TRICKLING FILTERS

Introduction

Trickling filters (TFs) also called as trickling biofilter, biofilter, biological filter and biological trickling filter are used to remove organic matter from wastewater. The TF is a fixed-bed, biological reactor that operates under (mostly) aerobic conditions, that utilizes microorganisms attached to packing materials such as rock, gravel, Slag, Sand, redwood, and a wide range of plastic and other synthetic materials to remove organic matter from wastewater.

This type of system is common to a number of technologies such as rotating biological contactors and packed bed reactors (biotowers). These systems are known as attached-growth processes, where pre-settled wastewater is continuously 'trickled' or sprayed over the filter. In contrast, systems in which microorganisms are sustained in a liquid are known as suspended-growth processes.

The trickling filter is one of the most common attached cell (biofilm) processes. Unlike the activated sludge and aerated lagoons processes, which have biomass in suspension, most of the biomass in trickling filters are attached to certain support media over which they grow.

Trickling filter is considered as a best method for waste water treatment, in this episode we are understanding the TF process under the following topics

1. Design criteria
2. Process description
3. Microbiology of the trickling filter
4. Types of filters and operation and maintenance
5. Advantages and disadvantages of the method

1. Design criteria

TF consists of permeable medium made of a bed of rock, slag, or plastic over which wastewater is distributed to trickle through. Rock or slag beds can be up to 60.96 meters (200 feet) in diameter and 0.9-2.4 meters (3 to 8 feet) deep with rock size varying from 2.5-10.2 cm (1 to 4 inches). Most rock media provide approximately 149 m^2 /m^3 (15 sq ft/cu ft) of surface area and less than 40 percent void space. Packed plastic filters (bio-towers), on the other hand, are smaller in diameter (6 to 12 meters (20 to 40 feet)) and range in depth from 4.3 to 12.2 meters (14 to 40 feet). These filters look more like towers, with the media in various configurations (e.g., vertical flow, cross flow, or various random packings). Research has shown that cross-flow media may offer better flow distribution than other media, especially at low organic loads. When comparing vertical media with the 60 degree cross-flow media, the vertical media provide a nearly equal distribution of wastewater minimizing potential plugging.

The design of a TF system for wastewater also includes a distribution system. Rotary hydraulic distribution is usually standard for this process, but fixed nozzle distributors are also being used in square or rectangular reactors. Overall, fixed nozzle distributors are being limited to small facilities and package plants. Recently some distributors have been equipped with motorized units to control their speed. Distributors can be set up to be mechanically driven at all times or during stalled conditions. In addition, a TF has an underdrain system that collects the filtrate and solids, and also serves as a source of air for the microorganisms on the filter. The treated wastewater and solids are piped to a settling tank where the solids are separated. Usually, part of the liquid from the settling chamber is recirculated to improve wetting and flushing of the filter medium, optimizing the process and increasing the removal rate.

It is essential that sufficient air be available for the successful operation of the TF. It has been found that to supply air to the system, natural draft and wind forces are usually sufficient if large enough ventilation ports are provided at the bottom of the filter and the medium has enough void area. The following four basic categories of filter design are based on the organic loading of the trickling filter.

Trickling filters also require primary treatment for removal of settleable solids and oil and grease to reduce the organic load and prevent the system blocking. Rock or blast furnace slag have traditionally been used as filter media for low-rate and intermediate-rate trickling filters, while high-rate filters tend to use specially fabricated plastic media, either as a loose fill or as a corrugated prefabricated module. The advantage of trickling filters is their low energy requirement, but the disadvantage is the low loading compared to activated sludge, making the plant larger with a consequent higher capital cost. The overall BOD removal efficiency can be as great as 95%, but this is dependent on the loading applied and the mode of operation.

Generally trickling filter design is based on empirical relationships to find the required filter volume for a designed degree of wastewater treatment. There are different types of equations employed in the process such as NRC equations (National Research Council of USA), Rankins equation, Eckenfilder equation and Galler and Gotaas equation. Out of which first two reactions are widely used. NRC equations results in highly satisfactory values when there is no re-circulation, the seasonal variations in temperature are not large and fluctuations with high organic loading. Rankin's equation is used for high rate filters.

NRC equations

These equations are applicable to both low rate and high rate filters. The efficiency of single stage or first stage of two stage filters, E_2 is given by

$$E_2 = \frac{100}{1+0.44\,(F_{1.BOD}/V_1.Rf_1)^{1/2}}$$

For the second stage filter, the efficiency E_3 is given by

$$E_3 = \frac{100}{[(1+0.44)/(1-E_2)](F_{2.BOD}/V_2.Rf_2)^{1/2}}$$

Where,

E_2= % efficiency in BOD removal of single stage or first stage of two-stage filter

E_3=% efficiency of second stage filter

$F_{1.BOD}$= BOD loading of settled raw sewage in single stage of the two-stage filter in kg/d

$F_{2.BOD}$= $F_{1.BOD}(1-E_2)$= BOD loading on second-stage filter in kg/d,

V_1= volume of first stage filter, m^3

V_2= volume of second stage filter, m^3

Rf_1= Recirculation factor for first stage

R_1= Recirculation ratio for first stage filter

Rf_2= Recirculation factor for second stage

R_2= Recirculation ratio for second stage filter

Rankins equation

This equation also known as tentative method of ten states. USA has been successfully used this equation over wide range of temperature. It requires following conditions to be observed for single stage filters:

1. Raw settled domestic sewage BOD applied to filters should not exceed 1.2 kg BOD_5/day/ m^3 filter volume.
2. Hydraulic load (including recirculation) should not exceed 30 m^3/m^2 filter surface-day.
3. Recirculation ratio (R/Q) should be such that BOD entering filter (including recirculation) is not more than three times the BOD expected in effluent. This implies that as long as the above conditions are satisfied efficiency is only a function of recirculation and is given by:

$$E = \frac{(R/Q) + 1}{(R/Q) + 1.5}$$

In order to achieve optimum operation, several design criteria for trickling filters must be followed:

- Roughing filters may be loaded at a rate of 4.8 kg BOD_5/day/m^3 filter media and achieve BOD_5 reductions of 40–50%;
- High-rate filters achieve BOD_5 reductions of 40–70% at organic loadings of 0.4–4.8 kg/BOD_5/day/m^3; and
- Standard rate filters are loaded at 0.08–0.4 kg/BOD_5/day/m^3 and achieve BOD_5 removals greater than 70%.

With regard to the packing over which the biomass grows, the void fraction and the specific surface area are important features; the first is necessary to ensure a good circulation of air and the second is to accommodate as much biomass as possible to degrade the organic load of the wastewaters. Although more costly initially, synthetic packings have a larger void space, larger specific area, and are lighter than other packing media. Usually, the air circulates naturally, but forced ventilation is used with some high-strength wastewaters. The latter may be used with or without recirculation of the liquid after the settling tank. The need for recirculation is dictated by the strength of the wastewater and the rate of oxygen transfer to the biomass. Typically, recirculation is used when the BOD5 of the seafood-processing wastewater to be treated exceeds 500 mg/L. The BOD5 removal efficiency varies with the organic load imposed but usually fluctuates between 45 and 70% for a single-stage filter. Removal efficiencies of up to 90% can be achieved in two stages.

2. Process description

The following steps were observed in trickling filter process

- ❖ The wastewater in trickling filter is distributed over the top area of a vessel containing non-submerged packing material.
- ❖ Air circulation in the void space, by either natural draft or blowers, provides oxygen for the microorganisms growing as an attached biofilm.
- ❖ During operation, the organic material present in the wastewater is metabolised by the biomass attached to the medium. The biological slime grows in thickness as the organic matter abstracted from the flowing wastewater is synthesized into new cellular material.
- ❖ The thickness of the aerobic layer is limited by the depth of penetration of oxygen into the microbial layer.

- The microorganisms near the medium face enter the endogenous phase as the substrate is metabolized as a result of increased thickness of the slime layer and lose their ability to cling to the media surface. The liquid then washes the slime off the medium and a new slime layer starts to grow. This phenomenon of losing the slime layer is called ***sloughing***.
- The sloughed off film and treated wastewater are collected by an under drainage which also allows circulation of air through filter. The collected liquid is passed to a settling tank used for solid- liquid separation.

Excess growths of microorganisms wash from the rock media and would cause undesirably high levels of suspended solids in the plant effluent if not removed. Thus, the flow from the filter is passed through a sedimentation basin to allow these solids to settle out. This sedimentation basin is referred to as a secondary clarifier, or final clarifier, to differentiate it from the sedimentation basin used for primary settling. An important element in trickling filter design is the provision for return of a portion of the effluent (recirculation) to flow through the filter.

TFs enable organic material in the wastewater to be adsorbed by a population of microorganisms (aerobic, anaerobic, and facultative bacteria; fungi; algae; and protozoa) attached to the medium as a biological film or slime layer (approximately 0.1 to 0.2 mm thick). As the wastewater flows over the medium, microorganisms already in the water gradually attach themselves to the rock, slag, or plastic surface and form a film. The organic material is then degraded by the aerobic microorganisms in the outer part of the slime layer.

As the layer thickens through microbial growth, oxygen cannot penetrate the medium face, and anaerobic organisms develop. As the biological film continues to grow, the microorganisms near the surface lose their ability to cling to the medium, and a portion of the slime layer falls off the filter. This process is known as sloughing. The sloughed solids are picked up by the underdrain system and transported to a clarifier for removal from the wastewater.

Overall the trickling filter involves the aerobic conversion of the waste and it is summarized as follows

$$\textbf{Organic waste} + O_2 \longrightarrow \textbf{Cells} + CO_2 + H_2O$$

3. Microbiology of the trickling filter

Two types of microorganisms live in waters: suspended organisms, floating in the water, and sessile organisms, which often settle on the surface of stones and form biofilms.

Biofilm processes such as fixed-bed or trickling filter processes are examples of the technical application of these natural processes.

Typical microorganisms present in trickling filters are *Zoogloea*, *Pseudomonas*, *Alcaligenes*, *Flavobacterium*, *Streptomyces*, *Nocardia*, fungi, and protozoa. The crux of the process is that the organic contents of the effluents are degraded by these attached growth populations, which absorb the organic contents from the surrounding water film. Oxygen from the air diffuses through this liquid film and enters the biomass. As the organic matter grows, the biomass layer thickens and some of its inner portions become deprived of oxygen or nutrients and separate from the support media, over which a new layer will start to grow. The separation of biomass occurs in relatively large flocs that settle relatively quickly in the supporting material. Media that can be used are rocks (low-rate filter) or plastic structures (high-rate filter). Denitrification can occur in low-rate filters, while nitrification occurs under high-rate filtration conditions; therefore, effluent recycle may be necessary in high-rate filters.

4. Types of filters and operation and maintenance

Trickling filters are classified as high rate or low rate, based on the organic and hydraulic loading applied to the unit.

Sl.No.	Design Feature	Low Rate Filter	High Rate Filter
1.	Hydraulic loading, $m^3/m^2.d$	1 - 4	10 - 40
2.	Organic loading,kg BOD / m^3.d	0.08 - 0.32	0.32 - 1.0
3.	Depth, m.	1.8 - 3.0	0.9 - 2.5
4.	Recirculation ratio	0	0.5 - 3.0 (domestic wastewater) upto 8 for strong industrial wastewater.

- The hydraulic loading rate is the total flow including recirculation appied on unit area of the filter in a day, while the organic loading rate is the 5 day 20°C BOD, excluding the BOD of the recirculant, applied per unit volume in a day.
- Recirculation is generally not adopted in low rate filters.
- A well operated low rate trickling filter in combination with secondary settling tank may remove 75 to 90% BOD and produce highly nitrified effluent. It is suitable for treatment of low to medium strength domestic wastewaters.

- The high rate trickling filter, single stage or two stage are recommended for medium to relatively high strength domestic and industrial wastewater. The BOD removal efficiency is around 75 to 90% but the effluent is only partially nitrified.
- Single stage unit consists of a primary settling tank, filter, secondary settling tank and facilities for recirculation of the effluent. Two stage filters consist of two filters in series with a primary settling tank, an intermediate settling tank which may be omitted in certain cases and a final settling tank.

The efficiency of different filters can be accessed through its ability to reduce BOD of the waste. It is estimated that low rate filters remove BOD up to 80 – 90 %, intermediate rate filters up to 50 – 70%, high rate filters 65 – 85% and roughing filters up to 40 – 65%.

Operation and Maintenance

Disagreeable Odors from Filter

Potential Cause: Excessive organic load causing anaerobic decomposition in filter.

Remedy: Reduce loading; increase BOD removal in primary settling tanks; enhance aerobic conditions in treatment units by adding chemical oxidants, preaerating, recycling plant effluent, or increasing air to aerated grit chambers; scrub off gases; use plastic media instead of rock.

Potential Cause: Inadequate ventilation.

Remedy: Increase hydraulic loading to wash out excess biological growth; remove debris from filter effluent channels, underdrains, and the top of filter media; unclog vent pipes; reduce hydraulic loading if underdrains are flooded; install fans to induce draft through filter; check for filter plugging resulting from breakdown of the medium.

Along with this several other factors such as ponding on filter media, icing, rotating distributor slows down or stops need to be considered while operating the TF.

5. Advantages and disadvantages of the method

Even though TF is considered to be best method employed in waste water treatment, it has both advantages and disadvantages,

Advantages

- Simple, reliable, biological process.
- Suitable in areas where large tracts of land are not available for land intensive treatment systems.
- May qualify for equivalent secondary discharge standards.

- Effective in treating high concentrations of organics depending on the type of medium used.
- Appropriate for small- to medium-sized communities.
- Rapidly reduce soluble BOD in applied wastewater.
- Efficient nitrification units.
- Durable process elements.
- Low power requirements.
- Moderate level of skill and technical expertise needed to manage and operate the system.
- Because of the relatively high strength of slaughterhouse wastewater, biological filters are more suited to operation with effluent recirculation, which effectively increases surface hydraulic loading without increasing the organic loading. This gives greater control over microbial film thickness.
- For mill wastewater having high value of BOD (4075 mg/L) trickling filter is a best option.

Disadvantages

- Additional treatment may be needed to meet more stringent discharge standards.
- Possible accumulation of excess biomass that cannot retain an aerobic condition and can impair TF performance (maximum biomass thickness is controlled by hydraulic dosage rate, type of media, type of organic matter, temperature and nature of the biological growth).
- Requires regular operator attention.
- Incidence of clogging is relatively high and if neglected may impart bad odour.
- Requires low loadings depending on the medium.
- Flexibility and control are limited in comparison with activated-sludge processes.
- Vector and odor problems.
- Snail problems.
- An inherent problem is that trickling filters can be blocked by precipitated ferric hydroxide and carbonates, with concomitant reduction of microbial activity. In the case of overloading with dairy wastewater, the medium becomes blocked with heavy biological and fat films. Biological filters are not appropriate for the treatment of high-strength wastewaters, as filter blinding by organic deposition on the filter medium is generally found.

Conclusion

For treatment of industrial wastewater, trickling filters are often used as a popular biological treatment process. The most widely used design for many years was simply a bed of stones, 1–3 m deep, through which the wastewater passed. The wastewater is typically distributed over the surface of the rocks by a rotating arm. Rock filter diameters may range up to 60 m. As wastewater trickles through the bed, a microbial growth establishes itself on the surface of the stone or packing in a fixed film. The wastewater passes over the stationary microbial population, providing contact between the microorganisms and the organics. The biomass is supplied with oxygen using outside air, most of the time without additional technical measures. It is not surprising that BOD can be reduced to the extent of 90%. Due to microbial positive and negative interactions in the biofilm, it is also possible to reduce pathogenic microbial load even including viruses. Each rock particle represents a microcosm where several activities lead by microbial world cleans waste from industrial effluents. If properly managed it is the best method for waste water treatment.