Trickling Filter

A *trickling filter*, also called trickling biofilter, biofilter, biological filter and biological *trickling filter*, is a fixed-bed, biological *reactor* that operates under (mostly) *aerobic* conditions. Pre-settled *wastewater* is continuously 'trickled' or sprayed over the filter. As the water migrates through the pores of the filter, *organics* are aerobically degraded by the *biofilm* covering the filter material**.**

Introduction

Trickling filters are conventional *aerobic biological wastewater treatment* units, such as active sludge systems or rotating biological contactors. The advantage of all these systems is that they are compact (i.e. applicable in densely populated urban settings) and that they efficiently reduce *organic matter*. However, they are high-tech and generally require skilled staff for construction as well as for operation.

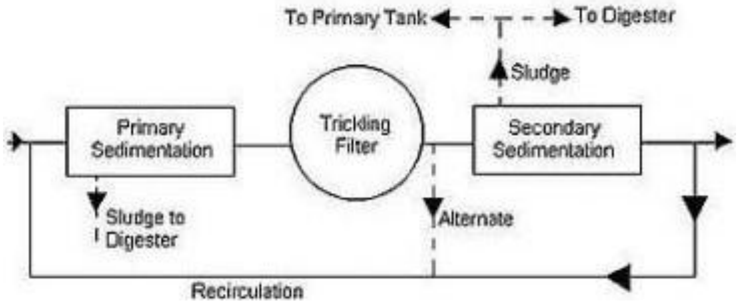


Figure: Typical flow-chart of a *trickling filter* system including a pre- and post treatment.

Trickling filters are a *secondary treatment* after a primary setting process.

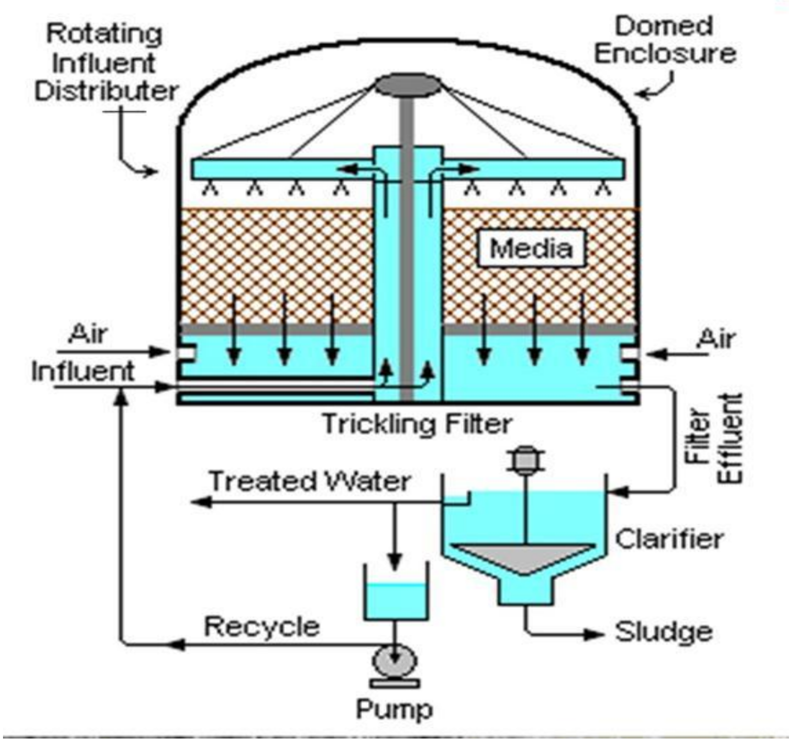


Figure: Schematic cross-section of a *trickling filter*.

The *trickling filter* consists of a cylindrical tank and is filled with a high *specific surface area* material, such as rocks, gravel, shredded PVC bottles, or special pre-formed plastic filter media. A high specific surface provides a large area for *biofilm* formation. Organisms that grow in the thin *biofilm* over the surface of the media oxidize the *organic* load in the *wastewater* to carbon dioxide and water, while generating new *biomass*. This happens mainly in the outer part of the slime layer, which is generally of 0.1 to 0.2 mm thickness .

The incoming pre-treated *wastewater* is 'trickled' over the filter, e.g., with the use of a rotating sprinkler. In this way, the filter media goes through cycles of being dosed and exposed to air. However, oxygen is depleted within the *biomass* and the inner layers may be *anoxic* or *anaerobic*.

The word filter is somehow misleading, as physical straining of solids is only marginal. The removal of *organic* substances occurs by use of bacterial action. Therefore *trickling filters* are also called bio-, or biological filters to emphasise that the *filtration*. Fixed film *biological treatment* are also used in other common treatment processes such rotating biological contactors of fixed film activated sludge systems.

Biofilm

The bio-film that develops in a trickling filter may become several millimetres thick and is typically a gelatinous matrix that contains many species of bacteria, cilliates and amoeboid protozoa, annelids, round worms and insect larvae and many other micro fauna. This is very different from many other bio-films which may be less than 1 mm thick. Within the thickness of the biofilm both aerobic and anaerobic zones can exist supporting both oxidative and reductive biological processes. At certain times of year, especially in the spring, rapid growth of organisms in the film may cause the film to be too thick and it may slough off in patches leading to the "spring slough".

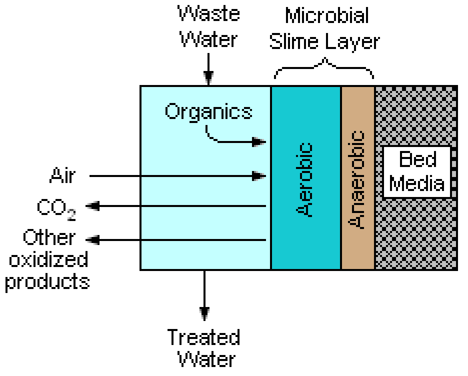


Figure: A schematic cross-section of the contact face of the bed of media in a trickling filter

Design Considerations

The filter is usually 1 to 2.5 m deep, but filters packed with lighter plastic filling can be up to 12 m deep. Oxygen is obtained by direct diffusion from air into the filter and the biological film from the bottom through a spontaneous airflow due to *temperature* difference. Therefore, both ends of the filter should be ventilated, and sub-soil construction is not common. However, in cold climates, and where *energy* for aeration and pumping is easily available, sub-soil construction can give protection against *temperatures* shocks.
The primary factors that must be considered in the design of *trickling filters* include:

- the type of filter media to be used
- the spraying system, and
- the configuration of the under-drain system

Filter media

The ideal filter material is low-cost and durable, has a high surface to volume ratio, is light, and allows air to circulate. Whenever it is available, crushed rock or gravel is the cheapest option. Specially manufactured plastic media, such as corrugated plastic sheets or hollow plastic cylinders, that optimise surface area for *bacteria* to attach free movement of air are also available. The particles should be uniform and 95% of them should have a diameter between 7 and 10 cm. A material with a *specific surface area* between 45 and 60 m^2/m^3 for rocks and 90 to 150 m^2/m^3 for plastic packing is normally used. Larger pores (as in plastic packing) are less prone to clogging and provide for good air circulation. *Primary treatment* is also essential to prevent clogging and to ensure efficient treatment.

Spraying System

Adequate air flow is important to ensure sufficient treatment performance and prevent odours. To evenly distribute the water on the filter, a “rotary sprinkler/distributor” is most often used. The rotary distributor consists of a hollow vertical centre 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.

1. The application of wastewater onto the medium is accomplished by a rotating distribution system
2. Distributor consists of two or more arms that are mounted on a pivot in the center of the filter and revolve in a horizontal plane
3. The arms are hollow and contain nozzles through which the wastewater is discharged over the filter bed

4. Nozzles are spaced unevenly so that greater flow per unit of length is achieved near the periphery of the filter than at the center
5. For uniform distribution over the area of the filter, the flowrate per unit length should be proportional to the radius from the center

Underdrain System

The underdrains should provide a passageway for air at the maximum filling rate. A perforated slab supports the bottom of the filter, allowing the *effluent* and excess *sludge* to be collected. The *trickling filter* is usually designed with a recirculation pattern for the *effluent* to improve wetting and flushing of the filter material.

With time, the *biomass* will grow thick and the attached layer will be deprived of oxygen; it will enter an endogenous state, will lose its ability to stay attached and will slough off. High-rate loading conditions will also cause sloughing.
The underdrain system must have following:

1. To catch the filtered wastewater and solids discharged from the filter packing for conveyence to the final sedimentation tank
2. Precast blocks of vitrified clay Fiberglass grating laid on a reinforced concrete subfloor
3. The floor and underdrains must have sufficient strength to suport the packing, slime growth and the wastewater
4. Underdrains may be open at both ends (so that they may be inspected easily and flushed out if they become plugged)
5. The underdrains also allow ventilation of the filter, providing the air for microorganisms
6. All underdrain systems should be designed so that forced air ventilation can be added at a later date

With time, growth and reproduction of the *bacteria* results in an increase of thickness of the *biofilm* layer, particularly at the top of the *trickling filter*. If the *biofilm* grows to thick, oxygen is prevented to enter and *anaerobic* organisms develop. The continuous growth, the metabolic waste *products* of the *anaerobic bacteria*, and the maintenance of a *hydraulic load* to the filter eventually *lead* to the fact that the *microorganisms* near the surface lose their ability to stick to the filter. When *microorganisms* fall off the medium and are carried with the *effluent*, this process is known as sloughing. The under-drain system allows transporting these solid to a clarifier, where the solids settle and separate from the treated *effluent*. To keep sloughing minimal, the *organic* and the *hydraulic load* to the filters should guarantee a balance between the growth of the *biofilm* and the amount of rinsed-out dead bio-film. The collected *effluent* should be clarified in a settling tank to remove any *biomass* that may have dislodged from the filter. It can then be discharged to *surface waters* , percolated to *groundwater* or used in irrigation. The hydraulic and *nutrient* loading rate (i.e., how much *wastewater* can be applied to the filter) is determined based on the characteristics of the *wastewater*, the type of filter media, the ambient *temperature*, and the discharge requirements.

Trickling filters can be combined in *decentralised wastewater treatment systems* (e.g. following septic tanks or anaerobic baffled reactors) but are also often part of large centralised *wastewater treatment* plants (e.g. following activated sludge treatment).

Although *trickling filters* are more easily operated and consume less *energy* than *activated sludge* processes, they have a lower removal efficiency for solids and *organic matter*, they are more sensitive to low air *temperatures*, and can become infested with flies and mosquitoes.

Classification of Trickling Filters

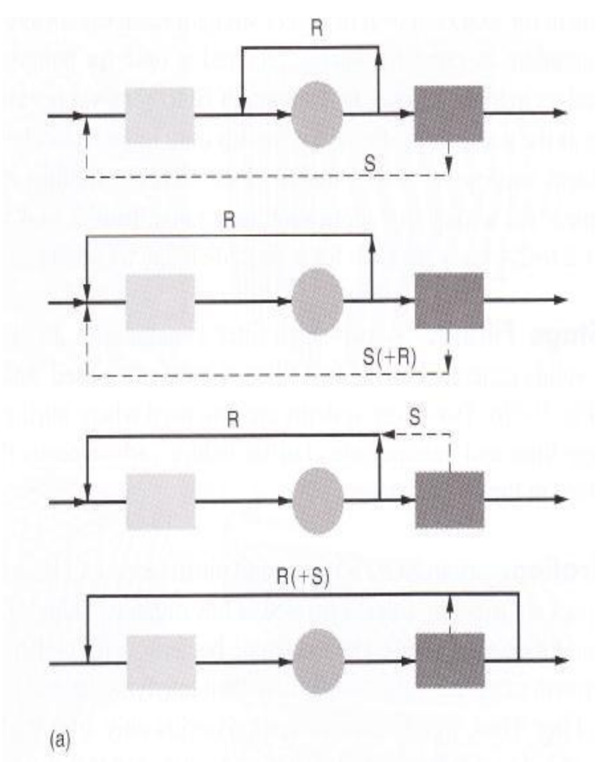
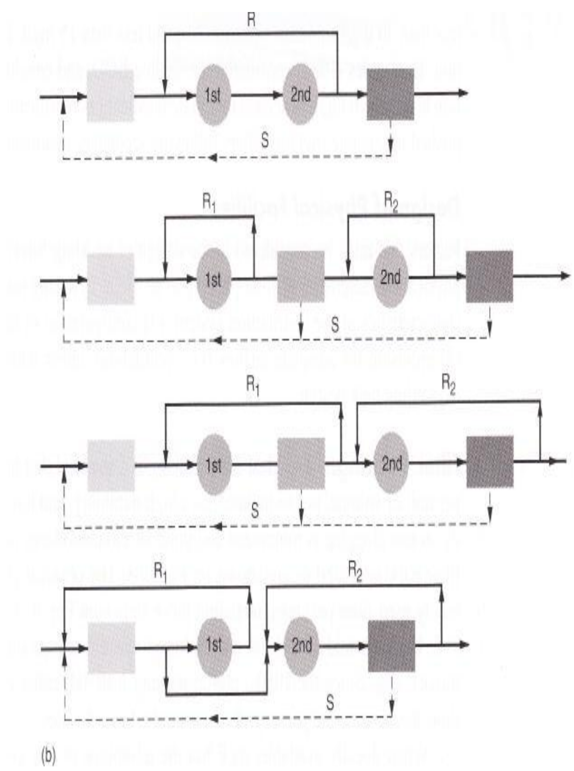
- Low rate filters
- Intermediate-and high rate filters
- Roughing filters

- **Low Rate Filters**
  - Relatively simple
  - Low hydraulic loading
  - do not include recycling
  - produces an effluent of consistent quality with an influent of varying strength
  - only top 0.6-1.2 m of the filter packing will have appreciable biological slime
  - the lower portions of the filter may be populated by autotrophic nitrifying bacteria
  - can provide good BOD removal and a highly nitrified effluent
- **Intermediate and High-rate Filters (Biotowers)**
  - recirculation of the filter effluent or final effluent permit higher organic loadings
  - either rock or plastic packing
  - recirculation = 1-3 times inflow
  - may be designed as single or two stage processes

- two filters in series operating at the same hydraulic application rate (m^3/m^2.hr) will typically perform as if they were one unit with the same total depth

❖ **Roughing Filters**
- very high organic and hydraulic loading
- plastic packing

Typical trickling filter process flow diagrams. Where used, the most common flow diagrams are the first two of each series

Single stage	**Double stage**
	

Treatment Capacity

Trickling filters are designed primarily for *BOD* removal. Treatment performances depend on *wastewater* characteristics, hydraulic and *organic* loading, medium type, maintenance of optimal *dissolved oxygen* levels, and recirculation rates *BOD* reduction of 60 to 85 % can be expected with loading rates of 1 kg *BOD*/m3/day. Bacterial reductions have been reported to be 1 to 2 logs of *faecal Coliforms*, respectively 60 to 90 % of *total Coliforms*. Physical *adsorption* of *virus* on the *biofilm* or elimination by predation are additional factors in *pathogen* elimination in *trickling filters*. *Total suspended solids* (*TSS*) removal is expected to be very low (due to the down-flow *regime*) and pre-*settling* as well as removal of the solids from the *effluent* is recommended. Because *aerobic bacteria* convert *ammonia* to nitrate, some *nitrification* can also be achieved, depending on the *organic* loading rate to the filter, the *temperature* and the aeration. *Total nitrogen* removal varies from 0 to 35 %, while *phosphorus* removal of 10 to 15 % might be expected. However, the capacity for *nutrient* removal of *trickling filters* depends strongly on the operation conditions, and while some sources indicate a high removal of *ammonia* other indicate no capacity of *trickling filters* for *nutrients*.

Health Aspects/Acceptance

Odour and fly problems require that the filter be built away from homes and businesses. Appropriate measures must be taken for pre- and *primary treatment* (*settling*), *secondary treatment* (eventually final clarifier), *effluent* discharge and solids treatment, all of which can still pose *health* risks.

Costs Considerations

Capital costs are moderate to high depending on type of filter materials and feeder pumps used. *Operation and maintenance* costs are moderate or high depending on electricity consumption of feeder pumps. In any case expert design and skilled labour is required for construction and maintenance (e.g. prevent clogging, ensure adequate flushing, monitor hydraulic and *organic* loads, control filter flies, etc.). Another cost factor is *energy* consumption of pumps (e.g. to bring the water to the top of the filter) and for the sprinkler system. However, this requirements are low compared to actively aerated systems such as activated sludge processes.

Operation and Maintenance

A skilled operator is required to monitor the filter and repair the pump in case of problems. The *sludge* that accumulates on the filter must be periodically washed away once in five to seven years or more (*WSP* 2008) to prevent clogging and keep the *biofilm* thin and *aerobic*. High hydraulic loading rates (flushing doses) (> 0.8 m3/m3h) and temporal collection of the *effluent* can be used to flush the filter. Optimum dosing rates and flushing frequency should be determined from the field operation.

- The rotary distributor may also require regular cleaning or technical maintenance.
- The packing must be kept moist. Constant hydraulic loading can be maintained through *suction* level controlled pumps or dosing *siphons*. This may be problematic at night when the water flow is reduced or when there are power failures. Recirculation of *effluent* may also be required to avoid low flow conditions, but a too strong flow overload would flush out the microbes.
- Besides drying out, excessive odour can also arise when *anaerobic* conditions arise due to excessive *organic* loadings or insufficient aeration.

- **Cold weather operation**
  Freezing may cause partial plugging of the filter medium

- **Filter flies**
  - High hydraulic loading rates and maintenance of a thin biological film assist in washing the fly larvae from filter before they can mature
  - Recirculation-increases hydraulic loading
  - The larvae--look like small worms to the naked eye
  - Removed easily from the flow in secondary clarifiers which are provided with skimmers

- **Snails**
  - In some areas, snails create problems in rock filters.
  - The snails feed on the slime growth, which is probably not harmful itself.
  - The difficulty lies in the snail shells which remain behind when the snails die and which are gradually fill the void spaces of the bed, interfering with the flow of both water and air
  - Removing shells--requires removing of medium (very expensive, time consuming)
    Control of problem--flooding the bed several days
    - The snails will drown
    - As they decay the gases produced will buoy the shells to the surface where they can be skimmed by hand

- **Odor**
  - Produced by anaerobic activity within the slime layer
  - is reduced by high recirculation rates which thin the film and supply additional oxygen

At a Glance

Working Principle	*Wastewater* trickles vertically through a porous media (e.g. a stone bed) with high specific surface. The *biofilm* growing on the media removes *organic matter* under *aerobic* conditions.
Capacity/ Adequacy	Semi-centralised to centralised. The system is usually applied in urban areas for treatment of domestic *wastewater*. It can be applied for bigger and smaller communities.
Performance	*BOD*: 65 to 90 %. Low *TSS* removal. *Total Coliforms*: 1 to 2 log units *N*: 0 to 35%. *P*: 10 to 15 %.

Costs	Medium; investment costs depend on type of filter materials and feeder pumps used; operational costs determined by electricity consumption of feeder pumps.
Self-help Compatibility	Low. Design, planning and implementation by expert consultants; no community labour contribution possible; feeder pumps required; permanent staff required for operation.
O&M	Civil engineer needed for construction, professional service providers required
Reliability	Resistant to shock loadings but the systems does not work during power failures.
Main strength	High treatment efficiency with lower area requirement compared to wetlands or ponds; resistant to shock loading.
Main weakness	Requires expert skills, pumps and continuous electrical power, as well as ample and continuous *wastewater* flow required

Applicability

This technology can only be used following primary clarification since high solids loading will cause the filter to clog. Since *trickling filter* only receive liquid waste, they are not suitable where water is scarce or unreliable. Moreover, *trickling filters* require some specific material (i.e. pumps and replacement parts) and skilled design and maintenance. A low-*energy* (gravity) trickling system can be designed, but in general, a continuous supply of power and *wastewater* is required. However, *energy* requirement for operating a *trickling filter* is less than for an activated sludge process or aerated lagoons.

Compared to other technologies (e.g., Waste Stabilization Ponds), *trickling filters* are compact, although they are still best suited for peri-urban or large, rural settlements.

Trickling filters can treat domestic *blackwater* or *brownwater*, *greywater* or any other *biodegradable effluent*. 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* (see also septic tanks or pre treatment) is compulsory to avoid clogging of the filter bed and a secondary clarification *step* and *post-treatment* of excess *sludge* (e.g. in sedimentation ponds, unplanted drying beds, planted drying beds or anaerobic digesters) is also compulsory.

Trickling filters can be built in almost all environments, but special adaptations for cold climates are required. Proper insulation, reduced *effluent* recirculation, and improved distribution techniques can lessen the impact of cold *temperatures* .

Advantages

- Can be operated at a range of organic and hydraulic loading rates
- Resistant to shock loadings
- Efficient nitrification (ammonium oxidation)
- High effluent quality in terms of BOD and suspended solids removal; in combination with a primary and tertiary treatment also in terms of pathogens
- Small land area required compared to constructed wetlands

Disadvantages

- High capital costs
- Requires expert design and construction, particularly, the dosing system
- Requires operation and maintenance by skilled personnel
- Requires a constant source of electricity and constant wastewater flow
- Flies and odours are often problematic
- Pre-treatment and treatment of excess sludge required
- Risk of clogging, depending on pre- and primary treatment
- Not all parts and materials may be locally available