# CE 421/521 Environmental Biotechnology

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- Design of clarifier depends on type of settling:
  - Type I: discrete settling
  - Type II: flocculant settling
  - Type III: zone settling
  - Type IV: compression settling







# **Trickling Filter Design Equations**

•Empirical Models for Trickling Filters with Plastic Media •Schulze Equation (WEF, 2000):

$$\frac{S_e}{S_o} = e^{\frac{-kD}{q^n}}$$

where Se = effluent BOD, mg/L

 $S_0 = influent BOD$ 

k = wastewater treatability and packing coefficient, (L/s)0.5/m<sup>2</sup>

D = packing depth, m

q = hydraulic application rate of primary effluent, excluding recirculation, L/m<sup>2</sup> · s

n = constant, characteristic of packing media (typically around 0.5)

#### **Temperature Correction:**

 $k_T = k_{20} (1.035)^{T-20}$ 



#### Modified Velz equation (WEF, 2000):

$$S_{e} = \frac{S_{O}}{(R+1) \exp\left\{\frac{k_{20}A_{S}D\theta^{T-20}}{\left[q(R+1)\right]^{n}}\right\} - R}$$

where  $S_e = effluent BOD$ 

 $S_0 = influent BOD$ 

R = recirculation ratio (flowrate with recirculation/influent flowrate)

 $k_{20}$  = filter treatability constant at 20 °C, (L/s)<sup>0.5</sup>/m<sup>2</sup>

 $A_s$  = clean packing specific surface area,  $m^2/m^3$ 

D = depth of packing, m

- $\theta$  = temperature correction coefficient, 1.035
- q = hydraulic application rate, L/m<sup>2</sup>@
- n = constant dependent on packing used

#### to adjust for different packing depths:

$$k_2 = k_1 \left(\frac{D_1}{D_2}\right)^{0.5} \left(\frac{S_1}{S_2}\right)^{0.5}$$

where  $k_2$  = normalized value for the site specific packing depth and influent BOD concentration  $k_1 = k$  value at depth of 6.1 m (20 ft) and influent BOD of 150 mg/L  $S_1 = 150 \text{ mg/L}$  $S_2 = \text{site specific influent BOD concentration, mg/L}$  $D_1 = 6.1 \text{ m (20 ft) packing depth}$  $D_2 = \text{site specific packing depth, m}$ 



### k values

#### $k_1$ values for different types of wastewater

## **Clarifier design**



### **Example problem**

Example: Given the following design flowrates and primary effluent wastewater characteristics, determine the following design paramters for a trickling filter assuming two towers at 6.1 m depth, cross flow packing with a specific surface area of 90 m<sup>2</sup>/m<sup>3</sup>, a packing coefficient n value of 0.5 and a 2-arm distributor. The required minimum wetting rate =  $0.5 \text{ L/m^2}$ . Assume a secondary clarifier depth of 4.2 m.

**Design** Conditions

Item	Units	Primary Effluent	Target Effluent
Flow	m <sup>3</sup> /d	15,140	
BOD	mg/L	125	20
TSS	mg/L	65	20
Minimum temp	°C	14	

Determine:

- 1. Diameter of tower trickling filter, m
- 2. Volume of packing required, m<sup>3</sup>
- 3. Recirculation rate required
- 4. Total pumping rate,  $m^{3/h}$
- 5. Flushing and normal dose rate, mm/pass
- 6. Flushing and normal distributor speeds, min/rev
- 7. Clarifier diameter, m (assume the ratio of the peak to average flowrate is 1.5)

## **Steps for design**

Steps for design:

- 1. Determine the  $k_2$  value for the specific BOD and depth of packing criteria.
- 2. Determine the hydraulic application rate and filter area, volume, and diameter
- 3. Determine the recirculation rate and the recirculation ratio
- 4. Determine the pumping rate  $(q + q_r)$
- 5. Determine the flushing and normal dose rate:

#### Dose Rate (DR) as a function of BOD Loading

BOD loading, kg/m <sup>3.</sup>	Normal Dose Rate, mm/pass	Flushing Dose Rate, mm/pass
0.25	10-30	\$200
0.50	15-45	\$200
1.00	30-90	\$300
2.00	40-120	\$400
3.00	60-180	\$600
4.00	80-240	\$800



$$n = \frac{(1+R)q(10^3 mm / \min)}{(A)(DR)(60 \min / h)}$$

where n = rotational speed, rev/min q = influent applied hydraulic loading rate,  $m^3/m^2$  (P) R = recycle ratio A = number of arms of distributor DR = dosing rate, mm/pass

















Figure 6-20 Definition sketch for a settling basin operating at steady state.

Data derived from settling tests must be available when applying this method, which is based on an analysis of the mass flux (movement across a boundary) of the solids in the settling basin.

In a settling basin that is operating at steady state, a constant flux of solids is moving downward, as shown in Fig. 6-20. Within the tank, the downward flux of solids is brought about by gravity (hindered) settling and by bulk transport due to the underflow that is being pumped out and recycled. At any point in the tank, the mass flux of solids due to gravity (hindered) settling is

$$SF_q = C_i V_i \times (10^3 \text{ g/kg})^{-1}$$
 (6-25)

where  $SF_g$  = solids flux due to gravity, kg/m<sup>2</sup> · h  $C_i$  = concentration of solids at the point in question, g/m<sup>3</sup> (= mg/L)

 $V_i$  = settling velocity of the solids at concentration  $C_i$ , m/h

The mass flux of solids due to the bulk movement of the suspension is

$$SF_{u} = C_{i} U_{b} (10^{3} \text{ g/kg})^{-1} = C_{i} \frac{Q_{u}}{A} \times (10^{3} \text{ g/kg})^{-1}$$
(6-26)

where  $SF_{\mu}$  = solids flux due to underflow, kg/m<sup>2</sup> · h

 $U_{h}$  = bulk downward velocity, m/h

 $Q_u$  = underflow flowrate, m<sup>3</sup>/h

$$A = cross-sectional area, m^2$$

The total mass flux  $SF_t$  of solids is the sum of previous components and is given by

$$SF_t = SF_q + SF_q \tag{6-27}$$

$$SF_{t} = (C_{i} V_{i} - C_{i} U_{b})(10^{3} \text{ g/kg})^{-1}$$
(6-28)

In this equation, the flux of solids due to gravity (hindered) settling depends on the concentration of solids and the settling characteristics of the solids at that concentration. The procedure used to develop a solids flux curve from column



Figure 6-21 Procedure for preparing plot of solid flux due to gravity as a function of solids concentration. (a) Hindered settling velocities derived from column settling tests for suspension at different concentrations. (b) Plot of hindered settling velocities obtained in step a versus corresponding concentration. (c) Plot of computed value of solids flux versus corresponding concentration.

settling test data is illustrated in Fig. 6-21. At low concentration (below about 1000 mg/L), the movement of solids due to gravity is small, because the settling velocity of the solids is more or less independent of concentration. If the velocity remains essentially the same as the solids concentration increases, the



Figure 6-22 Definition sketch for the analysis of settling data using the solids-flux method of analysis.

total flux due to gravity starts to increase as the solids concentration starts to increase. At very high solids concentrations, the hindered-settling velocity approaches zero, and the total solids flux due to gravity again becomes extremely low. Thus it can be concluded that the solids flux due to gravity must pass through a maximum value as the concentration is increased. This is shown schematically in Figs. 6-21*c* and 6-22.

The solids flux due to bulk transport is a linear function of the concentration with slope equal to  $U_b$ , the underflow velocity (Fig. 6-22). The total flux, which is the sum of the gravity and the underflow flux, is also shown in Fig. 6-22. Increasing or decreasing the flow rate of the underflow causes the total-flux curve to shift upward or downward. Because the underflow velocity can be controlled, it is used for process control.

The required cross-sectional area of the thickener is determined as follows: As shown in Fig. 6-22, if a horizontal line is drawn tangent to the low point on the total-flux curve, its intersection with the vertical axis represents the limiting solids flux  $SF_L$  that can be processed in the settling basin. The corresponding underflow concentration is obtained by dropping a vertical line to the x axis from the intersection of the horizontal line and the underflow flux line. This can be done because the gravity flux is negligible at the bottom of the settling basin, and the solids are removed by bulk flow. The fact that the gravity flux is negligible at the bottom of the tank can be verified by performing a materials balance around that portion of the settling tank that lies below the depth where the limiting solids flux occurs and comparing the gravity settling velocity of the sludge to the velocity in the sludge withdrawal pipe. If the quantity of solids fed to the settling basin is greater than the limiting solids-flux value defined in Fig. 6-22, the solids will build up in the settling basin and, if adequate storage capacity is not provided, ultimately overflow at the top. Using the limiting solids-flux value, the required area derived from a materials balance is given by

$$A = \frac{(Q + Q_u)C_0}{SF_L} \times (10^3 \text{ g/kg})^{-1}$$
(6-29)

$$= \frac{(1+\alpha)QC_0}{SF_L} \times (10^3 \text{ g/kg})^{-1}$$
(6-30)

where  $A = \text{area, m}^2$   $(Q + Q_u) = \text{total volumetric flowrate to settling basin, m^3/d}$   $C_0 = \text{influent solids concentration, g/m^3 (mg/L)}$   $SF_L = \text{limiting solids flux, kg/m^2 \cdot d}$  $\alpha = Q_u/Q$ 

Referring to Fig. 6-22, if a thicker underflow concentration is required, the slope of the underflow flux line must be reduced. This, in turn, will lower the value of the limiting flux and increase the required settling area. In an actual design, the use of several different flowrates for the underflow should be evaluated. Typical values for biological sludges are about  $7.1 \times 10^{-5}$  to  $1.4 \times 10^{-4}$  m/s (150 to 300 gal/ft<sup>2</sup> · d) [25]. The application of this method of analysis is illustrated in Example 6-6.

An alternative graphical method of analysis to that presented in Fig. 6-22 for determining the limiting solids flux is shown in Fig. 6-23. As shown, for a given underflow concentration, the value of the limiting flux on the ordinate is obtained by drawing a line tangent to the flux curve passing through the desired underflow and intersecting the ordinate. The geometric relationship of this method to that given in Fig. 6-22 is shown by the lightly dashed lines in Fig. 6-23. The method detailed in Fig. 6-23 is especially useful where the effect of the use of various underflow concentrations on the size of the treatment facilities (aerator and sedimentation basin) is to be evaluated. The use of this method is illustrated in Example 10-4.



Figure 6-23 Alternative definition sketch for the analysis of settling data using the  $\phi$  solids-flux method of analysis.