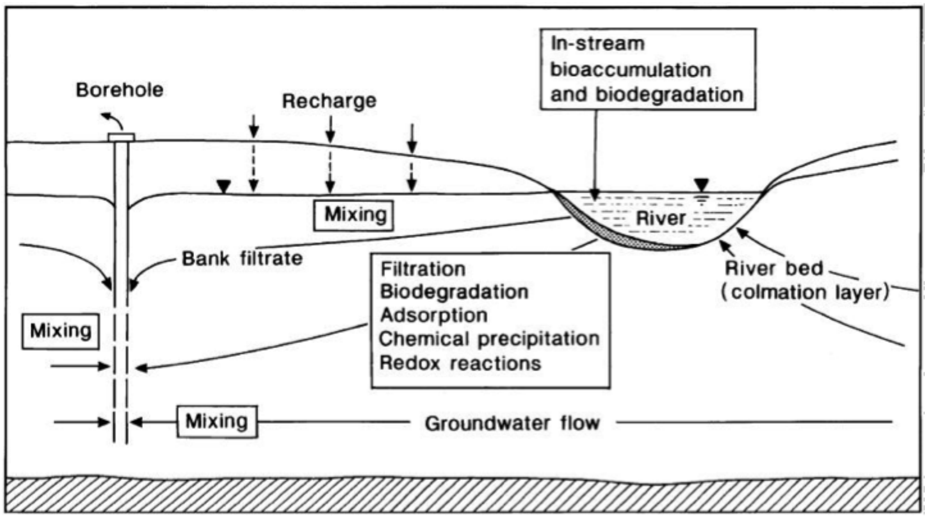
Operating Principles

Several physical, chemical, and biological processes are responsible for the improvement of water quality during soil passage. Major processes that remove contaminants in BF include:

Straining or filtration: The mechanical filtration process retains suspended matter in the soil, depending on pore size.

Biodegradation: Biodegradation is the main driver for redox processes occurring during soil passage and is responsible for the breakdown of dissolved and/or sediment-bound organic matter.

Adsorption: Trace elements such as iron, manganese and various heavy metals are eliminated during soil passage, mainly by sorption processes and by accumulating on the surface of an adsorbent or substrata. Biological contaminants such as protozoa, bacteria and viruses are reduced by a combination of processes including adsorption to aquifer materials and inactivation.



River bank filtration process

Ion exchange: some ions can be exchanged on negatively charged surfaces of clay minerals, amorphous ferric oxides and alumina and organic solid matter.

Precipitation: In anoxic aquifers, the removal of metal ions is dominated by precipitation reactions with Sulphide when insoluble compounds form and precipitate from the solution.

Utility & Efficiency

The performance of BF with respect to water quality improvements depends on: i) hydrogeological conditions including characteristics and composition of alluvial aquifer materials; ii) river/lake water quality; iii) groundwater dilution; iv) hydraulic characteristics and distance of the well(s) from river/ lake; v) temperature of the water; (vii) pumping rate; viii) soil/ sediment characteristics at the river/lake-aquifer interface.

Reliability

Reliability will depend on the quality of installation and mode of operation. It is usually reliable as long as the selection of the BF site is done well and the infrastructure is installed properly.

Replication Potential

BF is dependent on local conditions. Needs detailed technical feasibility analysis and experts support before installations of a BF.

Regulatory/Institutional Issues

Requires standard design, expert services and supervision. It should be operated and monitored by utility operators and regulated thorough the responsible authority.

Operation and Maintenance

Bank filtration is a useful technique as pre-treatment or even as the main treatment step for drinking water. Pathogens, toxic algae and suspended solids can be removed efficiently by BF. However, the overall treatment efficiency for organic and inorganic trace contaminants is often strongly redox-dependent.

The BF system is a low operation and maintenance system that does not require frequent attention of operators. The major operation includes pumping of water from abstraction wells and monitoring of flows in the surface water sources as well as groundwater levels in the abstraction as well as observation wells.

The biological layer on the side or bottom of the surface water sources is an important part of the BF treatment. This layer may get clogged overtime and would require cleaning if rate of infiltration reduces.

Advantages

1. Low cost and effective natural treatment process that can also reduce costs for subsequent treatment (e.g. chemical usage for coagulation and disinfection or run-time of activated carbon filters is extended).
2. Improves water quality by removing suspended solids, organic pollutants, microorganisms, heavy metals and nitrogen.
3. Dampens concentration peaks (shock loads) associated with spills (in river/lake) and dampens temperature peaks.
4. Simple technology that is easy for implementation and requires a little maintenance depending on purpose of output water. Low requirements of higher skills, energy and chemicals.
5. Increased storage capacity to balance supply and demand in areas with high variations of precipitation and run-off or to buffer extreme climatic conditions (floods, droughts).

Disadvantages

1. BF is site specific, and is feasible only when the local hydrogeological conditions are favorable.
2. Enhanced clogging of the infiltration zone is likely to be observed with high levels of suspended solids especially that may render BF unsustainable.
3. The presence of dissolved heavy metals (e.g., arsenic) and presence of iron and manganese may impair BF quality
4. Polar, persistent organic substances are often not completely removed during soil passage dependent on residence time, length of subsoil passage, redox status.
5. Other post-treatment methods are necessary such as oxidation and adsorption to reach drinking water quality.

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TECHNOLOGY

Soil Aquifer Treatment

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Soil Aquifer Treatment (SAT) is an artificial groundwater aquifer recharge option. In this process, water is introduced into the groundwater through soil percolation under controlled conditions. Soil aquifer treatment is either used to artificially augment the groundwater in order to withdraw freshwater again at a later stage or as a barrier to prevent saltwater or contaminants from entering the aquifer. During percolation, natural soil filtration occurs and the water enters the aquifer and possibly mixes with groundwater. This method can be used with wastewater effluent (treated blackwater) or slightly polluted water (e.g., pre-treated greywater or stormwater).

Design Criteria

SAT can be designed as a recharge/infiltration basin or an injection well (direct injection) depending on the availability of land.

The suitability of SAT dependent on the characteristics of the local geologic formation and groundwater. Its performance is related to the quality of the influent, soil type, and purpose of the treated water. Those factors will determine both the applicability of the technology and the level of required pre- and post-treatment.

Depending on the wastewater quality, land availability and intended usage, the influent to the SAT can be pre-treated using various treatment technologies that may include secondary, tertiary or advanced wastewater treatment.

SAT can be designed in three different ways :

- Infiltration by surface spreading in basins in sandy soils. This approach is not suitable for soils that contain too many clay layers or other soils that could restrict the infiltration of water.
- Vadose zone wells are used where the surface infiltration is low due to hydro-geological properties of the soil and where available land is expensive.
- Direct recharge to the aquifer through wells is done where permeable surface soils are not available, vadose zones have restricting layers, and/or aquifers are confined.

Applications

SAT can be applied for different purposes

Safe Water Storage: it reduces evaporation rate, avoids the potential for insect breeding and reduces risk of contamination and pollution compared to water stored on the surface. The increased storage capacity buffers seasonal and weather pattern variations of water availability and demand.

Improve social acceptance of reclaimed water: It provides additional treatment as well as the necessary dilution of the influent water. This give the notion that SAT treated wastewater is similar to groundwater abstraction. This promotes social acceptance for indirect potable use.

Quality Improvement: it is used to remove residual contaminants from wastewater effluent and stormwater. SAT removes suspended solids, organic matter and ammonia effectively. Furthermore, SAT effectively removes bacteria and viruses.

Mitigate Saltwater or Contaminants Intrusion: The water that infiltrates in SAT recharges aquifers that can help reduce salt water intrusion in coastal aquifers or or generally prevent intrusion of contaminants into the aquifer.

Components

Needs detailed analysis of the groundwater and depends on the local condition including quality of water to be treated.

Capacity

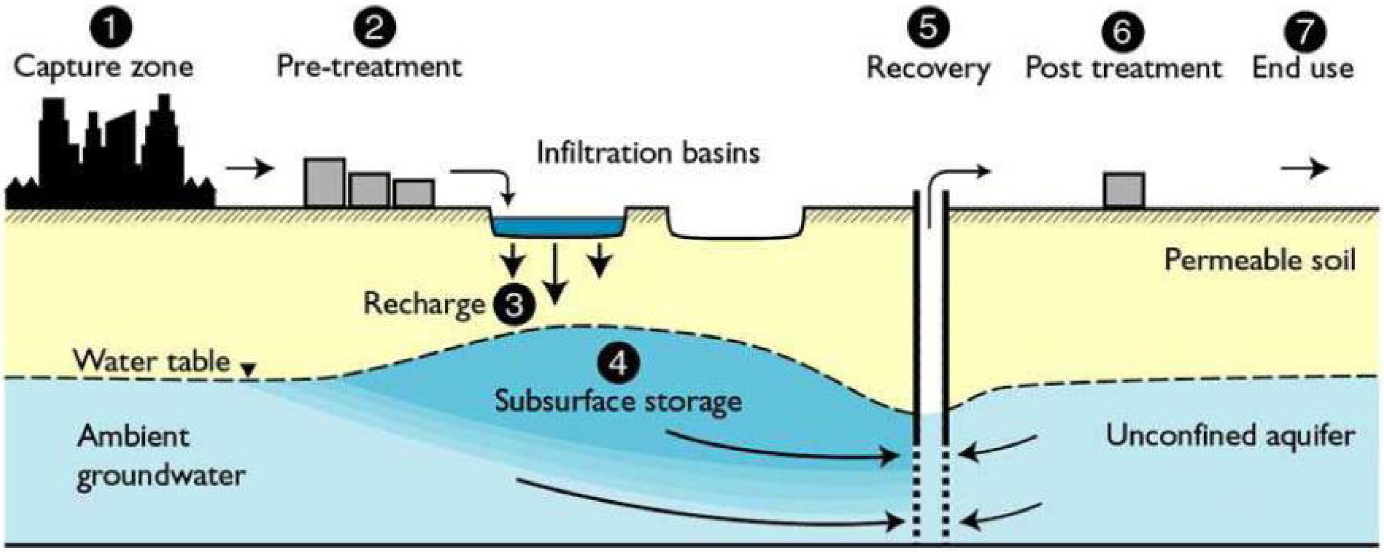
It varies and depends on the local condition.

Costs

Generally low-cost but variable to the local conditions.

Operating Principles

As the effluent moves through the soil and enters the aquifer, it undergoes significant quality improvements by physical, chemical and biological processes. The water is stored in the underlying unconfined aquifer generally for subsequent reuse, such as irrigation or even for drinking water purposes (generally after a water purification step).



Soil aquifer treatment process

The ideal porous medium for an SAT operation is one that has good permeability and effective removal of all constituents of concern. Often no such medium exists because the attributes required to achieve one goal hamper the achievement of the other. In surface soil, coarse-textured materials are desirable for infiltration because they transmit water readily; however, the large pores in these soils are inefficient at filtering out contaminants, and the solid surfaces adjacent to the main flow paths are relatively nonreactive.

In contrast, fine-textured soils are efficient at contaminant adsorption and filtration, but they have low permeability and their small pores clog easily.

Structured soils or cracks are permeable, but the large flow paths completely dominate the movement of material and much of the matrix is bypassed. The best choice for an SAT soil is therefore a compromise, such as fine sand or a sandy loam with relatively little structure.

The quality of water extracted from a recharge aquifer depends on the quality of the reclaimed water introduced (after pre-treatment), the method of recharge, the characteristics of the aquifer, the residence time, the amount of dilution in the aquifer and the history of the system-.

Especially groundwater recharge with recycled wastewater presents a wide range of technical and health challenges. Although the unsaturated part of the soil is known to act as a filter for a variety of contaminants, groundwater recharge should not be viewed as a treatment method.

Utility & Efficiency

SAT removes efficiently a variety of heavy metals and toxic elements by chemical precipitation and adsorption. It also removes efficiently pathogenic bacteria and viruses as a result of soil filtration and die -off resulting from the long detention time in the unsaturated zone and the aquifer.

Reliability

Reliability will depend on the quality of installation and mode of operation.

Replication Potential

Needs detailed technical feasibility analysis and experts support before installations of a BF.

Regulatory/Institutional Issues

Requires expert design, and supervision. Also, will be guided by the local regulation and byelaws for building, Operation and Maintenance of the SAT.

Operation and Maintenance

- The main removal process in Sat occurs at the biological layer where the influent flow enters the infiltration basin. As the biological layer develops it clogs and reduce rate of infiltration. This requires removal of the layer to re-establish the infiltration rate by opening up clogged surfaces.
- For application by injection wells, suspended solids accumulate at and near the well-aquifer interface, and because this circumferential area is limited and the flux through it is large, rapid hydraulic head loss and reduction in injection capacity occur quickly. The clogging caused by the accumulation of the suspended material and biological growth must be remedied by pumping the well for back flushing, by surging or jetting, or at times by dosing the well with chemicals to loosen and/or dissolve the accumulated clogging materials.
- Removal of suspended solids to a very low levels, i.e., less than 1 milligram per liter in the recharge water is required for successful operation of recharge wells, except where karstic or fractured rock aquifers are to be recharged.
- Wells recharging solution-riddled or fractured rock aquifers can tolerate water having higher levels of suspended solids without experiencing severe operational problems.

Advantages

1. Low cost option for wastewater reclamation.
2. Increases capacity of existing groundwater resources to buffer seasonal and weather variations (i.e., facilitating a drought-proof water supply).
3. Improvement of the quality of the infiltrated water through soil filtration and storage in the aquifer.
4. Reclaimed water can be mixed with groundwater resources, increasing its acceptance for reuse of reclaimed water.
5. Groundwater recharge can also preserve water levels in wetlands and mitigate saltwater or contaminant intrusion.
6. Some steps traditionally applied for wastewater treatment such as the removal of organic material, nitrogen and phosphorus may not be necessary when applying SAT.

Disadvantages

1. SAT in general requires large area for the infiltration basin which could be expensive in some areas.
2. Introducing pollutants into groundwater aquifers may have long-term negative impacts.
3. Can change the soil and groundwater hydrological properties.
4. If reclaimed water is used but not sufficiently pre-treated, discharge of nutrients and micro pollutants may affect natural water bodies and/ or drinking water.

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TECHNOLOGY

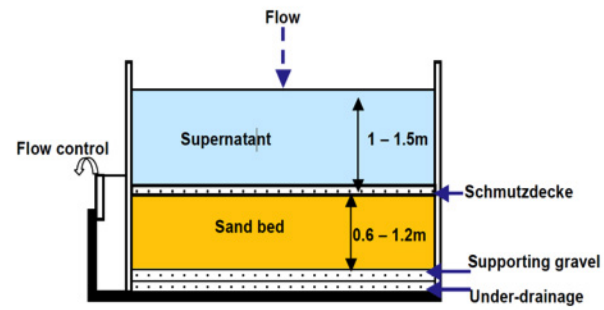
Slow Sand Filtration

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Slow sand filtration (SSF) is a commonly used effective water treatment technology that is applied in a centralized or semi-centralized system. A well-designed and properly maintained SSF effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step. The main treatment process occurs at the biological layer (schmutzdecke) that develops on the top few centimeters of the sand layer. In order for a SSF to have its best performance, it requires a ripening period of days to weeks for the schmutzdecke to develop sufficiently.. Only under the prevalence of a significantly high level of turbidity or algae-contamination, pre-treatment measures (e.g. roughing filtration or sedimentation) become necessary. The technology is very simple which does not require advanced technology and skills for construction, operation and maintenance.



Slow sand filtration

Design Criteria

Slow sand filters use sand with effective sizes of 0.15-0.35 mm with a uniformity coefficient between 1.5–3, preferably < 2. SSF is operated most effectively at a flow rate of 0.1–0.3 m/h.

SSFs require an influent turbidity below 30 NTU and preferably below 10 NTU. The pre-treatment measures (e.g. roughing filtration or sedimentation) are necessary to ensure that the filters do not clog frequently. SSFs are less effective in removing microorganisms from cold water because the biological activity within the filter bed and the ‘schmutzdecke’ declines as temperatures decrease.

Applications

SSF if effective for influent turbidity below 30 NTU and preferably below 10 NTU. If the turbidity is higher and it is required to remove organics, it can include additional treatment steps as mentioned above

It is widely applicable for the treatment of surface water in small, rural communities where land is no limiting factor. In urban areas with population less than 10,000, it can be used as the main treatment step. It is also used as a polishing unit in large centralized water treatment or in wastewater treatment systems.

Components

It consists of a concrete tank, filter media, underdrain system and support gravel. The tank is made of RCC or stone masonry or steel structure based on the local condition. The sand media is the main layer that removes contaminants. The drain and gravel layers are important in maintaining uniform flow in the sand medium.

Capacity

It varies according the quantity and quality of water to be treated and the local condition.

Costs

Investment is generally low - US$ 100–300 USD per square meter but variable to the local conditions.

It is a low energy, low chemical and low operator attention process, hence it has low operating and maintenance cost.

Operating Principles

Slow sand filtration is basically a biofiltration process. In this process contaminated freshwater flows through a layer of sand, where it gets physically filtered and biologically treated to remove suspended solids, organics and pathogens.

The top layers of the sand is always biologically active that establishes layer of a microbial community on the top layer of the sand substrate. The majority of the community is predatory bacteria that feed on water-borne microbes passing through the filter. In order to maintain an effective treatment performance, the schmutzdecke layer has to be active and never allowed to dry. Therefore a SSF should not be operated intermittently.

There are several modifications to SSF:

1. For high influent turbidity, a pre-treatment step in the form of roughing filter or a sedimentation tank is used
2. In order to improve the organic removal efficiency, SSF may be preceded by an oxidation process (usually ozonation) the breaks down large molecules of organics to biodegradable organic compounds that can be readily consumed in the biological layer.

3. For improved organic or other contaminants, a layer of granular activated carbon sandwitched between layers of sand is used as an adsorption layer. This is used to remove trace organics such as pesticides, metals etc.

Utility & Efficiency

Removes turbidity, protozoa, pathogens, viruses and heavy metals. Filters water @100–300 liters per hour per square meter of surface.

SSFs are very effective for the removal of microbiological pathogens; however, disinfectants (e.g., chlorination) are often used in treatment facilities as a step subsequent to the SSF unit.

Reliability

Very high if properly operated and maintained.

Replication Potential

Needs detailed technical feasibility analysis and experts support before installation.

Regulatory/Institutional Issues

Requires expert design, and supervision. Also, will be guided by the local regulation and byelaws for building, operation and maintenance.

Operation and Maintenance

SSFs are operated at low filtration rates (0.1–0.3m/h) in order to ensure that there is a stable flow of nutrients and oxygen to the microorganisms in the filter that are responsible for the treatment of the water.

Since SSF needs a ripening period until the schmutzdecke develops sufficiently, it is important that the treated water during this time is wasted or recycled (in what is referred to as filter-to-waste cycle). After several weeks to a few months, the population of microorganisms may get too dense and start to clog the filter. If flow rates are too low, the filter must be cleaned by scraping off the biological layer, washed, dried in the sun, and stored.

After several scrapings, the cleaned and dried sand is replaced back to the filter, together with new sand, to make up for losses during washing.

SSF required minimum operator attendance. The main routine operation requirements include adjusting the filtration rate, scarping any floating materials. The major operational requirements are filter cleaning and replacement of sand.

Advantages

1. Effective for the removal of bacteria, viruses, protozoa, and turbidity in contaminated fresh water.
2. Simplicity of design and only require basic skills and knowledge and minimal effort for construction, operation and maintenance.
3. If constructed with gravity flow only, no pumps are required.
4. Easy to install in rural, semi-urban, and remote areas.
5. High reliability and ability to withstand fluctuations in water quality.
6. Long lifespan relatively good (estimated >10 years).

Disadvantages

1. Relatively good quality is required: turbidity (<10-20 NTU) and low algae contamination. Otherwise, pre-treatment may be necessary.
2. Requirement of a large land area and manual labor for cleaning (if mechanical cleaning is not available).
3. Cold temperatures lower the efficiency of the process due to a decrease in biological activity.
4. Loss of productivity during the relatively long filter cleaning and ripening periods.
5. Chemical compounds, such as Fluorine, natural organic matter and other DBPs precursors are not sufficiently removed.

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TECHNOLOGY

Rapid Sand Filtration

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Rapid sand filtration (RSF) is an important treatment step for the removal of turbidity and microorganisms, which is preceded by coagulation and flocculation. It can be either a gravity or pressure filtration system. The rapid filter is designed to utilize the entire depth of a filter bed to attain a higher throughput of water for a given surface area.

Design Criteria

Two types of RSF are typically used: rapid gravity and rapid pressure sand filters. RSF requires adequate pre-treatment usually coagulation-flocculation and post-treatment usually disinfection. RSF is more expensive and sophisticated (compared to SSF), requires energy input, regular backwashing and flow control of the filter outlet. Some of the design criteria for an effective RSF include:

- Filtration rate 5-15 m/h.
- Depth of bed: 0.50 of gravel and 0.75 m of sand,
- Size of sand: effective size: 0.4-1.2 mm
- Uniformity coefficient: 1.5 and lower

RSF can be designed as a mono-medium sand filter or multi-media filter. In the case of multi-media filter, the RSF media may include lighter (lower density) but coarser media on top of sand or heavier (more density) material below the sand layer. Some of the lighter filter media include anthracite coal and pumice. And the most common denser media is garnet.

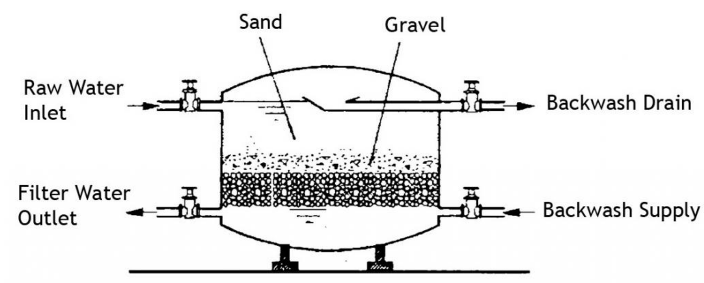
Multi media RSF are more effective and have longer filtration cycle since much of the media depth is used to effectively remove solids.

Applications

Rapid sand filtration requires highly skilled workers for construction and operation, and high energy inputs. Unless disinfection is applied, the filtered water is not safe for drinking. RSF can provide a very efficient method in larger urban water supply systems. It is also used as a polishing step (tertiary treatment) of secondary effluent in wastewater treatment.

Components

Filter tank, filter sand or mixed-media, gravel support bed, under drain system, wash water troughs, backwash system (including surface wash) etc.



Rapid sand filtration units: pressure (top) & gravity (bottom)

Capacity

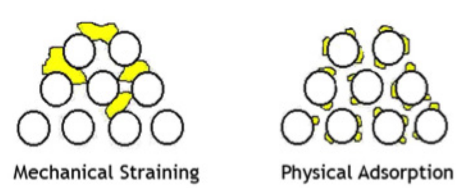
It is applicable for semi-central to centralized systems and capacity varies according the local conditions and need.

Costs

The construction cost and costs of operation vary according to the local condition.

Operating Principles

The influent water enters near the top of the tank and flows downward through the media and the filtered water is collected by the under drain system to a disinfection unit for further treatment.



Filtration process

As the influent travels through the filter media different transport and attachment mechanisms lead to suspended solids and microorganisms being removed from the water. Contaminants are either attached to the media surfaces or strained/trapped in the pore. The main removal mechanisms of RSF include straining, adsorption and settling. In some cases RSF can also be used as a biological filter if it is preceded by oxidation of organic matter (usually ozonation).

Utility & Efficiency

With pre-treated water influent, RSF can produce a filtrate quality with less than 1 NTU, 90% removal of coliforms, 50 – 90% removal of Cryptosporidium and Giardia cysts, 10% removal of color and 5% removal of Total Organic Content.

Reliability

Highly reliable, if properly operated.

Replication Potential

Standard design guidelines are available.

Regulatory/Institutional Issues

Pre-treatment is usually necessary for rapid sand filtration. Such treatments include coagulation and flocculation, followed by sedimentation. Since RSF get credit for certain removal efficiencies, they require close monitoring and controls by regulatory agencies.

Operation and Maintenance

One of the major operational activity of RSF is backwashing after each filtration cycle, flow control to ensure constant pressure or contend flow. RSF can have filter run length of 24-72 h depending on influent water quality, filter media design and filtration rate. Some filters can operate longer than one week before needing to be backwashed. However, this is not recommended as long filter runs can cause the formation of mud balls which makes backwashing difficult and influence uniform flow conditions, and hence result in short circuiting.

Treated water from storage is used for the backwash cycle. This treated water is generally taken from elevated storage tanks or pumped in from the clear well. The filter is backwashed when i) head loss is so high that the filter no longer produces water at the desired rate, ii) effluent turbidity does not meet standards (turbidity breakthrough, or iii) filter run reaches a given hour of operation.

Operational challenges and how to address them:

Air Binding: As the filter run length extends for a long period, headloss develops extensively and this might create the development of negative pressure in the filter bed. A stage reaches when the headloss by the filter media exceeds the static head of water above the bed. Most of this resistance is offered by the top 10 to 15 cm sand layer. The bottom sand acts like a vacuum, and water is sucked through the filter media rather than getting filtered through it. The negative pressure so developed, tends to release the dissolved air and other gases present in water and forms air bubbles that get attached to the sand grains. This phenomenon is known as Air Binding and results in more clogging of filter pores that will significantly reduce or stop filtration through the media. To avoid such troubles, the filters are cleaned as soon as the head loss exceeds the optimum allowable value.

Formation of Mud Balls: When the backwashing or surface wash processes are not effective, suspended solids start to grow overtime and form mudballs on the surface of the filter bed. When they have grown to a certain size, th mud balls may sink down into the sand bed during backwash and accumulate at the and affect the flow of water and even block underdrains. Formation of mudball is best avoided by making sure that the backwash step is properly done and it is assisted by surface wash or air backwash.

Cracking of Filters: The fine sand contained in the top layers of the filter bed shrinks and causes the development of shrinkage cracks in the sand bed. As the filter run extends over time, headloss builds up and the pressure on the sand bed increases and widens the cracks.

Remedial Measures to Prevent Cracking of Filters and Formation of Mud Balls

- Breaking the top fine mud layer with rakes and washing off the particles.
- Washing the filter with a solution of caustic soda.
- Removing, cleaning and replacing the damaged filter sand.

Advantages

1. Highly effective for removal of turbidity (usually < 0.1-1 NTU).
2. High filtration rate (4–12 m/h) and hence small land requirement.
3. No limitations regarding initial turbidity levels (if coagulant or flocculant is available and correctly applied).
4. Cleaning time (backwashing) is short minutes and filters can be put back into operation instantly.

Disadvantages

1. Not effective in removing bacteria, viruses, fluoride, arsenic, salts, odor, and organic matter; it requires pre- and post-treatment.
2. High capital and operational costs (high energy input required).
3. Frequent cleaning (backwashing) required in every 24-72h
4. Skilled supervision essential (e.g., for flow control).
5. Backwashing water and sludge needs treatment that might require sewage system or stabilization ponds.

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TECHNOLOGY

Activated Carbon Filters

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Activated carbon units are commonly used to remove organics (odors, micro-pollutants) from drinking water at centralized and decentralized levels. They are, particularly, important for the removal of non-biodegradable organic compounds and trace organics. They are utilized best when the influent water has low turbidity. Thus they are often preceded by filtration unit.

Design Criteria

Activated carbon is prepared in such a way that it exhibits a high degree of porosity and an extensive surface area. It is often produced from petroleum coke, bituminous coal, lignite, wood products, coconut shell or peanut shell. The carbon medium is “activated” by the process of pyrolysis, subjecting it to steam (a gas like water, argon or nitrogen) and high temperature (800-1000°C) usually without oxygen.

In some cases, the carbon may also undergo an acidic wash or be coated with a compound to enhance the removal of specific contaminants. The pyrolysis process produces carbon with high porosity and a high specific surface area. It is then crushed to produce a granular or powdered carbon product. The granular activated carbon is used in filtration units. The powdered activated carbon is however used as slurry in the coagulation flocculation units.

Applications

Activated carbon filters are widely used to remove certain organics, chlorine or radon from drinking water at household, community level and to treat industrial or municipal wastewaters. Activated carbon is not efficient for disinfection and nitrates removal.

Components

Needs detailed analysis of the system based on where it has been installed e.g., POU, POE or centralized treatment systems.

Capacity

It can be applied from a small to large scale systems.

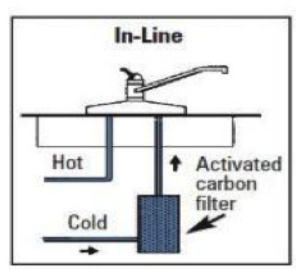
Costs

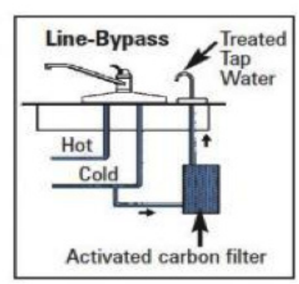
Installation costs are moderate but additional technical equipment is required. Operating costs are usually limited to regeneration of the carbon and replacement of the media. Depending on the type and concentration of the contaminant being removed, some carbon filters may require special hazardous waste handling and disposal, which can be costly.

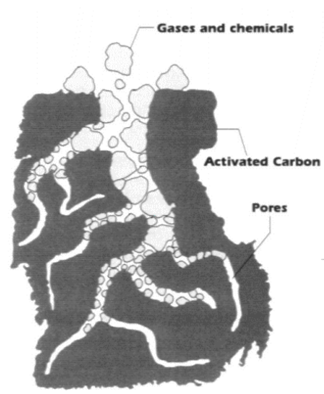
Activated carbon filtration units for groundwater treatment

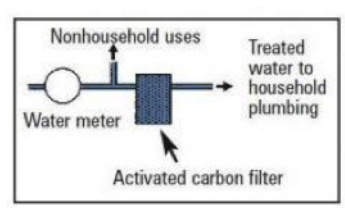
Operating Principles

A typical carbon particle has high porosity that provides a large surface area for adsorption sites of contaminants in water treatment. During water filtration through activated carbon, contaminants get adsorbed on to the surface of these carbon granules or become trapped in the small pores of the activated carbon. The characteristics of the carbon material (particle size, pore size and distribution, surface area, surface chemistry, density, and hardness) influence the efficiency of adsorption.









The characteristics of the chemical contaminant such as the tendency of the chemical to come out of solution are also important. Hydrophobic compounds (that are less soluble) are more likely to get adsorbed to a solid. A second characteristic is the affinity of the contaminant to the carbon surface. If several compounds are present in the water, compounds with high affinity will attach to the carbon in greater quantity than those with weak affinity. These combined factors enable the activated carbon material to draw the molecule out of the water.

When the adsorption capacity of the activated carbon is exhausted, it needs to be regenerated by releasing the attached contaminants. The regeneration process helps reuse the activated carbon for many cycles and requires energy and/or chemicals to get maximum recovery of its adsorption capacity.

Activated carbon filtration units can be applied in centralized or decentralized systems. At decentralized level, activated carbon filtration units can either be point-of-use (POU) or point-of-entry (POE) treatment. A POE device is recommended for the treatment of radon and volatile organic compounds because these contaminants can easily vaporize from water in showers or washing machines and become health hazards. POU devices are useful for the removal of lead and chlorine. The structure of POU devices can either be in-line, line-bypass faucet mounted or pour.

Utility & Efficiency

Efficient for pollutant having high affinity for activated carbon surface.

Reliability

Reliable if the water composition is taken into account when choosing the type of activated carbon used as filter material.

Replication Potential

Needs detailed technical feasibility analysis and experts support before installations.

Regulatory/Institutional Issues

Requires expert design, and supervision

Operation and Maintenance

Carbon filters are relatively easy to install and maintain but skilled labor is required at least occasionally for monitoring the removal performance over time.

Activated carbon filters have a limited lifetime. After long filtration volumes, the adsorption capacity of the activated carbon gets exhausted that is often indicated by breakthrough of contaminants. The filter material is, therefore, regenerated to restore its adsorption capacity according to manufacturer's instructions.

Replacement intervals should be calculated based on the filtered water volume and the amount of contaminant being removed. In small scale installation a carbon cartridge can be backwashed and then reused or discarded if non-toxics have been adsorbed.

Advantages

1. Easy to install and maintain.
2. Can be used at the point of entry (semi-centralized drinking water treatment plants, wastewater treatment plants) or at the point-of-use (household/community filters).
3. Efficient to remove certain organics, chlorine, radon.
4. Materials are available everywhere.
5. Activated carbon can also be used as a pre-treatment to protect other water treatment units.

Disadvantages

1. Filter has to be replaced regularly.
2. Skilled labor required occasionally.
3. Water analysis is required to choose the most adapted type of activated carbon.
4. Contaminants are separated from water but not destroyed.
5. It is not efficient for disinfection and nitrates removal.

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TECHNOLOGY

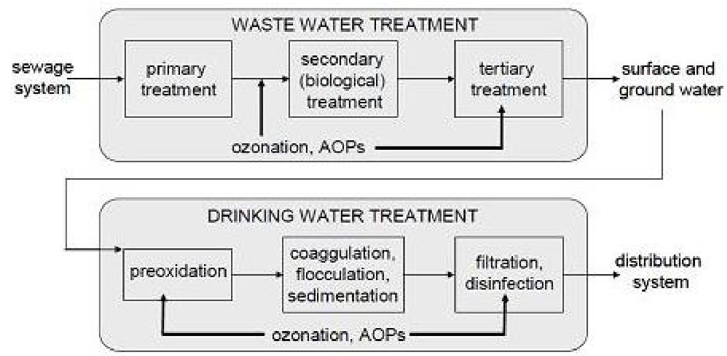
Advanced Oxidation Processes

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Advanced Oxidation Processes (AOPs) refer to a set of chemical treatment procedures designed to remove organic (and sometimes inorganic) materials in water and wastewater by oxidation through reactions with hydroxyl radicals (·OH). In real-world applications of wastewater treatment, however, this term usually refers more specifically to a subset of such chemical processes that employ ozone (O3), hydrogen peroxide (H2O2) and/or UV light. AOPs are successful in transforming toxic organic compounds (e.g., pharmaceutically active compounds, pesticides, endocrine disruptors etc.) into biodegradable substances. Advanced oxidation is also used as quaternary treatment or a polishing step to remove micro-pollutants from the effluents of municipal wastewater treatment plants and for the disinfection of water. The combination of several AOPs is an efficient way to increase pollutant removal and reduce costs.



Possible applications of Ozonation and AOPs in wastewater and drinking water treatment

Design Criteria

Many methods are available under the broad definition of AOPs. AOP generally uses strong oxidizing agents like hydrogen peroxide (H2O2) or ozone (O3), irradiation (UV light, solar light, ultrasounds) and catalysts (iron ions, electrodes, metal oxides) separately or in combination under low temperature and pressure.

AOP is governed by the influent contaminant concentration, target effluent contaminant concentration, desired flow rate, and background water quality parameters such as pH, bromide concentration, and alkalinity.

The key design parameters for AOPs include: chemical dosages and ratios with other chemicals, reactor contact time, and reactor configuration. The optimum dosages, ratios, and contact time are water-specific and treatment scenario-specific, and are often determined through pilot studies using the water matrix of interest. Higher chemical dosages and contact times are typically expected to result in higher removal rates; however, increasing dosages results in higher O&M costs and possible by-product formation.

Among the different available AOPs, those driven by light seem to be the most popular technologies for wastewater treatment. Solar AOPs are particularly attractive due to the abundance of solar light due to their relatively low costs and high efficiencies.

Dark AOP	Light driven AOP
Ozone (O3)	Photolysis (UV +H2O2)
Fenton (Fe2++ H2O2)	Photocatalysis (Light + Catalyst)
Electrolysis (electrodes +current)	Photo-Fenton (Solar light + Fenton)
Sonolysis (Ultrasounds)	

Applications

AOPs are driven by external energy sources such as electric power, ultraviolet radiation (UV) or solar light.

AOPs have a wide range of applications such as air (odor elimination, purification), soil (remediation) and water decontamination. In water, these processes have the ability to destroy organic pollutants but they can also be adapted to the removal of inorganic metals. AOPs are also commonly applied for the disinfection of water, air.

Components

Needs detailed analysis of the systems, water streams and mode of application.

Capacity

It can vary from small scale application to large scale treatment systems.

Costs

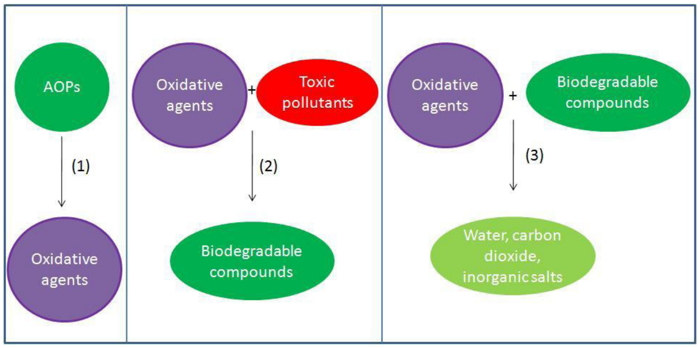
Mostly costs of AOPs are too high, since a continuous input of expensive chemical reagents are required to maintain the operation of most AOPs system.

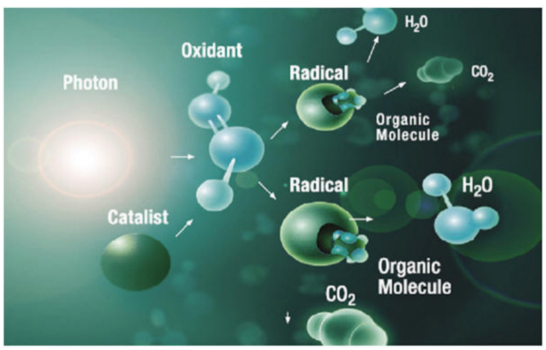
Given the potential costs, AOPs are usually deployed in the final stage after primary and secondary treatment has successfully removed a large proportion of contaminants.

Operating Principles

Advanced oxidation involves several processes as shown in the Figure. The steps in AOP include:

- Formation of strong oxidants (e.g., hydroxyl radicals).
- Reaction of these oxidants with organic compounds in the water producing biodegradable intermediates.
- Reaction of biodegradable intermediates with oxidants referred to as mineralization (i.e., production of water, carbon dioxide and inorganic salts).





Advanced Oxidation Processes

AOPs rely on in-situ production of highly reactive hydroxyl radicals (·OH). These reactive species are the strongest oxidants that can be applied in water and can virtually oxidize any compound present in the water matrix, often at a diffusion controlled reaction speed. Consequently, ·OH reacts unselectively once formed and contaminants will be quickly and efficiently fragmented and converted into small inorganic molecules. Hydroxyl radicals are produced with the help of one or more primary oxidants (e.g. ozone, hydrogen peroxide, oxygen)and/or energy sources (e.g. ultraviolet light) or catalysts (e.g. titanium dioxide). Precise, pre-programmed dosages, sequences and combinations of these reagents are applied in order to obtain a maximum •OH yield. In general, when applied in properly tuned conditions, AOPs can reduce the concentration of contaminants from several-hundreds ppm to less than 5 ppb and therefore significantly bring COD and TOC down, which earned it the credit of “water treatment processes of the 21st century”.

Effectiveness/Efficiency

Due to the high oxidation potential of OH radicals, AOPs are successful in oxidizing most of the organic compounds present in water and wastewater, inorganic substances and varieties of microorganisms (including resistant microbes). Different kinds of water are therefore suitable for an AOP treatment: for example industrial wastewater containing toxic compounds can be treated by solar photo-Fenton; surface or ground water can be disinfected by means of improved solar water disinfection by adding H2O2; both bacteria in drinking water plants or micro-pollutants in sewage systems can be degraded using ozonation. Dissolved arsenic can be removed from water by co-precipitation in presence of iron.

Reliability

Reliable if properly designed and operated.

Replication Potential

Needs detailed technical feasibility analysis and experts support before installations.

Regulatory/Institutional Issues

Requires expert design, and supervision.

Operation and Maintenance

Operation and Maintenance of the AOPs depends on the types of AOP. If the Ozone generator is set up with a clean airflow, routine maintenance of cleaning the dielectrics in the generator, dusting the interior of the generator and reassembly will be required every six months to one year or more. All electrical components in the generator are based on easily replaceable circuit boards or on an easily replaced dielectric. System failure is very rare. Air Dryer - Desiccant in the air dryer generally lasts from 2 - 3 years before needing replacement. UV reactors also require cleaning of lamps to reduce fouling of the sleeves that may affect UV intensity.

Advantages

1. Destroys toxic organic compounds without pollution transfer to another phase.
2. Very efficient to treat almost all organic pollutants and remove some toxic metals.
3. Applicable for water disinfection and wastewater treatment.
4. Scalability allows to use them in small scale treatment technologies.

Disadvantages

1. Relatively high operation costs due to chemicals and/or energy input.
2. Formation of oxidation intermediates potentially toxic.
3. Skilled technicians are required for the design and operation.
4. Emerging technologies and still a lot of research is required.

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TECHNOLOGY

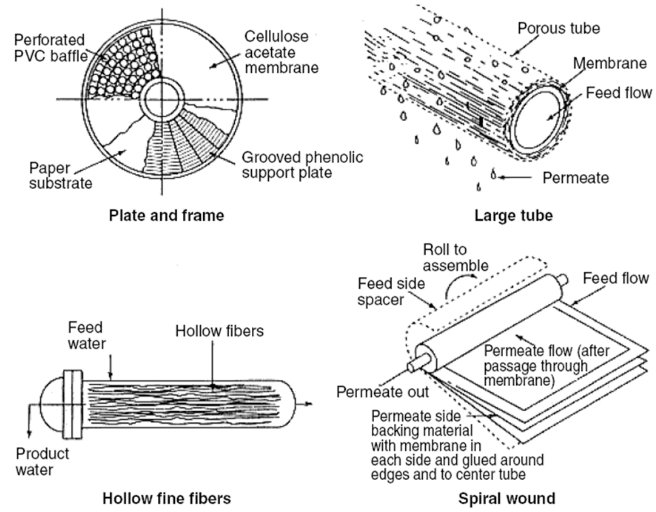
Membrane Filtration

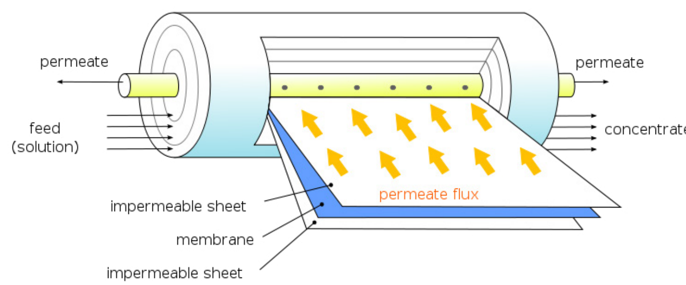
SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Membranes are thin and porous sheets of material able to separate contaminants from water when a driving force is applied. Once considered a viable technology only for desalination, membrane processes emerged as a significant innovation increasingly employed for treatment of both drinking water and wastewater. It has been used for removal of microorganisms, particulate material, micro-pollutants, and natural organic material, which can impart color, tastes, and odors to the water and react with disinfectants to form disinfection by-products (DBP). As advancements are made in membrane production and module design, capital and operating costs continue to decline. The scalability of membrane filtration systems has allowed them to be very effective technologies at all scales that range from house hold to large centralized systems. Advances in material sciences and design have significantly improved the widespread use of membrane technology in water and wastewater treatment.





Membrane module designs

Design Criteria

Most membranes are synthetic organic polymers (e.g., polysulfone, cellulose acetate). Microfiltration and ultrafiltration membranes are often made from the same materials, but they are prepared under different membrane formation conditions so that different pore sizes are produced.

Membranes can also be prepared from inorganic materials such as ceramics or metals. Ceramic membranes are micro-porous, thermally stable, chemically resistant, and often used for microfiltration. However, high cost and mechanical fragility have hindered their widespread use.

Metallic membranes are often made of stainless steel and can be very finely porous. Their main application is in gas separations, but they can also be used for water filtration at high temperatures or as a membrane support.

The current tendency on membrane development is to use Nano-functionalized membranes. Polymer membranes doped with silver nanoparticles to avoid bio-fouling is an example of such modern membranes.

There are mainly four types of membrane modules commonly available that include plate-and-frame, tubular, spiral wound, and hollow fiber.

- **Plate-and-frame module** is the simplest configuration, consisting of two end plates, the flat sheet membrane, and spacers.
- **Tubular modules membrane** is often on the inside of a tube, and the feed solution is pumped through the tube.
- **Spiral wound module** is the most popular module in industry for Nano-filtration or reverse osmosis membranes. This module has a flat sheet membrane wrapped around a perforated permeate collection tube. The feed flows on one side of the membrane. Permeate is collected on the other side of the membrane and spirals in towards the center collection tube.
- **Hollow fiber modules** consist of bundles of hollow fibers in a pressure vessel. They can have a shell-side feed configuration where the feed passes along the outside of the fibers and exits the fiber ends. Hollow fiber modules can also be used in a bore-side feed configuration where the feed is circulated through the fibers. Hollow fibers employed for wastewater treatment and in membrane bioreactors are not always used in pressure vessels. Bundles of fibers can be suspended in the feed solution and the permeate is collected from one end of the fibers.

Applications

Water treatment processes employ several types of membranes. They include microfiltration (MF), ultrafiltration (UF), Nano filtration (NF) and reverse osmosis (RO) membranes.

For wastewater treatment applications, membranes are currently being used as a tertiary/advanced treatment for the removal of dissolved species; organic compounds; phosphorus; nitrogen; colloidal solids; and microroganisms, including bacteria, protozoan cysts, and viruses. Membrane technologies for wastewater treatment include:

- **Membrane bioreactors**—usually microfiltration (MF) or ultrafiltration (UF) membranes immersed in aeration tanks (vacuum system), or implemented in external pressure-driven membrane units, as a replacement for secondary clarifiers and tertiary polishing filters.
- **Low-pressure membranes**—usually MF or UF membranes, either as a pressure system or an immersed system, providing a higher degree of suspended solids removal following secondary clarification.
- **High-pressure membranes**—Nano filtration or reverse osmosis pressure systems for treatment and production of high-quality product water suitable for indirect potable reuse and high-purity industrial process water. Also, recent research has shown that micro pollutants, such as pharmaceuticals and personal care products, can be removed by high-pressure membranes.

Components

Needs detailed analysis of the systems, water quality, and types of membrane technology used.

Capacity

Very flexible and can be applicable from smaller unit to the largest treatment plants.

Costs

Membrane filtration systems' capital costs on a basis of dollars per volume of installed treatment capacity and do not escalate rapidly as plant size decreases. This factor makes membranes quite attractive for small systems. The unit rate of costs varies according to the types of membrane.

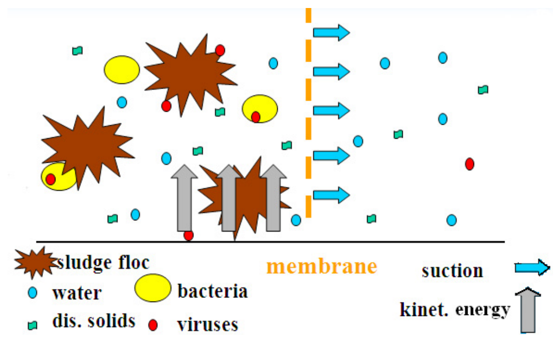
Operating Principles

Membrane separation processes can be operated in cross-flow or dead-end mode:

Cross-flow operation: is used in Nano-filtration and reverse osmosis. In this mode, the feed is pumped parallel to the membrane surface and the permeate is withdrawn diagonally to it. Cross-flow mode induces turbulence at the membrane surface to inhibit the buildup of the fouling layer on the membrane surface.

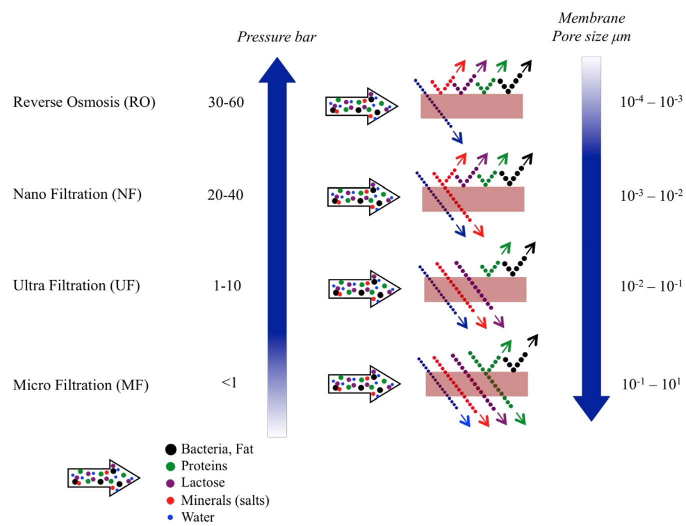
Dead-end operation: the membrane is fed orthogonally, comparable to a "coffee filter". In this mode, retained particles accumulate to form a cake layer and fouling tendencies are therefore high.

In ultra- and microfiltration both operating modes are possible.



Filtration process by membrane

Membrane processes differ in their molecular separation size and the driving force which has to be expended. The main types of membrane filtration processes include micro filtration, ultra-filtration, nano-filtration and reverse osmosis.



Membrane types

Microfiltration (MF) closely resembles conventional coarse filtration and is used for the separation of particles between 0.1 and 10µm, such as suspended solids (colloids), bacteria and large proteins. MF employs membranes with a porous structure corresponding to low operating pressures in the 0.1 to 2 bar range. MF is applied for clarification and sterilization purposes, for cell harvesting, separation of oil-water emulsions, etc.

Ultrafiltration (UF) belongs to the pressure-driven membrane processes. This technique uses micro-porous membranes whose pore diameters are between 1-100 nm. Such membranes let through small molecules (water, salts) and retain the large molecules (polymers, proteins, colloids). Operating pressures are typically in the range of 1 to 5 bar for cross-flow application. With a semi-dead end operation mode, the pressures are much lower, around 0.2-0.3 bar. UF is ideally suited for fractionation, concentration and purification purposes.

Nanofiltration (NF) is a pressure-driven membrane process which is preferentially used for the recycling of aqueous solutions. Operating pressures are between 5 and 20 bars. NF has pore of around 0.001 micron in size.

Reverse Osmosis (RO) serves to separate components of a solution. It is based on a pressure-driven process, the driving force resulting from the difference of the electrochemical potential on both sides of the membrane. Operating pressures can range from 10 bars up to 100 bars. A typical RO application is seawater desalination. The major trends for RO for the past 15 years are improved performance and a significant reduction in cost.

Recent developments have greatly extended the capabilities of the membranes to withstand aggressive environments. Further progress was also made on improved performance with regard to both permeability and selectivity.

Another form of membrane filtration process is the Electrodialysis (ED), which is a membrane process where ions are transported through semi permeable membrane, under the influence of an electric potential. The membranes are Cation- or Anion-selective, which basically means that either positive ions or negative ions will flow through. For example cation-selective membranes are polyelectrolytes with negatively charged matter, which rejects negatively charged ions and allow positively charged ions to flow through.

In ED, ions can be removed from wastewater by placing multiple membranes in a row, which alternately allow positively or negatively charged ions to flow through. ED is used for desalination, demineralization and the removal of metals.

Utility & Efficiency

It has been used for removal of bacteria and other microorganisms, particulate material, micro-pollutants, and natural organic material, which can impart color, tastes, and odors to the water and react with disinfectants to form disinfection by-products (DBP).

Reliability

Reliable if operating conditions are scaled taking into account water or wastewater quality.

Replication Potential

Membrane technologies are more economical than other alternatives, or require much less land area than competing technologies, since they may replace several unit treatment processes with a single unit.

Regulatory/Institutional Issues

Requires expert design, and supervision. Membrane fouling is the key challenges.

Operation and Maintenance

- Membranes have to be backwashed on a regular basis to restore flux, to avoid fouling and to increase their lifetime.
- Early detection of raw water changes and making adjustments to the operational parameters to accommodate the changes are the key to successful plant operation.
- Raw water quality must be reviewed frequently and operational parameters of the membrane treatment train should be continually reviewed and compared to original start up conditions.
- Pretreatment efficiencies and post treatment works should also be monitored closely. While some changes in the treatment process may not significantly impact plant productivity or finished water quality, they may result in membrane degradation, more frequent cleaning, and generally higher operating costs over time if not properly addressed.
- Major obstacle to the widespread use of this technology is membrane fouling. It is a process where solute or particles deposit onto a membrane surface or into membrane pores in a way that degrades the membrane's performance.
- Membrane fouling can cause severe flux decline and affect the quality of the water produced. Severe fouling may require intense chemical cleaning or membrane replacement. This increases the operating costs of a treatment plant.
- Fouling can be caused by biological growth on the membrane surface (often termed as bio-fouling) or by the deposition of inorganic substances such as scale formation (often called inorganic fouling).
- Fouling can be reversible and irreversible based on the strength of attachment of particles to the membrane surface. Reversible fouling can be removed by a strong shear force of backwashing. Formation of a strong matrix of fouling layer with the solute during a continuous filtration process will result in reversible fouling being transformed into an irreversible fouling layer. Irreversible fouling is the strong attachment of particles, which cannot be removed by physical cleaning. It requires chemical cleaning process.

Advantages

1. High performance in removing most of the impurities from water and wastewater inflows.
2. Compact units and require less space than conventional treatment schemes.
3. Membranes available can be used to separate many kinds of contaminants.
4. Disinfection can be performed without chemicals.

Disadvantages

1. Membrane fouling is most critical.
2. Production of polluted water (from backwashing).
3. Membranes have to be replaced on a regular basis.
4. Needs advanced technology and skilled technical personal for design, operation and maintenance.
5. High operating cost due to high energy consumption (pumping)

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Gravel Filtration Beds

SOURCE Greywater
SCALE Household

Description

On-site greywater recycling is a relatively new practice. Only a few off-the-shelf systems are commercially available. Only few are tested on full scale for long time periods. Most treatment units reported in the literature (and advertised commercially) are based on physical processes (i.e., filtration and disinfection), while the more current ones incorporate biological treatment as well. The treatment technology developed at the household scale is therefore based on the filtration and biological processes.

Design Criteria

One of the constraints for the treatment technologies selected in urban areas is a small footprint due to space constraints.

Treatment units used for a single household are simple in design that use local materials and are easy to operate and maintain.

In rural areas, where much land is usually available, 'natural' treatment systems seem to be appropriate.

Type of technology and design standard depends on the quality and quantity of greywater to be treated and purpose of the reuse. Further information on operating principles and design criteria for available greywater technologies is presented in the next section.

Applications

Applicable for any place in household level.

Components

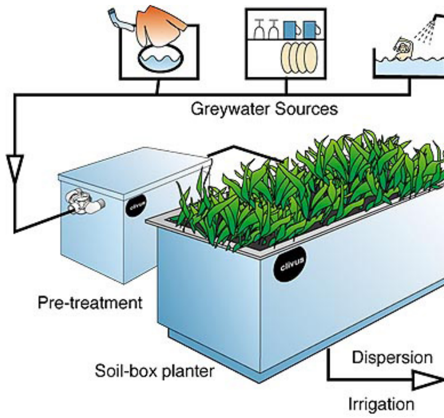
Filtration technologies are very common. However, level of advancement depends on the purpose of the water uses after treatment, i.e., for toilet flushing or car washing or gardening or portable uses.

Capacity

The systems are designed for a single household level.

Costs

Generally, low-cost- depending on availability of materials and frequency of back flushing and desludging.

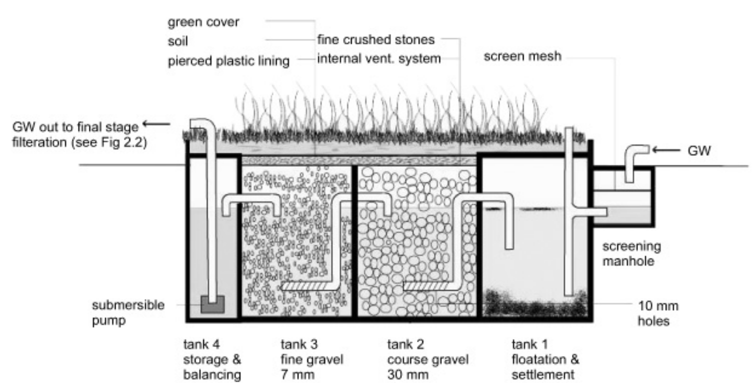


General principle of household level greywater treatment

Operating Principles

Main principles of treatment include physical/mechanical and biological process.

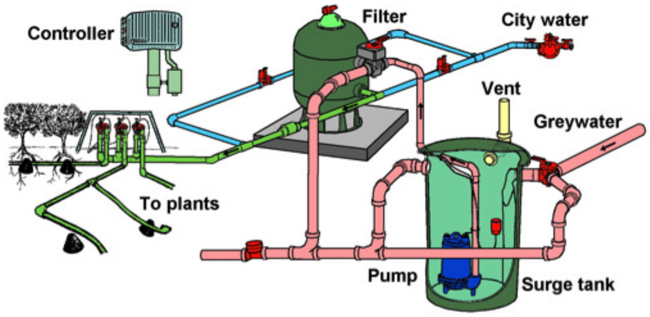
Physical greywater treatment systems: A typical greywater treatment unit comprises of compartments for settling and gravel filter beds unit with a plant/grass cover.



Physical greywater treatment system used in Qebia Village, Palestine (Source: Burnat and Eshtayah, 2010)

ReWater's greywater treatment system for outdoor irrigation is also commonly used grey water treatment technology for the household level. In this type of technology, physical and chemical treatment systems usually involve holding tanks, filters, and pumps. For example, the major components of the ReWater greywater treatment system are a surge tank, sand media filtration tank, and piping to an outdoor irrigation system. Many basic greywater treatment and storage systems also incorporate activated carbon and/or clay filters and disinfection (e.g., chlorination, purification with ultraviolet radiation).

These systems cost between $1,000 and $5,000 for a single family home and can be fairly land-intensive, requiring space for holding tanks and filtration units. The performances of this technology has been tested and replicable for different other similar condition.

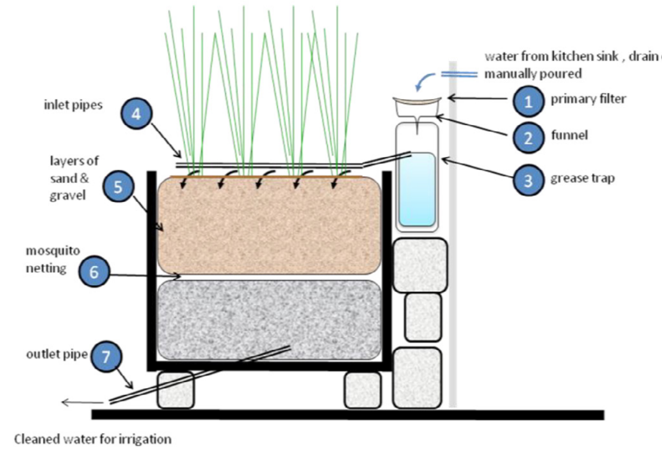


Greywater Treatment Box:
This technology is very simple and fabricated at the household level in Kenya and nearby by region in Africa. It consists of a container that is watertight (generally, depth 50cm ideal, length and width to give surface area of approximately 0.5 m², i.e. length 1m, width 0.5m), locally available and cheap. Perforated distribution pipes (40 mm pipe for surface, 20 mm pipe for base). Coarse gravel bases is laid over pipes (10cm), followed by ½" gravel (20cm), a layer of netting and finally coarse sand (20cm).

Water loving plants (sedges, papyrus, reeds, Vetiver grass etc) planted into sand between inlet pipes. Gravel placed immediately below perforations to reduce scour.

A plastic container of 20 liters is used and a 40mm diameter hole is cut for outlet pipe and slice open 75% of the upper section (so that the container may be opened for cleaning).

A funnel is used to sieve for inlet and channel water into container and remove large particles. Outlet pipe passes through 40 mm hole via a down pipe so that fats and greases are retained and not passed through to bed (see following schematic).



Greywater treatment at household level

Another, less sophisticated but cheaper grey-water treatment system was implemented by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Water Management Institute (IWMI) in neighboring Jordan. The system consist of a septic tank followed by an intermittent sand filter was installed in some communities. This cost effective system yielded positive results for treated grey-water and can be used for agricultural purposes.

Utility & Efficiency

It varies according to the types of technologies and purpose of the treatment units.

Reliability

Reliable if construction is watertight and influent is primary settled.

Replication Potential

Standardized designs are available that can be replicated in similar environment. It has a high potential of integrating with other post treatments technologies such as DEWATS.

Regulatory/Institutional Issues

Requires expert design, but can be constructed with locally available material.

Operation and Maintenance

- The Operation and Maintenance depends on the treatment technologies and materials used for processing.
- Generally all the M and O used for the filtration technologies and biological treatment technologies are applicable.
- Recently MBR are also used for the household level greywater treatment. However it is has not been proved to be cost effective. At the same time, it requires all the backwash and cleaning process as presented in the MBR section.

Advantages

1. They are mostly very simple and based on the local technologies.
2. Due to local technology, it can be built and repaired with locally available materials.
3. In many cases, they don't need any chemical and electricity.
4. It has a reasonable service life, more than 5 years.
5. No real problems with flies or odors if used correctly.
6. Low capital costs and moderate operating costs depending on emptying.

Disadvantages

1. Requires expert design and construction in most of the cases.
2. Required frequent monitoring by the experts.
3. Low reduction in pathogens, solids and organics.
4. Having a high health risk issue.
5. Likely implications of neglect/misuse.
6. Many cases low public acceptability.

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    Construction of domestic greywater systems

    http://www.susana.org/docs_ccbk/susana_download/2-1547-greywater-treatment-system-construction-greenwater.pdf

TECHNOLOGY

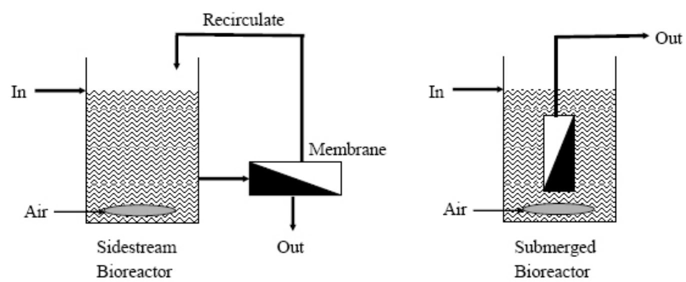
Membrane Bioreactor

SOURCE Greywater

SCALE Semi-centralized and Centralized

Description

The coupling of a membrane to a biological treatment units has increased interest both academically and commercially because of the inherent advantages of the process offered over conventional biological wastewater treatment systems. The membrane bioreactor (MBR) combines biodegradation with membrane filtration for solid liquid separation. Due to its relatively low content of pollutants, greywater is easy to treat with MBRs. The pollutants contained are decomposed by the bacteria of the activated sludge tank. The treated greywater is of high quality and hygienically safe so that it can be reused, alone or combined with rain water, for toilet flushing, laundry or for irrigation purposes. The MBR has been regarded as an innovative technology for grey water treatment due to its process stability and its ability to remove pathogens.



(MBR Types: Sidestream and Submerged MBR)

Design Criteria

Low pressure membrane filtration, either micro- filtration of ultrafiltration is used to separate effluent from activated sludge.

The two main MBR configurations used for the MBR are either submerged membranes or external circulation (side-stream configuration). The submerged are more often used in domestic wastewater treatment.

Membrane used in submerged MBRs can be either hollow fiber membranes or plate membrane module design.

Successful introduction of MBR systems into small scale and decentralsied application has led to the development of packaged treatment solutions.

In the last couple of years the use of MBRs for medium to large-scale domestic wastewater application is growing gradually. The main factors that contributed to their development were the experiences gained with pilot/small scale projects, the drastic decrease in the cost of membranes, the availability of subsidies and the improvements in membrane performance. Other reasons were footprint limitations, strict standards for discharge into sensitive/bathing water and the development of guaranteed on membrane life spans and maintenance contracts.

Submerged MBR	Side-Stream MBR
Aeration costs high (~90%)	Aeration costs low (~20%)
Very low liquid pumping costs (higher if suction pump is used ~28%)	High pumping costs (60-80%)
Lower flux (larger footprint)	Higher flux (smaller footprint)
Less frequent cleaning required	More frequent cleaning required
Lower operating costs	Higher operating costs
Higher capital costs	Lower capital costs

Comparative advantages and disadvantages of membrane configuration

Applications

This is possible where communities are willing to collect greywater separately and reuse for irrigation and other purposes.

Membrane technologies for wastewater treatment are usually based on membranes immersed in aeration tanks (vacuum system), or implemented in external pressure-driven membrane units, as a replacement for secondary clarifiers and tertiary polishing filters. They usually employ microfiltration (MF) or ultrafiltration (UF) membranes that provide a higher degree of suspended solids and microbial removal. UF membranes are effective for virus removal.

Components

Generally it consists of combination of the collection tank, pumps, filtration, biological treatment, disinfection, storage tank/ cistern, pipe work.

Capacity

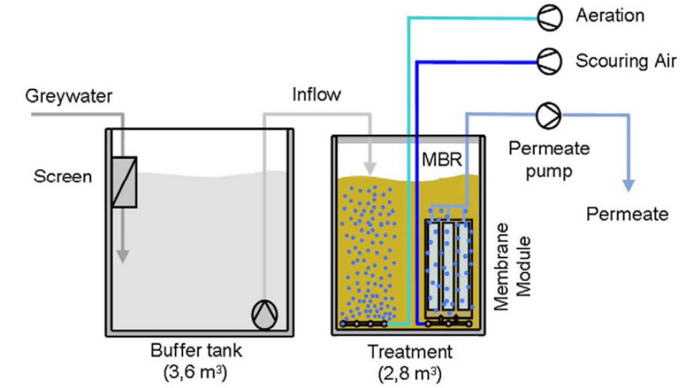
It varies forma family of four to large communities.

Costs

The unit costs vary with the quality and quantity of grey water to be treated and purpose of reuses.

Operating Principles

The greywater is collected in a first tank for preliminary sedimentation and coarse filtration by a 3mm screen. The water is pumped into the second tank with the activated sludge and the membrane incorporated. Due to aeration, the fluid is moved perpendicular to the membrane surface, where the treated water passes through the membrane plate, while the sludge stays in the tank.



Technical data:
- Membrane surface: 18 m²
- Membrane modules: 6
- Membrane material: PES
- Separation size: 38 nm

Operating parameters:
- Flow: 3,000-4,500 l/d
- MLSS: 3.0-4.5 g/l
- Average F/M: 0.06 kg COD/(kg MLSS *d)

MBR Technology

Utility & Efficiency

COD reduction can reach more than 90%.

For example HUBER GreyUse effluent meets the German standards for the reuse of treated water for toilet flushing, laundry washing and irrigation. The treated greywater also meets bathing water quality according to the EU directive 76/160/EEC. Example of performance of MBR plant in Vietnam

Requirements on effluent quality for the reuse as toilet flush water, laundry wash water and irrigation purposes (fbr sheet H201) and effluent properties of the MBR plant in Vietnam.

Parameter	Guide values of fbr-H201[a] (Limits of Directive 76/160/EEC)[b]	MBR plant effluent Can Tho, Vietnam
BOD_7	<5 mg/l (–)	<4.2 mg/l
Oxygen saturation	>50% (80–120%)	>50%
Anionic tensides	–	0.79
Total coliform bacteria	<100/ml (100)	<1/ml
Faecal coliform bacteria	<10/ml (20)	<1/ml
Pseudomonas aeruginosa	<1/ml (–)	–

[a] fbr sheet H201.
[b] EU directive for bathing waters 76/160/EEC.

Reliability

Reliable if construction is watertight and influent is primary settled; generally good resistance to shock loading.

Parameter	Activated sludge	MBRs
COD	94.5	99
DOC	92.7	96.9
TSS	60.9	99.6
Total P	88.5	96.6
Ammonical N	98.9	99.2

Replication Potential

Standardized designs are available and can be modified considering the local condition.

Regulatory/Institutional Issues

Requires expert design, but can be constructed combining with the locally available material.

Operation and Maintenance

Operation and Maintenance of similar technologies described for black water treatment is also applicable here.

Controlling membrane fouling is the key issue in the operation of an MBR. This requires sufficient pre-treatment and effective cleaning of membranes by scouring chemical cleaning.

Intensive training and technological support of operators is one of the most critical factors to ensure a quick and efficient operation and reliable control of the system.

Advantages

1. Smaller footprint and smaller reactor volume
2. Decreased sludge production
3. Good effluent quality
4. Potential scalability. Some MBR applications have also been successfully commercialized for decentralized usage in single or double family houses with 4-8 person equivalents.
5. High biomass concentration and higher sludge age compared to other technologies
6. Effective removal of bacteria and viruses.
7. Lower sensitivity to peak contaminant loads

Disadvantages

1. Higher level of maintenance, more sophisticated control units.
2. Requires expert design and construction
3. Relatively expensive to install and operate
4. Potential of discharging floating or settled sludge during the draw or decant phase
5. Frequent fouling and clogging of bioreactor
6. Limited experience in use of membrane in wastewater reuse
7. Limitations imposed by pressure, temperature, and pH requirements to meet membrane tolerances
8. Membrane could be sensitive to some chemicals and chances of producing byproducts

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TECHNOLOGY

Compost Privy

SOURCE Blackwater

SCALE Household

Description

A compost privy is similar in structure to a pit latrine or aqua privy with some variations like sloping floor and liquid storage. It receives the feces, urine, anal cleansing materials with the addition of other organic matter such as garbage, leaves and grass. Biological decomposition takes place inside the privy producing humus called "compost".

Design Criteria

The volume of the pit depends on the needs for fertilizer and the numbers of people using the privy. Proportion of excreta to refuse (organic matter) should be about 1 to 5 by volume. Design value of 0.3 m^3/person/ year is used for calculating the volume of the pit (in many cases ranging 0.1 to 0.15 m^3/person/ year).

General formula for the calculation is: $V = 1.33 \times N \times R \times P$ where, V is the required volume in m^3, N is the number of users, R is the rate of filling (m^3/person/year), P is the emptying period (usually one year)

A design can also provide separate urine drainage, which would separate urine and prevent it from going to the compost.

This would then reduce nitrogen and moisture levels in the compost pile.

Applications

A compost privy is appropriate for use in areas where there is a tradition of using human excreta on the land. Composts can also be used in fishponds.

Components

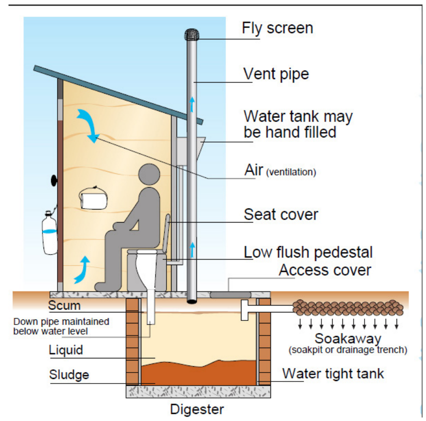
Privy pit; slab; superstructure; removable covers; ventilation pipe.

Capacity

One average household could produce 1 m^3 of digested sludge in 4 years. Allowing refuse to fill up the tank will shorten the cycle to 9-10 months for composting.

Costs

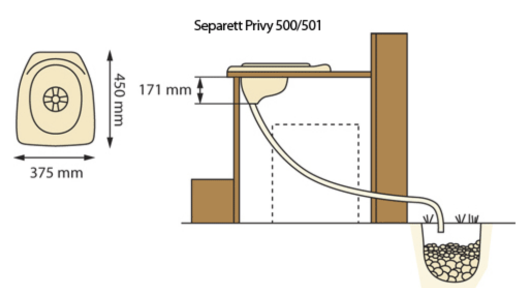
Investment cost is very low and depends on the types, size and local condition.



A sectional view of a compost privy

Operating Principles

Composting involves the biological degradation of the organic compounds of wastes which have relatively high concentration of solids. Initially, psychrophilic and mesophilic bacteria (10-40°C) present in the organic waste, decompose it and generate heat. The temperature rises until it limits the growth of the mesophilic bacteria. The temperature then begins to drop, the mesophilic bacteria take over again as decomposition approaches completion. Length of time for the decomposition process is not fixed. Sludge in open compost piles/windrow is composted for 21 to 28 days, but in a compost privy, it takes at least a year.



Schematic diagram of a compost privy

Anaerobic composting is much slower process in the absence of oxygen, and pathogenic bacteria can survive longer in cooler temperature.

For efficient composting, the correct balance of materials must be maintained for the microbes which digest and degrade the materials.

These microbes need carbon for energy and nitrogen to form proteins for growth.

To achieve suitable C:N ratio, it is necessary to add organic matter such as crop residues, leaves, grasses, sawdust or some other easily compostable materials. In addition, wood ash can be added regularly to the composts to reduce acidity and odor of the compost and speed up the composting process. Likewise, urine should be separated to reduce nitrogen and moisture levels in the compost. For the same reason, water should not be added to the pit.

The humus produced by a compost latrine that is functioning well is a dark friable and inoffensive material, rather like a good, moist organic soil.

Utility & Efficiency

The correct balance of nutrients must be maintained for efficient composting. The microbes need carbon for energy and nitrogen for growth.

Reliability

Reliable if construction is watertight and influent is primary settled; generally good resistance to shock loading.

Replication Potential

Self-help potential is highly possible. Training in installation, Operation and Maintenance can be instituted.

Regulatory/Institutional Issues

Requires an entity to conduct training/implementation support.

Operation and Maintenance

The compost must be collected regularly and hauled to a point of application/disposal. For multiple- or double-vault composters, when the contents of the tank/privy reach a level of 0.5 m below the round surface, the slab superstructure are moved to another compost privy. The first pit is filled with grass or leaves and earth.

The compost is removed when the second pit is full and the first one is reused.

Advantages

1. Suitable in tropical areas where nutrients are quickly leached from the soil.
2. Satisfies most sanitary requirements.
3. Used as soil fertilizer in agricultural practices.
4. Needs no water for flushing as composting requires little moisture.
5. Can be built on bedrock; need not penetrate the subsoil.
6. Low pollution/health risks, especially if in a sealed unit.

Disadvantages

1. Needs organic matter to correct the C:N ratio.
2. Process is rather complicated and needs close supervision, education and follow-up.
3. Not free of hazards and regular attention.
4. Not suitable in areas with high groundwater table, due to possible infiltration with leachate.
5. More expensive than the ordinary pit latrine.

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TECHNOLOGY

Ventilated Improved Pit (VIP) Latrine

SOURCE Blackwater

SCALE Household

Description

A pit latrine consists of a hole in the ground covered with either a squatting plate or a slab provided with riser and seat. A housing or toilet room is built over the pit. A pit latrine operates without water. Liquid portion of the excreta soaks away into the soil. The VIP is a pit latrine with a screened vent installed directly over the pit. The vent provides odor control and the screen on top of the vent prevents entry of insects attracted by the smell. Filled pits are covered with soil for composting. There are two types of VIP latrines: single pit and alternating-pit. For the latter, there are two adjacent pits below the toilet room and one pit is used at any given time. When one pit becomes full, it is closed and the other pit is used. By the time the second pit becomes full, the first has fully decomposed and becomes innocuous. Materials in the filled pit are removed and the pit can then be returned to service till it becomes full.

Design Criteria

The pit volume is given by the product of: Sludge accumulation rate x Number of people x Filling time

- Sludge accumulation rate = 40 liters/person/year or rate decreased to 20 liters/person/year if pit is seasonally flooded or water from washings is added to the pit. Increase rate by 50% to allow bulky materials for anal cleansing.
- Design use of single pit (filling time) = period of 2 years
- Pit bottom not lined to enable liquid to soak away

Applications

Single-pit VIP latrines are suitable for use in rural areas where the soil is deep and space is available to construct succeeding pits. Alternating double-pit VIP latrines are appropriate for urban areas where people can afford a permanent latrine that does not require relocating after every few years.

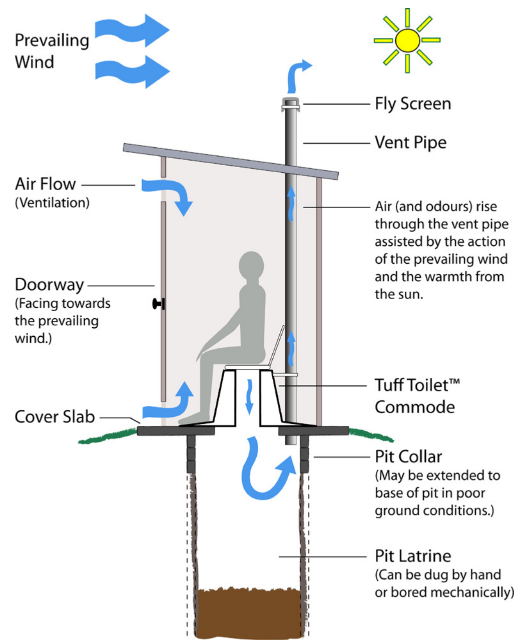
VIP latrines can be used in areas where there are no on-site water supplies. Water is needed for hand washing.

Components

Pit; squatting plate or wooden seat & cover; cover slab; and a housing or toilet room.

Capacity

- Minimum pit volume = 1 m^3 for household of 6 persons for use in about 2 years
- Increase in capacity can be achieved by making the pit at least 0.5 m deeper than the minimum since the latrine cannot be used after the sludge surface gets close to the slab cover.



Costs

One of the cheapest options of treatment at household level. The costs of construction, Operation and Maintenance vary according to the local condition.

Operating Principles

Two important actions take place in the pit which reduce the rate at which it fills:

1. The liquid portion of the excreta soaks away into the soil.
2. The solids in the excreta are broken down into simpler compounds by biological digestion. Soluble products are carried into the soil by the liquid portion of the excreta.
3. Gases (foul air) produced by the digestion are pus

Utility & Efficiency

50% reduction of solids by digestion. It can be a single pit, double pit or multiple pits.

Reliability

Can be relied upon to maintain protection with limited supervision for long periods of time.

Replication Potential

Self-help potential is highly possible. Training in installation, Operation and Maintenance can be instituted.

Regulatory/Institutional Issues

This option should be tried first on a pilot scale in the rural areas with agricultural officials and LGUs. Requires an entity to conduct training/implementation support.

Operation and Maintenance

- Regular cleaning and repairs.
- Periodic inspection of the fly screens and signs of erosion around the edges of the slab.
- Use of a little bleach or disinfectant to wash the floor slab.
- Where there is standing water in the latrine pit, small quantities of special oils, kerosene, old engine oil can be added to the pit to prevent mosquitoes from breeding.
- Stop use of pit when level of solids reaches 0.5 m from the underside of the slab. Fill the pit immediately with soil.

Advantages

1. Easy for construction using local materials.
2. Minimal water requirement
3. Low annual cost
4. Easy maintenance
5. All kinds of anal cleansing materials may be used

Disadvantages

1. Lack of space for relocating; the pit is dense in urban areas
2. Potential for groundwater pollution
3. Does not dispose of large quantities of sullage water
4. Not suitable in areas with high groundwater table, due to possible infiltration with leachate
5. Not suitable in areas with impermeable, rocky underground, due to limited infiltration capacity latrine

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TECHNOLOGY

Septic Tank

SOURCE Blackwater

SCALE Household

Description

The septic tank is an underground water tight chamber that receives both excreta and flush water from toilets with or without other household wastewaters (or sullage). The tank serves as a sedimentation tank for the removal of incoming solids, while allowing the liquid fraction (or settled effluent) to pass; as a biochemical reactor for the anaerobic decomposition of the retained solids; and as a storage tank in which the non-degradable residual solids accumulate. Scum, such as fats and greases, rises to the top. The clarified liquid flows through the outlet pipe and is usually disposed through a subsurface soil absorption system. The effluent should not be discharged to surface drains, creeks, streams or lakes, without treatment.

Design Criteria

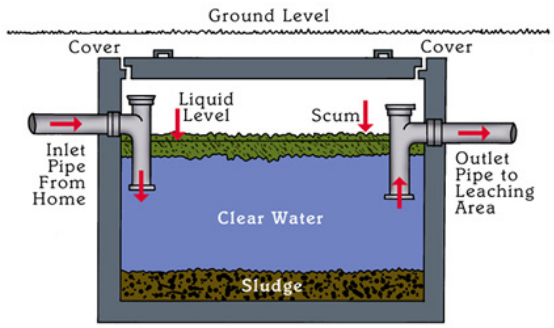
- Retention time of at least 24 hours
- Two thirds of tank volume is reserved for sludge and scum storage
- Wastewater inflow (50- 120) liter/person/day
- Sludge accumulation rate = 40 liter/person/year
- Maximum filled volume = 50% of tank volume
- Desludging interval is approximately every 4 years
- Provide ventilation pipe to permit gas produced in the tank to escape.
- Must be water tight with one or two chambers.

Applications

Satisfactory and acceptable facility for excreta disposal and other liquid wastes from individual houses, cluster of houses, apartments, and institutions (schools).

Components

Inlet tee pipe; digestion chamber and settling chamber (for 2-chamber tank); outlet tee pipe; manhole cover, clean outs



Septic tank

Capacity

No. of person served	4	8	12	16	20
Length (m)	2.0	2.5	3.0	3.8	4.0
Width (m)	0.6	0.9	1.1	1.2	1.4
Liquid depth (m)	1.5	1.5	1.5	1.5	1.5
Freeboard (m)	0.3	0.3	0.3	0.3	0.3
Tank volume (m^3)	2.0	4.0	6.0	8.0	10.0

Costs

Varies based on the according to the local condition.

Operating Principles

The septic tank operates similar to an aqua-privy, i.e., settling solids, anaerobic digestion of solids and storage of digested sludge. Light solids float on the surface of the water in the tank, called scum, is also retained in the tank. Liquid effluent disposed to absorption fields/soil infiltration, leaching or soakaway pits, evapotranspiration mounds or soil conditioner on agricultural land. Sludge from septic tanks or septage is removed by vacuum tankers and co-treated with sewage or other sludge, undergoes own treatment, or disposed in lahar areas or various land applications or surface disposal.

Utility & Efficiency

About 30-60% BOD removal; 80-85% suspended solid removal; 50% coliform removal.

Reliability

Reliable if regularly cleaned and desludged. ST resistant against Shock load.

Replication Potential

Basic septic tank design, materials and technical know-how are readily available. It can be upgraded to piped collection for secondary treatment

Regulatory/Institutional Issues

Local agency and bye laws.

Operation and Maintenance

- Effluent from septic tank should be inspected periodically to ensure that neither scum nor suspended solids are leaving the system.
- Regular desludging of septic tank contents should be done when the sludge and scum occupy 2/3 of the tank's capacity.
- Normally done every 2 to 5 years.

Advantages

1. Flexible and adaptable to wide varieties of households waste disposal.
2. It can be built and repaired with locally available materials.
3. Little space required due to underground construction;
4. No real problems with flies or odors if build and operated correctly.
5. It has long service life.
6. Low investment costs; low Operation and Maintenance costs.

Disadvantages

1. Constant and sufficient amounts of piped water required to bring the waste to the treatment unit.
2. Only suitable for low-density housing in areas with low water table and not prone to flooding.
3. Manual cleaning of the tank is highly hazardous, while mechanical cleansing (vacuum trucks) requires sophisticated instruments.
4. Low reduction in pathogens, solids and organics thus it requires secondary treatment for both effluent and faecal sludge

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TECHNOLOGY

Imhoff Tank

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

The Imhoff tank consists of an upper compartment, which serves as a settling basin, and a lower compartment in which the settled solids are anaerobically digested. Scum and gas vent chambers are located at the sides of the tank. It can be an open or covered tank. Imhoff tanks are used by small communities with raw wastewater flows in the order of 950 m^3/day (population about 8,000 people or 1,300 households).

Design Criteria

The design of the Imhoff tank depends on the type of influent and local conditions. In general,

- Imhoff tanks are normally designed with a hydraulic retention time of 2 to 4 hours;
- Length equals 3 times its width
- Depth of 7.2 to 9 m,
- 20% of the total surface area is typically provided for gas vent with width of 0.45 to 0.75 m at both sides.
- About 2.5 m^3/capita storage capacity for sludge digestion is usually provided at the lower compartment.

Applications

Applicable for small communities in urban or peri-rural areas.

Components

Settling compartment; digestion compartment; gas vent and gas chamber; inlet and outlet channels and piping; sludge withdrawal piping; gas vent pipe; tank structure with or without manholes.

Capacity

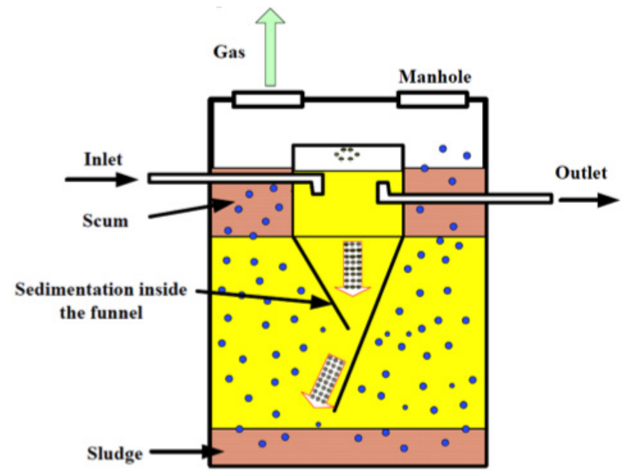
Mostly relatively small plants but it can range from 100-2,000 m^3/day capacity depending on the design.

Costs

Cost varies according to the types of design, size and materials used for the construction.

Operating Principles

Settling of solids occurs in the upper compartment. Sludge falls through the slot to the bottom of the settling compartment into the lower tank, where it is digested. Digestion process generates biogas which, is deflected by the baffles to the gas vent chamber, preventing the disturbance of the settling process.



Imhoff Tank

Utility & Efficiency

BOD reduction is about 30-50%, depending on available discharge options; further treatment may still be needed.

Reliability

Reliable if well designed and de-sludging is carried out routinely. Imhoff tank is resistant against shock loads.

Replication Potential

Standard designs are available and the technology can be easily replicated in different locations. Since the anaerobic sludge digestion will require higher temperature, heating may be required in some cases.

Regulatory/Institutional Issues

Requires skilled personnel to maintain the facility

Operation and Maintenance

Regular checking for water tightness, scum and sludge levels required. Sludge needs to be dug out every 1 to 5 years and discharged properly (e.g. in composting or drying bed). In addition, it requires:

- Periodically desludging (once or twice a year) and daily removal of floating debris, such as coarse materials and grease and scum.
- The sludge can be removed by pumping or hydraulic pressure pipes right from the bottom or by a vacuum truck.
- Twice a month reversing the flow (backwash) of water to even up the solids in the digestion chamber.
- Regular cleaning of the sides of the settling chamber and slot by rake or squeegee is very important

Advantages

1. Good for small settlements and clustered houses
2. Small area required and it can be constructed under roads or public places
3. Low costs of investment
4. Do not require highly skilled supervision
5. Simple operation and maintenance
6. More efficient settling than septic tank

Disadvantages

1. Very low treatment efficiency
2. Additional treatment might be needed
3. Requires more often desludging
4. Odor from escaping gases

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TECHNOLOGY

Anaerobic Baffled Reactor (ABR)

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Anaerobic baffled reactor is similar to a septic tank in series, where wastewater is forced to flow down through the existence of down-shaft or down-pipe and distributed over the entire area of the floor where it inoculates with active sludge for digestion. The up-flow also causes sludge particles to settle.

Design Criteria

The design calculation includes detail attention on chamber's geometry, up-flow velocity, organic load, temperature, desludging interval, and retention time.

- A hydraulic retention time (HRT) is considered between 48 to 72 hours, up-flow velocity of the wastewater less than 0.6 m/h, and the number of up-flow chambers (2 to 3).
- Anaerobic treatment is preferred- if BOD>2,000 mg/l.
- Temperature should be between 29-38°C with pH ranges of 6.5-7.5.
- Recommended solids detention time is between 15-30 days.
- Area required ranges from 40 - 150 m^2 depending on the detention period used.

Applications

Anaerobic baffled reactor is suitable for all kinds of wastewater such as wastewater from settlement, hospital, hotel/resort, public market, slaughter house, and food processing industries. The more organic loads, the higher its efficiency.

This is also appropriate for areas where land may be limited since the tank is installed underground and requires a small area.

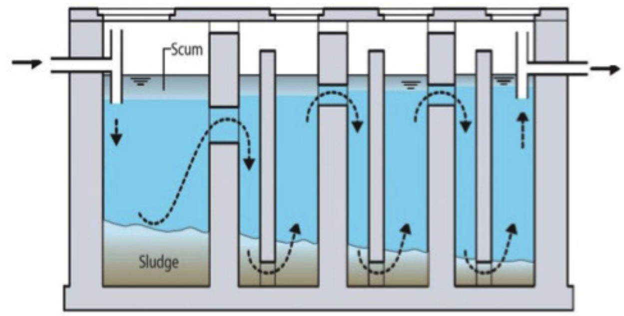
Components

Settler/integrated with septic tank, designated series of baffled Chambers, and down-shaft or down-flow pipe.

Capacity

The anaerobic reactor can be efficiently designed for a daily inflow of up to 1,000 population equivalent community wastewater and with BOD of up to 10,000 mg/l.

Digester volume can be up to 150 m^3 with inflows up to 10 m^3/d. If used in combination with septic tank and horizontal gravel filter, baffled reactor increases its treatment scalability up to 1,000 m^3.



Anaerobic baffled reactor

Costs

Generally low-cost; however vary depending on availability of materials and economy of scale.

Operating Principles

Anaerobic Baffled Reactors (ABR) use baffles to create multiple treatment zones in a primary clarifier. A sludge blanket is established in each baffled zone, and different microbiological populations establish themselves in each zone. The overall effect is to provide both primary treatment and some secondary treatment in a single basin.

As illustrated in the diagram, incoming wastewater is usually diverted to the tank from an elevated pipeline preferably using only gravitational force so as not to create unnecessary turbulence inside the reactor. As wastewater starts to buildup and increase in level, the carryover water will start to overflow to the next compartment leaving heavy solids behind to settle at tank bottom. Usually this method is more effective especially for household discharge and agriculture wastewater whereby high amount of heavy solids can be expected.

Vertical baffles in the tank force the pre-settled wastewater to flow under and over the baffles guaranteeing contact between wastewater and resident sludge. This will allow an enhanced anaerobic digestion of suspended and dissolved solids thorough - at least 1 sedimentation chamber and 2–5 up-flow chambers.

The majority of settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50 % of the total volume. The up flow chambers provide additional removal and digestion of organic matter. About 90% BOD may be reduced, which is far superior to that of a conventional septic tank. The accumulated sludge needs desludging every 2 to 3 years.

Utility & Efficiency

Reduction of BOD is about 75-90%. Only moderate reduction of infectious organisms; effluent has slight odor (methane).

Reliability

High reliability due to low effect when hydraulic and organic shock loads occur.

Replication Potential

Standardized designs are available. It has high potential to be integrated with other post treatments, such as Anaerobic Filter Reactor and Horizontal Gravel Filter Plant.

Regulatory/Institutional Issues

Requires skilled personnel to maintain the facility.

Operation and Maintenance

- Check scum blanket, break up if too thick, control foaming
- Monitor total solids build up and gas production
- Regularly schedule cleaning of solid waste build up by manual or vacuum desludging.
- Desludging must regularly be done on a calculated interval and some sludge must be left to ensure continuous efficiency.
- Regular control of solid intervention to every chamber must be done

Advantages

1. Suitable for smaller and larger settlements
2. Little space required due to underground construction
3. Low investment costs
4. Very low Operation and Maintenance costs. No moving parts power needed. Hardly any blockage
5. Simple and durable
6. High treatment efficiency
7. Robust to both organic and hydraulic shock loads

Disadvantages

1. Experts are required for design and supervision
2. Skilled mason is required for water-tight plastering
3. Effluent is not completely odorless
4. Slow growth rate of anaerobic bacteria means long startup period
5. Less efficient with weak wastewater

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TECHNOLOGY

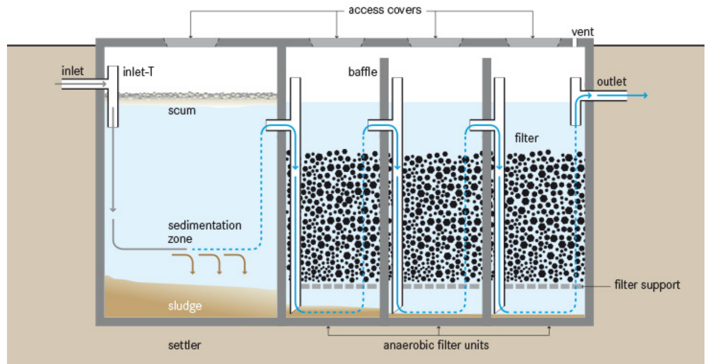
Anaerobic Filter

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Anaerobic Filter is a fixed-bed biological reactor. Dissolved organic matter and non-settleable solids are anaerobically digested by bacteria of the biofilm attached to the filter media. Anaerobic filters are widely used as secondary treatment in household black- or greywater systems and improve solids removal compared to septic tanks or anaerobic baffled reactors. Anaerobic filters can be designed as anaerobic digesters allowing recovery of the produced biogas.



Three chamber anaerobic filter following a septic tank

Design Criteria

Anaerobic filter can be built above or below the ground. The hydraulic retention time should be in the range of 1.5 and 2 days for pre-settled blackwater and 0.7 to 1.5 days for greywater.

Filter material such as gravel, rocks, cinder or specially formed plastic pieces can provide additional surface area for bacteria to attach. Typical filter material sizes range from 12 to 55 mm in diameter. Filters with two to three filter layers and a minimum depth of 0.8 to 1.2 m are recommended.

Generally, simple anaerobic filter starts with a first layer of large-sized cinder or rocks (5 to 15 cm), which are bedded on a perforated concrete slab about half a meter above ground parallel to the flow direction. The water level should cover the filter media by at least 0.3m to guarantee an even flow regime.

Anaerobic filters may be operated as down-flow or up-flow systems. The up-flow systems (anaerobic up flow filters) are normally preferred as the risk of washing out active bacteria is less in this case.

Applications

Anaerobic filters are widely used as secondary treatment step in household greywater or blackwater treatment systems or biodegradable industrial wastewater. It can be a component of DEWATs.

Components

Settler, designated series of baffled chambers, and filter chamber and filter media.

Capacity

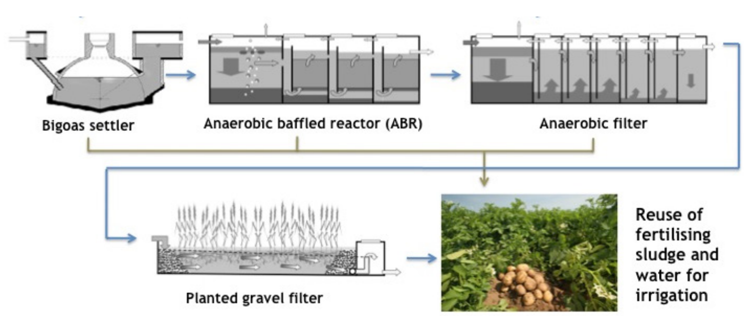
It varies and can be designed from a single household to a large community/city scale as well.

Costs

Generally low-cost; depending on availability of materials and frequency of back flushing and de-sludging.

Operating Principles

Anaerobic filters are different from septic tanks in that they also include the treatment of non-settleable and dissolved solids by bringing them in close contact with the active bacterial mass fixed on the filter material, which anaerobically digests the dissolved organic matter within short retention times. This is similar to Anaerobic Baffled Reactors (ABRs) where this contact is provided by discharging wastewater to the bottom of the up-flow treatment directly into the biomass which is settled in the sludge.



Main DEWATS modules for physical and biological wastewater treatment

Utility & Efficiency

BOD: 50 to 90%; TSS: 50 to 80 %; Total Coliforms: 1 to 2 log units.

Reliability

Reliable if construction is watertight and influent is primary settled; generally good resistance to shock loading.

Replication Potential

Standardized designs are available. It has high potential to be integrated with other post treatments such as DEWATS.

Regulatory/Institutional Issues

Requires expert design, but can be constructed with locally available material.

Operation and Maintenance

- Anaerobic filters need to be "seeded" in the beginning of the treatment process to allow for the formation of the required biofilm for anaerobic digestion.
- Full treatment performance is not likely until approximately six to nine months later.
- With time, the solids will clog the pores of the filter and the treatment efficiency decreases. This happens when the bacterial film becomes too thick and the wastewater finds a channeled way through only some open pores.
- When the efficiency goes down, the filter needs to be cleaned by back flushing of wastewater or by removing the filter mass for cleaning outside the reactor
- As with septic tanks, de-sludging of the primary settling chamber should be done at regular intervals.
- Both de-sludging and cleaning of the filter material can be a health-hazard and appropriate safety precautions should be taken.

Advantages

1. Resistant to organic and hydraulic shock loadings
2. High reduction of BOD and TSS
3. Effluent nutrient content allows it to be used in agriculture
4. Low sludge yield
5. No external energy required
6. Can be built and repaired with locally available materials.
7. Long service life
8. No real problems with flies or odour if used correctly
9. Moderate capital costs, moderate operating costs depending on emptying.

Disadvantages

1. Reliable and ample piped water required to bring the wastes to the treatment unit.
2. Low reduction in pathogens and suspended solids: Secondary treatment for both effluent and faecal sludge required, as well as regular de-sludging.
3. Only suitable for low-density housing in areas with low water table and not prone to flooding.
4. Manual cleaning of the tank is highly hazardous and an inhumane task, while mechanical cleansing (vacuum trucks) requires sophisticated instruments.
5. Requires expert design and construction.
6. Long start-up time.

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TECHNOLOGY

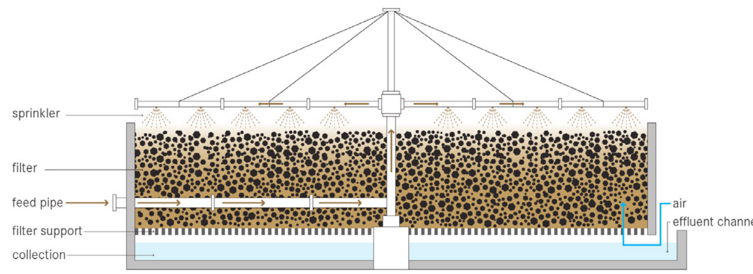
Trickling Filter

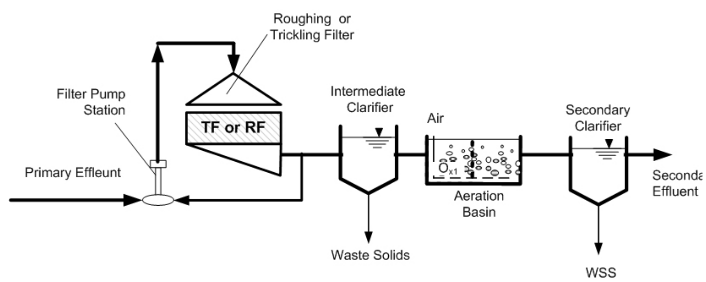
SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Trickling filters (also called biological trickling filters) are aerobic fixed film systems that contain filter bed of rocks, gravel, plastic modules, etc. Wastewater is sprayed on the filter bed (with a rotating sprinkler) and trickles through the filter media. A biofilm, growing on the filter material aerobically degrades organic pollutants. Trickling filters are a secondary treatment (after septic tanks or other primary treatment) and are based on attached growth processes such as other fixed film reactors (e.g., anaerobic filters, rotating biological contactors, etc.). Trickling filters are followed by secondary settling tanks to remove suspended solids.





Arrangement of Trickling filter with other treatment units

Design Criteria

The primary design factors include: i) the type of filter media, ii) the spraying system, and iii) the configuration of the under-drain system.

Filter materials with specific surface area should be at least 30 m^2/m^3. The priority is to use larger sizes. Stones with a diameter of 7 cm can avoid ponding, but they limit the surface area per unit volume available for the biofilm to grow on. A diameter of 2.5 cm for the stones is recommended. An upper size limit of about 10 cm is therefore recommended. The particles should be uniform such that 95 % of the particles have a diameter between 7 and 10 cm.

A “rotary sprinkler/distributor” is most often used to evenly distribute the water on the filter. The rotary distributor consists of a hollow vertical center column carrying two or more radial pipes or arms some cm above the filter media (to spread out uniformly and prevent interfering with ice accumulation during winter season in colder climates), each of which contains a number of nozzles or orifices for discharging the wastewater onto the bed.

An under-drain system made in trickling filters serves two purposes: i) to carry the wastewater passing through the filter and the sloughed solids from the filter to the final clarification process; and ii) to provide air to move up by natural convection for ventilation of the filter to maintain aerobic conditions. Typically, the solid media is placed on a support with openings, for instance a perforated slab.

Applications

Trickling filters can treat domestic blackwater or greywater or any other biodegradable effluent in semi and centralized wastewater treatment. They are typically applied as post-treatment for upflow anaerobic sludge blanket reactors or for further treatment after activated sludge treatment.

In any case, primary sedimentation is compulsory to avoid clogging of the filter bed and a secondary clarification step and post-treatment of excess sludge (e.g., in thickening and drying beds or anaerobic digesters) are also required.

Components

Filter media, rotating blade, and under drainage configuration.

Capacity

The system is usually applied in urban areas for treatment of domestic wastewater. It can be also applied for smaller communities.

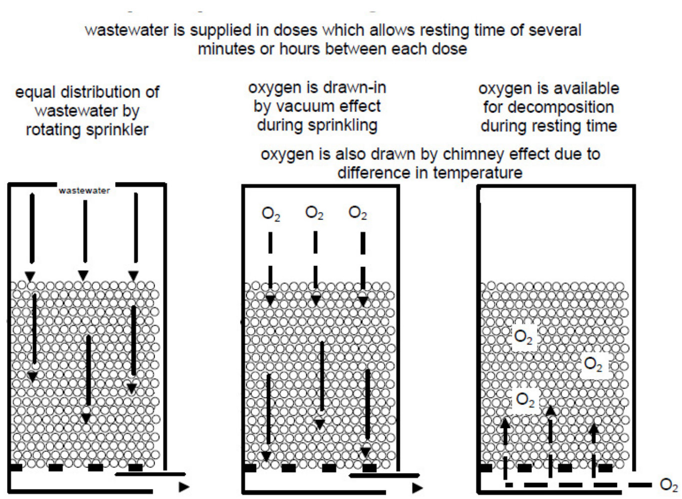
Costs

Investment costs depend on type of filter materials and feeder pumps; operational costs determined by electricity consumption of feeder pumps.

Operating Principles

Wastewater is sprayed on filter and trickles vertically through the solid media. The biomass growing on the media brakes down organic matter under aerobic conditions.

Trickling filters are biological filters and the filtration process is not mechanical straining of solids, but the removal of organic substances occurs by use of bacterial action.



Operating principles of trickling filter

Utility & Efficiency

BOD: 65 - 90 %. Low TSS removal. Total Coliforms: 1 - 2 log units. N: 0 - 35%. P: 10 - 15 %.

Reliability

Resistant to shock loadings but the systems does not work during power failures.

Replication Potential

Standardized designs are available and applicable for different size of the population.

Regulatory/Institutional Issues

Design, planning and implementation by expert consultants; feeder pumps required; permanent staff required for operation.

Operation and Maintenance

- The bacterial film has to be flushed away once in five to seven years or more to prevent clogging and excessive sloughing as well as to remove the dead sludge. This can be done using high hydraulic loading rates (> 0.8 m^3/m^2h, and temporal collection of the effluent.
- The rotary distributor may also require regular cleaning or technical maintenance.
- Constant hydraulic loading can be maintained through suction level controlled pumps or dosing siphons.
- Recirculation of effluent may also be required to avoid low flow conditions, but a too strong flow overload would flush out the microbes.
- Moisture control of the filter is very important on the one hand to prevent odor (i.e., if too dry) and on the other hand to prevent nesting of flies and mosquitoes.
- Besides drying out, excessive odor can also arise when anaerobic conditions arise due to excessive organic loadings or insufficient aeration. The odor and fly problems require that the filter be built away from homes and businesses.

Advantages

1. Simple, reliable, biological process.
2. Can be operated at a wide range of organic and hydraulic loading rates.
3. High effluent quality in terms of BOD and suspended solids removal; in combination with a primary and tertiary treatment also in terms of pathogens.
4. Suitable in areas where large tracts of land are not available for land intensive treatment systems.
5. May qualify for equivalent secondary discharge standards.
6. Effective in treating high concentrations of organics depending on the type of medium used.
7. Appropriate for small- to medium-sized communities.
8. Efficient nitrification units.
9. Durable process elements.
10. Low power requirements.
11. Moderate level of skill and technical expertise needed to manage and operate the system.

Disadvantages

1. Additional treatment may be needed to meet more stringent discharge standards.
2. Pre-treatment and treatment of excess sludge is required.
3. High capital costs and moderate operating costs.
4. Not all parts and materials may be available locally.
5. Reliable and ample water flow required to bring the waste to the treatment unit.
6. Requires energy (shutdown during power-cuts and pump failures)
7. High organic loadings can cause anaerobic conditions and odor problems
8. Incidence of clogging is relatively high, flies and odors are often problematic
9. Vector and odor problems.

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TECHNOLOGY

Upflow Anaerobic Sludge Blanket (UASB) Reactor

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Upflow Anaerobic Sludge Blanket (UASB) reactors are anaerobic centralized or decentralized wastewater treatment systems achieving high removal of organic pollutants. The UASB is a single tank process where wastewater enters the reactor from the bottom, and flows upward. A suspended sludge blanket treats the wastewater as the wastewater is filtered through it. UASB require a post-treatment to remove pathogens, but due to a low removal of nutrients, the effluent water as well as the stabilized sludge can be used in agriculture.

Design Criteria

The pH-value of influent needs to be between 6.3 and 7.85 to allow bacterial growth for anaerobic digestion. The pH-value is important because at high pH-values, ammoniac (NH4+) dissociates to NH3 which inhibits the growth of methane producing bacteria.

The temperature should be between 35°C to 38°C. Below this range, the digestion rate decreases by about 11% for each 1°C temperature decrease. Below 15°C the process is not very efficient, although bacterial activity can still be observed at temperatures less than 10°C.

Influents should have concentrations of above 250 mg COD/L, as for lower rates, anaerobic digestion is not beneficial. Optimum influent concentrations are above 400 mg COD/L.

The hydraulic retention time (HRT) generally lies between 2 to 20 hours. Anaerobic microorganisms, especially methane producing bacteria, have a slow growth rate. At lower HRTs, the possibility of washout of biomass is more prominent.

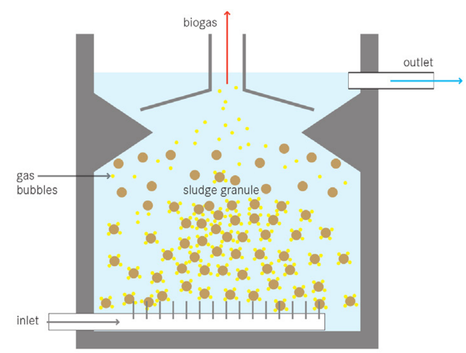
Typically, up-flow velocity should be in the range of 0.2 to 1 m/h. Sludge should not be washed out of the reactor, and on the other hand, a minimum velocity needs to be maintained to keep the blanket in suspension.

Applications

It is a well-established process for large-scale industrial wastewater treatment processes. Its application to domestic sewage is still relatively new. Typically it is used for brewery, distillery, and food processing and pulp and paper waste.

Components

A single tank with gas collection system, inlet and outlet structures.



Upflow Anaerobic Sludge Blanket Reactors

Capacity

The sizes vary and applicable mostly for centralized

Costs

Costs vary according to the size, design and local conditions.

Operating Principles

Industrial or domestic wastewater flows into the bottom of an anaerobic upflow tank. As particles aggregate during upflow they form forms granules, which turn into a sludge blanket overtime. Microorganisms living in the granules or sludge blanket degrade organic pollutants by anaerobic digestion. The sludge blanket is kept in suspension by the flow regime and formed gas bubbles. A separator at the top of the reactor allows to recover biogas for energy production, nutrient rich effluent for agriculture and to retain the sludge in the reactor. Sludge accumulation is low (emptying is only required every few years) and the sludge is stabilized and can be used as soil fertilizer.

As domestic or municipal wastewater contains the composition of nutrients and micronutrients required for bacterial activity and growth, they are generally less problematic than industrial wastewaters.

Utility & Efficiency

60 to 90 % BOD; 60 to 80 % COD and 60 to 85 % TSS; low pathogen reduction minimal nutrient removal.

Reliability

Not resistant to shock loading and sensitive to organic load fluctuations. It requires long startup period for effective performance until the sludge blanket is well developed.

Replication Potential

Standardized designs are available and applicable for different size of the population.

Requires skilled staff, electricity and is sensitive to variable flows.

Regulatory/Institutional Issues

Can be constructed with locally available material but requires skilled staff for construction.

Operation and Maintenance

- The construction and maintenance of UASB requires skilled staff. UASB reactors require several months of start up time until the sludge blanket is fully developed.
- Granular sludge is developed when bacteria aggregate and form chains that flocculate flocs or granules into bigger sizes.
- High organic loading in connection with lower hydraulic loading rates quicken the granulation process in the starting phase.
- The hydraulic load must correspond to the upflow velocity maintain the blanket in proper position
- The flow rate must be controlled and properly geared in accordance with fluctuation of the organic load.
- A permanent operator is required to control, monitor and repair the reactor and the dosing pump.
- Desludging is infrequent and excess sludge needs to be removed only every few years (2 to 3 years).

Advantages

1. High treatment efficiency for high-strength wastewater.
2. Biogas can be used for energy (but usually requires scrubbing first)
3. No aeration system required (thus low energy consumption).
4. Low sludge production and treated sludge can be used for soil fertilization.
5. Effluent is rich in nutrients and can be applied on agricultural.
6. Low land area requirement, can be constructed underground and with locally available material.
7. Low odor emissions in case of optimum operation.

Disadvantages

1. Requires skilled personnel for construction, operation and maintenance (control of feeding pump and influent organic load).
2. Treatment may be unstable with variable hydraulic and organic loads.
3. Insufficient pathogen removal without appropriate post-treatment.
4. Long start-up phase.
5. Not resistant to shock loading.
6. Constant source of electricity and water flow is required.
7. Not adapted for cold regions.

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TECHNOLOGY

Rotating Biological Contractor (RBC)

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Rotating biological contactors (RBC), consist of a series of closely spaced circular disks of polystyrene or polyvinyl chloride or polypropylene. RBC also called rotating biological filters, are fixed-bed reactors consisting of stacks of rotating disks mounted on a horizontal shaft. The disks are partially submerged in wastewater and rotated slowly as wastewater flows through. They are used in secondary wastewater treatment units for domestic wastewater or any other biodegradable effluent.

Design Criteria

RBCs are usually designed on the basis of hydraulic and organic loading rates derived from pilot-plant and full-scale installations.

The organic loading rate is 29-49 kg of BOD/m^2/day and 16-96 kg of BOD/1000 m^3 of media. The submerging depth varies from 40 to 80% and a usual rotating speed is 1 to 2 rpm. The common disc diameter is between 0.6 and 3 m.

Applications

RBCs can achieve a high level of biodegradable organic removal form domestic wastewater as well as from high-strength industrial wastewater (e.g. from dairies, bakeries, food processors, pulp, paper mills).

A great variety of applications are known, either as post-treatment for activated sludge processes in conventional domestic wastewater treatment plants, or for decentralized application at the level of small to medium-sized communities, industries or institutions.

Components

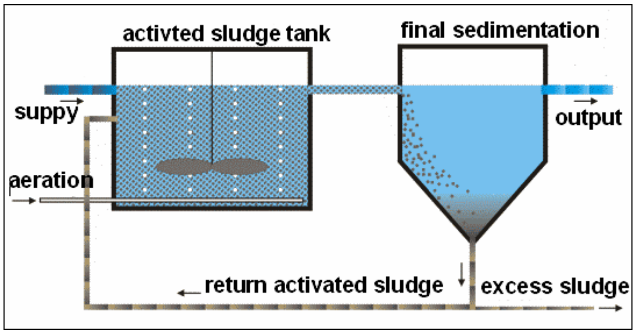
RBC tanks, shaft of steel or corrugated plastic media, motors and energy supplying systems, pipes and fitting associated with other treatment systems before and after the RBC.

Capacity

Smallest packaged unit for 10-15 houses; for communities and industrial waste application.

Costs

Generally, RBCs involve high capital costs as not all materials may be locally available and motor and special material for



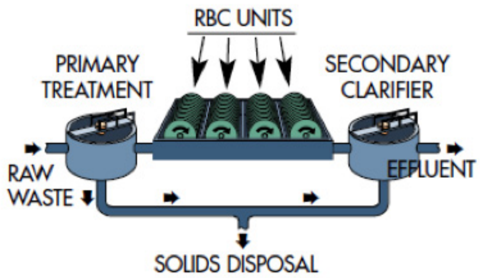
Sectional view of RBC

rotation is required. Another cost factor may be manufacturing and implementation, which requires skilled experts.

Operation and maintenance costs are also relatively high, because operation requires a continuous electricity supply and supervision by a skilled labor.

Operating Principles

The process consists of large diameter steel or corrugated plastic media centered around a horizontal shaft, placed in a concrete tank. The media is slowly rotated (mechanical or air drive). At any given time during the rotation, about 40% of the media surface area is in the wastewater.



Organisms in the wastewater attach and multiply on the rotating media until they form a thin layer of biomass.

This fixed film growth presents a very large, very active population for the biological degradation of organic pollutants.

During rotation, the media carries the biomass and a film of wastewater into the air where oxygen is transfered. The dissolved oxygen and organic materials in the wastewater diffuse into the biomass and are then metabolized.
Radial and concentric passages in the media allow unrestricted

entry of the wastewater and air throughout the unit's total surface area for continued growth of the biomass. Biomass thickness ranges from 0.030 inch (0.75 mm) to 0.125 inch (3 mm) depending upon organic concentration, temperature and other process variables.

The disk rotation affects oxygen transfer and maintains the biomass in an aerobic condition. The rotation is also the mechanism for removing excess solids from the disks by shearing forces it creates and maintaining the sludge in suspension so they can be carried over to a clarifier. RBCs can be used for secondary treatment, and they can also be operated in the seasonal and continuous-nitrification and de-nitrification modes.

Sectional view of RBC

Utility & Efficiency

60 to 90 % BOD; 60 to 80 % COD and 60 to 85 % TSS; low pathogen and nutrient removal.

HRT: minimum 2 hours, generally 4 to 20 hours.

Reliability

Generally more reliable than other fixed-film processes because of the large biological mass present.

Adaptability of the biological films offers excellent opportunity for the purification of wastewater and displaceable modular design.

Replication Potential

Available in modular units and can be installed in locally built tanks.

Regulatory/Institutional Issues

Can be constructed with locally available material but requires skilled staff for construction.

Operation and Maintenance

- The system must be supervised by professional operators.
- It takes 6 to 12 weeks for the biofilm to establish for a good treatment performance
- Maintenance includes lubrication of moving parts, motors and bearings; replacing seals, motors, servicing bearings; and cleaning the attached-growth media (spray-washing of discs and purging of settled sludge)
- The discs may also be checked for debris accumulation, ponding and excessive or not sufficient biomass accumulation
- Purging of settled sludge on monthly or bimonthly

Advantages

1. High contact time and high effluent quality (both BOD and nutrients).
2. High process stability, resistant to shock hydraulic or organic loading.
3. Short contact periods are required because of the large active surface area.
4. Low space requirement.
5. Low sludge production that can easily be drained or dewatered.

Disadvantages

1. Adequate primary treatment and secondary clarifier required
2. Continuous electricity supply required, however, uses less energy than trickling filters or activated sludge processes for comparable degradation rates.
3. Contact media not available at local market
4. High investment, operation and maintenance costs
5. Must be protected against sunlight, wind, rain and the cold weather, especially in cold climates.
6. Odor problems may occur.
7. Requires skilled technical labor for operation and maintenance

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TECHNOLOGY

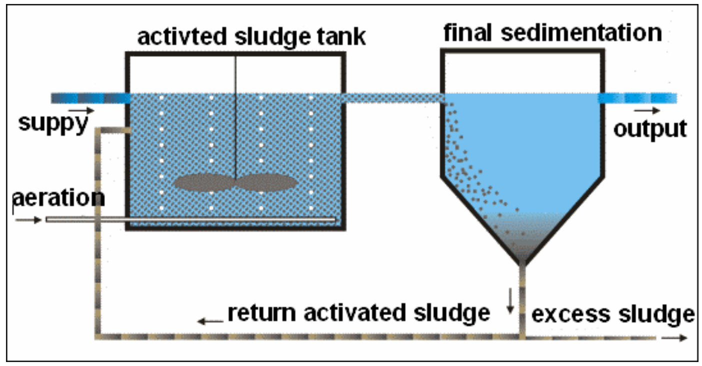
Activated Sludge

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Activated Sludge is a multi-chamber reactor unit that makes use of aerobic microorganisms to degrade organic matter in wastewater and to produce a high-quality effluent. It consists of suspended bacterial growth mixed with wastewater in an aerated tank. The bacteria consume the organic pollutants to grow and transform it to energy, water, CO2 and new cell material. A physical pre-treatment unit, a post-settling unit (a clarifier) from which active sludge is re-circulated to the aerated tank, and excess sludge treatment, are necessary. In addition, a constant and well-timed supply of oxygen is required to maintain aerobic conditions and to the keep the active biomass suspended.



Design Criteria

Activated sludge reactors include a primary treatment (including screening and pre-settling), one or more main aerated treatment chambers, aeration devices, a mixer to keep the sludge in suspension, a secondary clarifier to separate the biomass from the treated effluent and a return activated sludge system the circulates return sludge from the secondary sedimentation tank to the aeration tank. Excess sludge is directed to sludge treatment system usually by anaerobic digestion.

Design of the each of the unit depends on the quality of waste streams, local socio-economic and climatic conditions.

Applications

Activated sludge systems can treat blackwater, grey water, faecal sludge and industrial wastewater as long as the pollutants to be treated are biodegradable.

The process is highly mechanized and thus mainly adapted for centralized systems where energy, mechanical spare parts and skilled labor are available. This technology is effective for centralized wastewater treatment systems.

Components

Aeration tank, clarifier, aeration system, mixing equipment.

Capacity

Common in centralized system, not adapted for small communities. Almost every wastewater can be treated as long as it is biodegradable. Usually applied in densely populated areas for treatment of domestic wastewater.

Costs

High capital, operation and maintenance costs. Cost per unit treatment varies according to the quality of influent and effluent as well as local condition.

Operating Principles

The activated sludge process consists of two basic units: The aeration basin and the clarifier.
The aeration tank provides an environment where bacteria grow and are continually mixed with the organics in the presence of dissolved oxygen. Microorganisms, through aerobic biological oxidation, remove the organics from the wastewater.

The secondary clarifier provides liquid-solid separation where the biological flocs are settled, concentrated and a portion is returned to the aeration basin. The settled solids undergo anaerobic degradation to stabilize the organic matter. This is a continuous cycle of microbial growth and death. Excess growth leaves the clarifier for further sludge treatment and disposal.

Nitrogen is removed by nitrification/denitrification and phosphorus is either removed chemically or biologically or accumulated in the excess sludge.

Utility & Efficiency

BOD and TSS removal rates are about 80 to 100%. High nitrogen removal. P accumulated in biomass and sludge. Low pathogen removal. HRT of some hours up to several days

The overall process of the activated sludge system, if well operated, is highly efficient for the removal of both settable (physical primary treatment) and dissolved, colloidal and particulate organic matter and nutrients (biological removal in the activated sludge) in almost every climate, though pathogen removal is low.

Reliability

Reliable systems but can fail in case of power failure or fall-out of technical equipment.

Replication Potential

Standardized designs are available and applicable for different size of the population.

Requires skilled personnel, electricity and is sensitive to variations in flows.

Regulatory/Institutional Issues

System parts not locally available; implementation only possible by experienced professional.

Operation and Maintenance

- Mechanical equipment (e.g., pumps, aerators, mixers) require continuous maintenance and control to ensure supply of oxygen and sludge circulation and removal.
- Technical appliances (e.g. pH-meter, temperature, oxygen content etc.) need to be maintained carefully to control concentrations of sludge and oxygen levels in the aeration tanks.
- The influent and effluent flows should be supervised and controlled constantly (e.g. by a centralized computerized monitoring system) to ensure optimal living conditions for the required bacteria are guaranteed
- Two of the most serious problems with the activated-sludge process are (i) a phenomenon known as bulking, in which the sludge from the aeration tank will not settle, and (ii) the development of biological surface foam. It is important that these conditions are controlled before the system fails seriously.
- Bulking can be caused either by organisms that grow in filamentous form instead of flocs and will not settle, or the growth of microorganisms that incorporate large volumes of water into their cell structure, making their density near that of water. Filamentous organisms can be controlled by the addition of chemicals (e.g. chlorine or hydrogen peroxide) to the recycled activated sludge; the alteration of the dissolved-oxygen concentration in the aeration tank; the addition of nutrients and growth factors to favor other microorganisms etc.
- Foaming (the development of biological surface foam) is caused most often by the excessive growth of an organism called Nocardia. Nocardia can be controlled by avoiding the recycling of the skimmed foam or the addition of a chemical agent (e.g. polymers or chlorine) on the surface.

Advantages

1. Good resistance against shock loading.
2. Can be operated at a wide range of organic and hydraulic loading rates.
3. High effluent quality and high reduction of BOD and pathogens (up to 99%).
4. Can be modified to meet specific discharge limits.
5. Small land required.

Disadvantages

1. Prone to complicated chemical and microbiological problems.
2. Effluent might require further treatment/ disinfection before discharge.
3. Not all parts and materials may be available locally.
4. Technical complexity: requires expert design and supervision.
5. Requires large amount of energy input- mainly aeration.
6. Constant source of electricity is required.
7. Mixing of industrial effluent with domestic wastewater can lead to toxicity and major malfunctioning.

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TECHNOLOGY

Sequencing Batch Reactor (SBR)

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

The Sequencing Batch Reactor (SBR) is a fill and draw activated sludge treatment system. The processes are similar to the conventional activated sludge system. The SBR, however, uses a single reactor basin for aeration and sedimentation. One or multiple compartments can be used. SBR, oxidation ditch and submerged membrane bioreactor are biological sewage treatment processes identified as preferred processes for a capacity of 1,000 to 20,000 m^3/d.

Design Criteria

SBRs generally do not have primary settling tanks; therefore, effective removal of grit, debris, plastics, excessive oil or grease, and scum, as well as screening of solids should be accomplished prior to the SBR process.

In addition to the key design parameters (influent characteristics of the wastewater and the effluent requirements for the proposed system), the design include determining number of cycles per day, number of basins, decant volume, reactor size, and detention times. Additionally, the aeration equipment, decanter, and associated piping can then be sized.

General design criteria include:

- Detention time: 16-36 min
- BOD loading: 0.02-0.07 kg BOD/kg
- Area requirement: 180-1,000 m^2 for equivalent people of 1,000- 10,000.

Applications

Capable of handling domestic, commercial, and industrial wastes in limited spaces. Also flexible for treatment in a community level scale.

SBRs are typically used at flow rates of 5 MGD or less. The more sophisticated operation required at larger SBR plants tends to discourage the use of these plants for large flow rates.

Components

The SBR system consists of a tank, aeration and mixing equipment, a decanter, and a control system. The central features of the SBR system include the control unit and the automatic switches and valves that sequence and time the different operations. SBR manufacturers should be consulted for recommendations on tanks and equipment.

Capacity

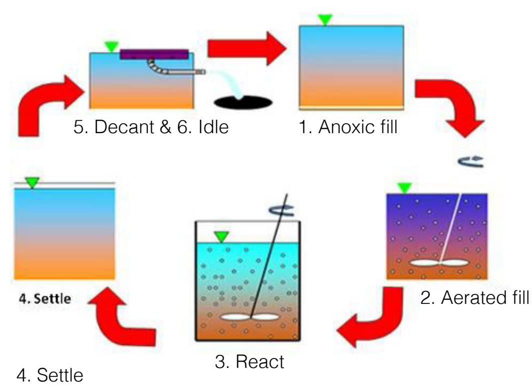
Recommended capacity range of 1,000 - 20,000 m^3/day or an urban community with a population of about 3,500 to 200,000. Smaller plants to 100 m^3/day capacity can be made available.

Costs

It varies depending on the quality of waste stream, local conditions and quality of treated waste streams.

Operating Principles

The SBR system is a set of tanks that operate on a fill-and draw basis. Each tank in the SBR system is filled during a discrete period of time and then operated as a batch reactor. After desired treatment, the mixed liquor is allowed to settle and the clarified supernatant is then drawn from the tank. The cycle for each tank in a typical SBR is divided into five discrete periods: Fill, React, Settle, Draw and Idle as shown in the figure below.



The SBR process cycle

Fill: The feed volume is determined based factors including desired loading and detention time and expected settling characteristics of the organisms. The time of Fill depends upon the volume of each tank, the number of parallel tanks in operation, and the extent of diurnal variations in the wastewater flow rate.

Any aeration system (e.g., diffused, floating mechanical, or jet) can be used. The ideal aeration system must be able to provide both a range of mixing intensities, from zero to complete agitation, and the flexibility of mixing without aeration.

React: Biological reactions, which are initiated during Fill, are completed during React. As in Fill, alternating conditions of low dissolved oxygen concentrations (e.g., mixed react) and high dissolved oxygen concentrations (e.g. aerated react) may be required. Time dedicated to react can be as high as 50% or more of total cycle time. The end of React may be dictated by a time specification (e.g. the time in React shall always be 1.5 h) or a level controller in an adjacent tank.

Settle: Solids separation takes place under quiescent conditions (i.e., without inflow or outflow) in a tank, which may have a volume more than ten times that of the secondary clarifier used for conventional continuous-flow activated sludge plant..

Draw (Decant): The withdrawal mechanism may take one of several forms, including a pipe fixed at some predetermined level with the flow regulated by an automatic valve or a pump, or an adjustable or floating weir at or just beneath the liquid surface. The time dedicated to Draw can range from 5 to more than 30 % of the total cycle time.

Idle: The period between Draw and Fill is termed Idle. This "idle" time can be used effectively to waste settled sludge. While sludge wasting can be as infrequent as once every 2 to 3 months, more frequent sludge wasting programs are recommended to maintain process efficiency and sludge settling.

Utility & Efficiency

The performance of SBRs is typically comparable to conventional activated sludge systems and depends on system design and site specific criteria. Performances are excellent in most cases having BOD and TSS removal rate of about 85-98%.

Reliability

Relatively easy to operate due to micro-process technology and fewer mechanical equipment. It is very reliable provided regular energy supply

Greater flexibility is achieved by changing operational strategy (cycle duration, cycle sequence and aeration mixing strategy).

Replication Potential

Packaged plants already available, but design, materials, equipment and labor are also readily available.

Regulatory/Institutional Issues

Requires an entity to operate and maintain the facility.

Operation and Maintenance

The operation of an SBR is based on the fill-and draw principle, which consists of the: Idle, Fill, React, Settle, and Draw process. More than one operating strategy is possible during most of these steps. For industrial wastewater applications, treatability studies are typically required to determine the optimum operating sequence.

For most municipal wastewater treatment plants, treatability studies are not required to determine the operating sequence because municipal wastewater flow rates and characteristic variations are usually predictable and most municipal designers will follow conservative design approaches.

SBRs operate in time rather than in space and the number of cycles per day can be varied to control desired effluent limits, offering additional flexibility with an SBR.

The SBR system consists of the controls, automatic valves, and automatic switches. These systems may require more maintenance than a conventional activated sludge system. An increased level of sophistication usually equates to more items that can fail or require maintenance. The level of sophistication may be very advanced in larger SBR wastewater treatment plants requiring a higher level of maintenance on the automatic valves and switches.

Advantages

1. Efficient treatment
2. Handles hydraulic and organic shock loads (high inflow variation)
3. Modular construction facilitates future expansion
4. Provides a simple and reliable wastewater treatment process within a basin (simple design and construction)
5. Highly flexible and fully automatic
6. Relatively small space requirement

Disadvantages

1. A higher level of sophistication is required (compared to conventional systems), especially for larger systems, of timing units and controls.
2. Most of the component parts are patented and comes from abroad
3. More expensive than other treatment methods. Higher level of maintenance (compared to conventional systems) associated with more sophisticated controls, automated switches, and automated valves
4. Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.
5. In case of power failure, reactor may overflow
6. Requires more skilled attention

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TECHNOLOGY

Constructed Wetland: A Free Surface Type

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Constructed wetlands are secondary treatment facilities for household and/or biodegradable municipal or industrial wastewater. There are three different types of constructed wetlands classified according to the water flow regime as i) free-surface constructed wetlands, ii) horizontal flow constructed wetlands, and iii) vertical flow constructed wetlands. These three types of CWs may be combined as hybrid constructed wetlands in order to exploit the specific advantages of the different systems. The free-surface constructed wetlands systems, to be presented here, typically consist of basins or channels, with some sort of subsurface barrier to prevent seepage, soil or another suitable medium to support the emergent vegetation.

Design Criteria

The treatment processes that occur in an artificial wetland are similar to those that occur in other forms of land treatment. Removal of settleable organics occurs primarily as a result of sedimentation whereas removal of colloidal and soluble organics occurs primarily by aerobic microbial oxidation.

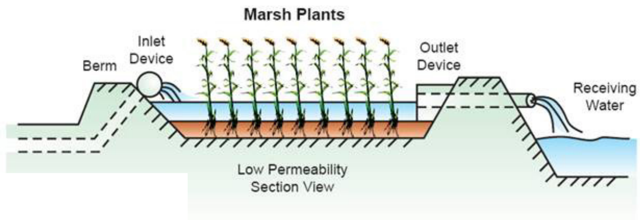
Design criteria for free surface type wetlands depend on the expected treatment performances. The treatment performance is a function of detention time, ground slope, water depth, vegetation, areal extent, and geometric shape. Moreover, precipitation, infiltration, evapotranspiration, hydraulic loading rate, and water depth can all affect the removal of organics, nutrients, and trace elements not only by altering the detention time, but also by either concentrating or diluting the wastewater.

In selecting a site for a free water surface wetland, the underlying soil permeability must be considered. The most desirable soil permeability is 10-6 to 10-7 m/s. Typically bed depth is about 0.4 m.

A detention time of 6-7 days has been reported to be optimal for the treatment of primary and secondary wastewater. Shorter detention times do not achieve required pollutant degradation; on the other hand longer detention times can lead to stagnant, anaerobic conditions.

The detailed design standards are available for specific local condition and flow characteristics. General guide as per USEPA are:

- Hydraulic Retention Time (HRT): 2 to 3 days in each cell
- Depth: Surface Flow: 0.1m to 0.6m
- Open Water Zone: ≥ 1.2m
- L:W Ratio: 2:1 to 5:1
- Vegetation Porosity:0.65 to 0.75



Free-surface flow type constructed wetland

Applications

Wetland systems can be most cost effective treatment alternatives where suitable land is available at reasonable cost. They also provide enhanced habitat and recreational values. Land requirements and costs tend to favor application of FWS technology in rural areas.

Components

The total site area will include the surface area of the Free Water Surface (FWS) wetlands, the dike area, buffer zone (if required) around the wetlands, and the area of the access roads associated with the site.

Capacity

Varies from small community level to a large city scale.

Costs

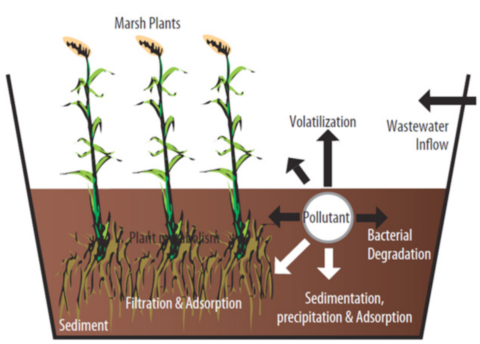
Constructed wetlands are usually cheaper to build. There is a wide variation of cost for these systems owing to a lack of design uniformity. Total costs vary according to the location, land values and costs of the construction materials.

Surface-flow constructed wetlands have also often lower maintenance and repair costs than subsurface systems.

Operating Principles

A free-surface constructed wetland (also called free water surface flow) is a series of flooded planted channels or a basin that aims to replicate natural wetland.

As water slowly flows through the wetland, particles settle, pathogens are destroyed, and organisms and plants utilize the nutrients. It is especially appropriate for pre-treated and settled wastewater.



Constructed wetland

Settleable and suspended solids that are not removed in the primary treatment are effectively removed in the wetland by filtration and sedimentation.

Attached and suspended microbial growth is responsible for the removal of soluble organic compounds, which are degraded biologically both aerobically and anaerobically. The oxygen required for aerobic degradation is supplied directly from the atmosphere by diffusion or oxygen leakage from the vegetation roots into the rhizosphere, however, the oxygen transfer from the roots is negligible.

The mechanisms for phosphorus removal in constructed wetlands are adsorption, complexation and precipitation, storage, plant uptake and biotic assimilation.

The removal mechanisms for nitrogen in constructed wetlands are manifold and include volatilization, ammonification, nitrification/denitrification, plant uptake, and matrix adsorption. The major removal mechanism in most of the constructed wetlands is microbial nitrification/denitrification. Ammonia is oxidized to nitrate by nitrifying bacteria in aerobic zones. Nitrates are converted to nitrogen gas by denitrifying bacteria in anoxic and anaerobic zones.

The process of metal removal in wetlands include sedimentation, filtration, adsorption, complexation, precipitation, cation exchange, plant uptake and microbially-mediated reactions especially oxidation. Adsorption involves the binding of metal ions to the plant or matrix surface, whereas the presence of bacteria causes the precipitation of metal oxides and sulphides within the wetland. Some wetland species have a well-established ability for direct uptake of metals.
Pathogens are removed in wetland during the passage of wastewater through the system mainly by sedimentation, filtration and adsorption by biomass. Once these organisms are entrapped within the system, their concentration decrease rapidly, mainly by the processes of natural die-off and predation.

Utility & Efficiency

BOD removal efficiency is 95-97%; Has removal efficiency equal to that of tertiary treatment plants.

Reliability

Capability to handle hydraulic shock loadings. Process is flexible with consistent to high quality effluent.

Replication Potential

Packaged plants already available, but design, materials, equipment and labor are also readily available.

Regulatory/Institutional Issues

It will be guided by the local authorities' standard bye laws and design manual.

Operation and Maintenance

The most important maintenance task includes regular checking of the efficiency of the pre-treatment process, of pumps, of influent load and distribution on wetland.

Regular maintenance should ensure that water is not short-circuiting, or backing up because of fallen branches, garbage, or beaver dams blocking the wetland outlet. Vegetation may have to be cut back or thinned out periodically.

Flows must be balanced, and water levels in the wetlands adjusted occasionally. In some climates the vegetation must be regularly harvested.

Typical failures in FWS wetlands are caused by excess organic loading which turns the wetland to anaerobic condition causing odors and potentially killing the emergent vegetation. Excess solids will create problems for emergent vegetation if allowed to settle in the FSW wetlands.

Service providers who perform O&M for constructed wetlands must have appropriate training and expertise.

Advantages

1. System does not required chemical and electrical energy.
2. Less expensive to construct and have a low Operation and Maintenance costs.
3. Can be built and repaired with locally available materials
4. Provides aesthetically pleasing "green space" to a community, and include the incorporation of wildlife habitat and public recreational opportunities.
5. Have a less odor and flies incidence.
6. Can be combined with aquaculture and agriculture services.
7. The removal of BOD, TSS, COD, metals, and persistent organics in municipal wastewaters can be very effective with a reasonable detention time. The removal of nitrogen and phosphorus can also be effective with a significantly longer detention time.

Disadvantages

1. May facilitate mosquito breeding.
2. Long start up time to work at full capacity.
3. Requires large land area.
4. Requires expert design and supervision.
5. Moderate capital cost depending on land, liner, etc.
6. Not very tolerant to cold climates.
7. FWS constructed wetlands can remove fecal coliforms by at least one log from typical municipal wastewaters. This may not be sufficient to meet discharge limits in all locations and supplemental disinfection may be required. The situation is further complicated because birds and other wildlife in the wetland produce fecal coliforms.

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TECHNOLOGY

Constructed Wetland: Horizontal Sub-Surface Flow

SOURCE Blackwater

SCALE Semi-centralized and Centralized

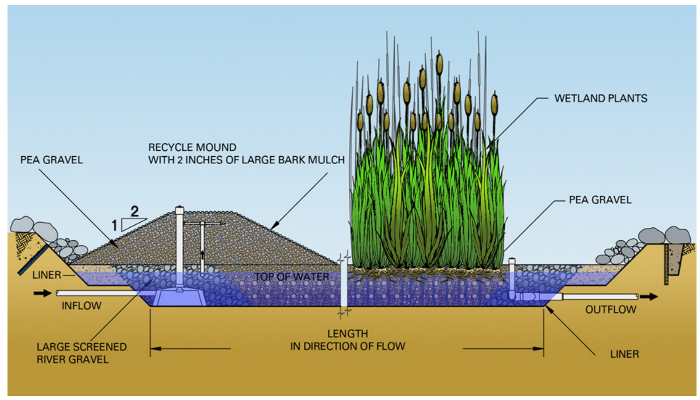
Description

A Horizontal Subsurface Flow (HFWS) is a large gravel and sand-filled channel that is planted with aquatic vegetation. As wastewater flows horizontally through the channel, the filter material filters out particles and microorganisms degrade organics. Removal of settleable organics occurs primarily as a result of sedimentation. Removal of colloidal and soluble organics occurs primarily by aerobic microbial oxidation.

Design Criteria

Treatment performance of a HFWS wetland is a function of detention time, ground slope, water depth, vegetation, areal extent, and geometric shape. Basic design principles include:

- The surface of the filter is kept at a level so that erosion is prevented. The bottom slope should be 0.5-1% from inlet to outlet to achieve good drainage.
- The depth of filter beds is normally around 60 cm with an additional 15 cm freeboard for water accumulation.
- The required specific surface area is about 3-10 m^2/p.e. depending on temperature and other factors. In warm climates less area is required due to the higher biological activity. In cold climates (e.g., Europe) the minimum design value should not be below 5 m^2/p.e.
- The organic loading per surface area should not exceed 4-10 gBOD/m^2·d (16 gCOD/m^2·d) in cold climates. No data is available for warm climates with coarse sand substrate.
- The hydraulic loading should be 60-80 mm/d for greywater and 40 mm/d for wastewater
- However, the limiting factor is the organic load, which means that greywater can probably be applied at higher hydraulic loads.
- Pre-treatment is essential to prevent clogging and ensure efficient treatment.
- The bed should be lined with an impermeable liner (clay or geotextile) to prevent leaching. Small, round, evenly sized gravel (3–32mm in diameter) is most commonly used to fill the bed to a depth of 0.5 to 1m.
- To limit clogging, the gravel should be clean and free of fines. Sand is also acceptable, but is more prone to clogging. In recent years, alternative filter materials such as PET have been successfully used.
- The removal efficiency of the wetland is a function of the surface area (length multiplied by width), while the cross-sectional area (width multiplied by depth) determines the maximum possible flow. A well-designed inlet that allows for even distribution is important to prevent short-circuiting.



Sub-surface flow wetlands

Applications

This type of wetland can be appropriate for small sections of urban areas, peri-urban, and rural communities. They can also be designed for single household. HSFWs are best suited for warm climates but they can be designed to tolerate some freezing and periods of low biological activity.

Components

It consists of filter media, embankment/dike area, plants and buffer zone.

Capacity

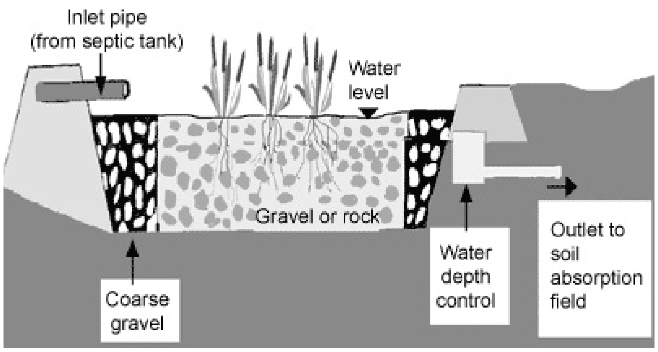
Varies from small household size to a large city scale.

Costs

Varies according to the location, land values, costs of the construction materials, and weather conditions.

Operating Principles

As wastewater flows horizontally through the channel, the filter material filters out particles and microorganisms degrade organic products.



The filter media acts as both a filter for removing solids, a fixed surface upon which bacteria can attach, and a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics as well. The plant roots play an important role in maintaining the permeability of the filter.

Any plant with deep, wide roots that can grow in the wet, nutrient-rich environment is appropriate. Phragmites australis (reed) is a common choice because it forms horizontal rhizomes that penetrate the entire filter depth.

Pathogen removal is accomplished by natural decay, predation by higher organisms, and sedimentation.

Other principles as presented for free surface wetlands are also applicable for this type as well.

Utility & Efficiency

Can achieve high removals of suspended solids and moderate removal of pathogens, nutrients, and other pollutants such as heavy metals phosphorus.

BOD = 80 to 90 %; TSS = 80 to 95 %; TN = 15 to 40 %; TP = 30 to 45 %; FC ≤ 2 to 3 log

Reliability

Capability to handle hydraulic shock loadings and reliable if operation and maintenance is as planned.

Replication Potential

Packaged plants already available, but design, materials, equipment and labor are also readily available.

Regulatory/Institutional Issues

It will be guided by the local building standard bye laws and design manual prescribed for a specific location to preserve the environment and public health.

Operation and Maintenance

The water level in a HFWS Constructed Wetland is maintained at 5 to 15cm below the surface to ensure subsurface flow. The bed should be wide and shallow so that the flow path of the water is maximized. A wide inlet zone should be used to evenly distribute the flow.

The filter material will require replacement every 8 to 15 or more years to remove the clogged gravel will clog with accumulated solids and bacterial film.

Maintenance activities should focus on ensuring that primary treatment is effective at reducing the concentration of solids in the wastewater before it enters the wetland. Maintenance should also ensure that trees do not grow in the area as the roots can harm the liner.

Advantages

1. Requires less space than a Free-Water Surface Constructed Wetland.
2. High reduction in BOD, suspended solids and pathogens.
3. Does not have the mosquito problems compared to the Free-Water Surface Constructed Wetland.
4. Can be built and repaired with locally available materials.
5. No electrical energy and chemical required for operation.
6. Low Operation and Maintenance costs compared to the mechanized systems.

Disadvantages

1. Requires expert design and supervision.
2. Not very tolerant to cold climates.
3. Moderate capital cost depending on land, liner, fill, etc.
4. Pre-treatment is required to prevent clogging.

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TECHNOLOGY

Constructed Wetland: Vertical Sub-Surface Flow

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

A Vertical Flow Constructed Wetland (VFW) has higher treatment efficiency and needs less space. VFW is a filter bed that is planted with aquatic plants. Wastewater is poured or dosed onto the wetland surface from above using a mechanical dosing system. The water flows vertically down through the filter media. The important difference between a vertical and horizontal wetland is the direction of the flow path and the aerobic conditions for the treatment.

Design Criteria

Basic design principles for VFW treating domestic wastewater include:

- The top surface of the filter has to be kept level and the distribution pipes are often covered with gravel to prevent open water accumulation during the pumping periods.
- The distribution pipes should be designed in such way that they achieve an even distribution of the pre-treated wastewater on the entire constructed wetland bed. This is ensured by selecting the right diameter of the distribution pipes, length of pipes, diameter and spacing of openings in the distribution pipes.
- The distance between drainage pipes is based on the detailed design but may be around 5 m. The drainage pipes are covered with gravel to enable good drainage.
- A bottom slope of 0.5-1% in direction to the outlet is important for large VFWs.
- The depth of the sand filter beds should be at least 50 cm, with an additional 20 cm of gravel at the base to cover the drainage pipes, 10 cm gravel on the top of the bed. The gravel on top prevents free water accumulation on the surface, and could in fact be omitted if there is no access to the CW for the public.
- The required specific surface area is usually 3-4 m^2/p.e. in cold regions and 1-2 m^2/p.e. in warm regions.
- The organic loading per surface area should be limited to 20 gCOD/($m^2 \cdot d$) in cold climates. This applies to greywater and wastewater. However, this may also vary depending on the reuse option and local legislation.
- The hydraulic loading for VFWs in cold climates should not exceed 100-120 mm/d. In warm climates hydraulic rates up to 200 mm/d of pre-treated wastewater could be applied without negative influence.
- During rain events, a short-term hydraulic loading of up to 500 mm/d can be applied.

A combination of two vertical subsurface flow wetlands and a Horizontal subsurface flow wetland

Vertical subsurface flow wetland

Applications

It is applicable for single households or small communities as a secondary or tertiary treatment facility of grey water or black water. Effluent can be reused for irrigation, or is discharged into surface water.

Components

See Figures and their components.

Capacity

Varies from small a household to a large city scale.

Costs

Varies according to the location, land values and construction materials.

Operating Principles

In vertical filter beds wastewater is intermittently applied (either by pump or self-acting syphon device) onto the surface and then drains vertically down through the filter layers towards a drainage system at the bottom. In some cases, the distribution pipes are covered with gravel to avoid open water puddles, wastewater flows vertically through the channel, the filter material filters out particles and microorganisms degrade organics.

By dosing the wetland intermittently (four to ten times a day), the filter goes through stages of being saturated and unsaturated, and accordingly, different phases of aerobic and anaerobic conditions. The frequency of dosing should be timed such that the previous dose of wastewater has time to percolate through the filter bed so that oxygen has time to diffuse through the media and fill the void spaces.

Utility & Efficiency

Can achieve high removals of suspended solids and moderate removal of pathogens, nutrients and other pollutants such as heavy metals phosphorus.

BOD = 75 to 90%; TSS = 65 to 85%; TN < 60%; TP < 35%; FC ≤ 2 to 3 log

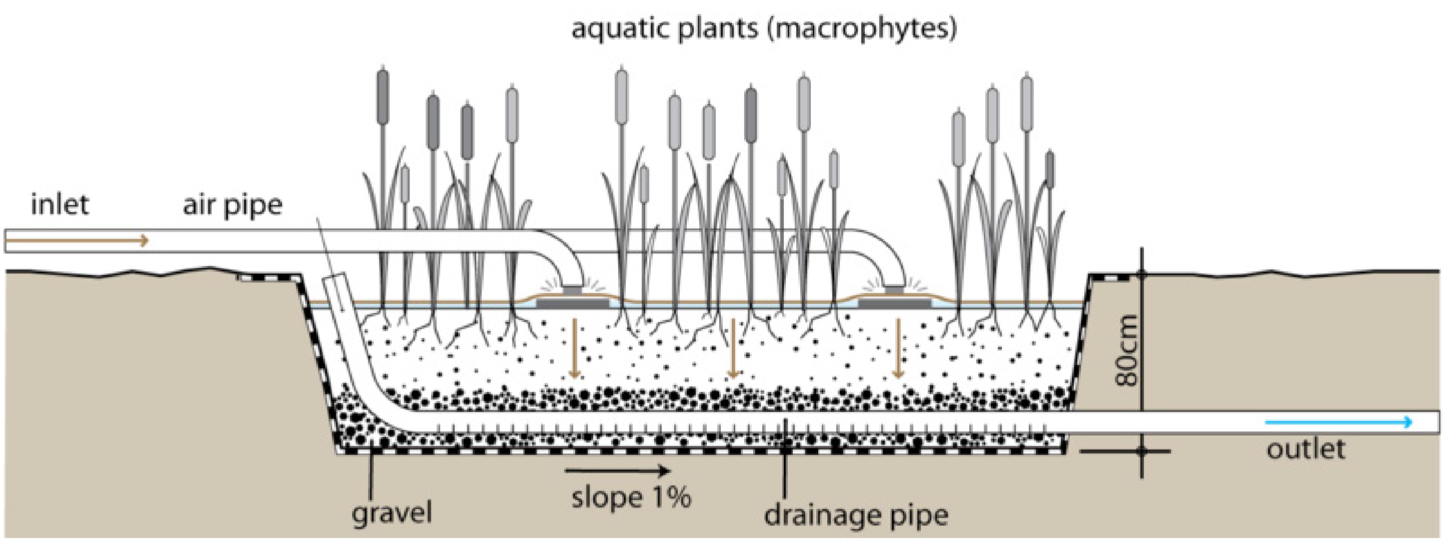
Reliability

Clogging of the filter bed is the main risk of this system, but treatment performance is always reliable provided the operation is satisfactory.

Adaptability to handle hydraulic shock loadings. Better performances than other wetlands types (horizontal and free surface).

Replication Potential

Standards design manual are available.



The filter media acts as both a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots which permeate the filter media.

During a flush phase, the wastewater percolates down through the unsaturated bed and is filtered by the sand/gravel matrix. Nutrients and organic material are absorbed and degraded by the dense microbial populations attached to the surface of the filter media and the roots. By forcing the organisms into a starvation phase between dosing phases, excessive biomass growth can be decreased and porosity increased. A drainage network at the base collects the effluent.

The design and size of the wetland is dependent on hydraulic and organic loads.

Pathogen removal is accomplished by natural decay, predation by higher organisms, and sedimentation.

Regulatory/Institutional Issues

It will be guided by the local authority's standard bye laws and design manual.

Operation and Maintenance

- The gravel will become clogged with accumulated solids and bacterial film with the time. The material may have to be replaced every 8 to 15 or more years.
- Maintenance activities should focus on ensuring that primary treatment effectively lowers organics and solids concentrations before entering the wetland.
- Testing may be required to determine the suitability of locally available plants with the specific wastewater.
- The vertical system requires more maintenance and technical expertise than other wetland technologies.

Advantages

1. Requires less space than a Free-Water Surface Constructed Wetland.
2. Less clogging than in a horizontal flow constructed wetland.
3. High reduction in BOD, suspended solids and pathogens.
4. Does not have the mosquito problems of the Free-Water Surface Constructed Wetland.
5. Can be built and repaired with locally available materials.
6. No chemical required.
7. Low Operation and Maintenance costs.

Disadvantages

1. Long start-up period to work at full capacity.
2. Requires expert design and supervision.
3. High quality filter material is not always available and expensive.
4. Pre-treatment is required to prevent clogging.
5. Dosing system requires more complex engineering.
6. Not very tolerant to cold climate.

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TECHNOLOGY

Waste Stabilization Ponds (WSP)

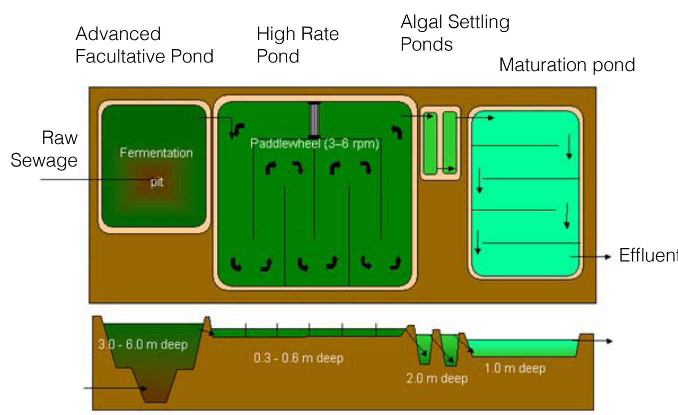
SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Waste Stabilisation Ponds (WSPs) are artificial man-made lagoons in which blackwater, greywater or faecal sludge are treated by natural processes and the influence of solar light, wind, microorganisms and algae. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds: anaerobic, facultative and aerobic (maturation), each with different treatment and design characteristics. The effluent still contains nutrients (e.g. N and P) and is therefore appropriate for the reuse in agriculture (irrigation) or aquaculture (e.g. fish- or macrophyte ponds) but not for direct recharge in surface waters.

Mini Waste Stabilization Ponds consisting of a anaerobic (right), facultative (middle) and aerobic pond (left)



Vertical subsurface flow wetland

Design Criteria

The different types of WSP can be used individually, but the most efficient and common system generally consists of three ponds in series: anaerobic, facultative and aerobic or maturation pond.

Generally anaerobic and facultative ponds are designed for BOD removal and maturation ponds for pathogen removal. However, some BOD removal occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds. Depending on the requirement for the final effluent, only anaerobic and facultative ponds are necessary in some instances.

Anaerobic ponds require approximately 4 m^3/m^2 daily flow and facultative aerobic ponds require 25 m^3/m^2 daily flows. Anaerobic ponds can be 3-6 m in depth and receive organic loads usually in the range of 100 to 350 g BOD/m^3/day. They should not be operated below 10°C, and the load, which can be treated increases linearly with temperature rise (e.g. 100 g/m^3/day at 10°C and 300g/m^3/day at 20°C). The design temperature should be the mean of the coldest month of the year. A Hydraulic Retention Time (HRT) of one day should be sufficient for a BOD5 lower than 300 g/m^3/day at 20°C, but the recommended HRT range varies from 2 to 5 days.

For high-strength industrial wastes, up to three anaerobic ponds in series might be necessary. The optimum pH for digestion lies at 6 to 8 and acidic wastewaters thus require neutralizing prior to treatment. Due to its toxicity to anaerobic bacteria, ammonia concentrations should not exceed >80 mg NH3-N/L.

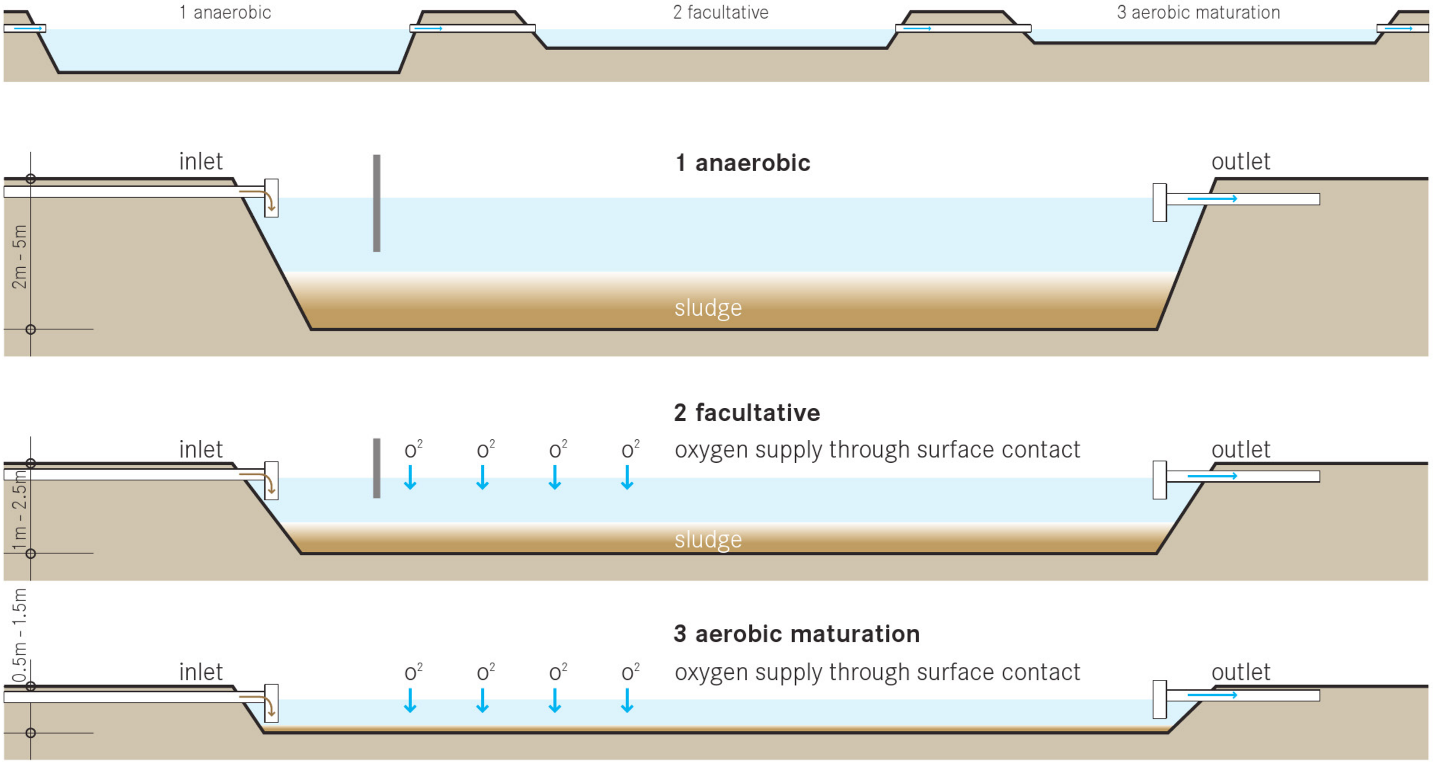
Facultative Treatment Ponds consist of large shallow ponds (depth of 1 to 2m). Facultative Treatment Ponds are designed for BOD removal on the basis of low surface loading and can treat water in the BOD range of 100 to 400 kg/ha/day corresponding to 10 to 40 g/m^2/day at temperatures above 20°C.

Maturation or polishing ponds are essentially designed for pathogen removal and retaining suspended stabilized solids. Maturation ponds are shallower (1 to 1.5 m), with 1 m being optimal. The size and number of maturation ponds depends on the required bacteriological quality of the final effluent. The principal mechanisms for faecal bacterial removal in facultative and maturation ponds are HRT, temperature, high pH (> 9), and high light intensity. Faecal bacteria and other pathogens die off due to the high temperature, high pH or radiation of the sun leading to solar disinfection.

The recommended hydraulic retention time is 15 to 20 days. If used in combination with algae and/or fish harvesting, this type of pond is also effective at removing the majority of nitrogen and phosphorus from the effluent.

Applications

WSPs are particularly well suited for tropical and subtropical countries because the intensity of the sunlight and temperature are key factors for their efficiency. In cold climates, the HRT



and loading may be adjusted, but when mean temperatures fall below 12 °C during several month of the years; WSPs seem not to be appropriate.

WSP are also recommended as treatment for reuse of the effluent in agriculture and aquaculture, because of their effectiveness in removing nematodes (worms) and helminth eggs, while preserving some nutrients. If reuse is not possible, WSPs may not be adequate for areas sensitive to eutrophication.

In Europe, WSPs are widely used for small population up to 2,000. However, larger size systems exist in the Mediterranean region.

Components

As shown in the Figures, components vary according to the types of the ponds.

Capacity

Almost all wastewaters (including industrial wastewater) can be treated, but more surface will required for a higher organic load.

Costs

Varies according to the location, land values and costs of the construction materials. However, stabilization ponds are the most cost-effective wastewater treatment technology. Stabilization ponds also have the advantage of very low operating costs since they use no energy compared to other wastewater treatment technologies and only low-tech infrastructure.

Typical scheme of a waste stabilization system: An anaerobic, facultative and maturation pond in series.

Operating Principles

Settled organics are digested anaerobically in the first pond (anaerobic pond). The **anaerobic pond** serves to i) settle undigested material and non-degradable solids as bottom sludge, ii) dissolve organic material, iii) break down biodegradable organic material.

Facultative Ponds consist of large shallow ponds (depth of 1 to 2m) with an aerobic zone close to the surface and anaerobic zone at a deeper. There are two types of facultative ponds: primary facultative ponds that receive raw wastewater (after grit removal), and secondary facultative ponds receiving settled wastewater usually from the anaerobic pond. In primary facultative ponds, the functions of anaerobic and secondary facultative ponds are combined.

In a second pond (facultative pond), algae growing on the surface provide oxygen leading to both anaerobic digestion and aerobic oxidation of the organic pollutants. Due to the algal activity, pH rises leading to inactivation of some pathogens and volatilization of ammonia.

Algae produce oxygen in excess of their own requirements, which they transfer to the water. It is this excess oxygen that is used by bacteria to break down organic matter by aerobic digestion (oxidation) transforming the organic pollutants into CO2. Additionally to aerobic and anaerobic digestion of BOD, in the facultative ponds “sewage BOD” is converted into “algal BOD”.

The facultative ponds are covered by algae. The algal production of oxygen occurs near the surface of aerobic ponds to the depth to which light can penetrate (i.e. typically up to

500 mm). Additional oxygen can be introduced by wind due to vertical mixing of the water. Oxygen is unable to be maintained at the lower layers if the pond is too deep, and the color too dark to allow light to penetrate fully or if the BOD and COD in the lower layer is higher than the supply. As a result of the photosynthetic activities of the pond algae, there is a diurnal variation in the concentration of dissolved oxygen.

At peak sun radiation, the pond will be mostly aerobic due to algal activity, while at sunrise the pond will be predominantly anaerobic. Peak algae activity also results in a pH rise to above 9 since carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, leaving an excess of hydroxyl ions. A pH above 9 for 24 hours can provide a 100% kill of E. coli and thus, most pathogenic bacteria.

The **maturation pond** serves for the retention of stabilized solids and the inactivation of pathogenic microorganisms via heating, rise of pH and solar disinfection. Virus removal occurs by adsorption on to settable solids (including the pond algae) and consequent sedimentation in the anaerobic and facultative pond. Some microorganisms such as protozoan cysts and helminth eggs are also removed by sedimentation.

Utility & Efficiency

Pond	BOD removal	Pathogen removal	HRT
Anaerobic pond	50 to 85%		1 to 5 days
Facultative pond	80 to 95%		5 to 30 days
Maturation pond	60 to 80%	90%	15 to 20 days

Reliability

Reliable, if ponds are maintained well, and if temperature is not too low.

Replication Potential

Standards design manual are available.

Regulatory/Institutional Issues

It will be guided by standard bye laws and design manual. Either private sector or any other wastewater management agency can operate and maintain the plant.

Operation and Maintenance

Solids in the raw wastewater as well as biomass produced will settle out in first-stage anaerobic ponds. General practice is to remove sludge when it has reached half depth in the pond. This usually occurs after up to 10 or 20 years of operation. In certain instances, anaerobic ponds become covered with a thick scum layer, which is thought to be beneficial but not essential, and may give rise to increased fly breeding.

To prevent scum formation, excess solids and garbage need to be removed before the wastewater enters the ponds; and pre-treatment (with grease traps) is essential to maintain the ponds.

Care should be taken to ensure that plant material does not fall into the ponds as this increase the BOD content of the water. Vegetation or macrophytes should be removed as it may provide a breeding habitat for mosquitoes and prevent light from penetrating the water column. The WHO does not promote pond systems if appropriate mosquito control measures are not guaranteed.

If the water is reused for irrigation, the salinity of the effluent should be controlled regularly in order to prevent negative impact on the soil structure.

Advantages

1. Can be built and repaired with locally available materials.
2. No external energy required for operation.
3. Low in construction and very low operating costs.
4. High reduction in pathogens.
5. Can treat high-strength wastewater to high quality effluent.
6. Generally reliable and well-functioning.
7. Effluent can be reused in aquaculture or for irrigation in agriculture.

Disadvantages

1. Requires large open land surfaces.
2. Requires expert design and supervision.
3. May promote breeding of insects in the pond (e.g. flies, mosquitoes).
4. De-sludging (normally every few years) and correct disposal of the sludge needs to be guaranteed.
5. If the effluent is reused, salinity needs to be monitored.
6. If the nutrients in the effluent cannot be reused (e.g. in agriculture), discharge can cause eutrophication.
7. Anaerobic ponds can cause bad odours if poorly designed.
8. Not always appropriate for colder climates.

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TECHNOLOGY

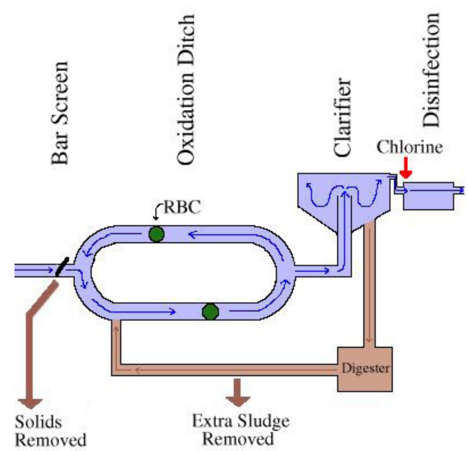
Oxidation Ditch

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

An oxidation ditch is a modified activated sludge biological treatment process that utilizes long solids retention times (SRTs) to remove biodegradable organics. In this process screened and de-gritted raw materials are mechanically aerated in various forms - ring-/oval-shaped ditch or channel, to provide BOD reduction. After treatment, liquid and sludge are separated in a final settling tank. The oxidation ditch process is a fully demonstrated secondary wastewater treatment technology, applicable in any situation where activated sludge treatment (conventional or extended aeration) is appropriate.



Design Criteria

The design criteria are affected by the influent wastewater parameters and the required effluent characteristics, including the decision or requirement to achieve nitrification, denitrification, and/or biological phosphorus removal.

The ditches are usually 4 to 6 ft deep with 45 degrees or vertical sidewalls.

Screened wastewater enters the ditch, is aerated, and circulates at about 0.25 to 0.35 m/s to maintain the solids in suspension.

Design Solid retention time (SRTs) values vary from 4 to 48 days. Typical SRTs required for nitrification range from 12 to 24 days.

BOD loading rates vary from less than 160,000 mg/1000 liters to more than 4x107 mg/1000 liters.

A BOD loading rate of 240,000 mg/1000 liters per day is commonly used as a design loading rate. However, the BOD loading rate is not typically used to determine whether or not nitrification occurs.

The hydraulic retention time within the oxidation ditch ranges from 6 to 30 hours for most municipal wastewater treatment.

Applications

This technology is very effective in small installations, small communities, and isolated institutions, because it requires more land than conventional treatment plants.

Components

Oval ditches; blower and diffusers; mechanical motors/mixers or submerged mixers; live feed system; adjustable weirs; covers; clarifiers

Capacity

For flow range of 200 - 3,000 m^3/day. Area required 465 m^2 for a 600 m^3/day flow.

Costs

Varies based on the local conditions, quality of wastewater before and after the treatment.

Operating Principles

A set of pre and post treatment units are required to apply the oxidation ditch. The pretreatment includes preliminary treatment, such as bar screens and grit removal. Primary settling prior to an oxidation ditch is sometimes practiced, but is not typical in this design. Post treatment includes tertiary filters after clarification, depending on the effluent requirements. Disinfection is required and re-aeration may be necessary prior to final discharge.

Flow to the oxidation ditch is aerated and mixed with return sludge from a secondary clarifier. A typical process flow diagram for an activated sludge plant using an oxidation ditch is shown at the beginning (see Figure).

Surface aerators, such as brush rotors, disc aerators, draft tube aerators, or fine bubble diffusers are used to circulate the mixed liquor. The mixing process entrains oxygen into the mixed liquor to foster microbial growth and the motive velocity ensures contact of microorganisms with the incoming wastewater.

The aeration sharply increases the dissolved oxygen (DO) concentration but decreases as biomass uptake oxygen as the mixed liquor travels through the ditch.

Solids are maintained in suspension as the mixed liquor circulates around the ditch. If design SRTs is selected for nitrification, a high degree of nitrification will occur.

Oxidation ditch effluent is usually settled in a separate secondary clarifier. An anaerobic tank may be added prior to the ditch to enhance biological phosphorus removal.

Utility & Efficiency

BOD removal efficiency is 95-97%; capable of removal efficiency equal to that of tertiary treatment plants.

Reliability

Capability to handle hydraulic shock loadings.
Process has very high flexibility with consistent high quality effluent.

Replication Potential

Process is flexible. Maximum flexibility with consistent high quality effluent.

Regulatory/Institutional Issues

Requires an entity to operate and maintain the facility.

Operation and Maintenance

- Adjustment of rotor immersion by raising/covering a weir
- Preventive maintenance on rotors and other equipment
- Maintenance of weirs, slide gates, structures and other appurtenances

Advantages

1. No primary settling tanks needed.
2. Capable of meeting strict discharge standards.
3. Relatively small space requirement.
4. Most stable performance of all continuous flow mechanical biological system.
5. Systems can be used with or without clarifiers, which affects flexibility and cost.

Disadvantages

1. Requires highly skilled attention and operation.
2. Large energy requirement for equipment operation.
3. Large volume of sludge generates.
4. Biological treatment is unable to treat highly toxic waste streams.

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TECHNOLOGY

Aquaculture

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Aquaculture in general refers to the controlled cultivation of aquatic plants and animals by making use of wastewater as a nutrient source for plants and fish. With the help of fishponds and aquaculture, pre-treated wastewater can be utilized and contained nutrients can be recycled into the food chain. In principle, pre-treated wastewater is let into a pond where the contents are utilized by different species of microorganisms, plants and fishes. For a full scale treatment and to maintain optimized conditions for the species it is common to use pond systems in series of two or three modules.

Design Criteria

The biochemical oxygen demand (BOD) should not exceed 1 g/m^2 per day and oxygen should be at least 4 mg/L. Fish introduced to aerobic ponds can effectively reduce algae and help control mosquito populations. But if the ponds are over fertilized, this increases the growth of phytoplankton and algae and their eventual degradation drastically reduces the levels of oxygen in the water leading to death of fish or other organisms.

Retention time is 10-40 days; mean depth is 0.9 m (0.5 m at inlet and 1.5 m at outlet).

Applications

Suitable in areas where there are fishponds or in areas near the sea, rivers, swamp/marshes, etc. Also applicable where space is available within urban settlements.

Components

Fishpond with earthen embankments, inlet and outlet pipes; types. Piping is required fish population.

Capacity

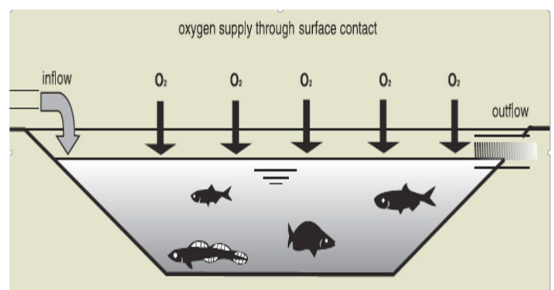
Small and large scale applications possible. Pre-treatment determines scope of aquaculture.

Costs

It varies according to the local condition. Feasibility of effluent reuse option depends on land prices/free land use possibility.

Operating Principles

Generally, three kinds of aquaculture designs for raising fish exist: (i) fertilization of fish ponds with excreta/faecal sludge; (ii) fertilization of fish ponds with effluents; and (iii) fish grown directly in aerobic ponds.



A well-functioning fish pond requires sufficient nutrients for the organisms at all levels and sufficient oxygen for fish to grow. When introducing nutrients in the form of effluent or sludge it is important to limit the additions so that aerobic conditions are maintained.

General working principle is similar to aerobic treatment units where effluents are treated in presence of oxygen and growth of bacteria and living animal including fish.

Utility & Efficiency

If proper function can be guaranteed, good treatment efficiency can be expected.

Reliability

Usually reliable provided regular operation. Collapse of the system can occur.

It can be upgraded with introduction of secondary treatment before the fishpond.

Replication Potential

High self-help potential where aquacultures have a tradition. But cooperation of experts is recommended for pollution control.

Regulatory/Institutional Issues

Subject to compliance with the Clean Water Act and local authority permission may require.

Operation and Maintenance

- Removal of weeds and other aquatic plants regularly
- Prevent formation of floating scum and to allow oxygen to come through
- Maintain the riprap of the embankments

Advantages

1. Utilization of nutrients.
2. Relieves rivers through the reduction of direct pollution load.
3. Can provide a cheap, locally available protein source.
4. Low to moderate capital cost;
5. Operating costs can be offset by production revenue.
6. Can be built and maintained with locally available materials.

Disadvantages

1. Hazardous to human health if not functioning properly, and collapse of the treatment unit is possible.
2. Cannot treat harmful industrial wastes
3. May need inclusion of anaerobic pond at head of works to reduce recycle of fish worm eggs

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Sludge Reuse: Honeysucker

SOURCE Resources Recovery (Nutrients and Other Resources/Materials)

SCALE Household

Description

A Honeysucker is a term used in India and South Africa for septic tanks and latrines emptier. Honeysucker uses a vacuum pump to suck septage from a cesspit, septic tank or latrine and discharges it either to the sewer network, to a wastewater treatment plant, in a pit for composting or into the environment. Composting can generate revenues since it replaces expensive fertilizer and could be a good technique of nutrient recovery.

Design Criteria

A typical Honeysucker truck in India has a capacity of 3,000 liters and serves about five buildings a day.

Assuming a 2-year emptying cycle one truck can cater to about 3,000 to 4,000 buildings or 15,000 to 20,000 people.

In the city of Bangalore alone, it is estimated that there were up to 200 such trucks in 2012, serving more than 3 million people.

Honeysuckers are operated by private companies without the need for subsidies. The charge for emptying a septic tank is between 1,200 and 3,000 Rupees (USD 24 and 60) every two years.

After three months of composting, a truckload of compost can be sold for 1,500 to 2,000 Rupees (USD 30 to 40). In the Bangalore area, compost is used primarily on banana and coconut trees.

If septage is discharged on land for composting, each Honeysucker requires one hectare of land for composting.

Applications

This is applicable for any urban setting where wastewaters are treated by onsite sanitation technologies, particularly septic tank.

Components

It requires a truck with the special pipes and motors; safe land for disposing and composting.

Capacity

Assuming a 2-year emptying cycle one truck can cater to about 3,000 to 4,000 buildings or 15,000 to 20,000 people.

Area of the disposal site varies according to the total amount of sludge to be disposed.

Costs

It varies based on the local condition. Indian case studies show that it will costs about $1/month for a single household for disposing the waste.

Operating Principles

Pit toilets and septic tank are common in the urban periphery in developing countries. Trucks are indigenously developed with a water jetting and vacuum sucking pump that vacuums and suck a pit toilet. This mechanization named as Honeysucker is a Mobile Technology. It eliminates manual scavenging and safe.

Collected sewage is transported in a natural ground for safe disposal and recovery of nutrients. The disposed waste is composted to turn into fertilizer. It can be applied directly in the fields or crops. The treatment process is completely natural therefore selection of disposal site is key for the safe and effective treatment and composting.

Utility & Efficiency

It is safe, easy and nutrients can be recovered.

Reliability

It requires careful monitoring and control.

Replication Potential

It is possible in all places where access for tracks is available.

Regulatory/Institutional Issues

Embedding of current practices as an officially accepted option to sanitation service delivery for all urban dwellers

Developing a protocol for the inclusion of non-sewerage based or on-plot sanitation systems in India

Developing a protocol and a legal frame-work for handling, transportation, composting and application of nutrients from septage and on-plot systems

Research on understanding nutrient – pathogens and safe application for nutrient reuse

Operation and Maintenance

- Selection of land treatment, monitoring of the treatment process is key
- Preparation of fertilizer from the composting will require special attention.
- Potential contamination of groundwater and other water bodies is also critical while selecting a disposal site.

Advantages

1. Relatively cheaper, safer, and faster than manual operation
2. Potential benefit from the composting
3. Driven by the market and no need of investment from the local bodies/government
4. Applicable in low income communities and slums

Disadvantages

1. Risks to the public health and environmental pollution
2. Requires land for the treatment
3. Higher risk of ground water pollution
4. Potential incidence of flies and insects

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TECHNOLOGY

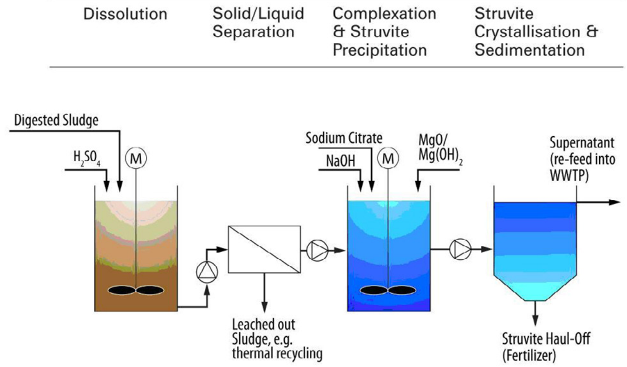
Struvite and Struvite Reactor

SOURCE Resources Recovery (Nutrients and Other Resources/Materials)

SCALE Semi-centralized and Centralized

Description

Urine contains valuable nutrients like Nitrogen and Phosphorus and can be applied to soil as a fertilizer for crops. Struvite (MgNH4PO46H2O), sometimes also called Magnesium Ammonium Phosphate Hexahydrate (M-A-P) is a crystallized white, odorless powder produced through a basic precipitation reaction in urine. Struvite is a bioavailable, slow-release fertilizer; it is compact and can be stored, transported and applied easily, and does not smell. Through struvite recovery, over 90% of Phosphate can easily be removed from urine.



Design Criteria

The struvite reactor consists of a stirring mechanism, which is fitted inside the tank; a nylon cloth filter bag hangs below a valve to allow the main reactor to be drained (see the figure below).

To start the process, the collected urine and magnesium are mixed for 10 minutes in the reaction tank. The valve is opened and the suspension is then drained into the filter bag. The filter bag retains the struvite while the effluent passes through. The struvite will be ready to use after the filter bag is air dried for one to two days.

In field experiments, this type of reactor was able to recover over 90% of the phosphate contained in the urine. In order to maximize nutrient recovery, any precipitate that precipitates naturally from urine should be incorporated into the final product.

The struvite reactor design in a community scale is still limited in the pilot and lab scale. Development of complete design guidelines and principles are still ongoing.

Applications

Struvite precipitation may be appropriate for any situation where significant quantities of urine can be collected and sufficient quantities of Magnesium, preferably in a soluble form, is available at an affordable costs.

Urine collection (labor) and transport (fuel) accounts for a large proportion of the costs, and therefore struvite production is more appropriate for areas where large volumes of urine are available within a small area such as public toilets, schools.

Struvite can also be produced from a variety of wastewaters (including domestic wastewater or liquid animal manure) but the process is more difficult and requires additional chemicals for pH control.

Components

It consists of systems that require collection, storage, and reactor for converting. Materials, mode of transportation and type of reactor will depend on the local condition.

Capacity

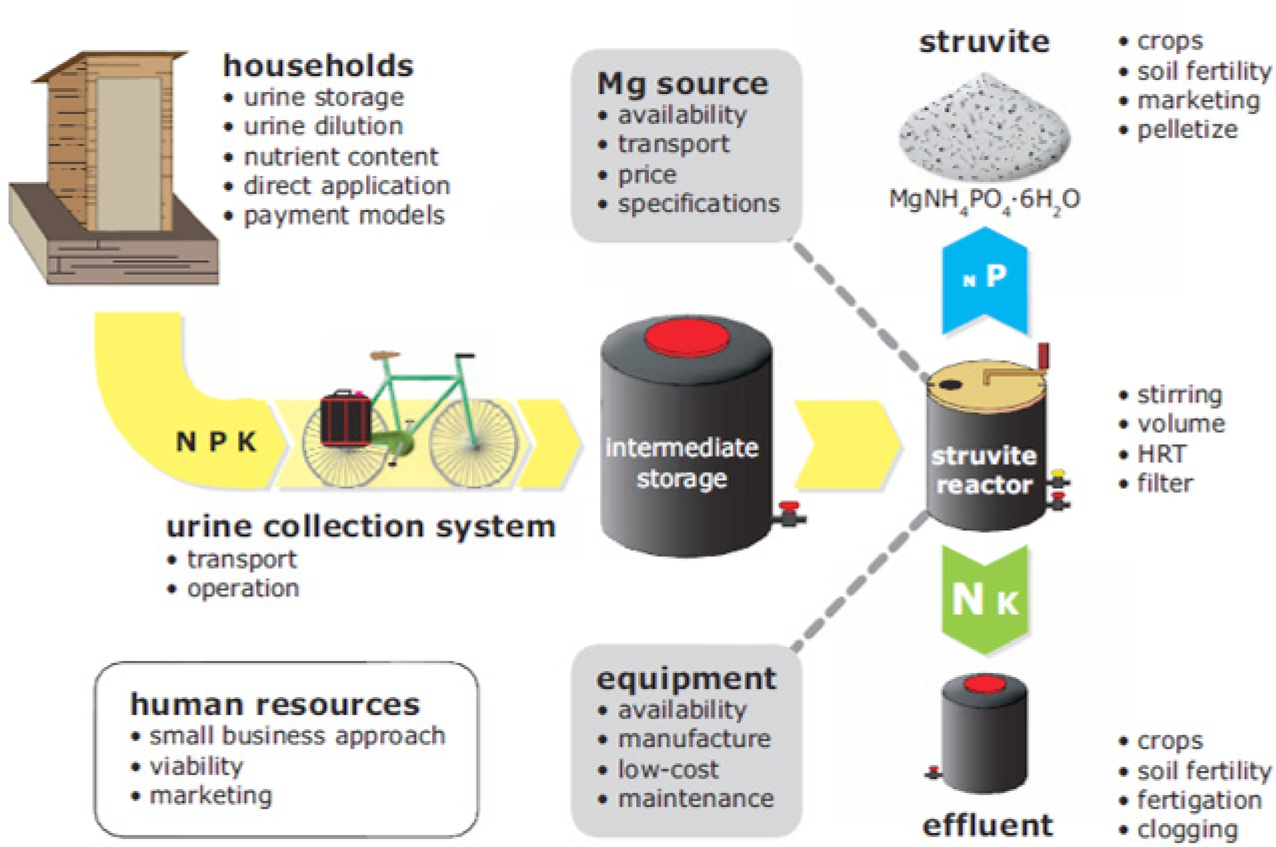
The struvite reactor has been tested for a community level.

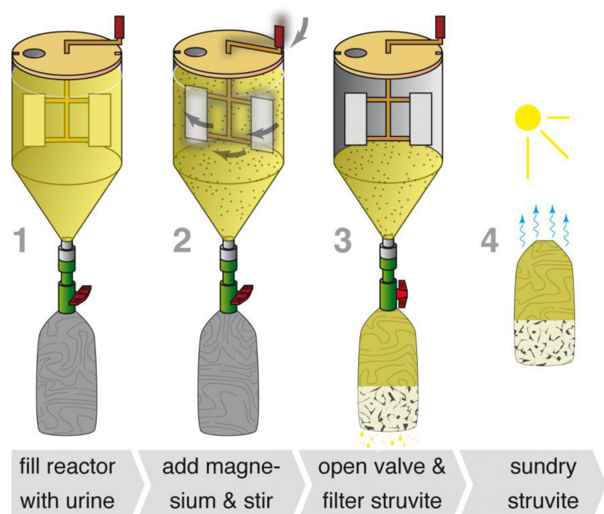
Costs

Case studies by Ewag in Nepal show that struvite precipitation reactor costs US$(50-60), or US $2-3 per liter treatment capacity or US$ (550-600) per kg struvite production capacity per day.

Operating Principles

Household and Decentralized system: Urine is collected from each household (using any type of urine transportation means). The collected urine is processed through the struvite reactor where Magnesium source is added. Main four steps for processing in the reactor include: i) filling reactor with urine, ii) adding and mixing of precipitating chemical (magnesium), iii) filtering struvite precipitates, and iv) drying the struvite.





Utility & Efficiency

This is on the pilot level and performances are still under the experimentations.

Reliability

The piloted systems are reliable. However reliability will vary according to mode of operation and also depends on the local condition.

Replication Potential

This is in early stage of development. However, the field results demonstrated that it can be replicable in any place where urine can be separated and other raw materials area available.

Regulatory/Institutional Issues

A standard byelaws and regulations will require for the safety of public health and environment.

Operation and Maintenance

Critical point in the struvite production process is always liquid-solid separation. The following points are important for the operation and maintenance process.

- Special attention must be paid to the filter
- Optimum stirring time is about 10 minutes
- Fittings must be metal as plastic causes frequent leakages
- A minimum settling time is 24 hours and this time has to be adjusted accordingly for bigger reactors
- Bottom and walls of the reactor have to be cleaned periodically from remaining struvite.

Results have shown that achieving a high Phosphorous removal from the liquid is not difficult, however the key problem is separating the precipitated struvite from the liquid.

Advantages

1. Reduced weight and volume of nutrients (compared to urine).
2. Easy transport, storage and handling, no bad smell.
3. Simple technology; can be built and operated almost anywhere.
4. Construction with local materials (for household level)
5. Easy operation (no electricity for household level).
6. User-friendly fertilizer product.
7. Lower operating and maintenance costs
8. Improved digestion performance in centralized unit
9. Treatment – improved efficiency and reliability
10. Smaller supernatant nutrient load returned.

Disadvantages

1. High volumes of urine required.
2. Low yields (approximately 1 kg struvite from 500 Liters of urine).
3. Partial recovery of Nitrogen and no recovery of Potassium.
4. Requires soluble Magnesium source.
5. Transport costs of urine (to the struvite production site) reduce economic viability.
6. Effluent requires treatment or controlled reuse (i.e. fertigation).
7. Possible corrosion of metal appliance.

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TECHNOLOGY

Nutrient Recovery Technology (E.g., Ostara's Pearl)

SOURCE Resources Recovery (Nutrients and Other Resources/Materials)

SCALE Semi-centralized and Centralized

Description

There are emerging technologies that can recover nutrients (e.g., Nitrogen, Phosphorous) from the wastewater. The recovery of phosphorus from domestic wastewater has been implemented at full-scale installations (e.g., Ostara process (USA), Crystallactor (Netherlands), Phosnix (Japan) processes). A number of processes such as stirred tank reactors and air-agitated and fluidized bed reactors have been investigated as possible configurations for struvite recovery. These processes have the ability to remove and recover over 85% of the soluble phosphorus in the water. In the wastewater, nutrients recovery would have the additional benefits of minimizing eutrophication and alleviating the scaling of process equipment at wastewater treatment plants.

The Pearl® Nutrient Recovery Process

Design Criteria

Based on existing literature, a variety of approaches exist to the recovery of phosphorus from wastewater, sludge, and sludge ash. The main approaches are categorized by the origin of the used matter (wastewater, sludge liquor, fermented or nonfermented sludge, ash) and the three significant recovery processes (precipitation from effluent or liquor; wet-chemical extraction and subsequent precipitation; and thermal, e.g., metallurgical, treatment).

The design criteria and standards, therefore depends on the types of approaches used for the recovery. For example, in the Netherlands, the phosphorus factory of Thermphos International uses a process which allows the use of sewage sludge incineration ash as a replacement for phosphate rock as a raw material. Similarly, the Ostara process, developed by University of British Columbia, is already proving successful in several sewage plants in Canada and the USA, and is now being tested in Israel, China and the UK.

Similar to other treatment technologies, the standard design practices will depend on the different approaches and local conditions.

Applications

Recycling phosphorus from the liquid phase can be done on a small or a large scale and at nearly every WWTP. The wet-chemical process requires fermentation of the sludge and a large number of chemicals, and is not economical on a small scale. The thermal-metallurgical process requires a lot of energy, which leads to high operational costs for both processes. Both thermal treatment and incineration are large-scale processes.

Several field studies show that semi-centralized or decentralized systems are preferred for the nutrients recovery compared to the centralized one.

Components

It can be installed in any types of centralized wastewater systems as shown in Figure. The technology and its components are advanced and developed on sophisticated engineering design.

Capacity

The technology has been installed and operated in a full centralized scale in Saskatoon and Ostara cities in Canada. However, the technology has flexibility with the sizes of the cities and quality and quantity of wastewater to be treated.

Costs

Varies according to the types of plants, size, wastewater quality and other local conditions.

Operating Principles

In the precipitation process, phosphate dissolved in the wastewater or sludge liquor is precipitated or adsorbed, whereas the metal ions remain bound in the sludge and are not (co-)precipitated with the phosphate. If phosphorus is to be recovered from the sludge, it first has to be dissolved using a strong acid, heat, and/or pressure.

In the wet-chemical extraction process the metal ions and phosphate have to be separated before the phosphate product can be precipitated. This requires intensive use of chemicals and makes the process complex and expensive.

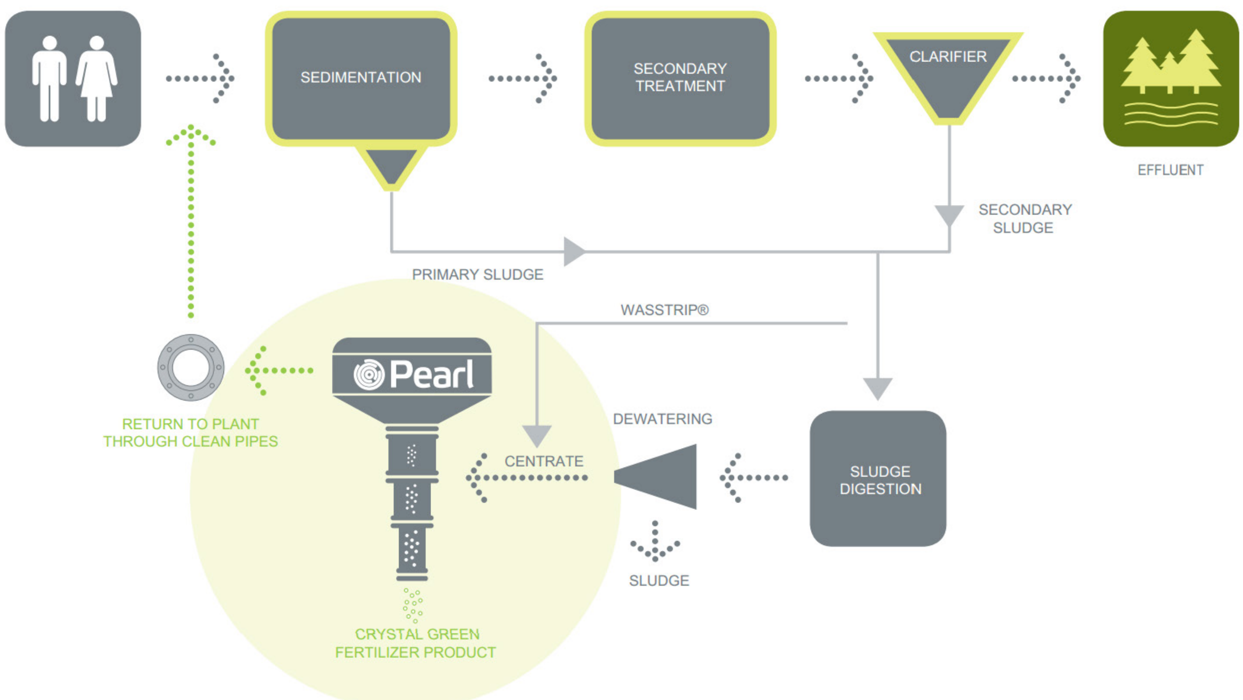
If sludge is incinerated, all of the organic substances, including toxic compounds and the most volatile metal compounds, are removed. To capture all or at least most of the remaining metal ions, the ash has to undergo a thermal-metallurgical treatment.

Example of Centralized system: the Ostara process:

Ostara designs, builds and markets a proprietary nutrient recovery technology that transforms phosphorus and nitrogen recovered from municipal and industrial water treatment facilities into a high-value, eco-friendly fertilizer, sold and marketed as Crystal Green. The Ostara technology is based on controlled chemical precipitation in a fluidized bed reactor that recovers struvite in the form of highly pure crystalline pellets or “prills”.

In this technology, nutrient-rich feed streams are mixed with magnesium chloride and, if necessary, sodium hydroxide and then fed into the Pearl reactor where minute particles or struvite “seeds” begin to form. Like a pearl, these seeds grow in diameter until they reach the desired size – 1.0 mm to 3.5 mm which is precisely controlled by varying key parameters. This mineral is formed by the leftover nitrogen and phosphorus present in wastewater after biological treatment and often precipitates to form crusty deposits that block pipes.

The Saskatoon WWTP based on the Ostara designs, features a Pearl 2000 reactor, which has an annual production capacity of 730 tonnes of Crystal Green, the slow-release, eco-friendly fertilizer created from the harvested nutrients. The City receives a share of the revenue generated from fertilizer sales which helps offset the costs of the system. Crystal Green is used in blends by the agriculture, turf and horticulture sectors throughout Canada and the United States.
In a municipal wastewater treatment plant, up to 90 per cent of the phosphorus and 40 per cent of the ammonia load is removed from sludge dewatering liquid using this process and the resulting product is marketed as a commercial fertilizer called Crystal Green.



Utility & Efficiency

The performances levels are proved to be satisfactory as the removal rate is above 80%. The full performances are still under the experimentations.

Reliability

The system is high tech and mechanized that has a very high level of reliability.

Operation and Maintenance

The operation and maintenance requires very high skilled and trained operators.

Replication Potential

Full nutrient recovery technology and approaches are still in early stages of the development. However, the field result demonstrated that their successful development and standards designs are available to recover the Phosphorous from the wastewater.

Regulatory/Institutional Issues

This is an advanced technology and will be operated only by licensed private sector with defined terms of references and quality control. A standard byelaws and regulations will require for the safety of public health and environment

Advantages

1. Applicable for all types of municipal wastewater
2. Highly engineered system and ensures a very high level of reliability in operation and production
3. High rate of Nutrient recovery (more than 80% of phosphorous and more than 40% Nitrogen)
4. Early studies indicates the technology is cost effective

Disadvantages

1. The technologies forwarded by different researchers are still on the development phase
2. It requires advanced technological knowledge and highly trained plant operators
3. Potential presence of toxic substance with phosphorous
4. Costs of operation is very high
5. The technologies are not installed yet in any developing countries.

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TECHNOLOGY

Sludge Drying Beds

SOURCE Resources Recovery (Nutrients and Other Resources/Materials)

SCALE Semi-centralized and Centralized

Description

Sludge drying bed is a method for dewatering sludge through reduction of moisture content by filtration and evaporation. The bottom of the filter bed is laid with perforated pipes for draining the filtrate or seepage water. Drying beds are either planted or unplanted sealed shallow ponds filled with several drainage layers and designed for the separation of solids from the liquid fraction of (faecal) sludge from latrines, septic tanks, biogas reactors, trickling filters, etc. Sludge is dried naturally by a combination of percolation and evaporation. Sludge drying beds are normally located near treatment plants to treat the sludge produced by primary/secondary treatment. After drying, moisture content is reduced by 35% or less.

Design Criteria

Unplanted sludge drying beds are simple sand and gravel filters on which batch loads of sludge are dewatered. The diameter of the medium and the height of the different gravel and sand layers vary according to the local condition.

Generally, the bed contains several layers of gravel beds. It contains a coarse gravel layer (diameter: 15 to 50 mm) is within 20 to 30 cm of height, another gravel layer (diameter of 7 to 15 mm) of 10 to 15 cm and a similar layer with slightly smaller diameter depending on local condition. There should be a final sand layer of 25 to 30 cm.

Land requirements are 0.05 m^2 per capita for a 10 days cycle. Drying takes up to 10 to 20 days. On an annual basis, about 100 to 200 kg TS/m^2 can be applied on a drying bed. Before fresh sludge is applied, dried sludge needs to be desludged and brought to a composting site.

Planted beds consist of an impermeable shallow pit filled with different layers of coarse to fine sand. Generally, there are three layers, starting with a large gravel layer (diameter of 20mm) of 25 cm height, followed by a fine gravel layer with granules of 5 mm in diameter (also 25 cm height) and finally covered with a sand layer of some 10 cm.

Unlike unplanted beds, planted beds do not need desludging before each new application as the root system of the plants maintains the permeability.

Applications

Drying beds are not suitable in regions with heavy rainfalls and frequent flooding or where the water table is high.

In any case, the ponds should be sealed to prevent infiltration of the pathogen containing percolate and a counter bound can prevent run-off to flow in.

Planted sludge drying beds

Sludge drying beds requires large surface areas and odor is frequent. Therefore, they should be constructed far away from housings.

Components

Construction of unplanted and planted sludge drying beds is similar. They require gravel/sand filters, drainage pipes in the bottom (perforated PVC pipes or hollow blocks), and different drainage layers.

The bed frame is usually made from concrete or a plastic liner with the bottom surfaces slightly sloped in order to facilitate percolation and drainage. The lowest layer of the bed consists of a drainage stratum made of coarse gravel. Upper layers consist of different sand and gravel with finer grain size at the top. For the sludge application, a splash spate may be used to avoid sputtering.

Capacity

Small and large scale applications possible.

Costs

The investment costs of sludge drying beds are moderate where land prices are low and filter material is locally available. However, the pond may need to be made impermeable and expert skills are required for design.

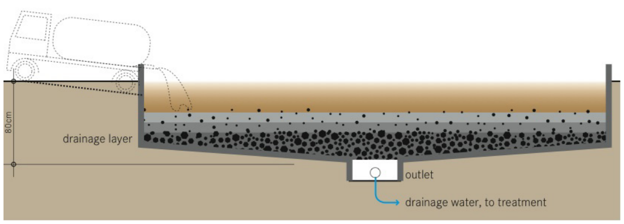
Operation costs are low as no energy or complicated equipment is required. However, desludging, in particular, for unplanted beds is laborious.

Operating Principles

Drying beds are simple sealed shallow ponds filled with several drainage layers. Sludge is applied on the top and dried by percolation and evaporation.

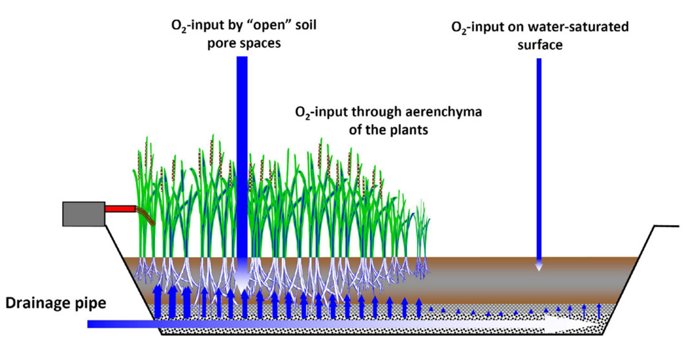
The sludge is applied in a batch mode about once per week intervals in layers of no more than 20 to 30 cm. About 50 to 80% of the initial volume is removed by percolation resulting in total solid (TS) content of 20 to 70% depending on the local weather conditions and climate. In regions with frequent rainfall, contour bounds can prevent surface runoff to enter the ponds and covering the drying beds with a roof may be considered.

Drying induces partial pathogen removal. However, the dried sludge still may contain pathogens, particularly Helminth eggs, and should therefore be handled carefully and receive further treatment such as composting or prolonged storage before use in agriculture. The percolate from dewatering contains also pathogens, mainly bacteria and viruses and has to be further treated as well. In the case of frequent application of sludge and to enhance retention times, two or more drying beds can be constructed in parallel and used alternately.



In planted drying beds, the plants maintain the porosity of the soil and enhance the evaporation by transpiration (evaporation). Dried sludge can be used as biosolid in agriculture.

Sludge is added intermittently once a week and only removed every 5 to 10 years. Once the sludge is removed it is well mineralized and has a soil-like structure with a TS content of 40 to 70%. Therefore, planted sludge drying beds are also called humification beds. It is best to stop applying sludge one or two years before removing it (while a parallel bed receives the sludge). In such a way, the humified sludge is nearly pathogen free and can be reused directly as biosolid in agriculture.



Utility & Efficiency

Depends on the local climate (rain, runoff); TS content of 20 to 70 % can be achieved. Some of NH4 is lost to air. Nutrients are captured in plants and in the nutrient rich dried sludge that can be applied on land.

Reliability

Usually high, if the area is kept dry (rain, runoff) but in cases of careless use, forms a hazard to residents.

Replication Potential

High self-help potential but cooperation of experts is recommended for pollution control.

Regulatory/Institutional Issues

Requires clear guidelines and byelaws.

Operation and Maintenance

Operation and Maintenance includes application of sludge, desludging, control of drainage system and the control of the secondary treatments for percolate or dried sludge. Even though experts are not compulsory for the Operation and Maintenance, a well-organized community group, which has experience in organic fertilizer use and preparation, is required.

Advantages

1. Simple to operate, no energy required.
2. Lowest cost option among sludge dewatering methods.
3. Dried sludge can be used as fertilizer (either directly in the case of planted beds or after composting in the case of unplanted beds).
4. Easy to operate (no experts, but trained community required).
5. High reduction of sludge volume and pathogen removal.
6. Can be built with locally available materials.

Disadvantages

1. Filtrate/seepage water has to be treated.
2. May produce odor and flies nuisance.
3. Requires large land area.
4. Requires treatment of percolate.
5. Only applicable during dry seasons or needs a roof and contour bund.
6. Manual labor or specialized equipment is required to remove dried sludge from beds.

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TECHNOLOGY

Anaerobic Biogas Reactor

SOURCE Energy Recovery System

SCALE Household

Description

Anaerobic biogas reactors are airtight reactors in which organic waste is decomposed and transformed into biogas by a biological process called anaerobic digestion. Biogas is a mix of methane, carbon dioxide and other trace gases. Biogas is recovered and transformed into heat or any other form of energy. The remaining sludge contains many nutrients and can be used in agriculture. Biogas is an alternative source of energy for use in household cooking, heating, lighting, and for municipal and industrial use. Mainly in industrialized countries, this technology has been evolved over the past centuries, resulting in various designs of different complexities

Design Criteria

There is a large range of different types and designs of anaerobic digester technologies for the treatment of organic waste. The complexity of design varies according to the composition of the substrate; dry and wet processes; mesophilic and thermophilic processes; mechanically mixed and no-mixed reactors, batch and continuous reactors, and one-stage or multi-stage processes etc. However, all those technologies are based on anaerobic process.

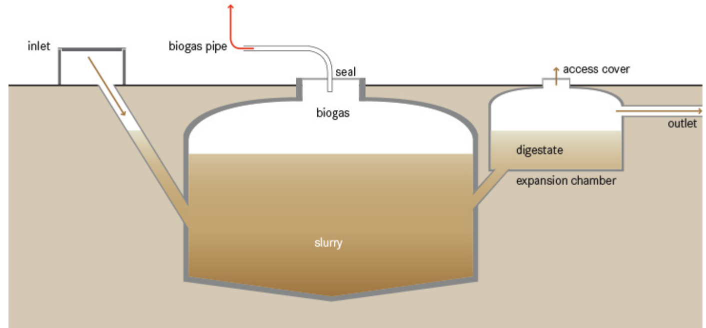
There are many commercial designs available for the bioreactor useful for different scale. Some examples include: design by Appropriate Rural Technology Institute (ARTI) for household level; BIOTECH Plants from South India for 3-5 families; The KOMPOGAS Compact technology developed in Switzerland treating municipal organic waste.

The ARTI compact biogas plants are based on a simple and low-cost floating-drum design applying a wet digestion process. The plants are made from conventional polythene water tanks (two tanks, with volumes of typically 0.75 m^3 and 1 m^3,) and standard plumber piping. The smaller tank is the gasholder and is inverted over the larger one, which holds the mixture of decomposing feedstock and water. An inlet is provided for adding feedstock, and an overflow for removing the digested residue. The overflow liquid can be mixed with the feedstock and recycled back into the plant to maintain optimal moisture condition for a wet digestion process. A pipe takes the biogas to a collection balloon or directly to the kitchen.

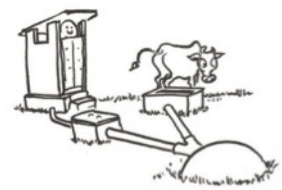
Empirical results show that 50 - 100 liters of waste can produce 2 m^3 of biogas per day. It results approximately 15 - 28 m^3 of methane gas per 1,000 persons per day.

Applications

The anaerobic treatment of organic solid waste is particularly adapted where there is a need for a renewable energy in a sub-urban and rural area.



A biogas reactor



Sources of organic wastes for a household level biogas plant

Components

Digestion tank; fixed or floating cover; sludge/waste inlet pipe; gas removal pipe; pressure relief and vacuum valve.

Capacity

Biogas plant can serve from a household to a community/city level.

Costs

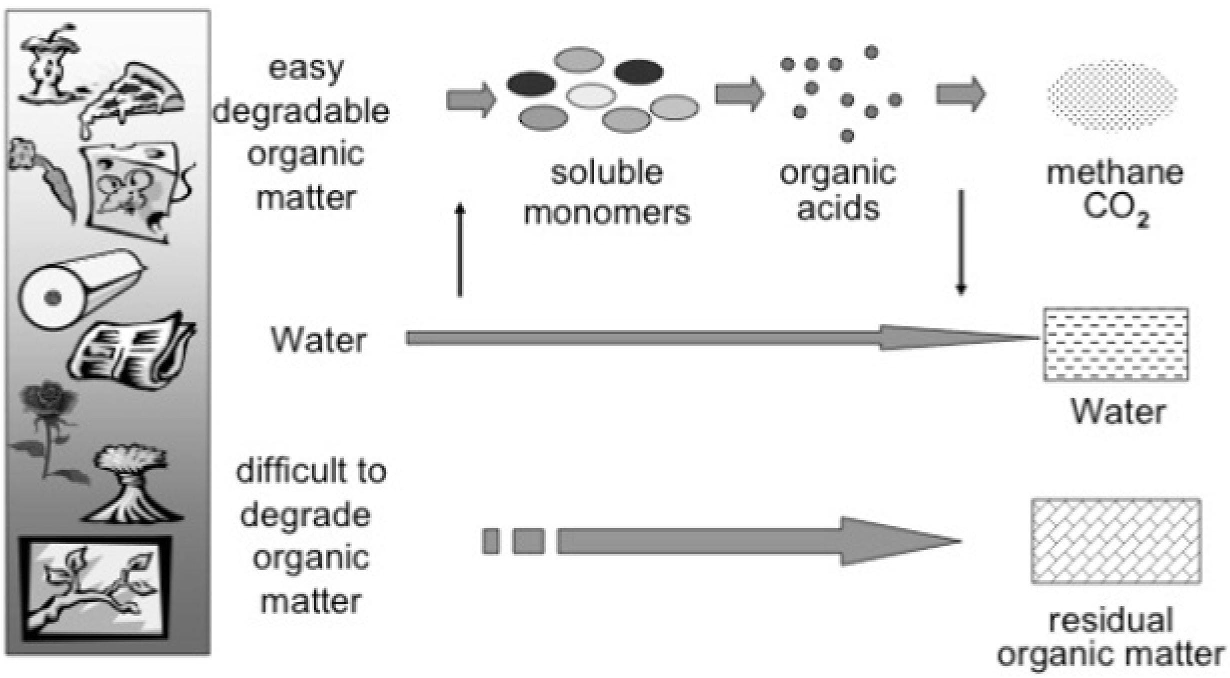
Costs vary according to the type of technology and local conditions.

Operating Principles

Anaerobic digestion operates in a four-stage process: i) Hydrolysis; ii) Fermentation (conversion of non-soluble organic biomass to soluble organic compounds); iii) Acidification (conversion of soluble organic compounds to volatile fatty acids and CO2, followed by the conversion of volatile fatty acids to acetate and H2); and iv) Methane formation. The final product, biogas, is a mixture of methane (CH4), carbon dioxide (CO2) and other trace gases.

There are many ways in which anaerobic digestion can occur. The simplest reactors are covered waste dumps, where anaerobic digestion can occur naturally in uncontrolled systems.

During the operation, human waste is mixed with animal manure and crop residues in an anaerobic digester, where it is decomposed without oxygen at relatively high moisture content (90-99.5%). Wastes are decomposed into volatile acids and biogas. Other by-products are Amines, Nitrates and Ammonia (fertilizer) by the breakdown of proteinaceous materials. Pure sludge introduced continuously or intermittently, can also be retained in a reactor for varying periods of time to produce biogas.



Anaerobic digestion principle of organic waste

Utility & Efficiency

Utilization of methane gas. BOD/COD reduction through anaerobic digestion is 80 - 85%

Reliability

Reliable if operated and maintained properly. Resistant against shock loads.

Replication Potential

The best practices with standard design and drawing are available that can be replicable at any local condition.

Regulatory/Institutional Issues

Requires skilled personnel to maintain the facility.

Operation and Maintenance

It will require the following simple operations:

- Check scum blanket; break up, if necessary
- Monitor gas production, acidity/alkalinity ratio
- Control foaming in digester
- Monitor total solids.

Advantages

1. Generation of biogas and fertilizer (N, P, and K)
2. Reduction of greenhouse gas emissions through methane recovery which effects equivalent to 25 times of CO2 emission.
3. Combined treatment of different organic waste and wastewaters
4. Reduction of sludge volume to be further handled.
5. Good pathogen removal depending on temperature.
6. Process stability (high-loads can be treated but anaerobic sludge can also be preserved for prolonged periods without any feeding).

Disadvantages

1. Usually needs other source of organic waste (solid waste) in addition to wastewater)
2. Users need to be trained in the use and maintenance of the system; expert supervision is required
3. Requires skill manpower in construction
4. High sensitivity of methanogenic bacteria to a large number of chemical compounds
5. High risk of corrosion problem and septic odor

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TECHNOLOGY

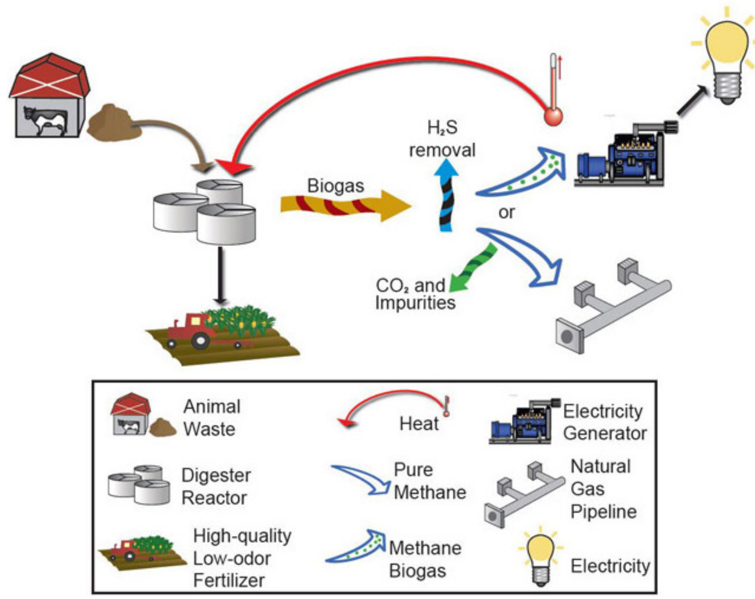
Anaerobic Digestion

SOURCE Energy Recovery System

SCALE Semi-centralized and Centralized

Description

Large-scale anaerobic biogas reactors used for the conversion of the organic fraction of large volumes of slurries and sludge into biogas by anaerobic digestion. Biogas is recovered and used either directly for heating the reactors or transformed into combined power and heat and fed into the grid. It can also be upgraded to natural gas quality. Typical substrates are excess sludge from wastewater treatment plants or waste slurries from agriculture (manure) or (diary) industry. Energy crops may also be added in order to increase the gas yield. Biogas is a green energy and has the potential to reduce greenhouse gas emission.



Biogas production form agriculture and food industry waste slurry. Products are electricity, clean fuel, carbon credits and liquid and solid fertilizer

Design Criteria

Large-scale anaerobic digesters have been mainly developed in industrialized countries. Most of them are high-tech. Different plants vary strongly in design and complexities, but all require expert staff for planning, design, operation and maintenance.

The design of the digester will be governed by several factors including influent and effluent flow rates, total and volatile solids content of influent and effluent, digester volume, retention time, heating system, control, and monitoring, methane yield, and process control and monitoring.

Anaerobic digesters are batch or continuous fed reactors, which run within the mesophilic range (i.e., typically between 20 and 45°C). The sludge retention time in the reactors is approximately 15 -21 days.

The operating temperature is normally achieved by heating. Generated biogas often gives enough power and heat to run the plant. Excess power (and heat) is fed into the public grid if possible.

In Europe, energy crops (e.g. maize and grass) are sometimes fed into the reactors to enhance biogas yields. However, the cultivation of energy-rich plants specifically for the production of bio-fuels is often not sustainable, due to the high inputs (water, nutrients, land); furthermore, their production competes with the production of food crops.

Applications

Large-scale anaerobic digesters are designed for the treatment of large-volumes of high-strength waste slurries form agriculture and industry (e.g. manure, slaughterhouses, paper manufacturing) or to treat the excess sludge from large-scale wastewater treatment plants (activated sludge systems).

Components

Varies according to the types of plants and inputs and outputs used in the plant.

Capacity

Varies from smaller community to a city scale.

Costs

This requires high capital and operation costs.

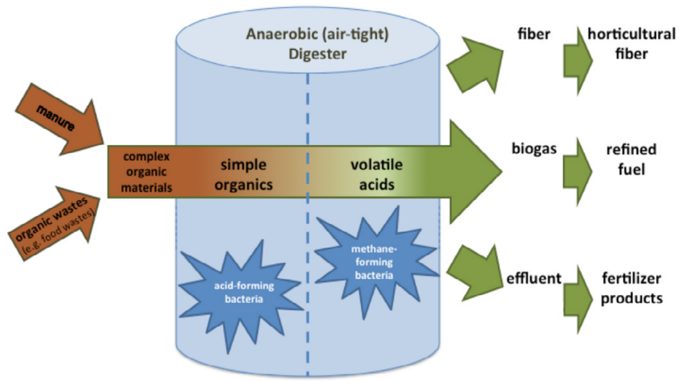
Operating Principles

High-strength slurries from wastewater treatment plants, agriculture or industry are fed in an airtight reactor where the organic fraction is transformed into biogas by anaerobic digestion. Biogas is transformed into heat and power and used as green energy source. The remaining sludge is rich in nutrients and could be used in agriculture. Sewage or municipal wastewater can be treated by anaerobic digestion, but due to the liquid nature of such wastes, the process requires high-rate anaerobic digestion reactors (e.g. up-flow anaerobic sludge blanket reactors).

Four key biological and chemical stages of anaerobic digestion are Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis (which are similar to the household level).

The anaerobic digestion is either carried out in the mesophilic

(20 to 35 °C) or the thermophilic range (50 to 60 °C). Thermophilic processes produce more biogas in shorter time. However, mesophilic processes are often preferred as high temperatures require higher input energy to obtain operation temperatures and the production of ammonia, which is toxic for the anaerobic microorganism producing the biogas.



Anaerobic digestion process

In order for the bacteria in anaerobic digesters to access the energy potential of the material, chains of large organic polymers must first be broken down into their smaller constituent parts. The process of dissolving the smaller molecules into solution is called Hydrolysis. This is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.

Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules such as volatile fatty acids (VFA's) must first be catabolized into compounds that can be directly utilized by methanogens.

The biological process of Acidogenesis is where there is further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here VFAs are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products. The process of acidogenesis is similar to the way that milk sours.

The third stage of anaerobic digestion is Acetogenesis. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen.

The last stage of anaerobic digestion is the biological process of Methanogenesis where methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and 8. The remaining, non-digestable material which the microbes cannot feed upon, along with any dead bacterial remains constitutes the digestate.

One way to optimize large-scale anaerobic digesters is to use multi-stage digestion, which allows to more accurately controlling pH and temperature. In such systems, the four stages of anaerobic digestion are separated in different consecutive compartments. Consequently, the optimum conditions for each type of bacteria must be maintained in a smaller volume (e.g. high temperatures for methanogenesis), resulting in a simplified maintenance and in energy savings.

Utility & Efficiency

Have high volume reduction of wastes; relatively high pathogen removal; nutrients remain in the sludge.

Biogas consists of 60-70% methane, 30-40% carbon dioxide, trace amounts of other gases like hydrogen sulfide and ammonia, along with a very small percentage of water vapor

Reliability

It depends on the types of technologies, design standards, and maintenance and operation. Mostly they are resistant to shock loading and reliable if operated and maintained well.

Replication Potential

Standard designs and best practices are available that can be replicated in the similar areas and environments.

Regulatory/Institutional Issues

Requires skilled personnel to maintain the facility. Also, it has to be regulated with standard guidelines and bye laws to prevent from potential negative impacts

Operation and Maintenance

Operation and Maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for its design.

The plan shall contain Operation and Maintenance requirements including but not limited to:

- Proper loading rate of the digester and total solids content of the influent.
- Operating procedures for the digester.
- Estimates of biogas production, methane content, and potential energy recovery.
- Description of the planned startup procedures, normal operation, safety issues, and normal maintenance items.
- Alternative operation procedures in the event of equipment failure.
- Instructions for safe use or flaring of biogas.
- Digester and other component maintenance.
- Troubleshooting guide.
- Monitoring plan with frequency of measuring and recording digester inflow, operating temperatures, biogas yield, and/or other information as appropriate.

Advantages

1. Combined treatment of different organic waste and wastewater
2. High reduction of the volume of waste.
3. Generation of a renewable energy (biogas).
4. Potential for greenhouse gas emission reduction
5. Remaining sludge could be used as fertilizer.
6. Low space requirements.
7. Anaerobic digestion is an efficient technology compared to other. For example, about twice as efficient as landfill gas production, but only a third as efficient as incineration (where a furnace burns the organic wastes), and only a fifth as efficient as gasification.

Disadvantages

1. Experts are required for the design, construction, operation and maintenance.
2. High sensitivity of methanogenic bacteria to a large number of chemical compounds including temperature changes, pH, alkalinity, volatility fatty acid,
3. Requires seeding and start-up can be long due to the low growth yield of anaerobic bacteria.
4. This process does not convert 100% of the waste into usable products and post digested solids require further treatment, like composting. Anaerobic digestion of organics with or without other organics on its own is not a completely sustainable waste management solution.
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TECHNOLOGY

Incineration and Co-Incineration of Sewage Sludge

SOURCE Energy Recovery System

SCALE Semi-centralized and Centralized

Description

The sludge incineration methods are used for energy recovery sludge in the form of heat or electricity. Sludge incineration does a complete oxidation of the organic compounds at high temperature. The biosolids are burned in a combustion chamber supplied with excess air (oxygen) to form mainly carbon dioxide and water and leaving only inert material (ash). The ash can be used as a source of building materials. The co-incineration technique aims to improve the energy recovery from the incineration of the sludge by: i) improving the dewatering and drying processes of the sludge; ii) Use of the low-caloric waste heat from the exhaust gases of the power plant.

Design Criteria

Some Incinerators generate energy from the burning of waste-called waste-to-energy plants.

Incinerators reduce the volume of waste by about 90 percent and weight by 75 percent. There are eight types of incinerators: fixed-hearth incinerators, rotary kiln, plasma arc, liquid injection, fluidized bed, multiple hearth, catalytic combustors, and static heart incinerator.

Specific sludge incineration facilities have been operating for many years. Rotary kiln furnaces and the multiple hearth furnace of the classic or pyrolytic type are today more and more frequently being replaced by fluidized bed systems, which tend to be easier to operate.

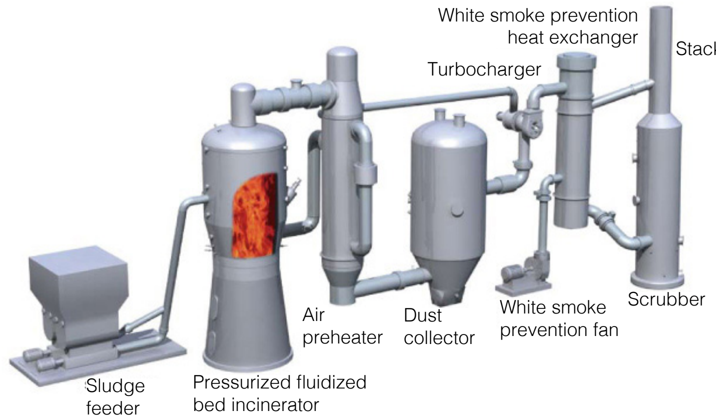
Small scale incinerator are also available, however, uses are limited only for specific purposes, such as hospital or any other industrial waste management.

The incinerators are based on complex and advanced technology. However, standard designs for each of the type are available in the literature that is applicable for a local condition.

Several other thermal processes, such as Gasification and Pyrolysis have been discussed in the earlier sections (see section Nutrients recovery).

Applications

This is one of the advanced technologies that require a higher level of technical inputs for design, operation, and maintenance. In addition, it is costlier for the investment. It is only cost-effective in regions where land suitable for landfilling is scarce due to geographical constraints (i.e. in urbanized regions or islands) or in regions where the water table is high.



Incineration of sludge to energy systems

Components

Varies according to the types of plants and influents characteristics, and scale and uses of the energy.

Capacity

Varies from smaller to greater city scale. Mostly cost effective if used for the centralized systems.

Costs

This requires high capital cost and operating cost- which vary according to the scale and objective of application.

Operating Principles

It is the process of combusting solid waste (or dried sludge from wastewater treatment plants) under controlled conditions to reduce its weight and volume, and often to produce energy (electricity, heat).

The main stages of incineration process are: waste storage and feed preparation.

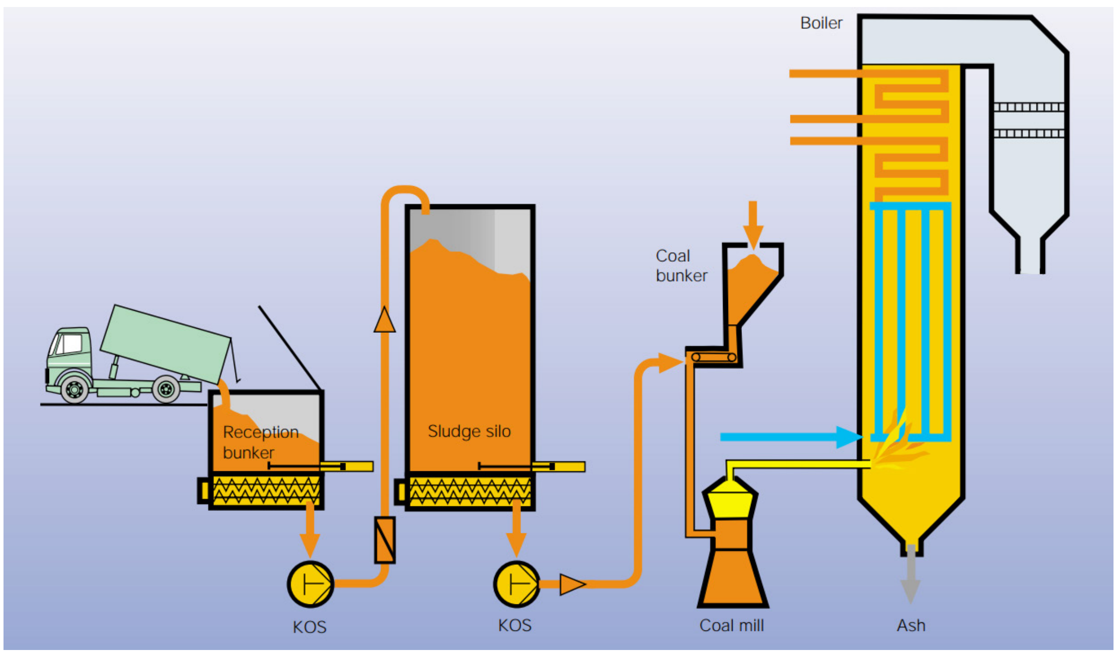
Incineration of sewage sludge is aimed at a complete oxidation at high temperature of the organic sludge compounds, also including the toxic organic compounds. The process can either be applied to mechanically dewatered sludge or dried sludge (e.g. drying beds). Potential environmental problems related to sludge incineration are the emissions of pollutants with the exhaust gases to the atmosphere as well as with the quality of the ashes.

The energy produced in the incineration process can be used for drying of mechanically dewatered sludge cake prior to the incineration process or can be used for the production of electricity. Currently, sludge incineration processes are increasingly focused on the recovery of energy from the sludge in the form of heat (steam) or electricity. Incineration of sludge is currently applied worldwide more and more in combination with energy recovery, mainly on a large scale.

Co-incineration: Co-incineration of sludge consists of incineration of dried sludge in a coal-fired power plant or in combination with municipal solid waste. It can be co-firing in rotary kilns for the pyroprocessing of cement; sewage sludge is co-combustion in dust boilers; sewage-sludge co-combustion with coal was in a thermal-electric power station; co-combusted with lignite, wood, or municipal waste.

Results have proven that by adding only small quantities of sewage sludge in relation to the total mass of burned fuel, these methods do not require any additional investment or any structural change of boiler. As a result, the high costs of a standalone incineration plant for sludge can be reduced. Beneficial use can be made from existing coal combustion installations and existing exhaust gas treatment systems.

Combined process: Combined processes for the thermal utilization of sewage sludge are usually a combination of pyrolysis and gasification or combustion and gasification. Their advantages, in addition to the disposal of sludge, are that it becomes possible to recover resources and energy.



Utility & Efficiency

One of the efficient technologies for recovering energy and controlling greenhouse gas emissions

Reliability

Mostly reliable, but there is a risk of malfunction if not properly maintained and operated as they are highly sophisticated with the advanced technology.

Regulatory/Institutional Issues

It has to be regulated with standard guidelines and bye laws to prevent from potential negative impacts.

The move to sludge incineration has been influenced by environmental law and restrictions to other routes of disposal.

Replication Potential

Standard designs and best practices are available that can be replicated in similar areas and environments.

Operation and Maintenance

The plant should be operated and maintained by highly specialized personnel. Monitoring equipment is costly and requires aggressive maintenance and servicing by trained technicians. Some of the points to be considered include:

- Combustion in a furnace, producing hot gases and a bottom ash residue for disposal.
- Gas temperature reduction, frequently involving heat recovery via steam generation.
- Treatment of the cooled gas to remove air pollutants, and disposal of residuals from this treatment process.
- Dispersion of the treated gas to the atmosphere through an induced-draft fan and stack.

Advantages

1. Combined treatment of different organic waste, wastewaters and the toxic organic compounds.
2. High reduction of the volume of waste.
3. Generation of a renewable energy (biogas).
4. Potential reduction for greenhouse gas emission (collection of methane; green energy production).
5. Remaining sludge could be used as fertilizer.
6. Low space requirements.

Disadvantages

1. Experts are required for the design, construction, operation and maintenance.
2. Requires a high initial investment costs.
3. Potential release if heavy metals.
4. Risk from handling of solid residues e.g. bed and filter ash
5. Potential emission of toxic substances and green house gasses.

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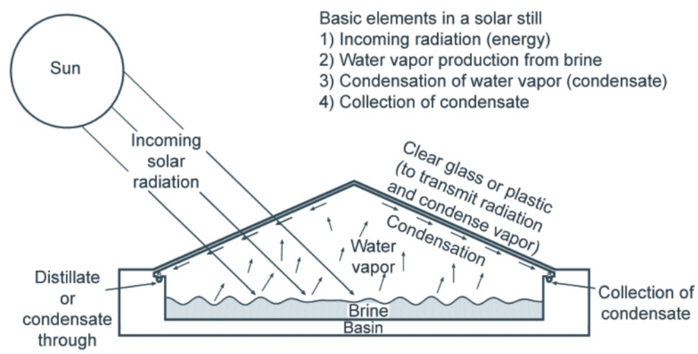
Thermal Distillation

SOURCE Desalination

Description

Thermal distillation is a process that involves changing saline water into vapor. This vapor or steam is generally free of salt, minerals and other contaminant There are different methods of achieving this thermal distillation. The three major, large-scale thermal processes are multistage flash (MSF) distillation, multi-effect evaporation (MEE) distillation, and vapor compression distillation. Another thermal method, solar distillation, is typically used for very small production rates. These technologies are widely used in the Middle East, primarily because of the low energy cost from petroleum reserves. In the Middle East and other similar regions with water of high salinity (total dissolved solid of about 35-45 g/kg and high temperature (about 30 to 35°C during summer) thermal desalination methods in particular MSF have historically been favored.



Desalination by thermal distillation technology

Design Criteria

The MSF technology has high process reliability and ability to continuously operate for duration more than two years. It requires minimal feed water pretreatment and has low potential of bio-fouling and scaling. However, MSF is highly energy intensive and has large investment cost.

The MEE or multi-effect boiling has been used in large scale production. However, due to severe scaling and fouling problems the plants experienced frequent shutdowns.

Applications

Thermal desalination technologies are required to produce drinking water in areas where only seawater or brackish water is available. Different types of technologies are available for desalination that can be used at different scales from small community water supply (e.g., solar distillation) to large plants for cities.

Components

Varies according to the type of technology.

Capacity

Varies according to the type of technology.

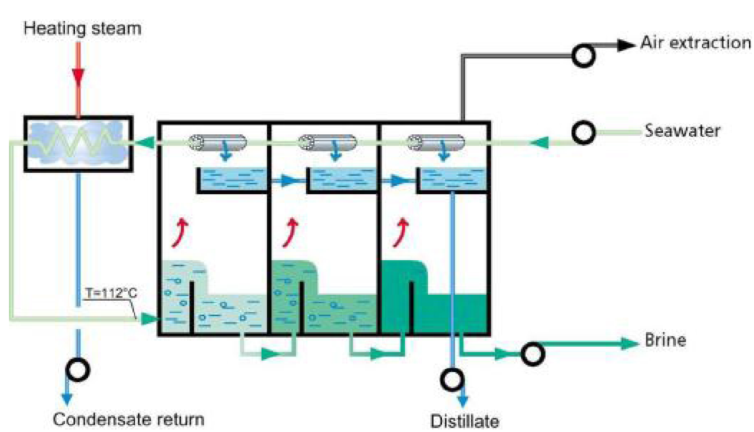
Costs

The cost of thermal desalination vary significantly depending on the size and type of the desalination plant, the source and quality of incoming feed water, the plant location, site conditions, qualified labor, energy costs and plant lifetime. As with all new technologies, progress in desalinating water has been rapid. Whereas it cost about $9.0/m^3 to desalinate seawater around 1960, the costs are now around $1.0/m^3 for the multi-stage flash distillation process. This trend is expected to continue in the future.

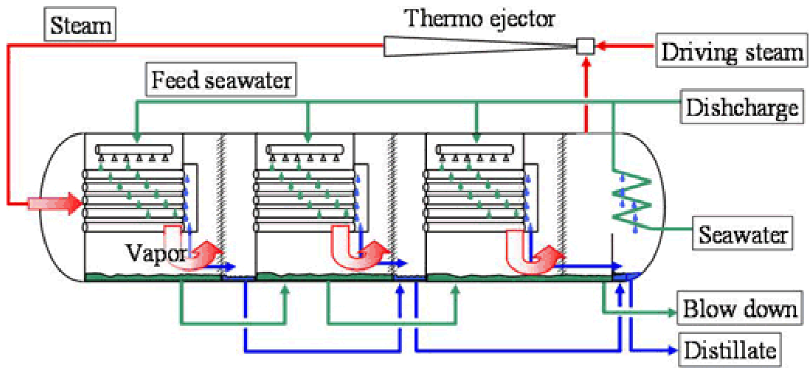
However, it should be noted that the costs of desalination still remain higher than other alternatives for most regions of the world.

Operating Principles

Multi-Stage Flash Distillation: is a process that sends the saline feed water through multiple chambers. In these chambers, the water is heated and compressed to a high temperature and high pressure. As the water progressively passes through the chambers, the pressure is reduced, causing the water to rapidly boil. This boiling causes vapor to be produced in each chamber. The vapor, which is composed of freshwater, is then is condensed and collected.

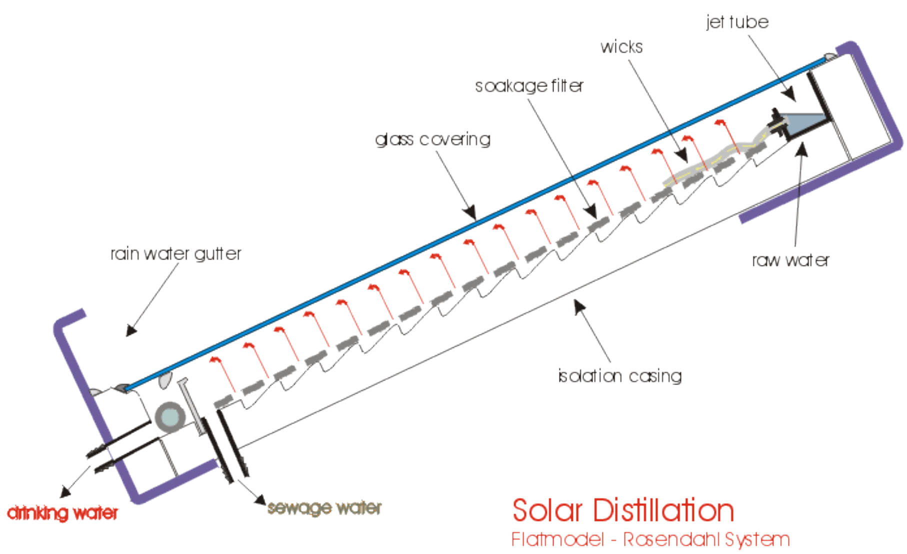


Multi-Effect Distillation: employs the same principals as the multi-stage flash distillation process except that instead of using multiple chambers of a single vessel (also known as an "effect"), multi-effect distillation uses successive vessels. A series of evaporator vessels produces water at progressively lower pressures. Water boils at lower temperatures as pressure decreases, so the water vapor of the first vessel serves as the heating medium for the second, and so on. The more vessels there are, the higher the performance ratio will be. The water vapor that is formed when the water boils is condensed and collected. The use of multiple vessels makes the multi-effect distillation process more efficient.



Vapor Compression Distillation: can function independently or be used in combination with another thermal distillation process. Vapor compression distillation uses heat from the compression of vapor to evaporate the feed water. Vapor compression distillation units are commonly used to produce freshwater for small to medium-scale purposes such as resorts, industries, and petroleum drilling sites.

Solar Distillation: is generally used for small-scale operations. Although the designs of solar distillation units vary greatly, the basic principle is the same: that the sun provides energy to evaporate freshwater from saline water.



In solar distillation, the water vapor formed from the evaporation process condenses on a clear glass or plastic covering and is collected as freshwater in a condensate trough.

The covering is used to both transmit radiant energy and allow water vapor to condense on its interior surface. The salt and un-evaporated water left behind in the still basin form the brine solution that must be discarded appropriately. Solar distillation is often used in arid regions where safe freshwater is not available. Solar distillation units produce differing amounts of freshwater, according to their design and geographic location. Recent tests on four solar still designs by the Texas AgriLife Extension Service in College Station, Texas, have shown that a solar still with as little as 0.7 square meter surface area can produce enough water for a person to survive.

Utility & Efficiency

Pure water produced by desalination processes is corrosive and not appropriate for human consumption. Thus, re-mineralization (e.g. limestone dissolution) is required before distribution and consumption.

Reliability

Highly reliable if plant is properly maintained.

Replication Potential

Technologies available are adapted to many scales from small to large communities.

Regulatory/Institutional Issues

Requires expert design, and supervision

Operation and Maintenance

Desalination plants' Operation and Maintenance depends on the technology used. For instance, multi-stage flash distillations require trained technicians to operate and maintain the plants.

The MSF technology has excellent process reliability and the ability to continuously operate for duration more than two years. It requires minimal feed water pretreatment and has low potential of bio-fouling and scaling. However, MSF is highly energy intensive and large investment costs.

Brine Management: Thermal desalination processes produce a stream of brine water. The brine water has a high concentration of salt and other minerals or chemicals that were either removed during the desalination process, or added to pre-treat the feed water. For all of the processes, the brine must be disposed of in an economical and environmentally friendly way.

Options for discharging the brine include discharge into the ocean, injection through a well into a saline aquifer, or evaporation. In all cases, the brine water should have a minimal impact on the surrounding water bodies or aquifers. Specific considerations for the water quality include saline concentration, water temperature, dissolved oxygen concentrations, and any constituents added as pre-treatment.

Mineralization of Water After Desalination: The lack of dissolved minerals in the high-purity water produced by desalination processes raises some problems. High-purity water tends to be highly reactive and, unless treated, it can create severe corrosion difficulties during its transport in conventional pipelines. Also, untreated desalinated water cannot be used directly as a source of drinking water. A certain degree of re-mineralization is necessary in order to make the water palatable and for re-introducing some essential ions required for health considerations (Such as cardiovascular health).

Advantages

1. Uses an abundant water source (seawater).
2. Allows drinking water production in arid, coastal regions.
3. Many processes available can be adapted to different local contexts.

Disadvantages

1. High energy consumption or investment costs.
2. Production of highly concentrated salty water is a by-product that has to be discharged properly.
3. Desalinated water has to be re-mineralized before it becomes drinking water.

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TECHNOLOGY

Membrane Based Desalination

SOURCE Desalination

Description

Membrane based desalination technologies mainly include reverse osmosis (RO) for seawater and electrodialysis for brackish water. RO membranes are impermeable to salt and infinitely permeable to water. Whereas ED membranes are permeable to water and selectively permeable to cations or anions, and have low electrical resistance.

Compared to thermal distillation, membrane based desalination processes purify salt water based on molecular size and charge, require less energy and their modular design allow scaling up or down easily

Design Criteria

Availability of energy, quality of water streams and technology available in the place will govern the design criteria.

Applications

Membrane desalination technologies are emerging and advanced than thermal desalination technologies. The choice depends on the local conditions and accessibility of advanced membrane technology. A number of membrane technologies have been developed for desalination that range from household scale to large centralized scale.

Components

Membranes, power (Electricity for current in ED and pumping for OR), and the necessary pre treatment and mechanical systems.

Capacity

This is applicable for household to city scale.

Costs

Advances in technologies have led to reduction in the costs rapidly. Costs of desalinated seawater around 1960 was about \$9.0/m^3 and the costs are now around \$1.0/m^3 for the multi-stage flash distillation process. The cost of brackish water desalination has now fallen to \$0.6/m^3.

Operating Principles

Electrodialysis (ED) and Electrodialysis Reversal (EDR): Electrodialysis uses the driving force of an electrical potential to attract and move different cations (positively charged ions) or anions (negatively charged ions) through the permeable membrane. The membranes used in ED are built to allow the passage of either positively or negatively charged ions, but not both. This way the process can effectively remove most of the salts from the water. Common ionic molecules in saline water are sodium, chloride, calcium, and carbonate. EDR similar to ED but the polarity of the electrodes is regularly reversed, thereby freeing accumulated ions on the membrane surface. This reversal in flow of ions helps remove scaling and other debris from the membranes, which extends the system's operating life. EDR does not require added chemicals, and eases cleaning as well.

Reverse osmosis (RO): Reverse osmosis (RO) uses a pressure gradient as the driving force to move high-pressure saline feed water through a membrane that prevents the salt ions from passing.

Since RO membrane are prone to fouling, the feed water should be sufficiently pretreated in order to prevent fouling precursors that include organic and inorganic suspended and dissolved matter as well as biological substances.

The great majority of pollutants in water and wastewater streams, such as microorganisms, endocrine disrupters, and pharmaceuticals etc. are usually completely removed or significantly reduced by reverse osmosis. One challenge with reverse osmosis is that about 15-30% of the influent is rejected, thus reducing the amount of drinking water produced.

Utility & Efficiency

Produce highest purity water free of suspended solids and dissolved substances. Pure water produced by desalination processes is corrosive and not appropriate for human consumption. Thus, re-mineralization (e.g. limestone dissolution) is required before distribution and consumption.

Reliability

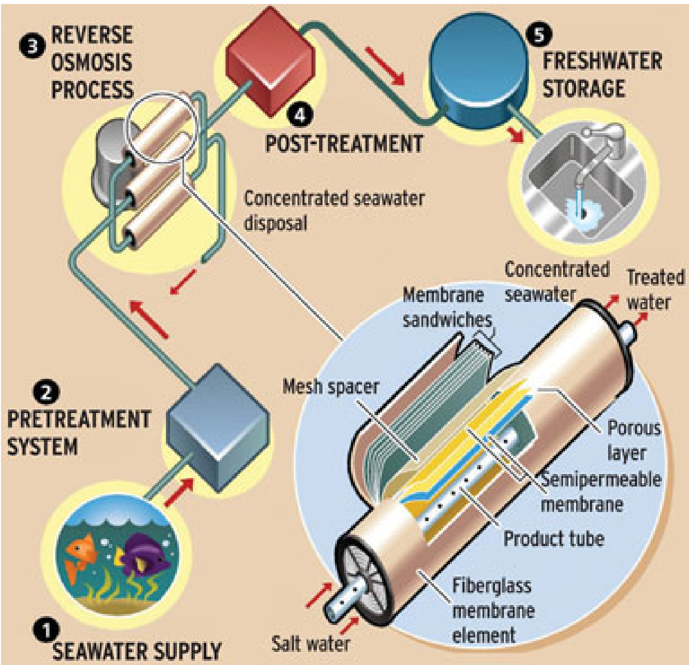
Highly reliable if plant is properly operated and maintained.

Replication Potential

Standardized designs are available and can be replicable where required.

Regulatory/Institutional Issues

Technologies are available suitable for different scales from small to large communities.



Advantages

1. Uses an abundant water source (seawater or brine water).
2. Allows drinking water production in arid, coastal regions.
3. Many processes available can be adapted to different local contexts.
4. Cheaper than thermal distillation process.
5. Modular construction and smaller footprint.

Operation and Maintenance

Operation and Maintenance involves several activities depending on the technology used and sources of water (sea water or brackish water).

Backwashing: As the desalination process continues, the membranes clog and reduce the flux and increase the energy required to produce the required amount of water. This requires frequent backwashing to restore porosity of the membranes. Backwashing is done by reversing the flow of water so that clogging materials are released from the membrane pores and surface. As backwashing may not remove all fouling substances, chemical washing is also required every now and then.

Brine Management: Membrane desalination processes produce a stream of brine water. The stream has a high concentration of salt and other minerals or chemicals that are either removed during the desalination process or added to help pre-treat the feed water. For all of the processes, the brine must be disposed of in an economical and environmentally friendly way.
Options for discharging the brine include discharge into the ocean, injection through a well into a saline aquifer, or evaporation. Each option has advantages and disadvantages. In all cases, the brine water should have a minimal impact on the surrounding water bodies or aquifers. Specific considerations for the water quality include saline concentration, water temperature, dissolved oxygen concentrations, and any constituents added as pre-treatment.

Mineralization of Water After Desalination: The lack of dissolved minerals in the high-purity water produced by desalination processes raises some problems. High-purity water tends to be highly reactive and, unless treated, it can create severe corrosion difficulties during its transport in conventional pipelines. Also, untreated desalinated water cannot be used directly as a source of drinking water. A certain degree of remineralization is necessary in order to make the water palatable and for re-introducing some essential ions required for health considerations

Disadvantages

1. High energy consumption or investment costs.
2. Production of highly concentrated salty water is a by-product that has to be discharged properly.
3. Desalinated water has to be remineralized before it becomes drinking water.
4. Membrane fouling is most challenging.

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TECHNOLOGY

Household Well

SOURCE Freshwater

SCALE Household

Description

Groundwater is one of the major sources of water supply for centralized and household level. Both deep and shallow water wells are used for the household level drinking water depending on the location of the impervious strata from which the water is obtained. The quality of groundwater varies according to the soil characteristics, catchment geology, hydrology and hydrogeology. Generally, the deeper the well, the higher quality groundwater.

Design Criteria

Different types of wells are commonly used to extract groundwater for household scales including dug wells, driven wells, and drilled wells.

Design principles of a well include initial water demand and safe yield assessment, identification of location, selection of well drilling technique, and well development and testing.

The assessment of the water balance estimation requires the collection of hydrological data, soil data, water availability prediction, and water demand analysis. The design process consists of analyzing the water aquifer, quantity and quality of water, and future recharge potential. The detailed design and standards of a specific well varies according to the local condition.

A dug well consists of three major components: the well head, the well shaft, and the intake. The well head is visible above the ground and generally has a well cover or apron, a concrete seal, a manhole, a drainage channel, and a pump. The well shaft is the section of the well between the head and the intake. The intake is generally lined (cased) with stones, brick, tile, or other material to prevent collapse. Design principles of dug wells include initial assessment, prerequisites, and construction.

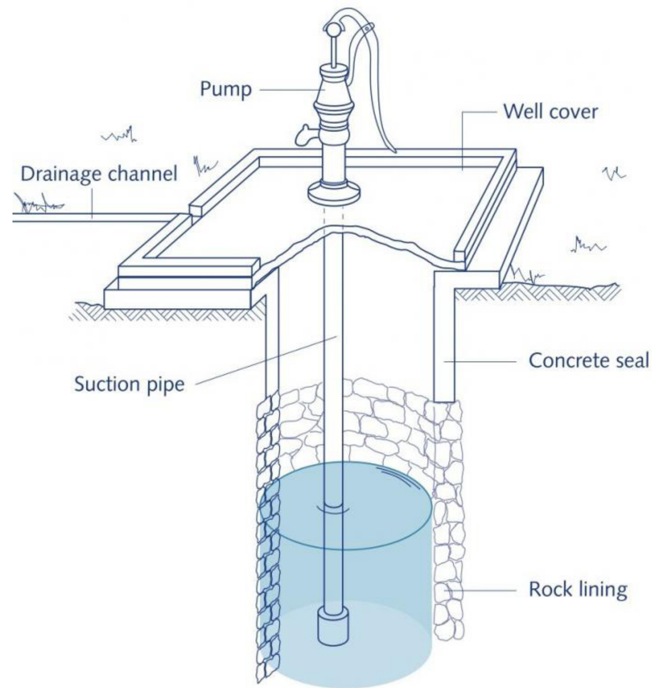
Applications

Dug wells are generally constructed in areas where the groundwater table is close to the land surface, the geologic deposits are tight and stable, and water quality is good. The dug well that are dug by hand are restricted to suitable types of ground such as clays, sands, gravels and mixed soils where only small boulders are encountered.

Components

The typical components of a well include the sanitary seal, casing, casing seal, well screen, and the pump.

A dug well consists of three major components: the well head, the well shaft, and the intake.



Dug well

Capacity

Mostly installed to meet a household scale water demand.

Costs

Depends on the groundwater level under the well and location..

Operating Principles

A hole is dug until the groundwater level is reached. A dug well gives access to an aquifer and facilitates its abstraction. Inflowing groundwater is collected and can be extracted with the help of pumps or buckets. Depths of hand-dug wells range from shallow dug wells (about 5 meter in depth) to deep dug wells (over 20 feet in depth). Dug wells act as cisterns as groundwater seeps slowly into the collection area to the same level as the surrounding water table.

The performance of the well in terms of quantity is largely determined by soil type, land uses, and depth of the well. Wells with a large diameter and depth expose a greater area for infiltration, and therefore provide fast recharge. Fluctuations, in the level of the water table may cause them to go dry and, unless they are adequately sealed to prevent infiltration of surface water, they are also vulnerable to contamination problems associated with the large annular space that typifies dug well construction.

Utility & Efficiency

Most effective for extracting water at the household scale. The efficiency depends on the types of well, methods of extraction and aquifer types.

Reliability

Technology is very simple and reliable.

Replication Potential

It can be developed where groundwater is available.

Regulatory/Institutional Issues

Development is required to follow the standard building guidelines and does not require any institution.

Operation and Maintenance

- Operation and maintenance will depend on the type of well. For example, in the case of dug wells, it will require consideration of structural maintenance and hygiene issues.
- Structural maintenance is required to ensure that a well is in good structural condition. Generally, that includes checking for any cracks, inspecting cover, improving the yield by deepening or removing infiltrated sand particles and the maintenance of the lifting device.
- Hygienic operation involves the protection and cleaning of the area (e.g. fencing and covering), checking water quality and disinfecting if necessary, monitoring the effects of withdrawal on environment and surrounding areas, and constantly educating water users in proper operation of the well and in the links of water sanitation and health.
- The pumping test shall be conducted at a constant rate for a period of at least normal operation either at the peak hourly demand, or at least 1.5 times the pump design rate if the well cannot sustain peak hourly flow.
- The groundwater can become contaminated, either directly via the well, or by pollutants seeping into the aquifer through the soil. Therefore, water quality tests (both physical and microbiological tests) should undertake to ensure the seasonal water quality variability.

Advantages

1. No skilled workers are required for the installation and operation
2. Low cost for construction and use of locally available material
3. Yield can be increased after construction
4. No substantial change of behavior required
5. Cheap source to augments city water supply
6. Mostly good quality water is available

Disadvantages

1. Motorized pump (power source) often required to extract more water from the deep water table
2. Shallow aquifers are susceptible to pollutants infiltrating from the surface (e.g. leachate from pit latrines)
3. Alteration of the groundwater level can adversely affect the surrounding environment
4. Potential of water contaminants from the neighboring environment
5. The water may contain harmful contaminants including iron, manganese and arsenic and may need advanced water treatment

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TECHNOLOGY

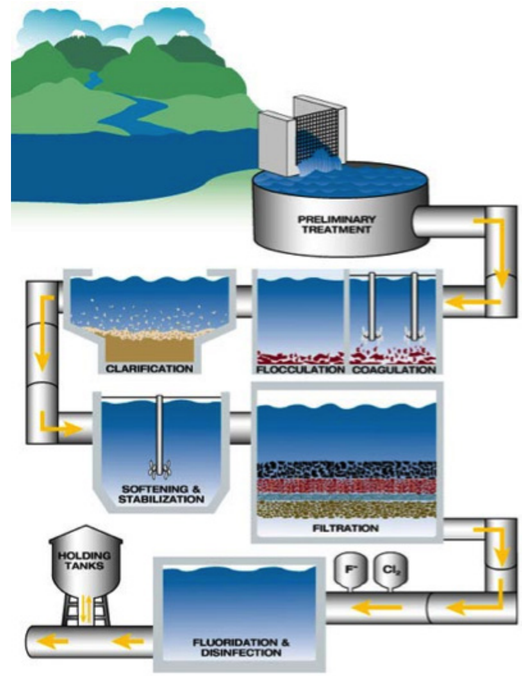
Plain Sedimentation

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Plain sedimentation, often referred to as pre-sedimentation, is used to remove easily settable sand and silt in treatment plants. In general, plain sedimentation occurs in water plants before other advanced treatment processes. The objective is to reduce the treatment loads in drinking water or wastewater processes.



Design Criteria

The design criterion of a plain sedimentation tank depends on the shape of the treatment unit, water quality (i.e., turbidity and total solid particles), water quantity, and topography.

In general, the size of a basin or tank will be 3.5 - 5 m in depth when the tank is installed without automated sediment removal, and 3 – 4 m in depth when the tank is installed with automated sediment removal. The detention time in an earthen basin varies on the order of 2 to 3 hours or more, depending on available space. Horizontal mean flow velocity is 0.05 m/s to 2 m/s during maximum daily.

Applications

Plain sedimentation is a pretreatment process to remove high turbidity and the total suspended solids in the water treatment process.

Components

Sedimentation basin and sludge removal equipment

Capacity

Capacity ranges from small to large depending on the scale of treatment and number of plants.

Costs

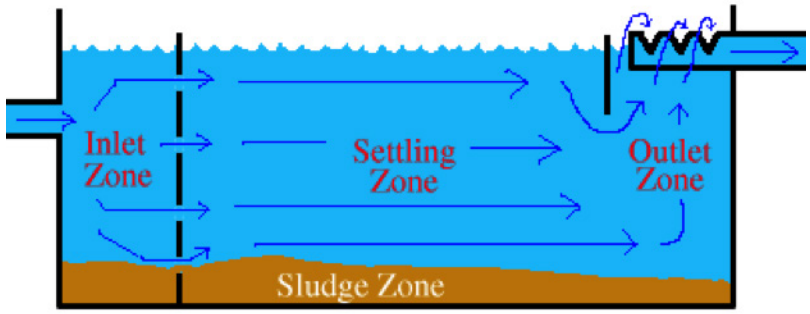
Capital costs vary depending on the capacity of a plant and local conditions. Costs for construction is very high compared to the almost negligible operating cost.

Operating Principles

Suspended particles are separated under different settling theories due to the influence of three forces acting on the particles in a fluid: gravity, buoyancy, and drag. The imbalance of these forces creates momentum. The particles settle to bottom as soon as gravity's force is big enough and the length of basin is long enough.

There are two components to particle trajectories in the settling zone: the settling velocity and the fluid velocity. For a rectangular sedimentation basin the fluid velocity is constant. The settling velocity for discrete particles is also constant in a rectangular basin because the particles do not flocculate or interfere with one another and the particle trajectories are linear. It is assumed that every particle that enters the sludge zone will be removed.

A settling tank is divided into four zones: inlet, settling, sludge, and outlet (see Figure). A particle from the inlet zone will enter at the top of the basin and settle in the sludge zone just before the outlet. Any particles in the inlet zone with a settling velocity greater than or equal to the critical settling velocity will be removed regardless of the starting position. Particles with less settling velocity may also be removed, depending on their position at the inlet. Particles at the top of the basin will pass through the settling zone and exit in the outlet zone and will not be removed. However, particles entering the sludge zone before exiting the basin will be removed.



Utility & Efficiency

The purpose of pre-sedimentation is to reduce the load of subsequent treatment processes. When the raw water has exceptionally high turbidity, plain sedimentation tanks are preferred.

The efficiency depends on factors such as flow velocity, characteristics of the suspended solids in the raw water, and hydraulic detention times (generally greater than 12 hours). The sedimentation process can remove suspended solids and reduce turbidity by about 50 to 90 percent.

Reliability

Proven technology and found reliable as per the design.

Replication Potential

The technology is very simple to construct and always replicable.

Regulatory/Institutional Issues

This is a component of process technology and will be run by the operators of water utilities. However, it is a basic unit and will not require skilled technical knowledge.

Operation and Maintenance

This is a basic and simple technology. The basic operation consists of monitoring the sludge removal rate throughout the operation period.

Advantages

1. Simple and low cost technology that reduces the treatment loads of the subsequent treatment units.
2. No chemical dosage required.
3. Most of the time it does not require electricity supply and advanced mechanical operation and control.

Disadvantages

1. More effective for settable solids such as sands, silts but not for clays and smaller microbes.
2. It requires considerable land space.
3. It could have risk of malicious influence due to its exposure to the environment.

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TECHNOLOGY

Aeration

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Aeration is an early step of the groundwater and wastewater treatment process that removes dissolved gases such as carbon dioxide and methane, as well as oxidizes dissolved metals such as iron and manganese. It can also be used to remove volatile organic chemicals (VOC) in the water. Generally, aeration processes are used in two types of water treatment applications. The first is the removal of a gas from water and is classified as desorption, or air stripping. The second is the transfer of a gas to water and is called gas absorption, or aeration.

Design Criteria

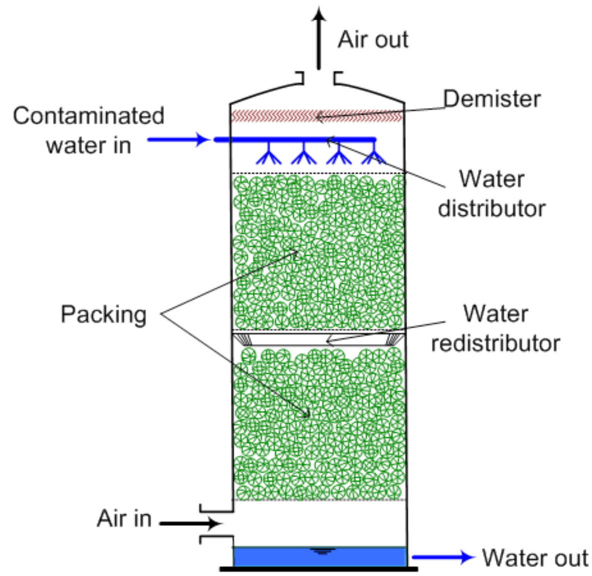
Aeration can be accomplished a variety of ways using different types of equipment including surface aeration, submerged aeration, and falling water unit. The design criteria for each type also vary with equipment used.

For example, for water treatment: i) Spray aerators—water sprayed into the air; ii) Cascade aerators and hydraulic jumps—these operate using waterfalls over a structure; iii) Fountain aerators or spray—water cascaded or sprayed over rocks or other types of material; iv) Multiple tray aerators with and without coke (often used for iron and manganese removal)—water cascaded over manufactured tray constructed from slats and coke; v) Packed column aeration—air flows up, water is sprayed down.

Packed column aeration is the most commonly used type of aeration in water treatment system (see Figure). This system has a tower that may be as tall as 10 feet, filled with packing material. This packing material can range from ¼ inch to 3 inches in size and may be pieces of ceramic or plastic. In general, the removal efficiency and the energy costs for air pumping will depend on the individual pieces of a particular type.

For the wastewater; i) Mechanical surface aerators—water is mechanically mixed to increase water to air interface. It can be achieved by either rotating a series of partially submerged circular brushes through the water surface to cause turbulence or by using a floating aerator to pump the water from beneath it up through a draft tube to the surface, which disperses water into the air; ii) Submerged Aerators, commonly used in the wastewater and water industries, can inject air with blowers by static tube or diffuser (fine bubble and coarse bubble) or by jet aeration (the injection of air into pumped water).

Fine Bubble Aeration is commonly used in wastewater treatment (see Figure). The main design consideration for fine bubble aeration is selecting a diffuser. There are many types of diffusers including porous, nonporous, and jet injectors which can fit into different local conditions. For fine bubble aeration the fine pore diffuser is chosen, which is usually made from ceramics and results in more bubble surface area per unit volume generated.



Packed tower aerator for drinking water system

Applications

Required for surface water, groundwater, and wastewater treatment to remove gases such as H_2S and CO_2, and promoting oxidation of iron and manganese.

Aeration is a very energy-intensive treatment process and may not be suitable in cases where energy supply is not possible (if it is not gravity based).

Components

Packed tower aerators for drinking water are composed of a tower, supply pumps, air blower, and influent and discharge pipes.

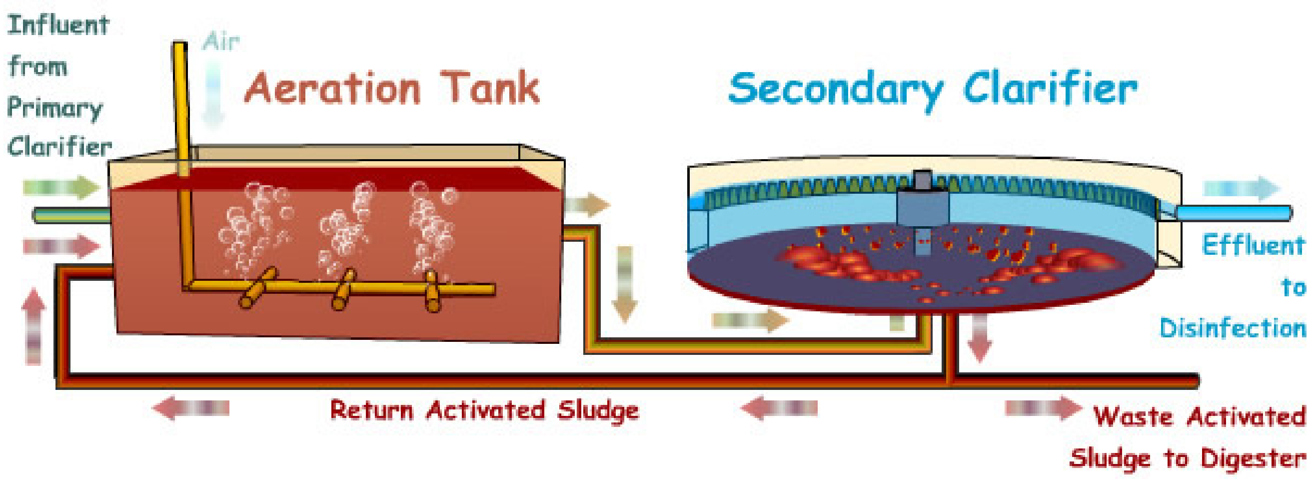
Fine bubble aerators for wastewater consists of an aeration tank, supply pumps, air blower, and influent and discharge pipes.

Capacity

The size can be flexible based on quantity of water to be treated.

Costs

The costs of construction and operation are site specific.



Fine bubble aeration tank for wastewater system

Operating Principles

When gas-free water is exposed to air, compounds such as oxygen and nitrogen will diffuse from the air into the water until the concentration of these gases in the water reaches equilibrium with the gases in the air. Conversely, if water in deep wells is drawn to the surface, dissolved gases such as methane or carbon dioxide will be released to the air because the groundwater concentrations typically exceed equilibrium conditions with air. In the case of iron and manganese, the air causes these minerals to precipitate out of solution. The water can then pass through a filter to trap the iron and manganese particles. The efficiency of aeration depends almost entirely on the amount of surface contact between the air and water.

Aeration treatment consists of passing large amounts of air through water and then venting the air to the atmosphere. The air causes dissolved gases or volatile compounds to release from the water. The goal is to allow the contaminants to volatilize into the air.

In a packed tower aerator system, water falls from the top of the tower while air is blown from the bottom of the unit in a direction opposite to the water flow. Volatile contaminants are transferred to the air by rising to the top of the tower and venting to the outside.

In the fine bubble aeration wastewater treatment process, aeration introduces air into a liquid, providing an aerobic environment for microbial degradation of organic matter. The aeration will metabolize microorganisms so that the microorganisms come into intimate contact with the dissolved and suspended organic matter.

Utility & Efficiency

Water aeration has been long used in water treatment for the removal of odor and taste-causing compounds, the oxidation of iron and manganese, as well as corrosion control and aesthetics. Aeration has been shown to be capable of removing up to 90 percent of the most highly volatile VOCs.

The effective of aeration depends upon the aeration method selected. Main factors such as air to water ratio, flow and loading rate, available area of mass transfer, temperature and pH will have direct influence on the performances.

Reliability

Reliable under well operation and maintenance condition.

Replication Potential

The technology has been widely applied worldwide and is replicable.

Regulatory/Institutional Issues

This is commonly used treatment unit. However skilled workers are required to operate the system along with the treatment process.

Operation and Maintenance

Aeration raises the dissolved oxygen content of the water. If too much oxygen is injected into the water, the water becomes supersaturated, which may cause corrosion or air binding in filters. Other problems with aeration are slow removal of the hydrogen sulfide from the towers, algae production, clogged filters, and overuse of energy. The amount of aeration needed will vary from plant to plant and will also vary with the season.

The packed columns aerators, in the case of water treatment, are operated automatically. Only daily supervision should ensure that all equipment is running satisfactorily. Maintenance requirements generally involve to service pump and blower motors and to replace air filter on the blowers, if necessary.

In wastewater, It is essential that fine bubble aeration diffusers be kept clean through cost-effective preventive maintenance procedures. Preventive maintenance can virtually eliminate air-side (blower filtration system) particulate fouling of fixed fine pore diffusers. Preventive maintenance is needed to keep an aeration system operating at the required level of performance and to decrease the need for corrective maintenance. In addition, preventive maintenance will reduce the number of interruptions in the air supply, thus preventing solids from entering the air distribution system.

Advantages

1. Packed tower aerator ensures:

   a. High flow capacity;

   b. Removes difficult to strip compounds;

   c. Low liquid pressure drop;

   d. Proven technology.

2. Fine bubble aeration for wastewater exhibits:

   a. High oxygen generation rate;

   b. High aeration efficiencies (mass oxygen transferred per unit power per unit time), satisfy high oxygen demands;

   c. Easily adaptable to existing basins for plant upgrades;

   d. Result in lower volatile organic compound emissions than nonporous diffusers or mechanical aeration devices.

Disadvantages

1. Packed tower aerator:

   a. Fouling results in loss of efficiency;

   b. Increased pressure drop;

   c. High gas pressure drop;

   d. Transportation/set t up more complex than low-profile systems, channeling of water through packing may short-circuit treatment, highly visible.

2. Fine pore diffusers:

   a. Susceptible to chemical or biological fouling, which may impair transfer efficiency and generate high head loss. As a result, they require routine cleaning.

   b. Susceptible to chemical attack (especially perforated membranes). Therefore, care must be exercised in the proper selection of materials for a given wastewater.

   c. Energy intensive

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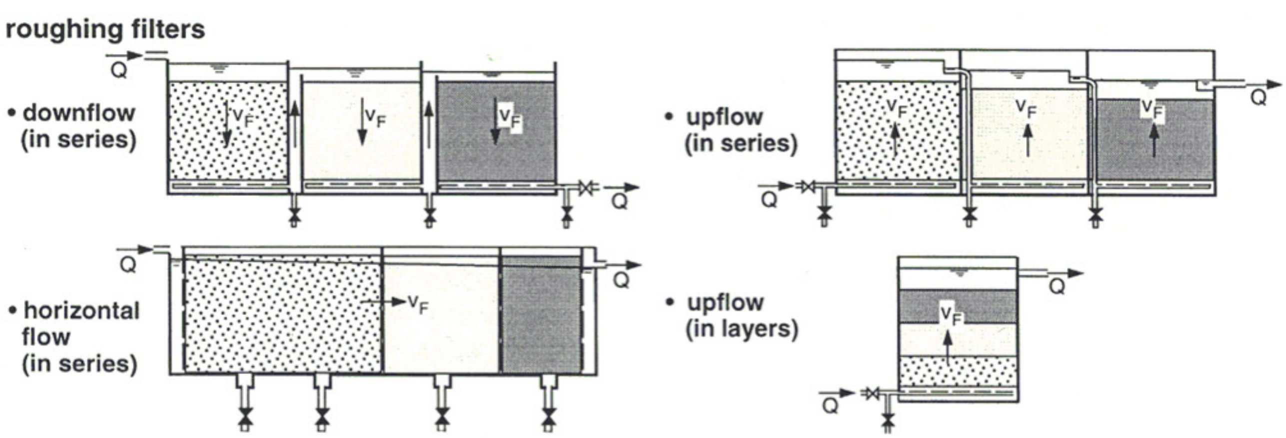
Roughing Filter

SOURCE Freshwater

SCALE Semi-centralized and Centralized



Different types of roughing filters

Description

Roughing filtration (RF) is a pretreatment process prior to slow sand filtration to reduce the turbidity and suspended solids matter in raw water. In this process turbid water flows through a bed of coarse media such as gravel or burnt clay pottery pieces. The gravel fractions of roughing filters are either installed in separate compartments and operated in series, or placed in layers of different sized gravel in the same compartment.

Design Criteria

Roughing filters usually consist of differently sized filter material decreasing successively in size in the direction of flow. The design criteria are based on the filtration rate, sizes of the gravels, turbidity of water and types of the flow. Roughing filters are usually composed of three gravel fractions. The size of the filter material usually ranges between 4 and 20 mm. The bulk of the solid matter is removed by the coarse filter fraction, the medium sized gravel has a polishing effect, and the finest gravel ought to remove only the remaining traces of solid matter.

Roughing filters are operated at small hydraulic loads - filtration velocity is usually in the order of 0.3 - 1.5 m/h. The applied filtration rate significantly influences filter performance, although removal efficiency is not affected in between varying filtration rates of 0.3 and 0.6 m/h.

Roughening filters can be operated as up-flow, down-flow or horizontal-flow types. The depth of up-flow and down-flow roughing filters is limited by structural constraints; however, it is generally between 80 - 120 cm. The horizontal flow roughing filters is, in this respect, not limited. However, length of the filter material is dependent on the filter type. Overall length normally lies within 5 and 7 m.

Applications

These are appropriate pretreatment technology for rural and urban water supply schemes where the turbidity level of water is too high for the sand filtration process.

Components

Comprises inlet flow control, raw water distribution, actual filter, treated water collection, outlet flow control, and drainage system.

Capacity

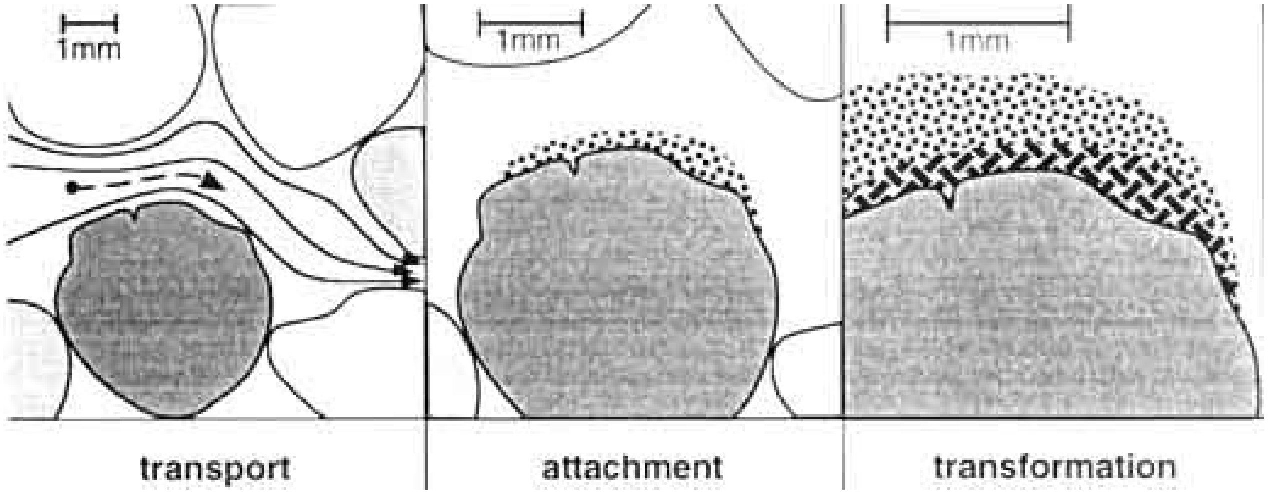
Flexible and can be applicable from smaller units to the largest treatment plants.

Costs

The cost of a roughing filter is quite cheap; up-flow roughing filters are relatively cheaper and easier to clean than down-flow or horizontal flow filters.

Operating Principles

Removal of suspended solids by roughing filters is achieved by sedimentation, adsorption and biological as well as bio-chemical activities. Basically, solid particles have to be transported to a surface and remain attached to that surface before they are transformed by biological and biochemical processes. The main mechanisms of these three processes include:



Operating principles of roughening filter

Transportation mechanisms

- Screening removes particles larger than the pores of the filter bed. The smallest pore sizes are roughly one sixth of the gravel size.
- The sedimentation process separates settable solids by gravity. The settling velocity depends on mass density, size and shape of the particle, viscosity, and hydraulic conditions of the water.
- The inception process enhances particle removal through gradual reduction of the pore size caused by accumulated material.

Attachment mechanisms

- Adsorption process by mass attraction and electrostatic force enable the particles to keep in contact with other solids and the filter material.
- Bacteria and other microorganisms will form a sticky and slimy layer around the gravel or may build a large chain of organic material floating in the pores of the filter material.

Transformation mechanisms

- Biochemical oxidation starts to convert organic matter into smaller aggregates and finally into water, carbon dioxide, and inorganic salts.
- Part of the dissolved matter is subjected to chemical and biochemical reactions.
- Turbidity and color also undergoes change as iron and manganese traces are precipitated and removed.

Utility & Efficiency

It is often used to pretreat water by removing suspended solids from incoming water prior to a slow sand filter. It also partly improves the bacteriological water quality and to a minor extent, changes other water quality parameters, such as color or amount of dissolved organic matter.

The treatment efficiency depends on the raw water characteristics, layout and operation of roughening filters. Several factors including, size, concentration, type of particles and suspension stability influence the filter efficiency.

Reliability

Reliable if the plant is designed and operated.

Replication Potential

It is predominantly designed for suburban and rural water supply systems.

Regulatory/Institutional Issues

The treatment is very simple and will be operated as one of the units of the treatment system.

Operation and Maintenance

This is a simple technology that requires less skilled operators for its operation and maintenance. Main O&M activities will be related to monitoring the turbidity level, regulating the flows and checking the filter media. For example:

- Regulating the water flow and checking the turbidity of the effluent
- Periodic filter cleaning is required-roughing filters
- Occasionally, repair or replace of the faulty valves

Advantages

1. The process does not require any chemical and external energy supply.
2. Large solid storage capacity at low head loss.
3. High sludge storage space lengthen filter run.
4. No skilled operators are required.

Disadvantages

1. Low hydraulic load results need of larger size roughing filter and more space.
2. Sludge management and filter cleaning needs regular attention.
3. Color removal is fair to poor.
4. It can handle only relatively low organic loads.

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TECHNOLOGY

Sedimentation after the Coagulation & Flocculation

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Refer to Conventional Surface Water Treatment section for Coagulation and Flocculation Process

Description

Sedimentation is a physical pretreatment of water prior to application of other purification treatments such as filtration and disinfection. The sedimentation process removes undesirable small particulate suspended matter (sand, silt and clay) and some biological contaminants from water under the influence of gravity. Sedimentation following chemical coagulation and flocculation is used to remove settable solids that have been rendered more settable by chemical treatment, such as the addition of coagulants to remove color and turbidity and the addition of lime and soda ash to remove hardness.

Design Criteria

Centralized sedimentation tanks form an integral part of a treatment cycle combining pure sedimentation with coagulation flocculation, filtration, disinfection, and storage facilities.

Selection of physical size and capacity of the sedimentation tanks will be based on the water quality and quantity to be treated in a system as well as coagulants and flocculants used in the water treatment process. The shape of sedimentation tanks could be either rectangular, square, or circular. Rectangular and circular sedimentation are the most commonly used shapes.

The inlet to a rectangular sedimentation basin should be designed to distribute the flocculated water uniformly over the entire cross section of the basin at low velocity, generally ranging from 0.15 to 0.6 m/s.

The basic design criteria to be considered for the horizontal-flow settling zone are surface loading rate, effective water depth, horizontal flow velocity, and minimum length-to-width ratio. Generally, it consists of typical surface loading rate of 1.25-2.5 m/h; horizontal flow velocity of 0.3-1.1 m/min; effective water depth around 3-5m; and minimum length-to-width ratio is 15:1.

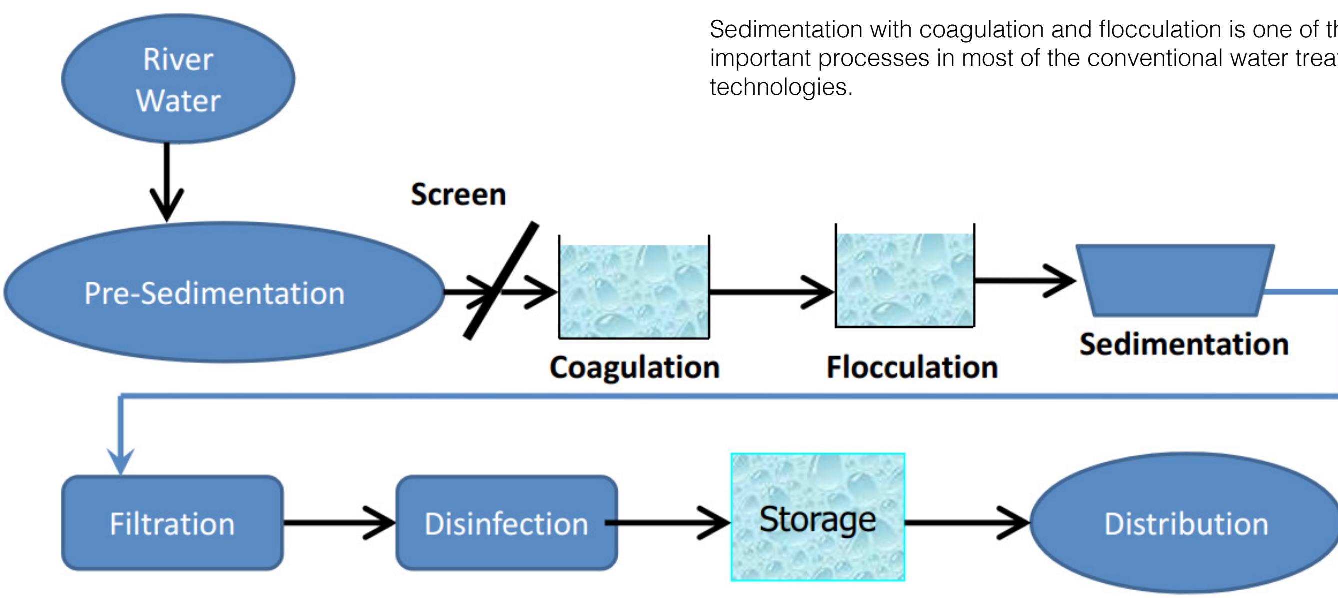
Water leaving the sedimentation basin should be collected uniformly across the width of the basin. The bottom of the basin is typically sloped towards a sludge hopper to facilitate sludge removal.

Circular tanks will have center feed with radial flow, peripheral feed with radial flow, or peripheral feed with spiral flow. The inlet structure used for center-feed configurations is a circular weir around the influent vertical rise pipe. For peripheral-feed tanks, the weir is located around the perimeter of the tank.

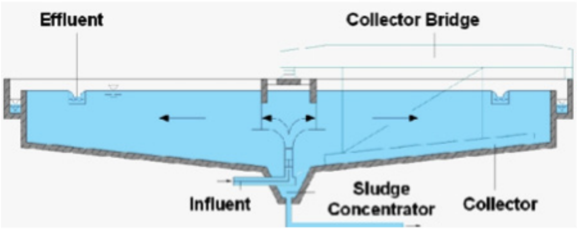
Applications

Sedimentation is always recommended prior to application of other purification treatments such as filtration and disinfection methods.

Sedimentation with coagulation and flocculation is one of the important processes in most of the conventional water treatment technologies.



Different types of roughing filters



Circular sedimentation tank

Components

Primarily the sedimentation basin and sludge removal equipment.

Capacity

Very flexible and can be applicable for smaller units to the largest treatment plants.

Costs

The main cost is associated with the construction. Operation and maintenance cost is very low.

Operating Principles

With or without adding coagulants, raw water is allowed to stand still in a sedimentation tank or basin until solid particles have settled to the bottom. One of the forces playing a dominant role in stabilization results from the surface charge present on the particles. Most solids suspended in water possess a negative charge and since they have the same charge sign, repel each other when they come close together. Therefore, they will remain in suspension rather than clump together and settle. Adding chemical or natural coagulants such as aluminum sulphate, polyaluminium chloride, and ferric sulphate, destabilizes the particles' charges. Once the charge is neutralized, the small-suspended particles stick together as a floc. As the water moves very slowly through these basins the flocs settle to the bottom of the basin. The floc that falls to the bottom of the basins is collected into a hopper by large rotating scrapers where it is removed several times daily by the plant operators (see Figure the process).

Utility & Efficiency

It has been used for reducing the solids load after coagulation and flocculation.

Sedimentation may remove suspended solids and reduce turbidity by about 50 to 90 percent, depending on the nature of the solids, the level of pretreatment provided, and the design of the clarifiers.

Reliability

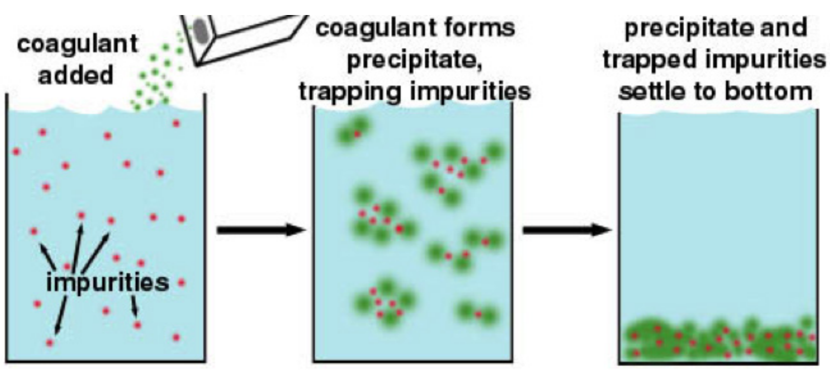
Reliable if the coagulations and flocculation systems are designed and operated properly.

Replication Potential

It is a proven technology that is replicable anywhere.

Regulatory/Institutional Issues

Requires expert design and supervision.



Sedimentation process after coagulation and flocculation

Operation and Maintenance

The operation and maintenance process depends on the sizes of the water treatment plants, turbidity in the water, and types of coagulants used for the treatment process.

The coagulants used for the treatment process requires accurate dosing equipment to function efficiently. Operational staff must be adequately trained to carry out jar tests.

Regular sludge removal is required either manually or by mechanical sludge removal equipment. For manual sludge removal systems, water is drained from the basin and pressurized water is used for solid flushing sludge. If the mechanical sludge scraper equipment is used, it has to be periodically inspected for its designed performances.

The sedimentation chamber needs to be emptied and cleaned on a regular basis to avoid overfilling and microbial contamination regardless of the turbidity level.

Advantages

1. This is a very simple and low cost water pretreatment technology.
2. Coagulants reduce the time required to settle out suspended solids.
3. Natural coagulants can sometimes be obtained for free or at a low cost.
4. Coagulation can also be effective in removing protozoa, bacteria and viruses, particularly when polyelectrolyte is used.
5. Certain contaminants such as lead and barium can be also effectively removed by coagulation.

Disadvantages

1. Maximum effectiveness requires a careful control of coagulant dose and pH, and consideration of the quality of the water being treated.
2. Some coagulants (e.g. polyelectrolytes) are expensive.
3. Coagulants may be toxic if used improperly.
4. Trained operators are required for dosing coagulant and undertaking jar testing.
5. Sedimentation isn't an effective process for removing dissolved chemicals.

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TECHNOLOGY

Disinfection

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

The disinfection process is essential to ensure the microbial safety of the treated water. The two most common methods to eliminate microorganisms in the water supply are oxidation with chemicals such as chlorine or ozone or irradiation with ultraviolet (UV) radiation. The most widely used chemical disinfection systems are chlorination, chloramination and ozonation.

Design Criteria

Chlorination

Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and on-site chlorine generators.

Chlorine dose is the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection. The chlorinator capacity must maintain at least 2 mg/L of free chlorine residue in the water for an effective contact time once all demands are met.

Different techniques of chlorination commonly used include breakpoint chlorination, marginal chlorination and superchlorination/dechlorination.

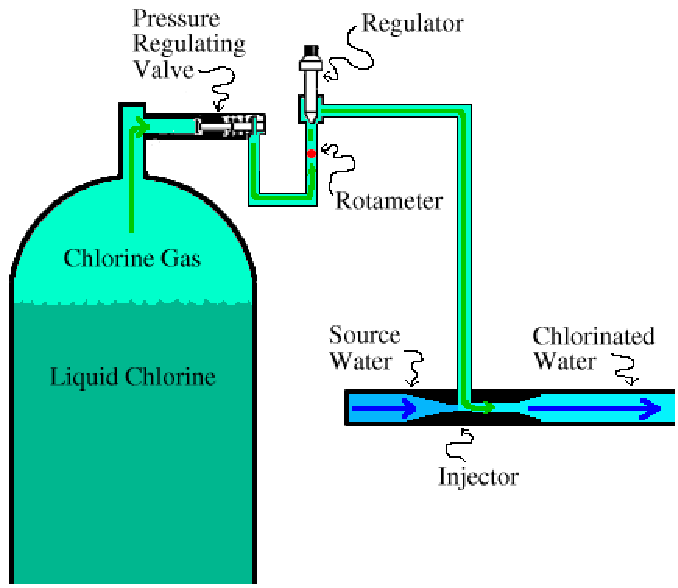
Breakpoint chlorination is a method in which the chlorine dose is sufficient to rapidly oxidize all the ammonia nitrogen in the water, leaving enough free residual chlorine available to protect the water against reinfection from the point of chlorination to the point of use.

Superchlorination/dechlorination is the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction, followed by reduction of excess free chlorine residual. It is used mainly when the bacterial load is variable or the detention time in a tank is not enough.

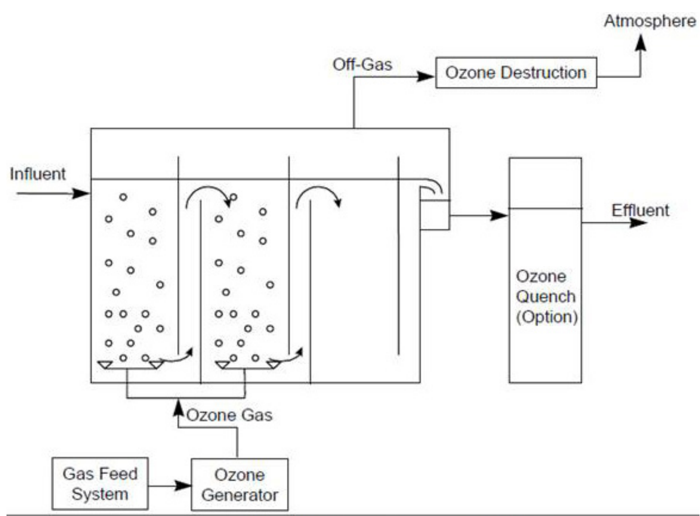
Marginal chlorination, used when to treat high-quality water supplies, is the simple dosing of chlorine to produce the desired level of free residual chlorine. The chlorine demand in these supplies is very low, and a breakpoint may not occur.

Ozone (also discussed in advanced oxidation process section)

Ozone gas (O3), formed by passing dry air or oxygen through a high-voltage electric field and emitted directly into the water through porous diffusers at the base of baffled contactor tanks. The contactor tanks, typically about 5 m deep, provide 10 – 20 minutes of contact time. Dissolution of at least 80% of the applied ozone should be possible, with the remainder contained in the off-gas, which is passed through an ozone destructor and vented to the atmosphere.



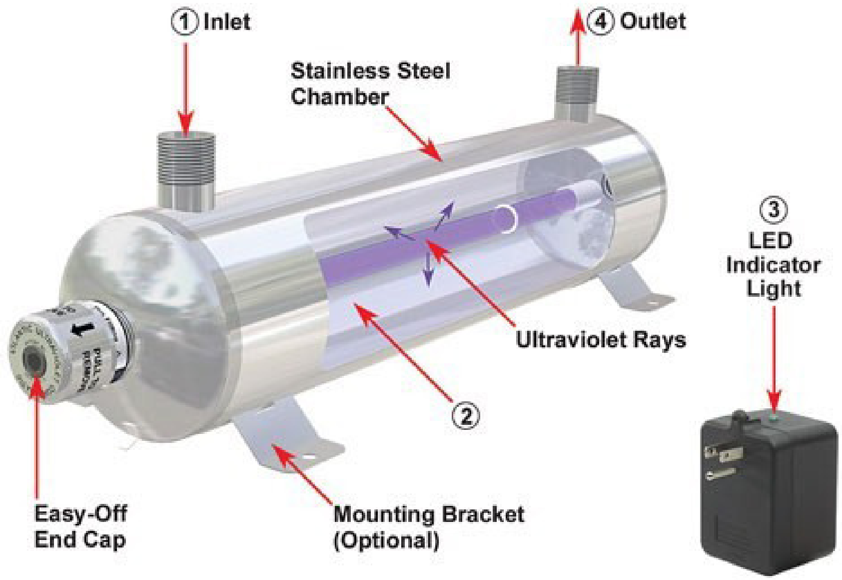
Chlorination



Ozonation

UV

UV disinfection is to produce UV radiation by powering UV lamps. The lamps typically used in UV disinfection consist of a quartz tube filled with an inert gas, such as argon, and small quantities of mercury. UV radiation is emitted by a low-pressure or medium-pressure mercury arc lamp with wavelengths of 180 and 320 nm. UV radiation quickly dissipates into water to be absorbed or reflected off material within the water.



Ultraviolet Radiation

Applications

Chlorine is a widely used disinfectant for water and wastewater treatment. However, alternative disinfectants are recommended for water with high concentrations of organic matter as chlorine may generate high-risk by-products.

Ozone is normally applied in drinking water in combination with chlorine. Ozone disinfection is also applied in wastewater treatment after at least secondary treatment. In addition to disinfection, another common use for ozone in wastewater treatment is odor control.

The UV process is affordable and popular with small-scale facilities but is not as effective as other disinfectants on surface water supplies with a high concentration of suspended particles. Turbidity can inhibit UV disinfection.

Components

Chlorination: Contact reactor, disinfectant storage or generation equipment, and disinfectant supply system.
Ozonation: Gas feed system, ozone generator, ozone contactor, and off-gas destruction system.
UV: UV lamp and UV contactor.

Capacity

All the options are very flexible and can be applicable from smaller units to the largest treatment plants.

Costs

The cost depends on raw water quality and type of disinfectant technology.

Operating Principles

Chlorination is achieved through the utilization of chlorine gas, sodium hypochlorite, or calcium hypochlorite. Chlorine dioxide disinfects drinking water that lead to the deactivation of microorganisms determining specific chemical reactions between chlorine dioxide and biomolecules. Chlorine dioxide deactivates viruses by altering the viral capsid proteins and disrupting of protein synthesis.

Chlorine gas hydrolyzes rapidly in water to form hypochlorous acid (HOCl) and dissociates slightly into a hydrogen ion. Sodium hypochlorite is produced when chlorine gas is dissolved in a sodium hydroxide solution. Sodium hypochlorite solution typically contains 12.5 percent of available chlorine. The application of sodium hypochlorite to water produces hypochlorous acid, similar to chlorine gas hydrolysis. However, unlike chlorine hydrolysis, the addition of sodium hypochlorite to water yields a hydroxyl ion that will increase the pH of the water. In addition, excess sodium hydroxide is used to manufacture sodium hypochlorite, which will further increase the pH of the water.

Calcium hypochlorite is formed from the precipitate that results from dissolving chlorine gas in a solution of calcium oxide (lime) and sodium hydroxide. The granular calcium hypochlorite commercially available typically contains 65 percent available chlorine.

Ozone water treatment systems have four basic components: a gas feed system, an ozone generator, an ozone contactor, and an off-gas destruction system. The gas feed system provides a clean, dry source of oxygen to the generator. The ozone contactor transfers the ozone-rich gas into the water to be treated, and provides contact time for disinfection (or other reactions). The final process step, off-gas destruction, is required as ozone is toxic in the concentrations present in the off-gas. Some plants include an off-gas recycle system that returns the ozone-rich off-gas to the first contact chamber to reduce the ozone demand in the subsequent chambers. Some systems also include a quench chamber to remove ozone residue in solution.

Because of its high oxidation potential, ozone oxidizes cell components of the bacterial cell wall. This is a consequence of cell wall penetration. Once ozone has entered the cell, it oxidizes all essential components (enzymes, proteins, DNA, RNA). When the cellular membrane is damaged during this process, the cell will fall apart.

UV radiation is efficient to deactivate protozoa, bacteria, bacteriophage, yeast, viruses, fungi and algae through electromagnetic radiation. The most potent wavelength for damaging deoxyribonucleic acid (DNA) is approximately 254 nm. Other UV wavelengths, such as 200 nm, have been shown to exhibit peak absorbance in aqueous solutions of DNA.

The germicidal effects of UV light involve photochemical damage to the RNA and DNA within the microorganisms. Microorganism nucleic acids are the most important absorbers of light energy in the wavelength of 240 to 280 nm. DNA and RNA carry genetic information necessary for reproduction; therefore, damage to either of these substances can effectively sterilize the organism. Damage often results from the dimerization of pyrimidine molecules.

Utility & Efficiency

Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal or chemical conversion of some chemicals - for example, decomposition of easily oxidized pesticides; oxidation of dissolved species (e.g. manganese to form insoluble products that can be removed by subsequent filtration) and oxidation of dissolved species to more easily removable forms (e.g. arsenite to arsenate).

Ozone is very effective against bacteria. However, protozoan cysts are much more resistant to ozone than vegetative forms of bacteria and viruses. Typically, viruses are more resistant to ozone than vegetative bacteria.

UV disinfection has been determined to be adequate for deactivating bacteria and viruses. Most bacteria and viruses require relatively low UV dosages for deactivation. Protozoan, in particular Giardia and Cryptosporidium, are considerably more resistant to UV deactivation than other microorganisms.

Reliability

Reliable if proper dosage and contact time are maintained.

Replication Potential

Chlorine is one of the most popular disinfectants worldwide, particularly in developing countries. Ozone and UV are also common in wastewater recycle and advanced treatment technology and applied in numerous treatment plants.

Regulatory/Institutional Issues

The process of creating chlorine dioxide is complicated; it requires skilled technicians and careful monitoring.

The operation of ozone and UV systems requires skilled personnel.

The treatment process will require set regulations and standards for the quality control.

Operation and Maintenance

The operation and maintenance process depends on the type of disinfection process. For example, there could be different forms of chlorination used such as liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and on-site chlorine generators.

Chlorine gas is a strong oxidizer and fire codes typically regulate the storage and usage of chlorine. Local safety management standards and regulations must be considered during the design and operation of chlorination facilities at a water treatment plant.

Sodium hypochlorite solution is a corrosive liquid with an approximate pH of 12. Therefore, typical precautions for handling corrosive materials such as avoiding contact with metals, including stainless steel, should be used.

Calcium hypochlorite is an oxidant and as such should be stored separately from organic materials that can be readily oxidized. It should also be stored away from sources of heat. Improperly stored calcium hypochlorite can cause spontaneous combustion fires.

Ozone is an unstable molecule; it should be generated at the point of application for use in water treatment. Backup units are usually installed. Generators should be checked daily when in operation. After a shutdown, dry air or oxygen should be allowed to flow through the generator to ensure that all moisture has been purged prior to energizing the electrodes.

On-site pilot plant testing is recommended to determine the efficiency and adequacy of UV disinfection for a specific quality of water. The efficiency test involves injecting select microorganisms into influent water and sampling effluent water to determine survival rates.

Advantages

1. Chlorine is an inexpensive treatment option used to improve water's taste and clarity while killing many microorganisms like bacteria and viruses.
2. Residual amounts of chlorine remain in treated water supplies. This chemical content continues to protect treated water from reinfection, and can be beneficial for water subjected to long periods of storage or time-consuming distribution over large areas.
3. Chlorine dioxide is effective against Giardia, bacteria, viruses, and to some extent, Cryptosporidium
4. Ozone can effectively eliminate biological contaminants like bacteria, viruses, Giardia, Cryptosporidium and organic chemicals.
5. UV disinfection is chemical-free and requires only a simple and affordable infrastructure investment.

Disadvantages

1. Giardia and Cryptosporidium are generally resistant to chlorine unless it is used in higher doses than those generally preferred for treatment.
2. Too much residual chlorine may also produce chemical byproducts, some of which may be carcinogenic.
3. The process of creating chlorine dioxide is complicated. It requires skilled technicians and careful monitoring.
4. Ozone cannot provide lasting residual protection.
5. Ozone has been known to produce unwanted byproducts, such as bromate, which may be harmful to human health.
6. UV disinfection has limited protection time. Exposure to UV rays is a one-time process that kills microorganisms, but does not prevent them from returning again.

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TECHNOLOGY

Rainwater Tank

SOURCE Rainwater/Stormwater Use

SCALE Household

Description

Rainwater harvesting refers to the collection of rainfall from the roof of a building. Its main objective is to reduce water demand from municipal water supply through its subsequent use for non-potable applications, such as water closet flushing, garden watering, car washing, etc. Rainwater harvesting is also useful in areas having significant rainfall but lacking any kind of conventional, centralized supply system, and also in areas where good quality of fresh surface water or groundwater is not available.

Design Criteria

Rainwater harvesting (RWH) is considered feasible if annual average rainfall in an area is more than 400 mm. Field research shows that efficiencies of rooftops range from 70% to 90% of rainfall based on the slope of the roof and roofing materials.

Rainwater tank designs require a solid secure cover, a coarse inlet filter, an overflow pipe, a manhole, sump, and drain to facilitate cleaning. Three basic types of systems for supplying non-potable water to buildings for internal and external uses include directly pumped, indirectly pumped, and gravity fed.

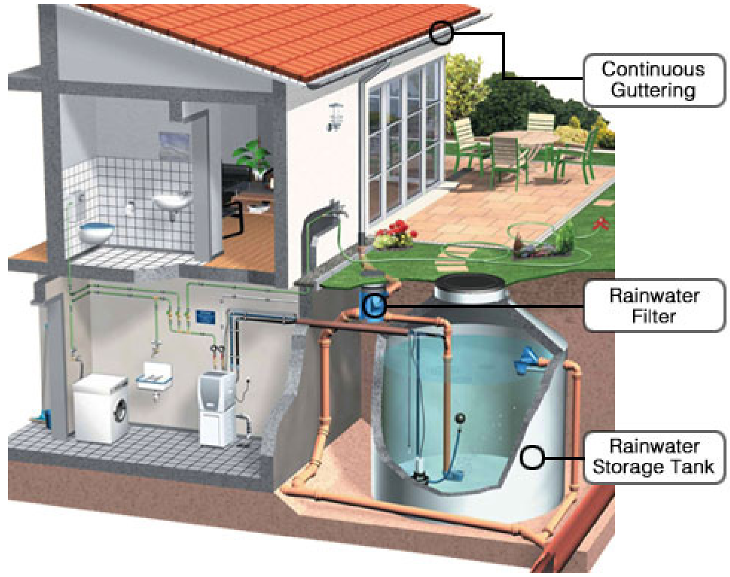
Collection area: A chemically inert roof surface area such as slates is preferred. Metal roof coverings are acceptable but the slightly acidic nature of rainwater can produce some dissolution of metal ions from the surface.

Green or planted roofs can also be used as a catchment area for rainwater systems. This type of roofing system can retain in excess of 50% of the incidental rainfall and is capable of filtering the rainwater depending upon the composition of its substrata.

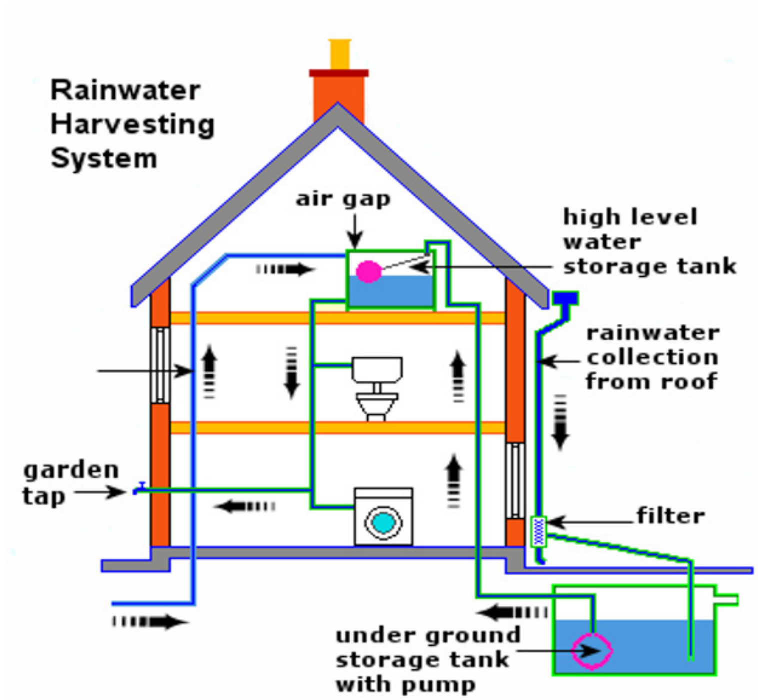
First flush diverters: The first flush of rainwater from the roof is usually more polluted than subsequent runoff. Collecting and discharging of the first flush before it enters the rainwater tank improves water quality significantly. Various designs for first flush diverters exist for initial separation of rainwater.

Treatment: For non-potable applications rainwater usually only needs filtration prior to entry into the storage tank. A range of different filter types including screen, cross-flow, cartridge, slow sand, rapid sand, membrane and activated carbon filters are commonly installed.

Storage: The storage tank is an essential component of RWH system, which can be constructed from a variety of materials such as plastic, concrete or steel. The preferred location is below ground sheltered from daylight, which minimizes algal growth in the collected water. In addition to the initial filtration, further treatment occurs within the storage tank via flotation and settlement. The storage tank should be designed to flush out at least twice a year to facilitate the removal of these particles.



Rain water harvesting systems



Rain water harvesting system

Applications

This technology is suitable for use in all areas as a means of augmenting water availability. In general RWH is suitable for an area with annual average rainfall of more than 400 mm; having suitable roofs and/or other catchment surfaces; and skilled manpower to maintain the system periodically if a treatment system is included.

Components

RWH systems require a pipe network for the collection, storage systems, a set of treatment systems including first flush.

Capacity

It varies from small to large size based on the rainfall patterns, size of the roof, and purpose of the collected water.

Costs

The cost of this technology varies considerably depending on location, type of materials used, pumping requirements, and whether there is a need for treatment or not.

The cost of a 30 m^3 cistern in rural areas of the Northeast Brazil, is around US $900 - $1000, depending on the material used. In the U.S. Virgin Islands, costs as low as $2 to $5 per 1000 Liters are reported.

Construction costs for underground cisterns can vary tremendously, based on the size and the amount of excavation required. In Saint Lucia, the average cost of a 1500 L plastic tank is $125.

Operating Principles

A rainwater harvesting system consists of three basic elements: a collection area, a conveyance system, and storage facilities. The collection area in most cases is the roof of a house or building. The effective roof area and the material used in constructing the roof influence the efficiency of collection and the water quality.

A conveyance system usually consists of gutters or pipes that deliver rainwater falling on the rooftop to cisterns or other storage vessels. Both drainpipes and roof surfaces should be constructed of chemically inert materials such as wood, plastic, aluminum, or fiberglass, in order to avoid adverse effects on water quality.

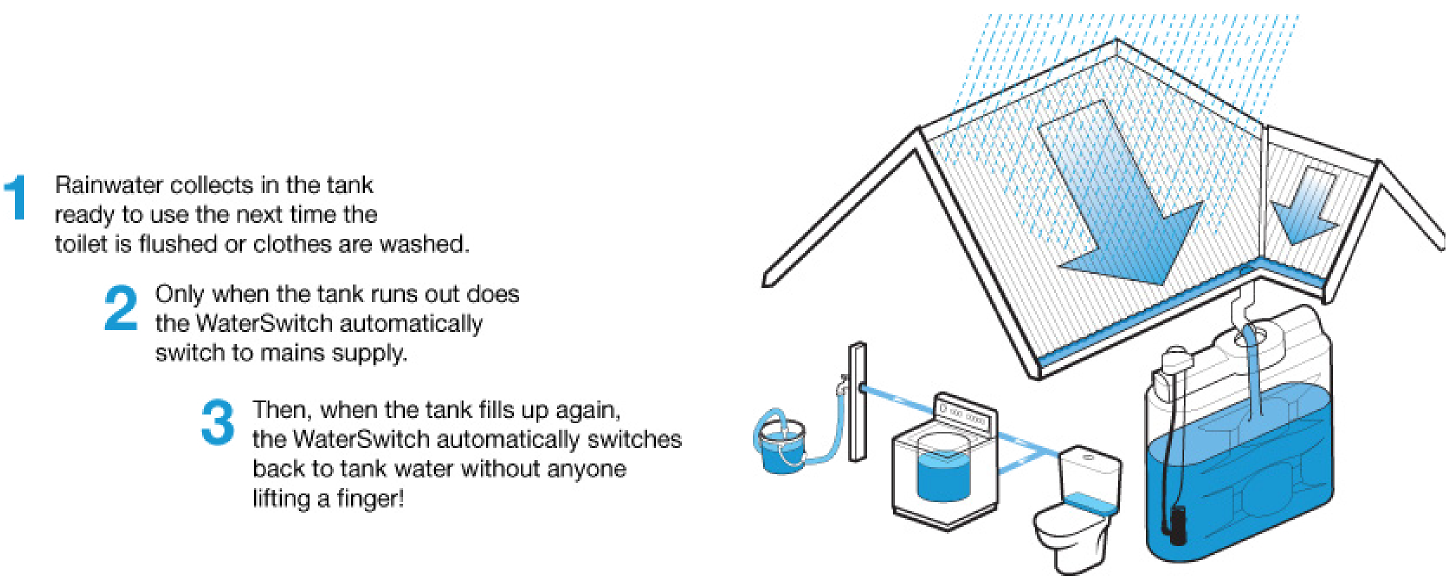
The water ultimately is stored in a tank or cistern, which should also be constructed of an inert material. Suitable materials include reinforced concrete, fiberglass, or stainless steel. Storage tanks may be constructed as part of the building, or may be built as a separate unit located some distance away from the building.

Utility & Efficiency

The performance will depend on the purpose of the rainwater collection and installed treatment systems.

Reliability

Reliability depends on the design, type of construction and operation. Most of the time the system is very reliable.



Replication Potential

Standardized designs are available and can be replicable wherever required.

Regulatory/Institutional Issues

Requires expert design, but can be constructed with locally available material. It also requires standard bylaws and regulation for the building and monitoring.

Operation and Maintenance

- A procedure for eliminating the "foul flush" after a long dry spell requires particular attention. The first part of each rainfall should be diverted from the storage tank since this is most likely to contain undesirable materials which have accumulated on the roof and other surfaces between rainfalls.
- The storage tank should be checked and cleaned periodically. All tanks need cleaning; their designs should allow for this. Cleaning procedures consist of a thorough scrubbing of the inner walls and floors. Use of a chlorine solution is recommended for cleaning, followed by thorough rinsing.
- Care should be taken to keep rainfall collection surfaces covered, to reduce the breeding of frogs, lizards, mosquitoes, and other pests.
- Chlorination of the cisterns or storage tanks is necessary if the water is to be used for drinking and domestic uses.
- Gutters and downpipes need to be periodically inspected and cleaned carefully.
- Periodic maintenance must also be carried out on any pumps used to lift water to selected areas in the house or building. More often than not, maintenance is done only when equipment breaks down.

Advantages

1. Rainwater harvesting provides a source of water at the point where it is needed. It is owner operated and managed.
2. It provides an essential service in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters.
3. The construction of a rooftop rainwater catchment system is simple, and local people can easily be trained to build one, minimizing its cost.
4. The technology is flexible. The systems can be built to meet almost any requirements. Poor households can start with a single small tank and add more later.
5. The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources.
6. Operating and maintenance costs are usually low.
7. Construction, operation, and maintenance are not labor-intensive.

Disadvantages

1. The success of rainwater harvesting depends upon the frequency and amount of rainfall; therefore, it is not a dependable water source in times of dry weather or prolonged drought.
2. Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water during low rainfall period.
3. Leakage from cisterns can cause the deterioration of load bearing slopes.
4. Cisterns and storage tanks can be unsafe for small children if proper access protection is not provided.
5. Possible contamination of water may result from animal wastes and vegetable matter.
6. Where treatment of the water prior to potable use is infrequent due to a lack of adequate resources or knowledge, health risks may result. Furthermore cisterns can be a breeding ground for mosquitoes.
7. Rainwater harvesting systems increase construction costs and may have an adverse effect on home ownership. Systems may add 30% to 40% to the cost of a building.

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    Components of a rainwater harvesting system

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TECHNOLOGY

Low Impact Development

SOURCE Rainwater/Stormwater Use

SCALE Semi-centralized and Centralized

Description

Low impact development (LID) is an approach for a land development and retrofit strategy that emphasizes the protection and use of distributed interventions to reduce the volume and rate of stormwater runoff from a developed landscape. It is achieved through the adoption of site and infrastructure designs that sustain, or attempt to replicate pre-development site hydrology in the post-development condition. The calculation of predevelopment hydrology is based on native soil and vegetation. LID systems include redirected roof leaders, stormwater infiltration systems, rain gardens, stormwater wetlands, rainwater harvesting, and reuse systems, and rooftop detention systems, distributed throughout the landscape. The terms low impact development and green infrastructure are used interchangeably.

Parking lot Bioretention with rain garden

Design Criteria

There are various types and measures of LID approach. Some of the key examples of key LID measures include: i) Vegetated filter strips at the edges of paved surfaces; ii) Residential or commercial rain gardens designed to capture and soak in stormwater; iii) Porous pavers, porous concrete, and porous asphalt; iv) Narrower streets, v) Rain barrels and cisterns; vi) Green roofs and retention basin. Some of those key techniques are presented in proceeding sections.

Many factors related to hydrological and hydrometrology governs the type and performance of a particular type of LID. For example, precipitation patterns, wind velocity, sunshine hours, topography of land, soil porosity, soil structure, plant types etc.

Applications

LID can be applicable to new development, redevelopment, or as retrofits to existing development. LID has been adapted to a range of land uses from high density ultra-urban settings to low density development to protect human health, prevent water pollution, use precipitation water and prevent damages to infrastructure. It is essential in urban areas where constructed surfaces change the hydraulic properties and prevent infiltration.

These approaches can be used to keep rainwater out of the sewer system so that it does not contribute to a sewer overflow and also to reduce the amount of untreated stormwater discharging to surface waters. Green infrastructure also allows stormwater to be absorbed and cleansed by soil and vegetation and either re-used or allowed to flow back into groundwater or surface water resources.

Components

It will depend on the type of LID options and standard design types.

Capacity

Different sizes considering the types of LIDs solutions and catchment area.

Costs

Costs vary according to the types of LIDs. Due to higher costs of land, it is usually more expensive to retrofit retention basins to already developed areas compared to constructing one in an undeveloped region. The cheapest SUDS options are simple detention basins, Infiltration swales bioswales etc whereas the more costly SUDS options are wet retention basisn, green roofs, constructed wetlands etc.

U.S. EPA study of 17 LID case studies around the country found that, in the majority of cases, total capital cost savings ranged from 15 to 80 percent when LID methods were used compared to conventional system.

Operating Principles

Green roofs

Green roofs systems comprised of various types and forms of vegetation that are placed on traditional rooftops. The terms living roof and vegetative roof are also used to describe the same system. Green roofs typically consist of a number of layers: a waterproofing membrane, a drainage system, root protection, growing media and vegetation.

Green roofs filter, absorb, and detain rainfall. The specialized soil and plants reduce runoff by holding back and slowing down water that would otherwise flow into the storm drains. For larger storms, the runoff volume and peak flow rate is reduced because of percolation and temporary storage in the soil.

Studies on green roofs show that Green roofs can reduce annual stormwater runoff by 50-75% while preventing atmospheric pollutants from entering the stormwater system. These vegetative roof systems intercept solar radiation and act to cool the building during summer, reducing the air conditioning costs by 25-75 %.

Rain gardens & Bioretention cells

Rain gardens (RG) can be used in suburban or urban areas. The garden is developed near the street or in a shallow depression where runoff can be diverted. RG capture runoff from impervious areas such as roofs and driveways and allow it to seep slowly into the ground. RG help to protect nearby water bodies (streams and lakes) by reducing the amount of runoff and filtering pollutants.

Rain gardens provide the natural infiltration of rainwater into the soil. Native perennial plants with hardwood are commonly used in rain gardens to reduce weeds. This helps to filter out pollutants including fertilizer, pesticides, oil, heavy metals, and other chemicals that are carried with the rainwater.

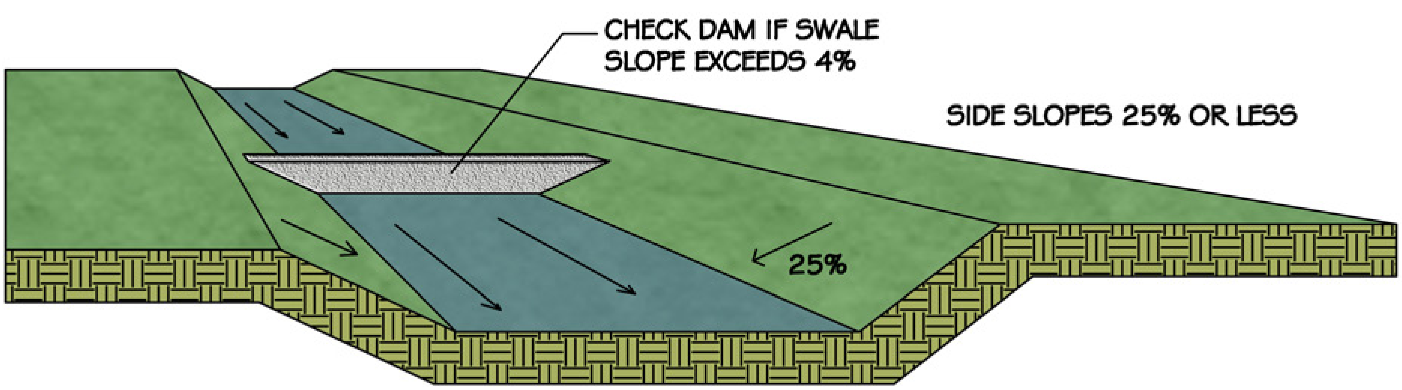
Bioretention cells are very similar to rain gardens. They are used on a larger scale and have under drains to handle larger quantities of water. The rain gardens are generally used in a residential setting, whereas bioretention cells are used in both parking lots, commercial and residential developments.

Lot Rain Garden

Bioretention Cell in Parking

Bioswale or vegetated swale

Bioswales are vegetated, mulched, or xeriscaped channels that provide treatment and retention as they move stormwater from one place to another. This is a form of bioretneiton used to partially treat water quality, attenuate flooding potential and convey stomrwater away from critical infrastructure. Vegetated swales slow, infiltrate, and filter stormwater flows. It is applied at parking lots and median, residential roadside swales, highway median and landscape buff. As linear features, vegetated swales are particularly suitable along streets and parking lots.



Vegetated (grassed) swale

Porous pavement

Permeable pavements allow recharge the ground water table, remove pollutants, and reduce runoff. Several types of permeable pavements are available, including pervious concrete, pervious asphalt, permeable pavers, concrete grid pavers, and plastic reinforced grass pavement. These permeable pavements are appropriate for a variety of uses, such as driveways, pedestrian walkways, overflow parking areas, parking lots, and residential roads.

Pervious pavement in a parking lot

Riparian buffers

A riparian or forested buffer is a vegetated area along a shoreline, wetland, or stream where development is restricted. The primary function of aquatic buffers is to protect and separate a stream, lake, or wetland from future disturbance or encroachment. A properly designed buffer can provide stormwater management, and act as a right-of-way during floods and sustains the integrity of stream ecosystems and habitats.

As conservation areas with aquatic buffers are part of aquatic ecosystem and urban forest. To maintain maximum effectiveness, buffer integrity should be protected against soil compaction, loss of vegetation, and stream incision.

Maintaining buffers around stream headwaters will likely be most effective at maintaining overall watershed water quality. USEPA has shown that creating ordinances and zoning to protect existing buffers will likely be cheaper than creating new buffers or restoring degraded ones.

Riparian buffers

Retention Basin

Retention basins are among the most frequently implemented storm water management systems. They are used to collect surface runoff and to improve the quality of water by natural processes such as sedimentation, decomposition, solar disinfection, and soil filtration. Retention basins constantly keep standing water and allow the development of a new habitat. This also allows settled particles to be treated biologically. Water from retention ponds can then be reused for groundwater recharge, irrigation or any other purpose, optionally requiring further treatment.

The size of a retention basin is dependent on several factors such as topography, the effective contributing area, and the relationship between the amounts of incoming and discharged water. Retention basins are best built where stormwater naturally flows and collects. Enough space should be available, as the ponds require a minimum contributing area of 5-10 hectares. The area required is generally 1 to 3 percent of its drainage area.

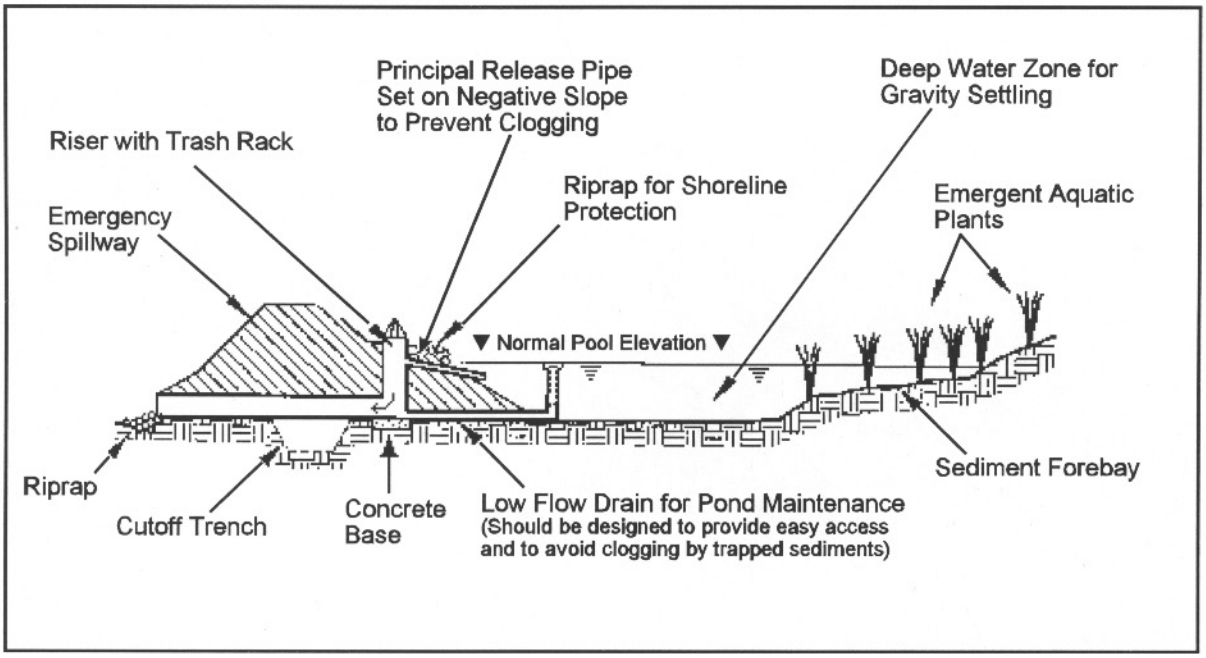
A small pool (called sediment forebay) of about 10 percent of the main pond's size can further help to pre-treat incoming water by keeping back rough particles. In addition, the design should consider other points including, the natural high groundwater table; should have 2 to 1 length to width ratio; robust and diverse vegetation surrounding wet ponds; relatively impermeable soils, Dewatering mechanism; forebay for sediment collection and removal; a perennial baseflow that exceeds losses must be physically and legally available.

Planting native aquatic vegetation further helps to improve the function of retention basins. Nutrients are removed more effectively because of the photosynthetic activities and bacteria attached to the plants.

By storing water in the basin, retention ponds help to impede the negative effects of excess storm water, preventing successional flooding, and can further be used to recharge groundwater. Also, water quality increases immensely, because the standing water is filtered from solid and soluble pollutants as well as excess nutrients. If not reused for groundwater recharge, it may be reused in agriculture (e.g., irrigation or aquaculture), industry or at household level after an appropriate secondary treatment, if required (e.g. free surface, vertical flow constructed wetlands or non-planted filter).

One main prerequisite for the construction of retention basins is space. A minimum contributing area of five hectares is necessary for a successful implementation. Retention ponds are not suited for areas with low precipitation because the basins must be able to constantly hold water. This can also be hindered if the soil is highly permeable.

Retention basin requires high investments for construction; however the overall marginal costs are low. This is due to a long -life mostly over 20 years and requiring only minimal maintenance and operation costs. The EPA states that between $17.50 and $35 USD need to be invested per cubic meter of water treated.



Retention Basin

Detention Basin

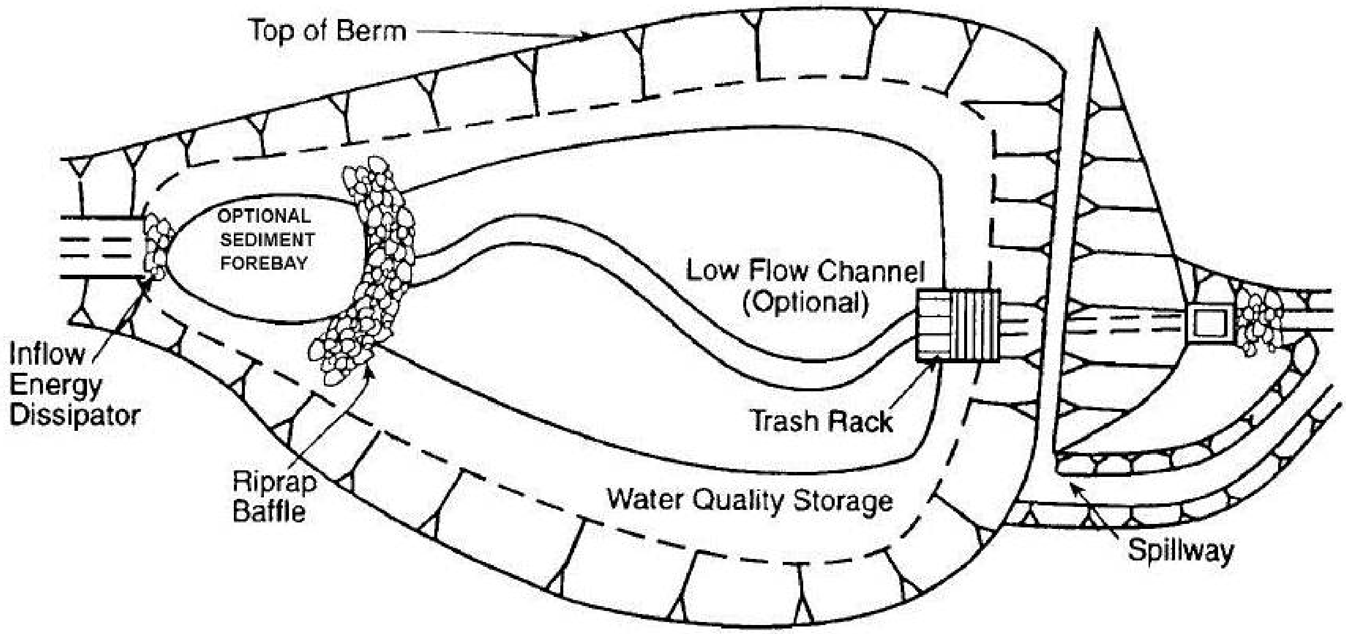
Detention basins temporarily store stormwater runoff, thereby reducing the peak rate of runoff to a stream or storm sewer. They help to prevent localized flooding and, if designed to do so, provide some water quality benefits and reduce stream bank erosion downstream. They provide temporary storage of stormwater runoff attenuation for both stormwater quality and quantity management. To remove the pollution, ponds must be designed to allow stormwater to sit long enough to settle out.

Detention ponds are designed to release all captured runoff over time, and do not allow for permanent pooling of water. Captured runoff is released through multi-level outlet structures consisting of weirs, risers, orifices or pipes, which provide for increased discharge as water levels in the basin increase. The ponds generally are earthen structures constructed either by impoundment of a natural depression or excavation of existing soil.

Main factors to be considered while designing the detention basin include: i) Suitable for capturing runoff from a drainage area of at least five acres, ii) inflow and discharge hydrographs should be calculated for each selected design storm, iii) Location of basin should be down gradient of disturbed/ developed areas on site, iv) Construction on or near steep slopes or modifying existing slope is not recommended, v) Planting of native vegetation on floor of basin and embankments is recommended, vi) Floor of basin should be at least two feet above high water table, vii) Design for maximum water depth of 10 feet, length to width ratio of 2:1, minimum, viii) Design for width of 10 feet; side slope ratio no greater than 3:1, maximum height of side embankments less than 15 feet, ix) Forebay for should contain 10% to 15% of total pool volume, and x) Outlet structures must be resistant to corrosion and clogging by debris, sediment and plant material.

Detention ponds are generally ineffective at removing pollutants in runoff because they do not provide adequate holding time for solids to settle before water is released into a stream or storm sewer system. However, extending the detention time of the basin and/or including a forebay to the basin in the design, when space allows, will enhance water quality and quantity benefits. Extended detention will require a larger basin. Forebays trap sediment to pretreat runoff prior to release to the main pond, and also provide additional temporary storage of runoff.

Detention Basin



Utility & Efficiency

Main objectives are to control the runoff volume, reduce the peak flow, and prevent water pollution in sewerage systems. Exact performances of the LID are reported elsewhere according to the types.

Reliability

The reliability depends on the type of LID solution as well as level of maintenance and operation of LID systems.

Replication Potential

Standardized designs are available and can be developed in any location provided experts' support is available.

Regulatory/Institutional Issues

Design and construction requires expert services. Operation, monitoring and maintenance will also require skilled staff. It will require clear policy for the maintenance and operation at the different level of the LID application.

Operation and Maintenance

- One of the critical barriers for the success of LID in stormwater management need of regular inspection and maintenance.
- The LID systems have to be cleared from excess sediment and trash. Also, regular inspections of water in-and outlets are needed.

Advantages

1. Most of the measures are based on the natural system and based on a simple technology.
2. They have a higher potential to recharge groundwater, reuse of rainwater, and surface run-off for irrigation, household water, and other uses.
3. It helps to avoid peak flooding and potential damages on infrastructure.
4. It can be integrated into the urban landscape and provide green and recreational areas.
5. Many LID practices prove to be attractive amenities to a neighborhood, using them may increase property values, reduces heat island effects etc.

Disadvantages

1. It requires support of experts for designing, implementation, operation, and maintenance.
2. This is a labor intensive undertaking and needs frequent Operation and Maintenance.
3. It has very high risk of clogging infiltration system caused by high sedimentation rates.

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TECHNOLOGY

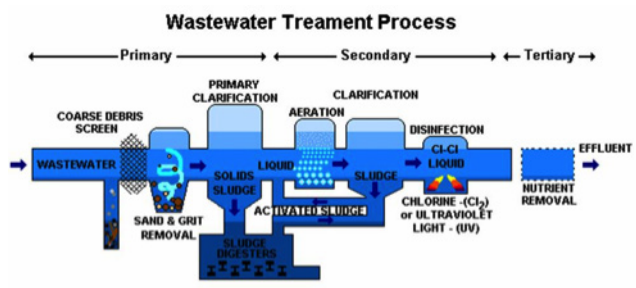
Preliminary Treatment

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

The purpose of preliminary treatment is to remove, reduce, or modify wastewater constituents the raw influent that can cause operational problems with downstream processes of wastewater treatment. The process consists of screening usually by bar screens, grit removal through constant velocity channels to remove the gross solid pollution, and removal of grease or oil films or fat accumulations.



Primary treatment unit in wastewater treatment system

Design Criteria

Design considerations of the preliminary treatment unit consist of design of screening, grit removal, and fat/grease removal.

Screens typically are located upstream from grit removal. Screen openings ranges from 3 to 12 mm. Finer screens, with openings from 1 to 3 mm, are used for the advanced treatment process such as membrane. In most cases mild steel is satisfactory for making screens but other materials may need to be considered in abnormally corrosive environments.

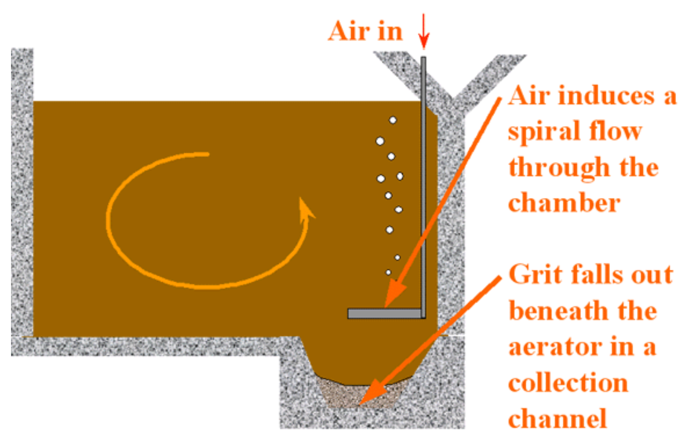
Grit removal: The quantity and characteristics of grit and its potential adverse effects on downstream processes are important considerations in selecting a grit removal process. Other considerations include head loss, space requirements, removal efficiency, and organic content.

Grit removal equipment typically is designed to remove 95% of particles larger than 0.21 mm. Generally a single grit removal unit with a bypass channel will be enough for small installations (average flow <15000 m^3/d). For larger plants, multiple grit removal units are necessary.

Oil, grease and fat are removal by skimming. This is required to prevent blockages, scum formation and the accumulation of fat on conveyors and other elements of the works resulting in reduced efficiency and excessive maintenance requirements.

The main design factors to be considered are maximum flow velocity through the screen apertures, minimum velocity in the approach channel, strength and durability of the screening medium and wastewater characteristics. A minimum velocity of 0.3 to 0.4 m/s is usually provided to prevent excessive accumulation of settled materials in approach channels.

Coarse screen



Grit removal chamber in Primary treatment

Applications

A preliminary treatment process is always required for screening and removing large objects that could damage influent pumps or block flow in raw sewage channels and piping system.
The grit removal reduces excessive wear of pumps and other equipment, clogging of aeration devices, or taking up capacity in tanks that is needed for treatment.

Components

Main components include screen, grit removal, and sludge removal in general.

Capacity

Capacity varies with the sizes of the wastewater treatment plants.

Costs

The cost of screens and grit removal systems vary with the type of technology used and ancillary equipment. Most of the time they are low-cost.

Operating Principles

As wastewater enters preliminary treatment, a screen removes large floating objects such as rags, cans, bottles and sticks that may clog pumps, small pipes, and downstream processes. The screens sizes vary from coarse to fine, and are constructed with parallel steel or iron bars with openings of about half an inch, while others may be made from mesh screens with much smaller openings.

After the wastewater has been screened, it may flow into a grit chamber where sand, grit, cinders, and small stones settle to the bottom. Many types of grit removal systems exist including aerated grit chambers, vortex-type (paddle or jet induced vortex) grit removal systems, detritus tanks (short-term sedimentation basins), horizontal flow grit chambers (velocity-controlled channel), and hydrocyclones (cyclonic inertial separation). The operation principle will be system dependent. For example, in aerated grit chambers, grit is removed by causing the wastewater to flow in a spiral pattern. Air is introduced in the grit chamber along one side, causing a perpendicular spiral velocity pattern to flow through the tank. Heavier particles are accelerated and diverge from the streamlines, dropping to the bottom of the tank, while lighter organic particles are suspended and eventually carried out of the tank.

In some plants, a finer screen is placed after the grit chamber to remove any additional material that might damage equipment or interfere with later processes. The grit and screenings removed (either manually or mechanically) by these processes must be periodically collected and incinerated or trucked to a landfill for disposal.

Utility & Efficiency

Preliminary treatment reduces the heavy solid and floating matters in wastewater that can cause operational problems with downstream treatment.

Reliability

It's a simple and reliable process technology in wastewater treatment.

Replication Potential

The technology has been successfully applied in many places and can be replicable in any place.

Regulatory/Institutional Issues

Centralized systems require standards, regulations, and institutions for operation.

Operation and Maintenance

Main operation and maintenance activities include cleaning screens and disposing of the grit safely.

Cleaning frequency depends on the characteristics of the wastewater entering into the plant. Manually cleaned screens require frequent raking to prevent clogging. Some plants have incorporated screening devices, such as basket-type trash racks, that are manually hoisted and cleaned. Mechanically cleaned screens must be routinely inspected because of their susceptibility to breakage and bending of the rake teeth.

Collected grit must be removed from the chamber; it should be drained, washed, and conveyed to a disposal site. Some smaller plants use manual methods to remove grit, but grit removal is usually accomplished by an automatic method. Four commonly used methods of automatic grit removal include inclined screw or tubular conveyors, chain and bucket elevators, clamshell buckets, and pumping.

The frequency of maintenance will depend on the types of technology and associated processing units within the system.

Advantages

1. Reduces treatment loads in the wastewater treatment process.
2. The process is simple and easy to operate.
3. Most of the time, it does not require energy supply
4. Manually cleaned screens require little or no equipment maintenance and provide a good alternative for smaller plants with few screenings.
5. Mechanically cleaned screens offer the advantages of improved flow conditions and screening capture over manually cleaned screens.

Disadvantages

1. Manually cleaned screens require frequent raking resulting in increased labor costs.
2. Mechanically cleaned screens have high equipment maintenance costs.
3. Risk of harmful, volatile organics and odors released from the aerated grit chamber.

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TECHNOLOGY

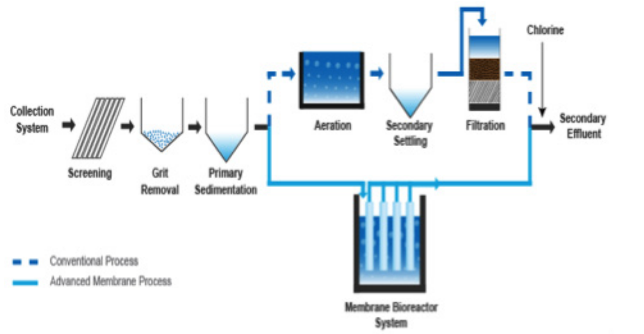
Primary Treatment

SOURCE **Blackwater**

SCALE **Semi-centralized and Centralized**

Description

Primary treatment involves the separation and removal of suspended solids and floatables including grease, oils, plastics, and soap from wastewater by physical/chemical methods. These methods involve settling of suspended solids or other processes in which the total suspended solids (TSS) and chemical oxygen demand (COD) or biochemical oxygen demand (BOD) loading of the incoming wastewater are reduced.



Primary tank in a wastewater treatment plant

Circular primary sedimentation tank

Design Criteria

Different types of sedimentation tanks are available for the primary treatment of wastewater, such as rectangular clarifiers, circular clarifiers, stacked sedimentation tanks, and plate and tube clarifiers.

Design factors to be considered for conventional sedimentation tanks are surface overflow rate, hydraulic detention time, water depth, surface geometry, and weir loading rate.

A hydraulic detention time of 20 - 30 minutes is necessary for floc formation and improved TSS, COD, and BOD removal. The exact quantity of air required is a function of the wastewater characteristics and tank geometry. Coagulant selection for enhanced sedimentation should be based on performance, reliability, and cost. Jar tests of the actual wastewater is required to design dosages and effectiveness.

Rectangular clarifiers range from 15 to 90 m in length and 3 to 24 m in width. Depths typically range from 3 to 4.9 m. Most tanks are between 3 and 3.7 m. Rectangular tanks with common wall construction are advantageous for sites with space constraints.

Diameters of circular clarifiers vary from small, 3 m, to more than 60 m. Depths typically range between 3 and 4.9 m. Circular tanks often have a lower capital cost per unit surface area than that for rectangular tanks.

Historically, primary clarifiers have been designed on the basis of the surface overflow rate (SOR). Typical SOR values for conventional sedimentation range between 30 - 50 m^3/m^2.d at average flow condition and depth range from 3 - 4.9 m.

Inlets are designed to dissipate the inlet port velocity, distribute flow and solids equally across the cross-sectional area of the tank, prevent short-circuiting in the settling tank, and promote flocculation before quiescent settling.

Enhanced sedimentation methods such as chemically enhanced primary treatment and high-rate clarification are used in the large-scale treatment which has high seasonal hydraulic loading variations and limited land availability.

Chemically enhanced primary treatment has been used to increase existing treatment capacities and reduce influent loads to biological treatment.

Applications

The primary treatment is the pretreatment process. It is required for all the secondary and tertiary physo-chemical and biological wastewater treatment plants.

Components

Depends on the specific process chosen. Generally, main components include sedimentation basin and sludge removal equipment (see Figure).

Capacity

The plant sizes are flexible; applicable from a small to large scale plant.

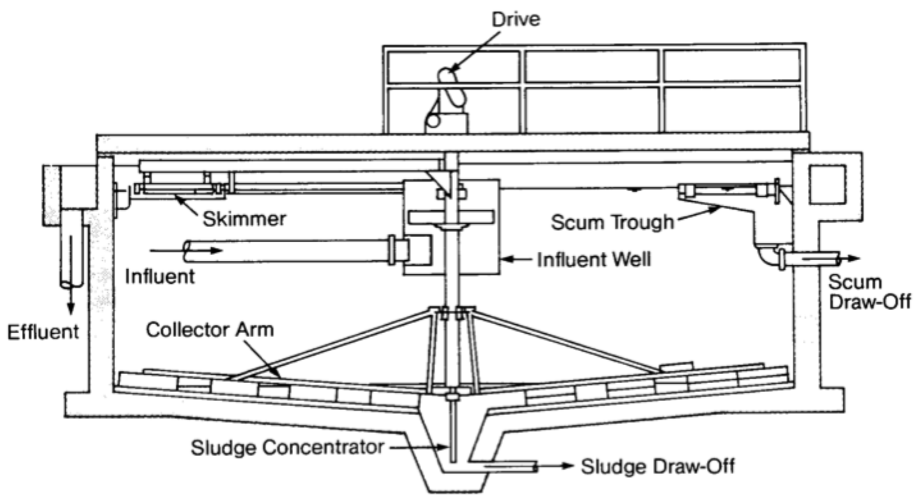
Costs

Varies according to the types and most of the costs is for the construction of the plant.

Operating Principles

Sedimentation, clarification, settling, and thickening are terms used to describe gravity separation of wastewater solids from liquids depending on whether the focus is clarified liquid or thickened solids. Sedimentation and clarification are used interchangeably along with terms such as sedimentation tank, settling tank, clarifier, and settler. Gravity separation removes more suspended solids and COD or BOD at less operational cost than any other method. Clarifiers (sedimentation tanks) equalize raw wastewater quality and flow to a limited degree; thereby protecting downstream unit processes (see Figure).

When the wastewater enters a sedimentation tank, it slows down and the suspended solids gradually sink to the bottom. Suspended particles in wastewater may be classified as granular or flocculent. As the wastewater enters into the tank, granular particles (sand and silt) settle at a constant velocity, with no change in size, shape, or weight. Ideally, most granular particles are removed upstream in the grit chambers. Flocculent particles (organic matter, flocs formed by coagulants, or biological growths) tend to flocculate during settling, with changes in size, shape, and relative density. The clusters ordinarily settle more rapidly than individual particles. Settable solids, including portions of the granular and flocculent material, settle under quiescent (calm) conditions within a reasonable time. Non-settable solids, finely divided and colloidal materials, are too fine to settle within usual settling times. Chemicals are used to remove more finely divided suspended and colloidal material. The settling precipitate traps the suspended and colloidal particles and adsorbs them on the floc surface. Under quiescent conditions, part of the grease and scum settles with the sludge, whereas the remainder floats to the surface for removal by a suitable skimming device.



Primary treatment process

Utility & Efficiency

Removal of suspended solids and floatables including grease, oils, plastics, and soap from wastewater helps to improve the effectiveness of the treatment process.

Generally, TSS removal, COD or BOD5 removal, phosphorus removal, and bacteria removal by chemically enhanced primary treatment (CEPT) are 60-90%, 40-70%, 70-90%, and 80-90%, respectively.

Reliability

Reliable in a controlled operation and supervision system.

Replication Potential

They are proven technologies and replicable elsewhere.

Regulatory/Institutional Issues

Skilled workers are required for operation and maintenance.

Operation and Maintenance

Flows should be adjusted not to exceed the design rate, if possible. The entrance velocity of the influent should be small and there should not be any turbulence in the tank. The water temperature in the tank should be uniform.

Weir and scum baffle conditions should be inspected regularly. No buildup of algae or debris should be allowed to interfere with their operation. The collector and skimmer arms should operate smoothly; no vibrations or stoppages should be present.

The drive mechanism should operate freely with no unusual noise or vibration. The effluent should flow smoothly over the weirs, into the launder, and out through the gullet. No debris should be present in the effluent launder. Any floating sludge or other abnormal conditions should be investigated and resolved.

The maintenance program should include a good preventive maintenance program, established written procedures for emergency maintenance, and a system to ensure an adequate supply of essential spare parts.

Advantages

1. Removes floating materials (oil and geese) and reduces suspension solids loads in the subsequent treatment units.
2. Reduction in BOD and load for the waste activated sludge in the activated-sludge plant.
3. Helps for the partial equalization of flow rates and organic load.
4. Circular tanks have thinner walls than those for rectangular tanks. As a result, they often have a lower capital cost per unit surface area than that of rectangular tanks.
5. Stacked sedimentation tanks increase the available clarifier area without increasing the clarifier footprint.
6. Enhanced sedimentation by pre-aeration or chemical coagulation and flocculation can increase suspended solids and BOD removal efficiency.
7. The use of screens instead of primary clarifiers can significantly reduce space requirements and investment costs.

Disadvantages

1. The sludge removal equipment requires greater maintenance requirements.
2. Fine screens can be used in lieu of sedimentation for primary treatment but may not achieve removal efficiencies of sedimentation.
3. Circular tanks require more yard piping than rectangular tanks and require separate structures for flow distribution and sludge pumping.
4. Enhanced sedimentation may increase mass of primary sludge; production of solids may be more difficult to thicken and drain.
5. Skilled operators and monitoring systems will be required.

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TECHNOLOGY

Nutrient Removal

SOURCE Blackwater

SCALE Semi-centralized and Centralized

Description

Nitrogen and phosphorous are removed by tertiary or advanced wastewater treatment processes. An excessive presence of nutrients (i.e., nitrogen and phosphorus) stimulates the growth of microorganisms (including algae) and other aquatic vegetation in receiving waters, leading to decreased oxygen levels. There are a wide range of technologies available to remove (and recover) nitrogen and phosphorus from wastewater based on physical and biological processes, and chemical precipitation. The scope of this section is only to provide an overview on the recent technological developments in this area.

Design Criteria

Nitrogen and phosphorous are removed from wastewater by physical processes (Ex., membrane filtration for particulate phosphorus), chemical processes (i.e., precipitation or physical-chemical adsorption) or biological processes (bio-accumulation). Recent development indicates that physical/chemical processes are not usually feasible for municipalities because of technical, regulatory, and cost considerations.

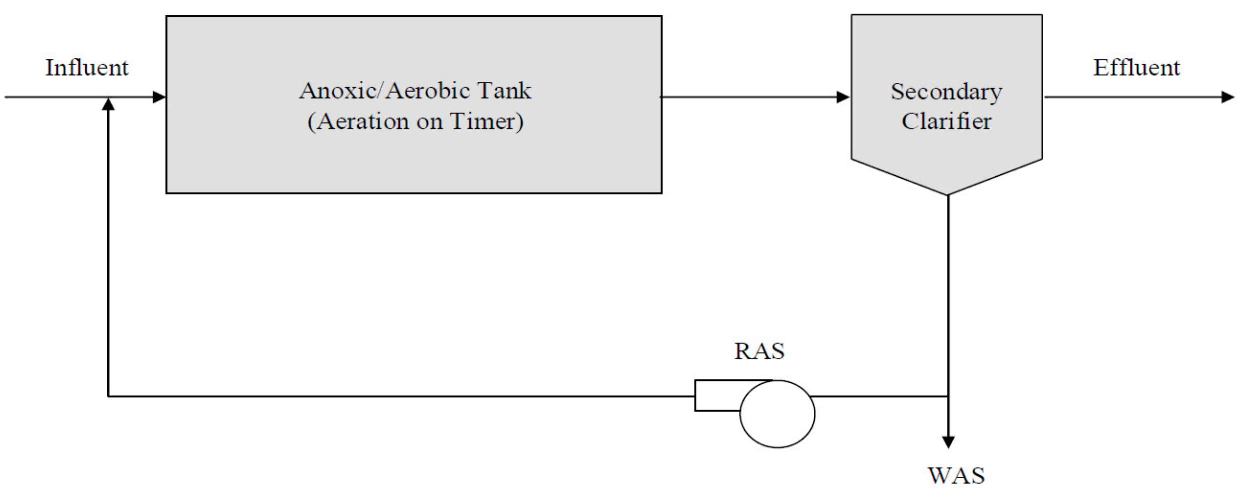
The design criteria of any technology or process depend on key factors including wastewater characteristics, process parameters, environmental parameters such as temperature, chemistry, and biology, and operating parameters.

Nitrogen removal: Commonly used nitrogen removal processes consist of physical/chemical processes (e.g., ammonia stripping, selective ion exchange, and breakpoint chlorination) and biological processes.

Ammonia stripping plant

Some of the commonly used technologies are Simultaneous Nitrification and Denitrification; Anaerobic Ammonium Oxidation; Aerobic Deammonitrification; Oxygen-Limited Autotrophic Nitrification-Denitrification.

The biological removal of nitrogen depends on key factors such as adequate supply of carbon from internal or external sources, the number of anoxic zones, favorable temperature, sufficient alkalinity, the sludge age and maintenance of a deep sludge blanket in the secondary clarifier, and proper management of the recycle flows.



Aerated activated-sludge process for Nitrogen removal

Phosphorus removal: Treatment technologies presently available for phosphorus removal also include physical, chemical, and biological based technologies. Depending on the target concentration, a plant might employ combinations of technologies. Such a combined approach might be of particular benefit if the target concentration is very low and the starting concentration is high. In such a case, biological removal is used to remove the bulk of the phosphorus, and chemical polishing follows to achieve the final concentration; such an approach tends to reduce sludge formation.

Examples of commonly used technologies are filtration for particulate phosphorous, biological assimilation, fermentation, anaerobic/oxic process, and oxidation ditch, to list a few.

The biological phosphorus removal is dependent upon the uptake of phosphorus in excess of normal bacterial metabolic requirements. The key factors for biological removal are the size of the anaerobic and aerobic zones, the number of swing zones, the sludge age, the control of secondary release, and the depth of the sludge blanket in the secondary clarifier.

Chemical removal of phosphorus involves the addition of calcium, iron and aluminum salts to achieve phosphorus precipitation by various mechanisms. For chemical removal, the key factors are the number of chemical application points for dosage, the need for a tertiary clarifier, and the type of filter for final polishing.

There are numerous technological processes to remove nitrogen and phosphorous simultaneously, such as anaerobic/anoxic process, five stage Bardenpho process, university of Cape Town process, and Virginia Initiative process.

Applications

Physical, chemical, and biological processes are commonly used for removal of nitrogen, phosphorous and combined nitrogen and phosphorous removal from the wastewater.

This is an advanced technology and is applicable in places where advanced technology and skilled operators are available.

Components

This is an advanced process and always associated with other wastewater treatment technologies.

Capacity

It can be applicable from smaller units to the largest treatment plants.

Costs

Very expensive process and unit cost varies according to the technology selected.

Operating Principles

Removal of Nitrogen: Biological removal of nitrogen is carried out through a three-step process: i) ammonification: the conversion of ammonia from organic nitrogen by hydrolysis and microbial activities; ii) nitrification: the aerobic conversion of ammonia to nitrate by reacting the ammonia with oxygen in a process; and iii) denitrification: the conversion of nitrate to nitrogen gas by reacting the nitrate with organic carbon under anoxic conditions.

The nitrogen removal processes depends on several internal factors. For example: i) quantity of carbon, in proportion to the nitrogen present in the wastewater, necessary to reduce the amount of nitrogen; ii) Hydraulic retention time (HRT) affects both nitrification and denitrification; iii) Having two anoxic zones allows lower Total Nitrogen (TN) effluent concentrations to be achieved because more of the nitrates produced after nitrification in the aeration basin can be treated by an internal recycle to the first anoxic zone or by flowing through the second anoxic zone; iv) Alkalinity is consumed as part of the nitrification process because hydrogen ions are created when ammonia nitrogen is converted to nitrate nitrogen. Denitrification restores a portion of the alkalinity during the conversion of nitrate nitrogen to nitrogen gas; v) At lower temperatures, the nitrification and denitrification rates decrease, leading to poorer performance in the winter if operational changes are not made to compensate for the decreased kinetic rates. Nitrification can occur in wastewater temperatures of 4 to 35 degrees Celsius; vi) Some facilities are required to remove only ammonia-N or Total Kjeldhal Nitrogen (TKN), with no current requirements to remove nitrate or nitrite. In such cases, the biological conversion of ammonia (or TKN) to nitrate is readily accomplished by increasing the solids retention time (SRT) in the biological system.

System designs in the past incorporated a two-sludge strategy. First, BOD was removed in an activated-sludge reactor with a clarifier, and then a second activated sludge system was run in series to accomplish nitrification. Current practice is to do both BOD removal and nitrification in a single sludge system, especially in retrofit situations, thereby saving land requirements by avoiding a new set of clarifiers and making the operation simpler. Significant energy savings is also anticipated in a single sludge system due to a reduced volume requiring aeration.

Cyclically Aerated Activated Sludge System: In a cyclically aerated activated-sludge system, the aeration system is programmed to turn off periodically, allowing denitrification and nitrification to occur in the same tank. The cyclically aerated activated-sludge system can be used to retrofit existing plants if sufficient SRTs can be maintained to allow nitrification to occur. The length of the cycle time depends on the loading rate and target limit, with the HRT being 2 to 4 times the cycle time. If the aerobic SRT is sufficient to achieve nitrification, the cyclic process can reduce TN in the effluent.

Sequencing batch reactors (SBRs) and oxidation ditches can be designed to operate as cyclically aerated activated-sludge systems. The range of TN effluent concentrations found at the case study facilities for this study was 3.1 mg/L to 10.4 mg/L.

Removal of Phosphorous: Biological phosphorus removal works by encouraging the growth of phosphate-accumulating organisms (PAOs), which are then subjected first to anaerobic conditions and then to aerobic conditions. Under anaerobic conditions, the microbes break the high-energy bonds in internally accumulated polyphosphate, resulting in the release of phosphate and the consumption of organic matter in the form of volatile fatty acids (VFAs) or other easily biodegraded organic compounds. When the microbes are then put under aerobic conditions, they take up phosphate, forming internal polyphosphate molecules. This uptake results in more phosphate being included in the cells than was released in the anaerobic zone, so the total phosphate concentration in solution is reduced. When the excess microorganisms are wasted, the contained phosphate is also removed. A sufficient supply of VFAs is the key to removing phosphorus biologically.

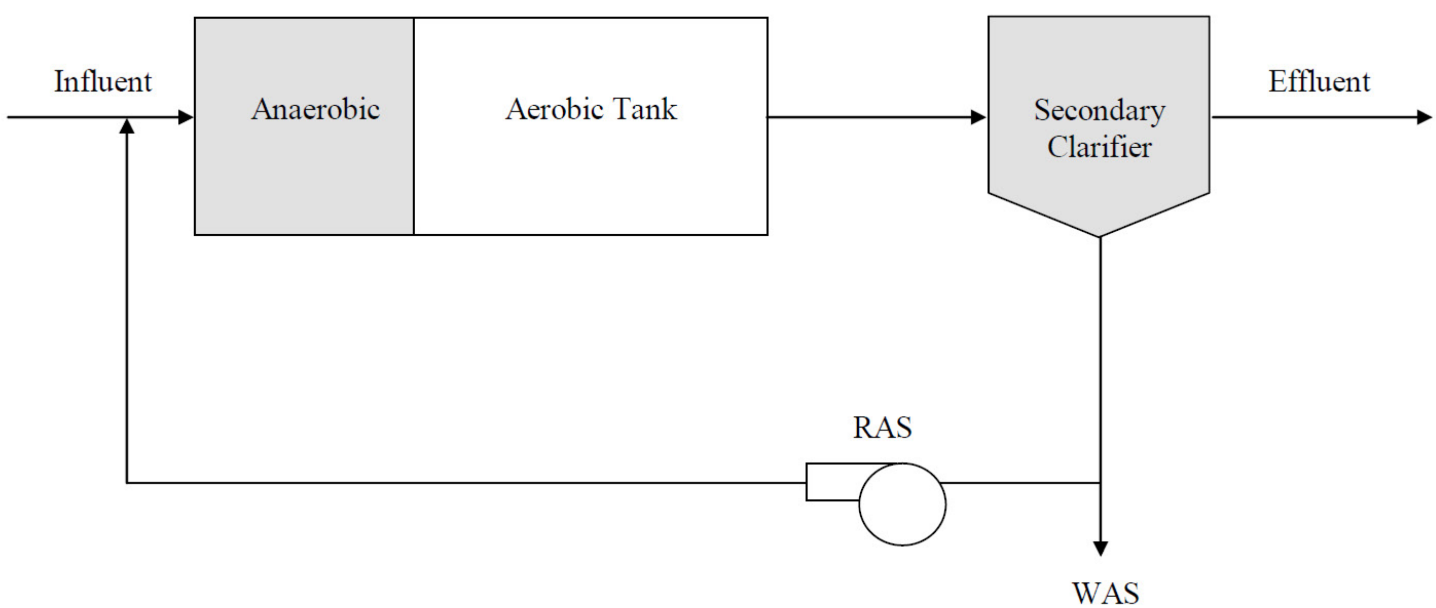
The phosphorus removal processes depends on several internal factors. For example: i) Lower phosphorus removal might occur in the winter because of reduced VFA production in the plants that use fermenters; ii) Very good biological phosphorus removal performance was reported when SRT values of 16 and 12 days were provided for wastewater at 5 °C and 10 °C, respectively; iii) Biological phosphorus removal occurs in a two-step process, in which phosphorus is released in the anaerobic zone by PAOs and then taken up by the same PAOs in the aerobic zone; iv) Nitrates in the return streams can negatively affect biological phosphorus removal; v) DO entering the anaerobic zone negatively affects biological phosphorus removal.

Anaerobic/Oxic (A/O), or Phoredox Process: This process (see Figure) is comprised of an anaerobic zone upstream of an aerobic zone. The return activated sludge (RAS) enters the head of the anaerobic zone with the influent. In the anaerobic zone PAOs release phosphorus, which is subsequently taken up in the aerobic zone. One potential problem for A/O operation is that any nitrates recycled from the aerobic zone of side streams can inhibit anaerobic growth of PAOs. To reduce this effect, the anaerobic zone is often split into an anoxic chamber for nitrate denitrification and a series of anaerobic zones for phosphorus release.

The process has a medium-sized footprint and is relatively easy to retrofit into an existing basin by installing baffle walls and mixers to produce an anaerobic zone. If sufficient VFAs are available, an additional carbon source is not needed. Because there is some additional pumping and additional electrical costs; however, less sludge is generated under anaerobic conditions. To obtain extremely low phosphorus (less than 0.1 mg/L), chemical addition should be examined.

Physico–chemical phosphorus removal process in essence comprises of the addition of a divalent or trivalent metal salt to wastewater, causing precipitation of an insoluble metal phosphate that is settled out by sedimentation. The most suitable metals are iron and aluminum, added as chlorides or sulphates. Lime may also be used to precipitate calcium phosphate. Anionic polymers may be used to assist solid separation.

Chemical precipitation of phosphorus removal can be applied at several stages during wastewater treatment. Primary precipitation is where the chemical is dosed before primary sedimentation and phosphorus removed in primary sludge. Secondary (or simultaneous) precipitation is where the chemical is dosed directly to the aeration tank of an activated sludge process and phosphate removed in secondary sludge. Tertiary treatment is where dosing follows secondary treatment and although a high-quality effluent can be produced, this approach is not generally favored because of high chemical costs and the creation of additional chemical tertiary sludge.



Anaerobic/Oxic (A/O), or Phoredox Process

Utility & Efficiency

High removal rate can be achieved under proper design, operation, and supervision.

Reliability

The process units are very complex and advanced; however, they have a very high level of reliability.

Replication Potential

They are proven technologies and can be replicable elsewhere if advanced technology and skilled operators are available.

Regulatory/Institutional Issues

Requires regulations and bylaws for controlling the overall performance of the effluents.

Operation and Maintenance

The technologies and process are very advanced and require skilled operators and monitoring facilities. The details of operations and maintenance vary according to the processes selected and other exiting process technologies. For example: testing and calibrating equipment, maintaining pumps and blowers, inspecting the tower periodically for fouling, maintaining proper air and water flows, pH adjustment with lime requires safe handling, clarifying the influent before stripping, monitoring and controlling noise from the stripping equipment.

Advantages

1. Biological processes are proven to be a more cost effective and efficient approach for removal of nitrogen and phosphorous from municipal wastewater systems compared to other methods.
2. Biological process is relatively simple for the operation, produces good settling sludge, and good phosphorus removal.
3. Ammonia stripping process is low cost, removes ammonia with minimal addition of dissolved solids, simplicity, and reliability.
4. Selective ion exchange process has high efficiency, insensitivity to temperature fluctuations, removes ammonia with minimal addition of dissolved solids, and eliminates any discharges of nitrogen to the atmosphere other than nitrogen gas.
5. Breakpoint chlorination process for nitrogen removal has the advantages of low capital cost, a high degree of efficiency and reliability, insensitivity to cold weather, and the release of nitrogen as nitrogen gas.
6. Chemical precipitation, especially lime, are very inexpensive.

Disadvantages

1. Removal by biological process requires more energy in terms of capacity of the aeration device than chemical phosphorus removal.
2. For SBR, disadvantages include a larger tank volume to incorporate anaerobic conditions, more complex design, and more suitable for smaller flows.
3. Ammonia stripping process has the disadvantages of poor efficiency in cold weather and the potential for scaling problems that may reduce its efficiency, and it raise concerns over ammonia gas discharge.
4. While ammonia is usually discharged to the atmosphere at low levels (6 mg/m^3), this may be unacceptable in certain locations due to air quality concerns or regulations.
5. Scale formation can be removed hydraulically in most cases but not all, resulting in a need to pilot test at most locations.
6. Water must be re-pumped to the stripping tower. Pumping requires higher maintenance and power requirements.
7. Air stripping often requires the addition of lime to control pH, which may create operation and maintenance concerns.
8. Selective ion exchange has the disadvantage of relatively high cost, and process control and operation are relatively complex.

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TECHNOLOGY

Adsorption Process

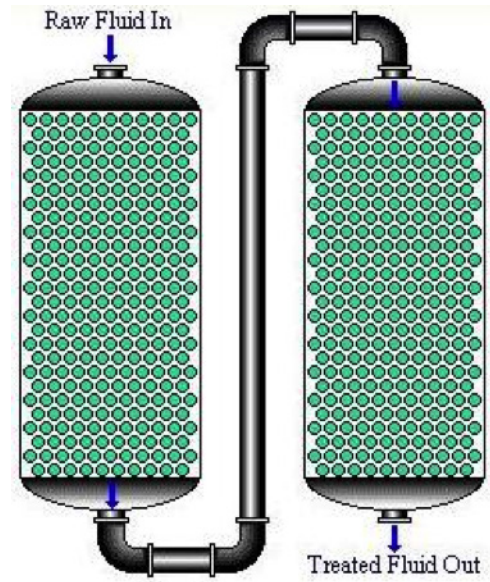
SOURCE Freshwater

SCALE Semi-centralized and Centralized

See Activated Carbon Filters in other section

Description

Adsorption is an advanced water treatment process for the removal of taste and odor-causing compounds, synthetic organic chemicals (SOCs), color-forming organics, and disinfection byproducts (DBP). Inorganic constituents including heavy metals and health hazards such as perchlorate and arsenic are also removed by adsorption. Synthetic polymeric resins, zeolites and activated alumina have been used in water treatment applications, but activated carbon is the most commonly used and cost-effective adsorption process.



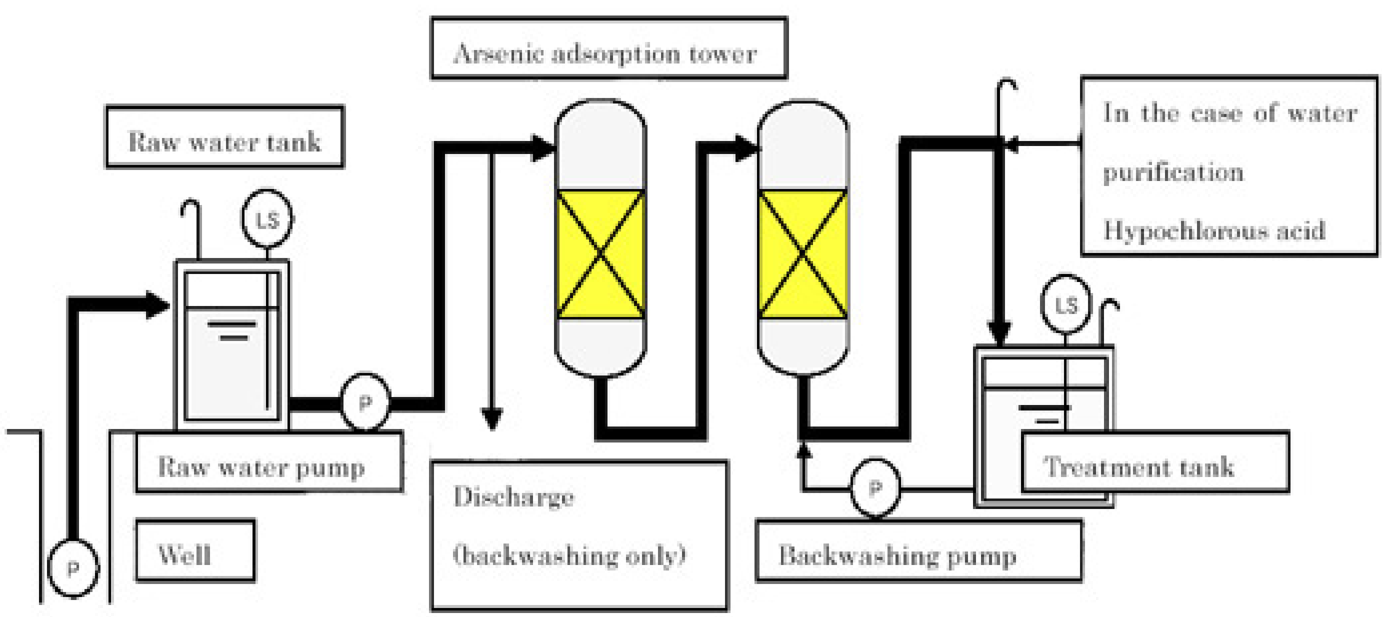
Design Criteria

Granular activated carbon (GAC) or powdered activated adsorbents are widely used in the removal of inorganic constituents, heavy metals and other contaminants such as organic chemicals. More information on activated carbon is included in the other section of the catalogue. This section presents discussion on adsorption technology used for the removal for the heavy metals and inorganic pollutants including arsenic from groundwater and wastewater.

Activated alumina (AA) is a commonly used physical/chemical process by which ions in the feed water are sorbed to the oxidized activated alumina surface. Although activated alumina is generally considered an adsorption process, the chemical reactions involved are actually an exchange of ions.

Similarly, heavy metals are also removed during adsorption by activated carbon zeolite, clinoptilolite, calcined phosphate, activated phosphate, and zirconium phosphate.
Recently various low-cost adsorbents, derived from agricultural waste, industrial by-product, natural material, or modified biopolymers, have been recently developed and applied for the removal of heavy metals from metal-contaminated wastewater. Biosorption processes are particularly suitable to remove heavy metal from wastewater. Typical biosorbents can be derived from i) non-living biomass such as bark, lignin, shrimp, krill, squid, crab shell, etc.; ii) algal biomass; iii) microbial biomass, e.g. bacteria, fungi and yeast.

The design procedures of any adsorbents will depend on the types of adsorbent used and the pollutants to be removed. Generally, adsorption is affected by temperature, the nature of the adsorbate and adsorbent, the presence of other pollutants and atmospheric and experimental conditions such as pH, concentration of pollutants, contact time, particle size and specific surface areas of the adsorbent.



Applications

Adsorption processes is applicable in any place where advanced technology is suitable, particularly for drinking water and wastewater treatment. The applicability of this technology in the future will be breoader due to continuous discoveries of new micro-pollutants such as pharmaceuticals and trace organic pollutants.

Components

The adsorbents can be part of other processes such as filtration or on their own. They can be installed in a fixed bed or fluidized bed reactors.

Capacity

Can be applicable with any size treatment plant that range from household to large scale plants.

Costs

The cost depends on water quality and absorbent used. Generally, activated carbon is less expensive than other absorbents.

Operating Principles

Adsorption is a mass transfer process by which a substance is transferred from the liquid phase to the surface of a solid, and becomes bound by physical and/or chemical interactions. It is based on the principle of sorption, which is transfer of ions from solution phase to the solid phase. Sorption actually describes a group of processes, which includes adsorption and precipitation reactions. Adsorption has become one of the alternative treatment techniques for water and wastewater laden with organics and heavy metals.

In general, there are three main steps involved in pollutant sorption onto solid sorbent: (i) the transport of the pollutant from the bulk solution to the sorbent surface; (ii) adsorption on the particle surface; and (iii) transport within the sorbent particle.

In the case of AA ions in the feed water are sorbed to the oxidized AA surface (see Figure). AA is prepared through dehydration of Al(OH)3 at high temperatures, and consists of amorphous and gamma alumina oxide. It is used in packed beds to remove contaminants such as fluoride, arsenic, selenium, silica, and NOM. Feed water is continuously passed through the bed to remove contaminants. The contaminant ions are exchanged with the surface hydroxides on the alumina. When adsorption sites on the AA surface become saturated, the bed must be regenerated. Regeneration is accomplished through a sequence of rinsing with regenerant, flushing with water, and neutralizing with acid. The regenerant is a strong base, typically sodium hydroxide; the neutralizer is a strong acid, typically sulfuric acid.

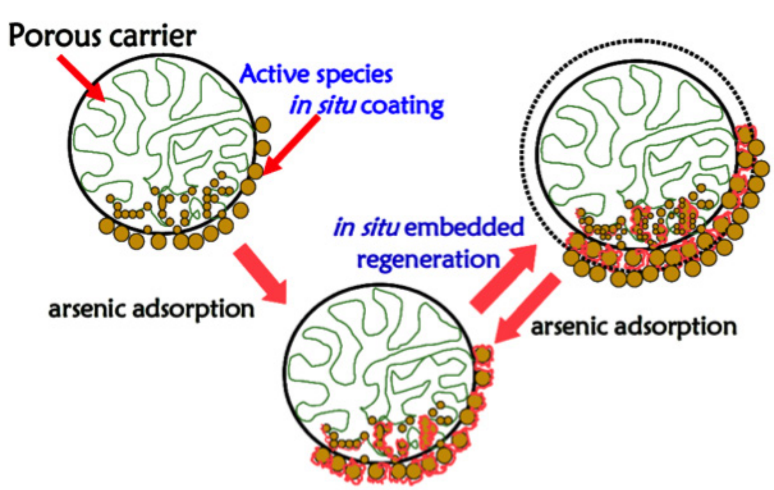
Activated carbon adsorbents are widely used in the removal of heavy metals. Its usefulness derives mainly from its large micropore and mesopore volumes and the resulting high specific surface area. The operating principles for most of the adsorbent-based technology for the removal of heavy metals such as lead, cadmium, chromium, copper, and nickel from the water and wastewater treatment process, are similar to that of arsenic removal (also see activated carbon section).

Utility & Efficiency

The performances of the process depends on the type of adsorbent, its dosage, contact time, and the presence of competing compounds and oxidants. If performed under controlled conditions, adsorption can remove heavy metals, organic and inorganic contaminants.

Reliability

Reliable if standard design procedures are followed during the installation and operations.



Adsoption Process for Arsenic Removal by Activated Alumina

Replication Potential

It can be applicable for any water treatment plants where advanced technology is feasible.

Regulatory/Institutional Issues

Skill worker is required to monitor treatment system's performance.

Operation and Maintenance

The adsorption process is an advanced treatment process. It requires controlled operation by skilled operators. The performances of the process depends upon several factors including pH, arsenic oxidation state, competing ions, empty bed contact time, and regeneration. For example, acidic pH levels are generally considered optimum for arsenic removal with activated alumina; the oxidation state of arsenic plays a large role in its removal as arsenic (As -V) is much more easily adsorbed than arsenic (As -III). Similarly, sorption onto activated alumina is relatively rapid during the first few hours of exposure and slower thereafter. Increasing sulfate has only a small impact on the sorption of As-V. However, the addition of organics has a much greater effect. Thus, it is essential to have controlled monitoring and column tests to achieve the intended performance.

When the adsorption capacity is exhausted, treatment efficiency drops and it needs to be regenerated by releasing the contaminants and restoring adsorption capacity. Depending on the adsorbent and adsorbate different methods of regeneration or chemical additions are employed.

Advantages

1. Easy to install and maintain
2. It can be applicable for any level (i.e., point of use at household to centralized systems)
3. Effective method for removal of heavy metals, organic and inorganic pollutants
4. Adsorbents can be regenerated
5. Low-cost and locally available adsorbents are becoming more available.

Disadvantages

1. Requires skilled operators and controlled monitoring processes
2. The absorbents need regeneration
3. Adsorbents, such as AA are expensive
4. It's not always the best option for hardness and arsenic removal

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Softening Process (Ion Exchange and Pellet Reactor)

SOURCE Freshwater

SCALE Semi-centralized and Centralized

Description

Softening is primarily used to remove calcium and magnesium mineral salts that cause hardness. Softening also removes harmful toxins like radon and arsenic. From a health standpoint, calcium and magnesium have no adverse effects. However, they buildup on contact surfaces, possibly plug pipes and damage water heaters, and decrease the effectiveness of soaps and detergents.

Design Criteria

The commonly available methods for water softening are: i) Ion exchange, ii) pellet reactor and iii) chemical precipitation and iv) membrane filtration (see other section for membrane filtration). This discussion is limited to the ion exchange and pellet reactor process.

In Ion exchange softening one or more undesirable ionic contaminants are removed from water and exchanged with a non-objectionable, or less objectionable ionic substance. Both the contaminant and the exchanged substance must be soluble and have the same type of electrical charge (positive or negative).

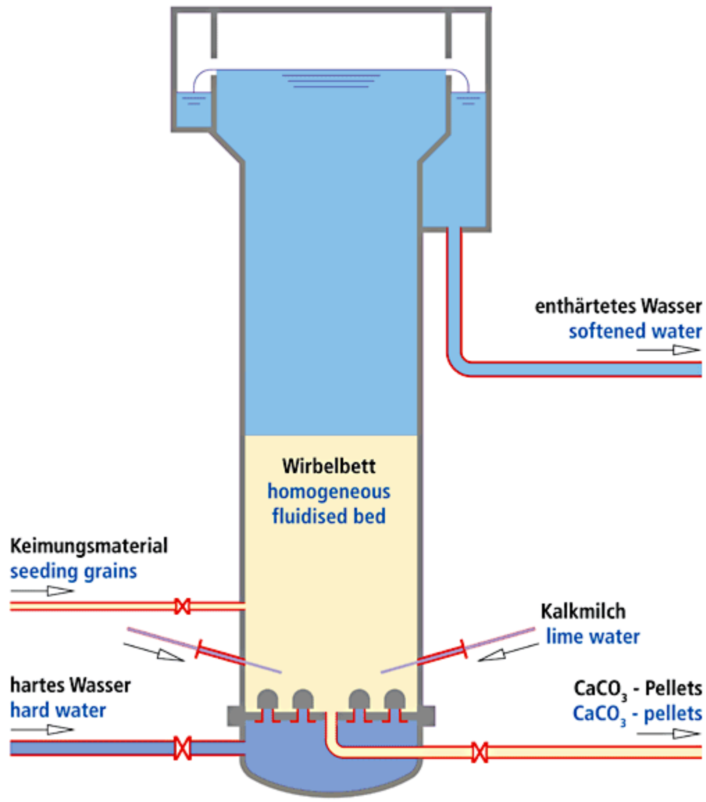
The main component of ion exchange equipment is a microporous exchange resin, which is supersaturated with a loosely held exchange ions solution. For water softening, this is usually done with sulfonated polystyrene beds that are supersaturated with sodium to cover the bed surface.

The next commonly used technique is softening in a ***pellet reactor***. In this process, by dosing the base in a reactor with seeding grains, crystallization will occur on the surface of the seeding grains, forming limestone pellets. The pellet reactor consists of a cylindrical vessel partially filled with seeding material. The diameter of the seeding material is approximate 0.2 - 0.6 mm and has a large crystallized surface. Water is pumped in an upward direction through the reactor at a velocity varying between 60 and 100 m/h. At these velocities the sand bed is in a fluidized condition (see Figure)

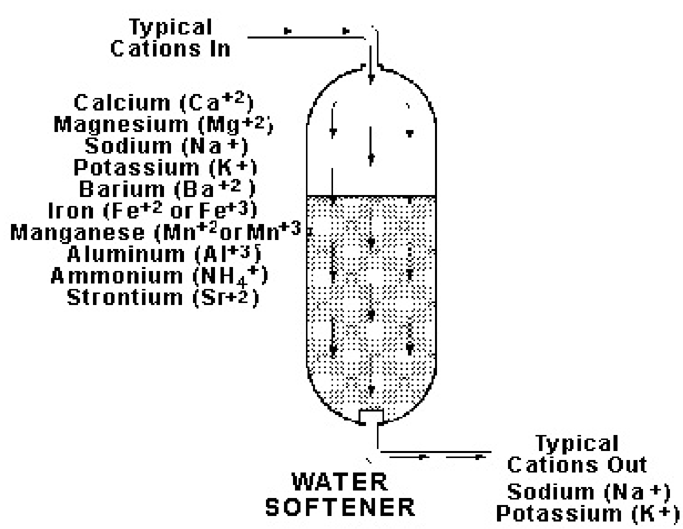
Mostly the design of softening processes is based on several criteria including quality of feed water, production flow rate, cycle length, required quality of the treated water, regeneration technology, dimension of the vessels and selection of resin types.

Applications

Softening is used to remove heavy metals, NOM, turbidity, and pathogens as well as it improves water quality which reduces costs for distribution system corrosion, boiler and cooling water feed, and home water heater systems.



Schematic representation of a pellet reactor



Schematic representation of an Ion exchange process

The concurrent removal of arsenic, chromium, iron, lead, manganese, and mercury provides an additional benefit to the removal of hardness and, in some cases, may be the overriding reason for selection of the technology.

A pellet reactor consists of an equalization tank, softening reactor, polishing filter, infiltration basin for backwash disposal, and chemical feed and storage.

Components

A water softener can be as simple as a tank to hold the exchange resin, together with appropriate piping for raw and treated water. Modern water softeners include a separate tank for the brine solutions used to regenerate the resin, additional valves to back-wash the resin, and switches for automatic operation.

Capacity

Available in any sizes from smaller units to centralized systems.

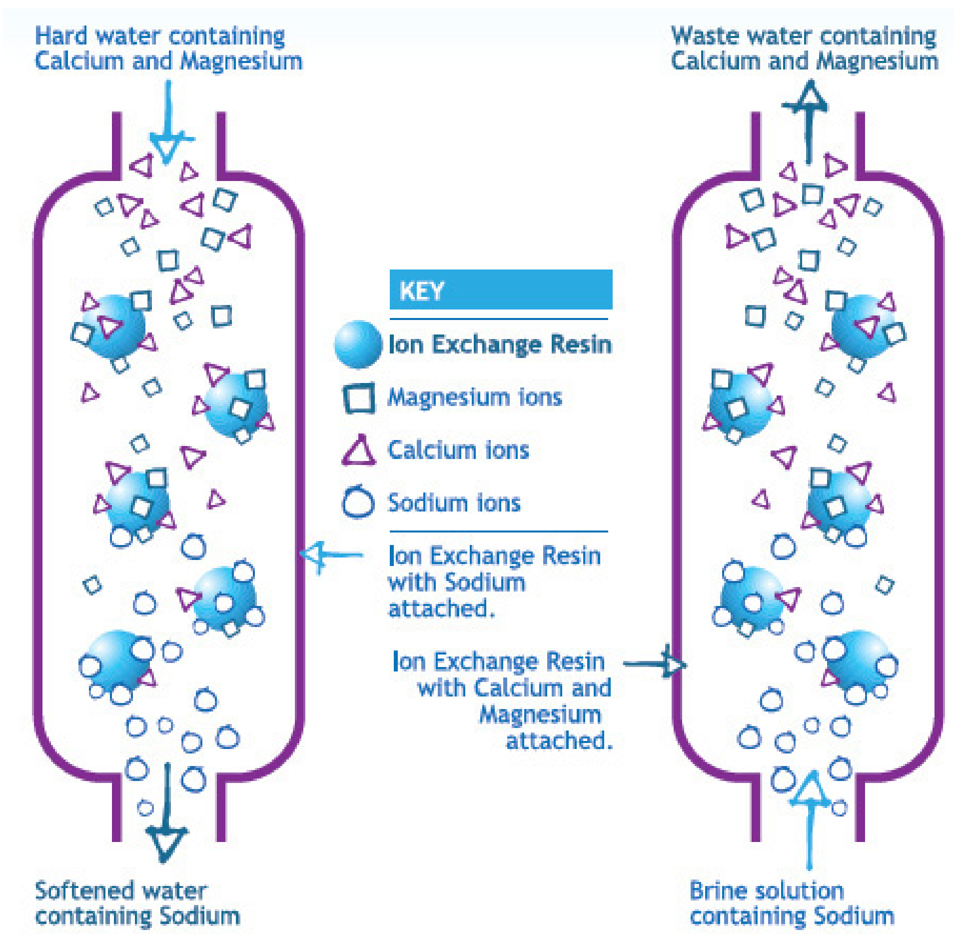
Costs

The technology is costlier due to high operational costs.

Operating Principles

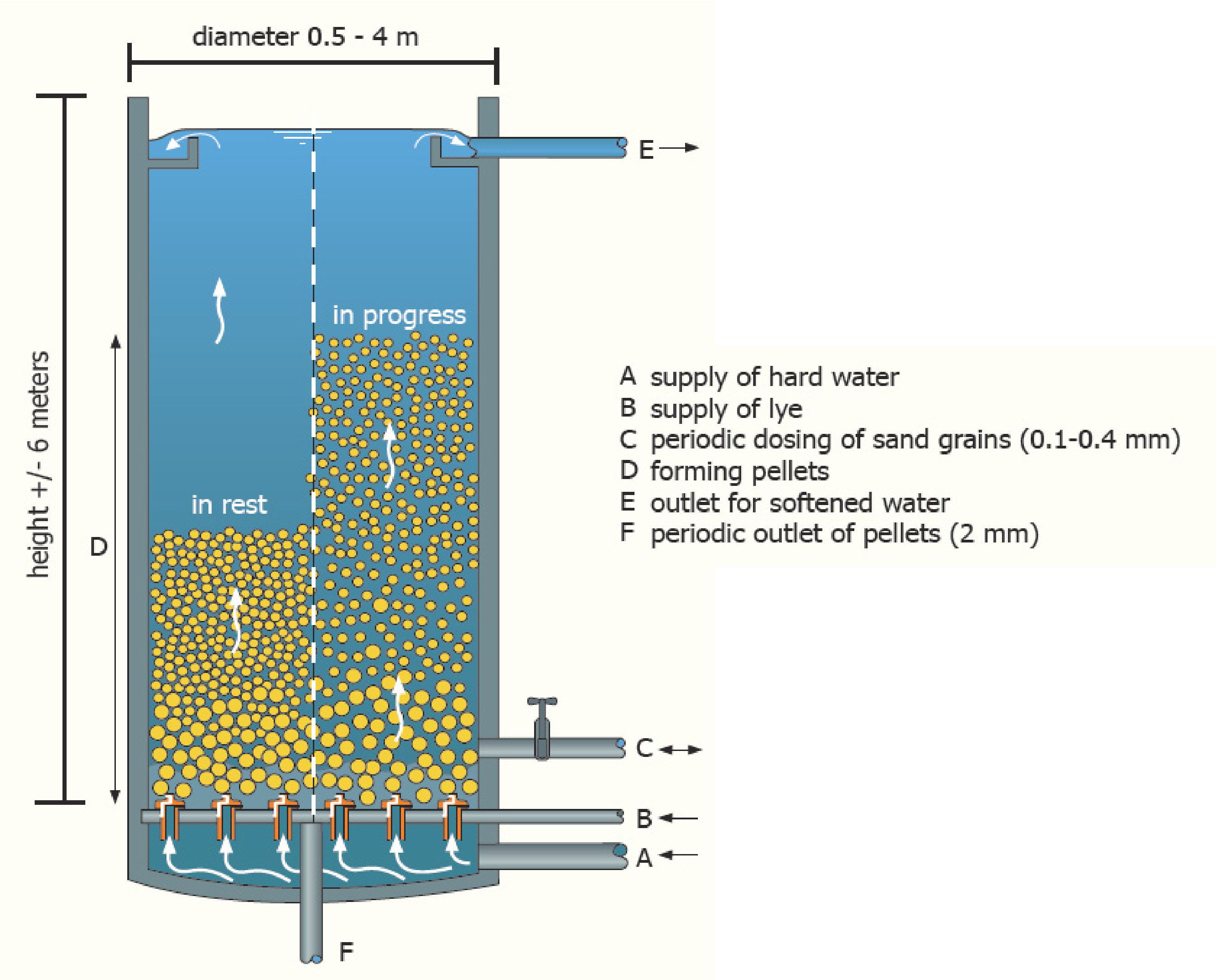
Ion exchange involves removing the hardness ions of calcium and magnesium and replacing them with non-hardness ions, typically sodium supplied by dissolved sodium chloride salt, or brine. The softener contains a microporous exchange resin, usually sulfonated polystyrene beads that are supersaturated with sodium to cover the bead surfaces. As water passes through this resin bed, calcium and magnesium ions attach to the resin beads and loosely held sodium is released from the resin into the water. After treating a large volume of hard water, the beads become saturated with calcium and magnesium ions. When this occurs, the exchange resin must be regenerated, or recharged. The regenerated ion exchange resin is flushed with a salt brine solution. The sodium ions in the salt brine solution are exchanged with the calcium and magnesium ions on the resin and excess calcium and magnesium is flushed out with wastewater (see Figure).

Frequency of the regeneration or recharge cycle depends on the hardness of the water, amount of water used, size of the softener, and capacity of the resins.



Ion-exchange softening process

In pellet reactors, raw water and chemical (base) are injected into the bottom of the reactor by separate nozzles. Water and chemicals are well-distributed over the cross-section of the reactor (plug flow) once sufficient flow resistance is realized over the nozzles. The process conditions (such as chemical doses and flow velocity) need to be selected so that the solubility product of calcium carbonate is exceeded. As a result, calcium carbonate will be formed and precipitate onto the seeding material. The seeding grains' diameter will increase as a result of the calcium carbonate deposit, forming pellets. The pellets will become heavier and settle to the bottom of the reactor. Finally, the pellets (at a diameter of 1.0 - 1.2 mm) will be removed from the reactor and new seeding grains will be brought in.



Pellet reactor softening process

Softening unit can be installed at an existing groundwater treatment plant to directly soften raw water, after aeration or after rapid filtration.

When softening of raw water directly, if iron and manganese are present in dissolved forms in the water (anaerobic water), these substances will be trapped in the CaCO3 grains. This arrangement has the advantage of reducing loading on the sand filters.

When softening takes place after an aeration phase, a lower chemical dose will be required, because some of the carbon dioxide is removed during aeration. An additional cost advantage of softening (aerated) raw water is that, in many cases, existing filters that have been used for iron and manganese removal can also be applied as 'carry-over' filters.

When softening after filtration is applied, the purest pellets are formed as iron and manganese are removed by the filters.

Utility & Efficiency

The performance of softening depends on several variables including raw water characteristics, the operation of the softener, resin, flow, and cleaning.

Operation of the softener during the softening phase can also influence efficiency. Specifically, the flow rate of the water through the softener influences how much hardness is removed.

The ion exchange water softening process can remove nearly all calcium and magnesium from source water. Softeners may also remove as much as 5 - 10 ppm of iron and manganese.

The efficiency of regeneration affects operation of the softener during the softening phase. The salt dosage during regeneration, the brine concentration, and brine contact time, all influence how well sodium is regenerated on the resin surface. If regeneration is not complete, then the softener will not operate as long before it requires another round of regeneration.

Reliability

Highly reliable, provided a high level of control process and skilled operators are available.

Replication Potential

The technologies are well-tested and replicable in any place.

Regulatory/Institutional Issues

A centralized system requires a clear guidance and regulation for the operators.

Operation and Maintenance

For ion exchange, maintenance is dependent on the type of softener. Generally, a high degree of monitoring or managing the regeneration process is required. The softener must be kept regenerated to avoid hard water flowing into pipes and appliances. The brine tank requires periodic checking and cleaning. The frequency of cleaning depends on the type and amount of salt and characteristics of the water being treated. The brine valve and float assembly, if used, should also be cleaned and inspected at least once a year. Adequate backwashing of the resin bed is important to ensure efficient regeneration of the unit. If backwashing is to be done manually or is semiautomatic, the backwash should be continued until the water runs clear. If the unit is fully automatic and backwash time is adjustable, adjust the time so the backwash is long enough to produce clear water in the drain.

For pellet reactors, the most important operation and maintenance task in softening is the selection of the appropriate chemicals and adjustment of the dose to changing raw water quality and flow rate. Regular monitoring of the chemical feed system to detect clogging of the lines and maintenance of the mixers ranks is essential. Annual removal of calcium carbonate build-up during seasonal low-demand periods is customary.

Advantages

A) Ion exchange

1. One of the most appropriate technologies to removes dissolved inorganic ions effectively
2. Possibility to regenerate resin
3. Relatively inexpensive initial capital investment
4. Ordinary variations of hardness in the raw water or in flow rate do not affect completeness of softening
5. Compact size and small footprint

B) Pellet

1. Prior clarification of the water is not usually necessary since suspended matter and turbidity are also removed in the process
2. Easily managed waste stream: water and sand, minimum environmental impacts
3. No high strength liquid waste stream generated
4. Environmentally benign solid - essentially damp sand, and potential solids reuse opportunities

Disadvantages

A) Ion exchange

1. High operation costs over long-term
2. The process of regenerating the ion exchange beds dumps salt water into the environment (regeneration)

B) Pellet

1. Initial capital cost is higher
2. The process requires a lot of operator control to get an efficient result, which may make lime softening too operator-intensive for small treatment plants
3. The high pH used in lime softening can set colors in water and make them difficult to remove
4. Lime softening produces large quantities of sludge which can create disposal problems

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TECHNOLOGY

Sludge Disposal Process

SOURCE Resources Recovery (Nutrients and Other Resources/Materials)

SCALE Semi-centralized and Centralized

Description

Sludge is produced from the treatment of wastewater in on-site (e.g. septic tank) and off-site (e.g. activated sludge) systems. This is an inherently important process since the primary aim of wastewater treatment is removing solids from the wastewater. Sludge can be collected from the preliminary tank, primary tank or from the secondary and tertiary treatment process. All coarse primary solids and secondary biosolids accumulated in the wastewater treatment process must be treated and disposed of in a safe and effective manner. Since such materials may be inadvertently contaminated with toxic organic and inorganic compounds (e.g. heavy metals). Faecal sludge contains essential nutrients (nitrogen and phosphorus) and is potentially beneficial as fertilizers for plants. It also contains organic carbon that once stabilized, is desirable as a soil conditioner as it provides improved soil structure for plant roots.

Design Criteria

Generally, the sludge disposal process consists of four main steps: sludge thickening, stabilization, dewatering, and sludge reuse and disposal. This process is very complex; there are numerous best practices and technologies available in the published literature. This unit briefly touches upon each of the processes and corresponding technologies.

Sludge Thickening: The sludge that comes out of wastewater treatment has a water content of between 97 and 99.5 percent. The objective of the thickening processes is to make primary solids or the combination of primary and waste activated solids (combined solids) more concentrated. Thickening reduces the volumetric loading and increases the efficiency of subsequent solids-processing steps.

Different methods for thickening processes include gravity-based thickening; solids-flotation, centrifugal, gravity-belt, and rotary drum. These methods differ significantly in process configuration, degree of thickening provided, and chemical, energy, and labor requirements. In sludge thickening – like in sludge dewatering – inorganic or organic flocculant aid chemicals (usually polymers) are used.

Gravity thickeners function much like settling tanks: solids settle via gravity and compact on the bottom, while water flows up over weirs. The most common gravity-thickener design is a circular tank with a side water depth of 3 to 4 m. Such tanks typically range from 21 - 24 m in diameter. Larger diameter tanks increase solids detention time, which can cause anoxic and anaerobic activity that leads to gasification and flotation problems. The tank floor typically has a steep slope allowing for minimum solids detention while maximizing solids depth over the withdrawal pipe in the center of the floor. It also reduces raking transport problems.

Sludge Stabilization: The aim of stabilization is to reduce biological and chemical reactions. Anaerobic digestion is one of the oldest and still most commonly used processes for sludge stabilization. Concentrated organic and inorganic sludge matter decomposes microbiologically in the absence of oxygen and converts to methane and inorganic end products. The main benefits from digestion are sewage sludge stabilization, volume reduction and biogas production. This process also reduces pathogens and odors—provided the solids are properly stabilized and remain stable over time—making the resulting biosolids appealing for beneficial use. The four most common stabilization processes used in the United States today are anaerobic digestion, aerobic digestion, composting, and alkaline stabilization. Further information on anaerobic digesters and other processes are presented in wastewater treatment section of this catalog.

Sludge Dewatering: Dewatering is the process of removing water from solids to reduce its volume and produce a material suitable for further processing, beneficial use, or disposal. Dewatering can be done naturally (dry beds, solar drying) over a long period of time. Machine processes such as pressing such as filter press and centrifugation are quicker and smaller, but also more cost intensive.

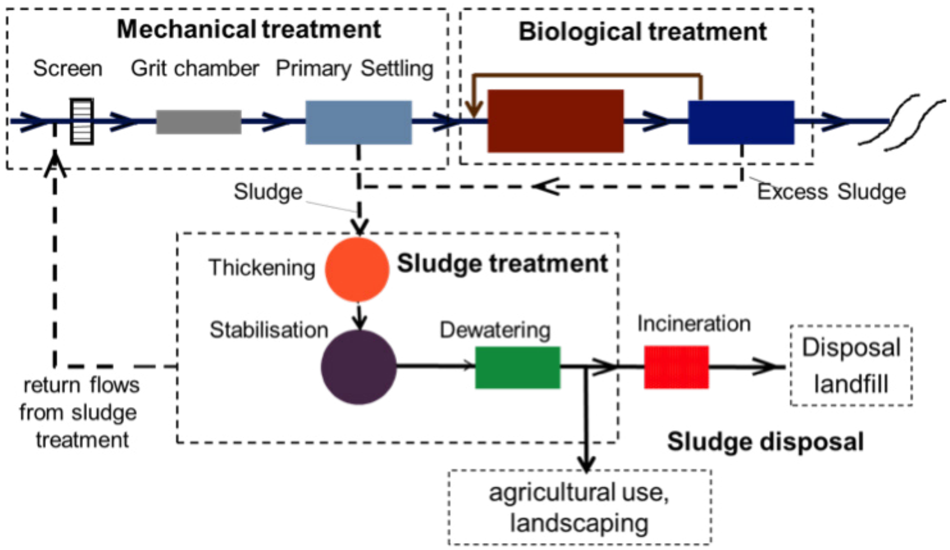
Different types of equipment used for the dewatering sludge include centrifuges, belt presses, recessed-plate filter presses, drying beds and lagoons, rotary presses, and screw presses. For example, centrifuges and belt filter presses are currently the most popular dewatering methods in municipal wastewater treatment plants due to their good performance and cost efficiency. Centrifuges work on the basis of sedimentation, much like clarifiers and thickeners. The centrifuge typically is designed to vibrate during operation (i.e., rotates to create a centrifugal force); all wetted parts are made of stainless steel.

Sludge Reuse and Disposal: The methods for reusing and disposing of wastewater solids vary considerably based on the type of solids involved and the approaches to manage them. Final or ultimate disposal of sludge that cannot be reused is destined for landfilling or incineration. Since sludge for landfilling usually contains heavy metals or toxic chemicals, it is necessary to line the landfill with clay or plastic to prevent contamination of groundwater. Sludge is incinerated by a multiple hearth furnaces or fluidised bed furnace. Combustion flue gases usually need treatment to meet air pollution control standards. Investment and operating costs are high.

- Sludge. Raw, primary, and secondary solids can be landfilled or incinerated, if dewatered. Most other use and disposal options require that solids first be treated to meet the local standards.
- Biosolids are any solids that have been stabilized to meet the local standards and can be beneficially used. There are a wide variety of stabilization processes, which produce differing types of biosolids (e.g., liquid or dewatered biosolids, compost, heat-dried biosolids, and alkaline-stabilized biosolids). Most of these products can be land-applied; some are suitable for commercial marketing and distribution.

- Ash produced by incineration can be used for landfill cover, a soil amendment, an ingredient in concrete, a fine aggregate in asphalt, a flowable fill material, and an additive in brick manufacturing.

Land application is the practice of adding biosolids to land for beneficial purposes (e.g., to promote crop or forest growth, to reclaim former mining sites and other disturbed land). In these applications, both the plants and soil benefit from the nutrients and organic matter in biosolids. The popularity of land application has grown dramatically over the last 30 years. Rising disposal costs has substantially increased the number of facilities undertaking land-application programs.



Sludge disposal in the wastewater treatment process

Applications

The costs of sludge management may be up to 50 % of the total costs of running a wastewater treatment plant. This is one of the most important processes and has numerous options, technologies, and variance depending on the local condition.

The agricultural use of sludge or incineration and the disposal of ashes allow the utilization of sludge as a material or energy resource. However, contaminants present in the sludge such as heavy metals restrict its use for agricultural purposes.

Land application is well-suited for managing solids from any size wastewater treatment facility. As the method of choice for small facilities, it offers cost advantages, benefits to the environment, and value to the agricultural community.

Components

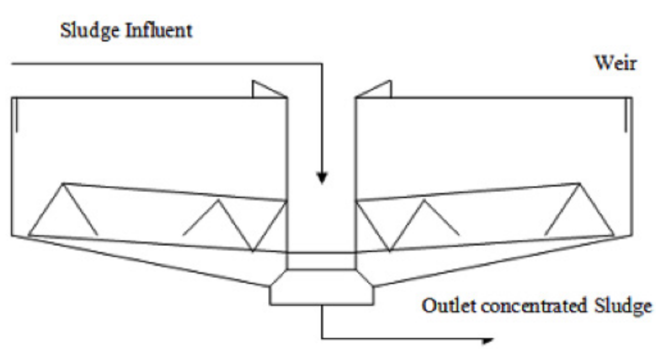
Vary according to the specific process chosen for sludge management.

Capacity

Very flexible and can be applicable from smaller units to the largest treatment plants.

Operating Principles

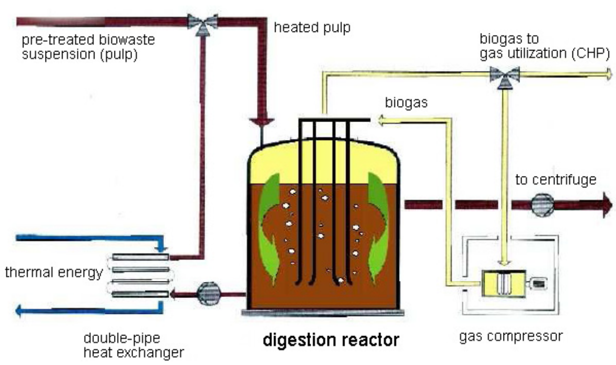
Sludge thickening: At larger treatment plants, separate thickening basins are used for the sludge thickening. These basins are equipped with slow rotating vertical rods, which create micro canals in the sludge for a better dewatering. Also pure machine thickening is gaining more significance with e.g. non-stabilized sludge that could rot during storage. At smaller wastewater treatment plants, where the sludge is driven off regularly, thickening usually takes place directly in the sludge storage tank. The sludge is compressed at the tank bottom only by the force of gravity, while above the sludge a cloudy water layer is formed, which is skimmed off and led back into the inlet. A volume reduction of approximately 30 – 80 % can be reached with sludge thickening before a further treatment.



Gravity thickener

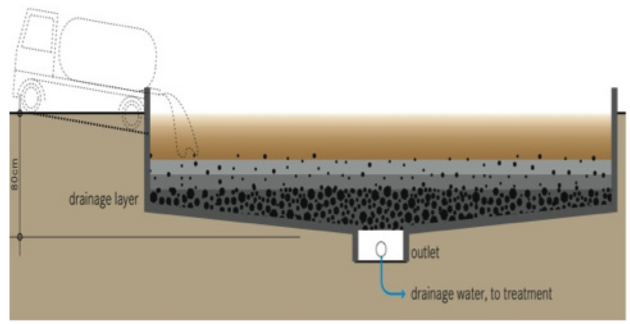
Sludge stabilization: Sludge stabilization can be achieved by aerobic or anaerobic processes. Aerobic stabilization is performed in an activated sludge plant whereby primary and secondary sludge are continuously aerated for long periods of time. In aerobic digestion, the microorganisms extend into a respiration phase where materials previously stored by the cell are oxidized, resulting in a reduction of the biologically degradable organic matter. Thus, aerobic stabilization is energy consuming.

In an anaerobic process, the facultative and anaerobic organisms break down the complex molecular structure of these solids. Anaerobic stabilization processes work at normal temperatures (< 40°C) or within the range of thermophile bacteria, where 50 - 65°C are reached by the heat development of the biochemical processes alone. The chemical stabilization of sludge by means of wet oxidation, or addition of quicklime and thermal stabilization under high temperature and pressure, are applied less often. Often, the anaerobic sludge digestion takes place in a digester.



Sludge dewatering: A further reduction of the sludge amount is usually necessary after the thickening. The liquid sludge has to be dewatered and conformed to a dry and porous form. The treatment process depends on the type of dewatering (i.e., natural or mechanical).

Drying beds are simple sealed shallow ponds filled with several drainage layers. Sludge is applied on the top and dried by percolation and evaporation. The sludge is applied in a batch mode in one week intervals with layers of no more than 20 to 30 cm. About 50 to 80% of the initial volume is removed by percolation, resulting in total solid (TS) content of 20 to 70% depending on the local weather conditions and climate. In regions with frequent rainfall, contour bounds can prevent surface runoff from entering the ponds. Covering the drying beds with a roof may also be considered.
Drying induces partial pathogen removal. However, the dried sludge still may contain pathogens, particularly Helminth eggs, and should therefore be handled carefully. Further treatment such as composting or prolonged storage is required before use in agriculture. The percolate from dewatering also contains pathogens, mainly bacteria and viruses and has to be further treated as well. In the case of frequent application of sludge and to enhance retention times, two or more drying beds can be constructed in parallel and used alternately.



Dewatering by Drying beds

The mechanical process requires the use of at least some flocculants aid to keep the excess sludge flocculated in the dewatering unit. Sometimes, coagulation chemicals such as iron or aluminum salts are added in order to enhance the efficiency of flocculants aids (polymers) and reduce the their consumption in sludge dewatering. Some research projects are developing dewatering methods without any chemicals; however, the separation effect and reliability are not yet sufficient.

Sludge reuse and disposal: Raw sludge from activated sludge treatment plants can be applied directly onto agricultural land and for aquaculture uses. The agricultural reuse of sludge or incineration and the disposal of ashes allow the utilization of sludge as a material or energy resource. The nutrient content, heavy metals, and organic micro pollutants in sludge and soil affect application rates. Hygienic risks are associated with the presence of pathogens.

The sludge is disposed of safely either by land application or incineration. The operating principles depend on the technology selected and local conditions. More information on sludge incineration and advanced treatment techniques are discussed in the energy and nutrient recovery sections.

Utility & Efficiency

Managing of the waste from the wastewater is one of main objectives of the wastewater treatment.

The efficiency of the process depends on the types of waste and treatment units selected.

Reliability

Reliable if the process is well designed and operated.

Replication Potential

The process and technologies are easily replicable.

Regulatory/Institutional Issues

Some of the processes are very simple to operate, while others require high-skilled workers. However, standard guidelines and regulations are required for the effective management.

Operation and Maintenance

All the processes are directly dependent on the other treatment processes and technologies. Therefore, the operations and maintenance should be in conjunction with the other techniques.

For example, in thickening and dewatering process, jar tests are required to analyze the conditions of biosolids. Centrifuge operations can be fully automated, but starting the bowl and putting feed into the machine are usually performed manually. A good grit removal system should be incorporated into the plant design in order to reduce abrasive wear. It is important to keep records of all performance parameters including volume of biosolids fed to the centrifuge and chemicals used. A sample of the feed biosolids to the centrifuge, cake discharge, and concentrate should be taken each shift and analyzed for total solids. Prior to shut down, the centrifuges should be emptied and the speed gradually reduced.

The O and M required for aerobic and anaerobic processes is applicable for the sludge stabilization process. For example, maintaining a stable operating temperature and pH within the digesters is critical, particularly for the methane formers, which are sensitive to changes in temperature and PH.

Land application systems generally use uncomplicated, reliable equipment. Operations include pathogen reduction processing, dewatering, loading of transport vehicles, transfer to application equipment, and the actual application. The other operations require labor skills of heavy-equipment operators, equipment maintenance personnel, and field technicians for sampling - all normally associated with wastewater treatment facilities. Control of odors, along with a viable monitoring program, is most important for public acceptance.

Advantages

1. Gravity thickeners are very simple; have a low operating cost; Ideal for dense rapidly settling sludge such as primary and lime, Provides a degree of storage as well as thickening, Conditioning chemicals not typically required, Minimal power consumption.
2. Dissolved air flotation thickeners are effective for WAS, will work without conditioning chemicals at reduced loadings, relatively simple equipment components.
3. Centrifuge thickeners control capability for process performance, effective for WAS, contained process minimizes housekeeping and odor considerations, will work without conditioning chemicals, high thickened concentrations available.
4. Gravity belt thickeners are space requirements, control capability for process performance, relatively low capital cost, relatively low power consumption, high solids capture with minimum polymer, high thickened concentrations available.
5. Rotary drum thickeners are space requirements, low capital cost, relatively low power consumption, high solids capture can be easily enclosed.
6. Compared to other mechanical dewatering devices, belt presses still have the lowest energy consumption per volume of solids dewatered.
7. A pressure filter press system typically produces cakes that are drier than those produced by other dewatering equipment.
8. Where elaborate lining and leachate control is not necessary and where land is available, capital cost of drying bed is low for small plants. Also they are low requirement for operator attention and skill, low electric power consumption, low sensitivity to sludge variability, low chemical consumption, and high dry cake solids content.
9. Rotary presses and rotary fan presses uses less energy than centrifuges or belt filter presses, small footprint, odors contained, low shear, minimal moving parts, minimal building requirements, minimal start-up and shutdown time, uses less wash water than belt filter presses, low vibration, low noise, and modular design.
10. Screw presses are low rotational speed resulting low maintenance and noise, low operating energy consumption, containment of odors and aerosol, low building corrosion potential, simple operation with low operator attention, lower than belt presses wash water demand and wash water pressure requirements.
11. Anaerobic digestion are good volatile suspended solids destruction, net operational cost can be low if gas is used, broad applicability, bio solids suitable for agricultural use, reduces total sludge mass, low net energy requirements.

Disadvantages

1. Gravity thickeners may cause odors, erratic for WAS, thickened solid concentration limited for WAS, high space requirements for WAS, floating solid.
2. Dissolved air flotation thickeners have relatively high power consumption, thickening solids concentration limited, odor potential, high space requirements compared to other mechanical methods, moderate operator attention requirements, building corrosion potential, if enclosed, requires polymer for high solids capture or increased loading.
3. Centrifuge thickeners are relatively high capital cost and power consumption, sophisticated maintenance requirements, best suited for continuous operation, moderate operator attention requirements.
4. Gravity belt thickeners are housekeeping, polymer dependent, moderate operator attention requirements, odor potential, and building corrosion potential, if enclosed.
5. Rotary drum thickeners are polymer dependent, sensitivity to polymer type, moderate operator attention requirements, and odor potential if not enclosed.
6. Filter presses are high capital cost, relatively high O&M costs, the substantial quantities of treatment chemicals required, and the periodic adherence of cake to the filter medium, which must be manually removed. It also requires significant amounts of energy to pressurize the units.
7. Drying beds lacks rational design approach for sound economic analysis, large land requirement, stabilized sludge requirement, impact of climatic effects on design, high visibility to general public, labor-intensive sludge removal, permitting and groundwater contamination concerns, fuel and equipment costs for bed cleaning systems, real or perceived odor and visual nuisances.
8. Rotary presses and rotary fan presses may be more dependent on polymer performance than centrifuges or belt filter presses, low throughput compared to other mechanical dewatering processes, screen clogging potential, need for heavy rated overhead crane to lift and maintain channels, and high capital cost.
9. Cake concentration from screw presses may be relatively low, in particular when there are no primary clarifiers. Screw presses have a larger footprint, few manufacturers available and equipment cannot be specified "as-equal." It must be sole-sourced or pre-purchased, requires wash water. Lower solids capture than other dewatering processes in some cases.
10. Anaerobic digestion requires skilled operators, may experience foaming, methane formers are slow growing, hence, "acid digester" sometimes occurs, recovers slowly from upset, supernatant strong in ammonia and phosphorus, cleaning is difficult, can generate nuisance odors resulting from anaerobic nature of process, high initial cost, potential for struvite, safety issues concerned with flammable gas.

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Desalination Pretreatment

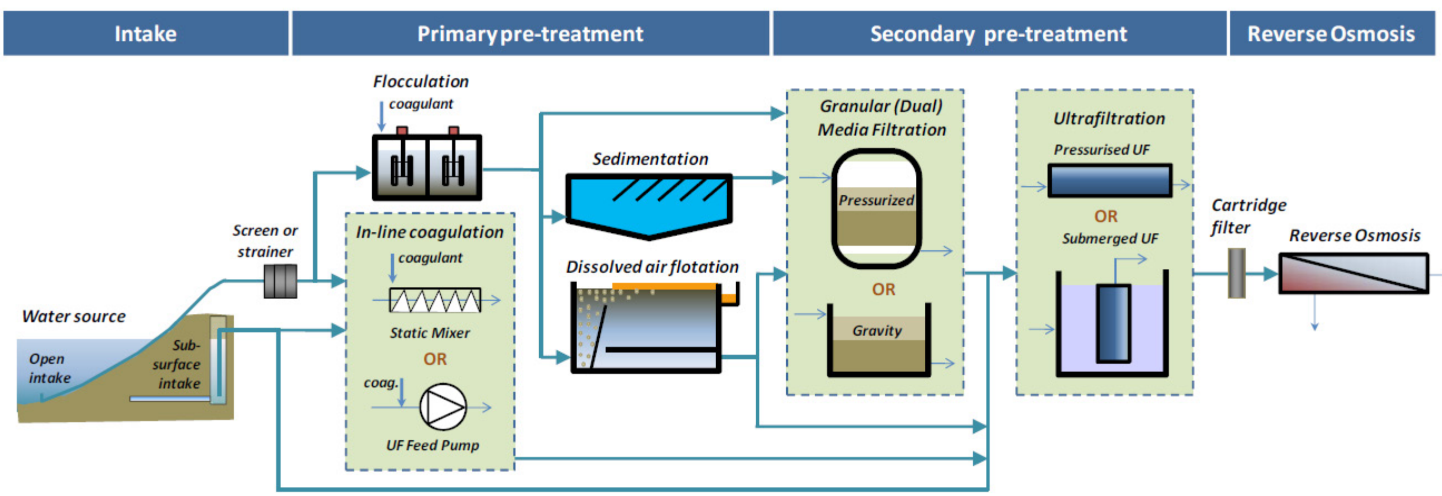
Description

Pretreatment in desalination systems is a preliminary step to treat the raw water to the required quality so that it will not have any adverse effects on the performances of the desalination system as the water passage through desalination units. The levels of pretreatments vary according to desalination technologies such as membranes, thermal and others. Mostly, the pretreatment process includes either conventional filtration plants or a membrane filtration system. The pretreatment prevents membrane fouling and helps to extend the lifetime of the membrane.

Design Criteria

Detailed physical, chemical and biological analyses of raw water at intake are fundamental for the selection and design determination of the pretreatment process. For example, water originating from a properly designed and operated well field has a very low concentration of suspended solids and the treatment process includes only cartridge filters by omitting any media filtration. In contrary, a full pretreatment process will be required for water from open seawater intakes.

Design criteria will be based on the type of water quality (i.e., turbidity, organic and inorganic matters and microbial, etc.) and types of membrane technologies selected for the desalination. As indicated in the Figure and Table below, there could be any potential arrangement for the pretreatment process prior to the desalination. The main objectives are to avoid scaling and/or fouling of membranes and evaporators.



Pretreatment options for sea water RO system

During the initial stage of pretreatment, large pieces of rocks and living organisms such as barnacles are first removed by the coarse screens. Subsequently, smaller particles and colloids are removed by the sand filters. In order to safeguard against any leakage of suspended particles from the sand filter, the filtrate is passed through a final stage of micron cartridge filtration. The cartridge filtration system serves as a polishing filter to ensure constant filtrate quality before the filtrate is channeled to the RO membranes. In addition to the above, coagulant is also dosed prior to the sand filters to enhance the removal of colloidal and suspended particles.

As shown in the Table, the process unit for the pretreatment could be in any order based on the local condition. Pretreatment technologies are continuously evolving to more fully address biofouling prevention and challenges such as algal blooms and unique needs of new water sources such as those presented by the oil and gas industry. Readers are suggested to consult other sections of this catalogue to get more information on the specific pretreatment systems that are discussed on water and wastewater treatment section.

For example, a pretreatment plant is comprises a coarse screen before the seawater supply pumps, gravity-driven single-medium sand filters and a three-stage (10-5-l pm) polishing cartridge filtration system.

Potential Pretreatment Option for Desalination System	
Alternative Option	**Pretreatment Process**
A	Open intake → screen → coagulation-flocculation → sedimentation → granular media filtration → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)
B	Open intake → microstraining → coagulation-flocculation → sedimentation → granular media filtration → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)
C	Open intake → microstraining → coagulation-flocculation → dissolved air flotation → granular media filtration → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)
D	Open intake → microstraining → coagulation-flocculation → dissolved air flotation → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)
E	Open intake → microstraining → inline coagulation → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)
F	Subsurface intake → microstraining → inline coagulation → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)
G	Subsurface intake → ultrafiltration → cartridge filtration → Desalination (e.g., RO, nanofilteration etc.)

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