19.2 Trickling Filter

A trickling filter is a fixed film attached growth aerobic process for treatment of organic matter from the wastewater. The surface of the bed is covered with the biofilm and as the wastewater trickles over this media surface, organic matter from the wastewater comes in contact with the aerobic bacteria and oxidation of organic matter occurs. In the past rock was used as a bed material with size ranging from 25 mm to 100 mm. Now plastic media which offers higher surface area per unit volume is used. The media is randomly packed in the reactor and the wastewater is applied on the top through rotary arm which trickles down over the filter media surface (Figure 19.12). Hence, this reactor is known as trickling filter. Since, the wastewater is applied through the rotary arm from the top of the reactor the biofilm grown on the media surface receives wastewater intermittently. As the wastewater trickles down leaving the wet biofilm, the biofilm is exposed to the air voids present in the media, and thus oxygen from the air, after solubalizing in the water adhering on biofilm, is made available to aerobic bacteria grown in the biofilm by diffusion of oxygen through the biofilm. The end product CO_2 diffuses out of the biofilm into the flowing liquid. Treated wastewater is collected from the bottom of the bed through an underdrainage system and is settled in the final settling tank.

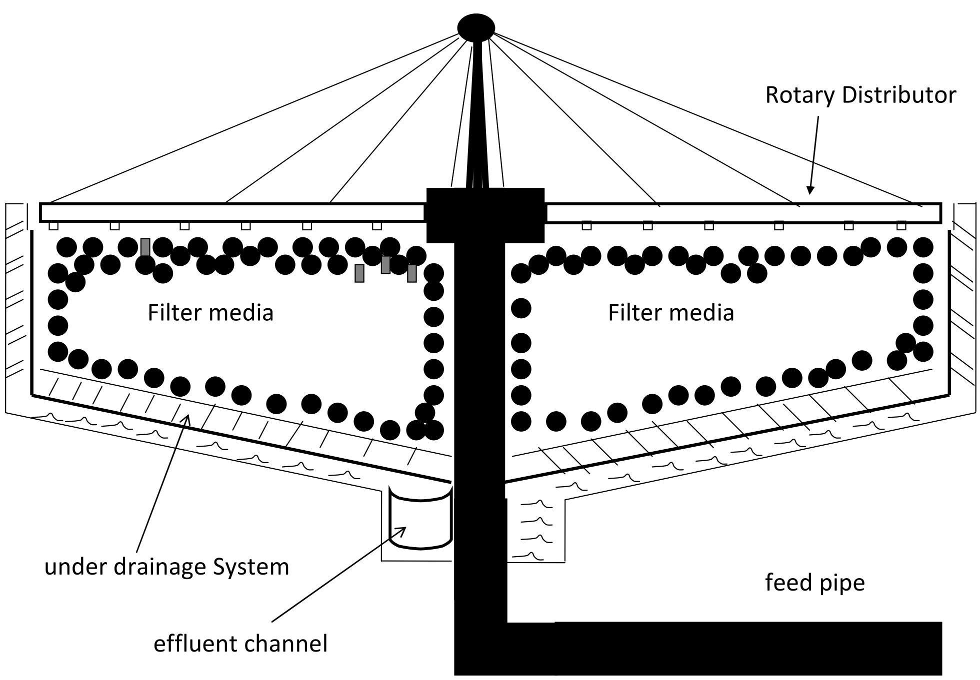


Figure 19.12 Trickling Filter

The biological film or slime forms on the surface of the filter media after application of wastewater. Organic matter is adsorbed on the slime layer and it is degraded by the aerobic microorganisms present in the slime. As the thickness of the slime layer increases the condition near the surface of the media becomes anaerobic because of limitations of availability of oxygen. At this stage the microbes lose their ability to cling to the surface of the media and the slime layer gets detached and washed out along with flowing liquid. This phenomenon is called as 'sloughing'. Soon after the sloughing the new slime layer formation starts. Hence secondary sedimentation tank (SST) is provided to settle this washed out biomass. SST can be circular or rectangular tanks designed such that the overflow rate at peak flow should not exceed 50 $m^3/m^2.d$.

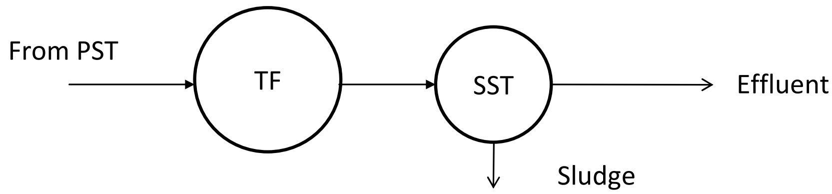
Diameter of the trickling filter depends on the mechanical equipments used for spraying the wastewater. Diameter more than 12 m for single filter unit is common. Rotary arm rotates as a result of jet action as the wastewater is sprayed horizontally on the filter bed; hence, external power is not required for rotation of the arm. However, for trickling filter of small diameter (less than 6 m) power driven rotary arm may be provided. Number of commercial packing media is available. These include vertical-flow random packed and cross flow media made of rock, polygrid, plastic media or asbestos sheets. In order to avoid filter plugging, a maximum specific surface of 100 m^2/m^3 is recommended for carbonaceous wastewater treatment and up to 300 m^2/m^3 for nitrification, because of slow growth rate of nitrifiers. Overall performance of the trickling filter depends upon the hydraulic and organic loading rate, wastewater pH, operating temperature and availability of air through natural draft within the pores, and mean time of contact of wastewater with biofilm, etc.

Mean time of contact of liquid with the filter surface is related to the filter depth, hydraulic loading rate and nature of filter packing. This contact time can be estimated as (Eckenfelder, 2000):

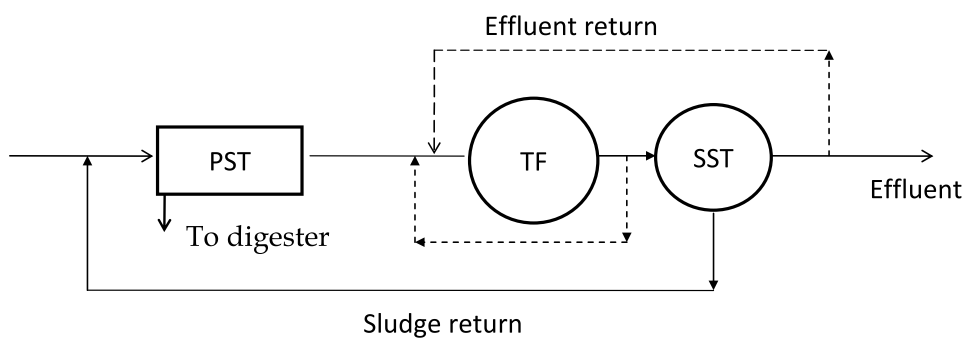
$$T = C.D/Q^n \qquad (37)$$

Where T = mean detention time, D = depth of filter bed, Q is the hydraulic loading $m^3/m^2.d$, C and n are constant related to specific surface area and configuration of the packing. Mean retention time increases considerably (up to 4 times) with formation of biofilm as compared to new filter media.

Based on hydraulic and organic loadings, the trickling filters may be classified as (1) Low rate trickling filter (Figure 19.13a) and (2) High rate trickling filter (Figure 19.13b). Recirculation is employed in high rate filters to improve efficiency. The recirculation helps in providing seeding to the filter bed and also dilutes the strong wastewater. Dilution is the major objective behind the recirculation.



(a)



(b)

Figure 19.13 (a) Low rate trickling filter and (b) High rate trickling filter

Super rate trickling filter: It is also called as 'roughing filter' or 'biotower'. Plastic media is used in this filter. Since the power required in trickling filter per unit of BOD removal is less as compared to ASP, these are becoming popular these days. They are used ahead of the existing trickling filter or ASP and are generally constructed above ground. The diameter of the biotower can vary from 3 m to 70 m. The walls of the biotower can be made from RCC or when modular plastic media is used the walls can be made from the plastic, since there is no hydrostatic pressure on the walls. Air blower may be provided in addition to natural air draft in biotower to enhance oxygen resources of the system to handle higher organic loading rates.

19.2.1 Additional Information on Trickling Filter

Sludge retention: The sludge is retained in the trickling filter for very long time as compared to ASP and typically the mean cell residence time (θc) of 100 days or more can be achieved. Estimation of actual biomass present in the reactor is difficult hence exact measurement of θc is not possible. Excess sludge generation in this process is expected to be lower due to longer retention time of biomass supporting endogenous decay. The sludge generation is 60 to 70% lower than that of ASP treating same wastewater. The sludge generation in high rate trickling filter is more than low rate trickling filter.

Air supply: Air is supplied in low rate and high rate trickling filter through natural draft. In trickling filter when wastewater temperature is less than ambient temperature there will be downward flow of air; whereas, when the wastewater temperature is more than ambient temperature there will be upward flow of air. To allow air circulation, the under-drainage system should be designed to flow not more than half full.

Details of the rotary arm: It rotates with the speed of 0.5 to 2 revolutions per minute. The peripheral speed for two arm system will be 0.5 to 4 m/min. The arm length could be as low as 3 m to as high as 35 m depending on the diameter of the filter. This rotary arm delivers the wastewater 15 cm above the filter bed. The velocity of wastewater moving through arm should be more than 0.3 m/s to prevent deposition of solids. Numbers of ports, generally of equal diameter, are provided on this arm to deliver wastewater in horizontal direction. Minimum 2 arms are provided, whereas they could be 4 in numbers. Design guidelines for the trickling filters are provided in the Table 19.1.

Table 19.1 Design values for trickling filters

Parameter	Low rate trickling filter	High rate trickling filter	Super rate roughing filter
Hydraulic loading, $m^3/m^2.d$	1 - 4	10 - 40	40 – 200
Volumetric loading, kg $BOD/m^3.d$	0.11 – 0.37	0.37 to 1.85	1.0 – 6.0
Depth, m	1.5 – 3.0	1.0 – 2.0	4 – 12
Recirculation ratio	0	1 - 4	1 - 4
Power requirement, $kW/10^3$ m^3	2 - 4	6 - 10	10 – 20
Dosing intervals	Less than 5 min.	15 to 60 seconds	Continuous
Sloughing	Intermittent	Continuous	Continuous
Effluent quality	Fully nitrified	Nitrified only at low loading	Nitrified only at low loading

19.2.2 Design of Trickling Filters

Organic loading rate and recirculation ratio are main consideration in design of trickling filter. The early performance equations for trickling filter were empirical as proposed by National Research Council (1946), Rankin (1955) and based on biochemical kinetics Velz (1948).

Rankine's formula

For single stage filters: the BOD of influent to the filter (including recirculation) shall not exceed three times the BOD required for settled effluent. Hence referring to the Figure 19.13 and using following notations, we have

$$S_2 + R_1(S_4) = 3\ (1 + R_1)S_4 \quad (38)$$

Or $$S_4 = S_2/(3 + 2R_1) \quad (39)$$

Where S_2 = BOD of settled influent, S_4 = BOD of TF effluent after SST, R_1 = Recirculation ratio, and if E = efficiency, then

$$E = (1 + R_1)/(1.5 + R_1) \quad (40)$$

Value of recirculation is given by

$$R = (Q_1 - Q)/Q \quad (41)$$

Where Q_1 is total flow including recirculation and Q is sewage flow.

For second stage filter: The BOD of the wastewater applied to the second stage filter including recirculation shall not exceed two times the effluent BOD. Therefore,

$$S_4 + R_4(S_6) = 2\ (1 + R_2)S_6 \quad (42)$$

Or $$S_6 = S_4 / (R_2 + 3) \qquad \text{and efficiency} = (1 + R_2)/(2 + R_2) \quad (43)$$

Where S_4 = BOD of influent to second stage filter, S_6 = BOD of TF effluent after SST, R_2 = Recirculation ratio.

Eckenfelder (1970) has developed performance equation based on the specific rate of substrate removal for a pseudo-first-order reaction.

$$-\frac{1}{x}\frac{ds}{dt} = K.S \qquad (44)$$

Where $\frac{1}{x}\frac{ds}{dt}$ = Specific rate of substrate utilization, $\frac{\text{mass of substrate}}{\text{Microbial mass x Time}}$

$\frac{ds}{dt}$ = rate of substrate utilization, $\frac{\text{mass}}{\text{(Volume)x Time}}$

K = rate constant, $\frac{\text{volume}}{\text{(mass of microbes) x Time}}$

S = Substrate concentration, $\frac{\text{mass}}{\text{Volume}}$

Rearranging the above equation (44) for integration,

$$\int_{S_o}^{S_t}\frac{ds}{S} = -K\,X\int_0^t dt \qquad (45)$$

X = Average cell mass concentration, $\frac{\text{mass}}{\text{Volume}}$

S_o = Substrate concentration applied for filter bed

S_t = Substrate concentration after contact time, t

Integrating the equation

$$\frac{S_t}{S_o} = e^{-K.X.t} \qquad (46)$$

X is proportional to surface area of the media (A_s) i.e.,

$$X \approx A_s^m \qquad (47)$$

Where, A_s is the specific area of the packing media

The mean contact time 't' for a filter is given by Howland (1950) (Reynolds & Richard, 1996).

$$t = \frac{C.D}{Q_L^n} \qquad (48)$$

Where t = mean contact time

D = Depth of filter bed

Q_L = Surface loading

C and n = constant

Substituting equation 46 & 47 in equation 48

$$\frac{S_t}{S_o} = e^{\frac{(-K{A_s}^m D)}{Q_L^n}} \qquad (49)$$

(Elimination of constant C as it is taken into account in K)

m = experimental constant

The value of 'n' depends on flow characteristics through packing and usually about 0.5 to 0.67. For specific wastewater and filter media equation 49 may be simplified by combining $K{A_s}^m$ to give

$$\frac{S_t}{S_o} = e^{\frac{-KD}{Q_L^n}} \qquad (50)$$

K= 0.01 to 0.1 for various wastewater and media

For Surfpac, Dow chemical (89 m^2/m^3), K = 0.088 and n = 0.5 (Reynolds & Richard, 1996)

When D- feet, Q_L = gal/(min-ft^2). Actual K values can be determined from the pilot performance. With temperature variation the value of K can be converted as below:

$$K_T = K_{20}\ x\ 1.035^{(T-20)} \qquad (51)$$

K_T = rate constant at temperature T

K_{20} = rate constant at 20˚C

T= temperature, ˚C

One of the most common kinetic equations for filter performance while treating municipal wastewater was developed by Eckenfelder, 1961 as

$$\frac{S_t}{S_o} = \frac{1}{1+C(\frac{D^{0.67}}{Q_L^{0.5}})} \qquad (52)$$

S_t = BOD_5 of effluent, mg/L

S_o = BOD_5 of influent, mg/L

C = constant = 2.5 for FPS unit and 5.358 for SI units

D = filter depth, ft (m)

Q_L = unit loading rate MG/acre-day (m^3/m^2-d)

The above equation is obtained from second order kinetics equation,

$$\frac{1}{x}\frac{ds}{dt} = KS^2 \tag{53}$$

Integrating

$$\frac{S_t}{S_o} = \frac{1}{(1+S_0.K.X.t)} \tag{54}$$

Substituting, $t = C(\frac{D^{0.67}}{Q_L^{0.5}})$ and combining constant S_o , K, X & C for the same wastewater treatment under steady state performance results, the equation becomes:

$$\frac{S_t}{S_o} = \frac{1}{1+Const(\frac{D^{0.67}}{Q_L^{0.5}})} \tag{55}$$