Trickling Filters and Rotary Biological Contactors

CE - 370

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Trickling Filters

- Definition: a biological process in which the microorganisms are attached to the filter media
- Trickling filters are composed of:
  - Influent pipe
  - Rotary distribution
  - Filter bed
  - Underdrain system
  - Effluent pipe
- At downstream, a sedimentation tank is used to remove microbial growth that sloughs from the medium
- Medium
  - Crushed stone, Large gravel, Slag, Plastic, and redwood

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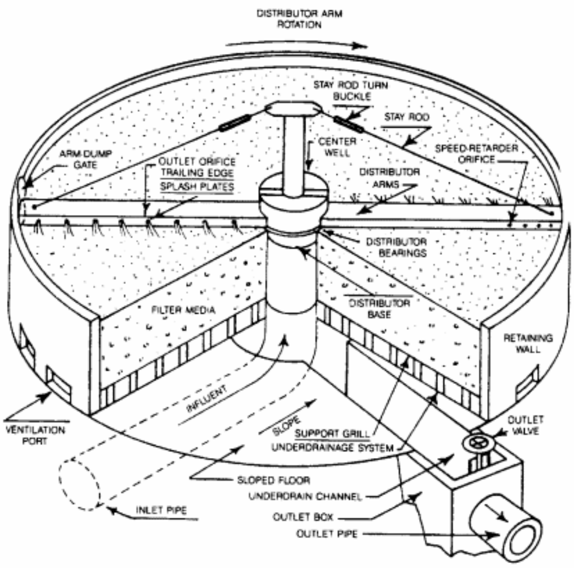
Typical Trickling Filter



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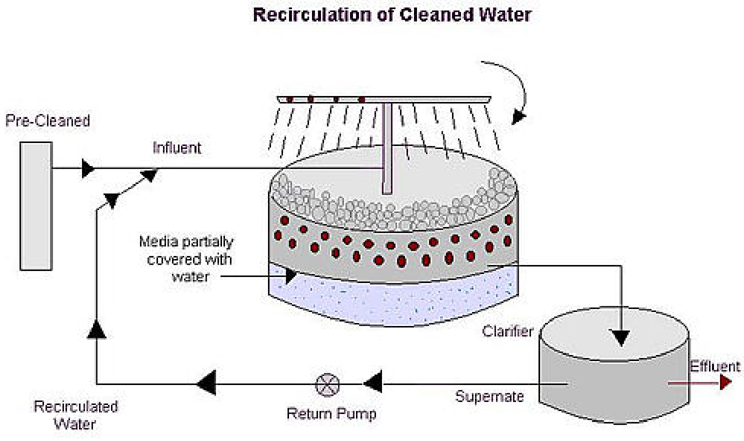
Trickling Filter



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Classifications of Trickling Filters

- Trickling filters are classified into:
  - Low-rate or standard-rate
  - Intermediate-rate
  - High-rate
  - Super-rate
- Classification is according to:
  - Organic loading
  - Unit liquid loading
  - Recycle employed

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Low-rate or Standard-rate Filters

- Organic loading = 0.08 to 0.32 kg BOD_5/m^3-day
- Unit liquid loading = 1 to 4 m^3/m^2-day
- Bed depth = 1.5 to 3 m
- Recycle is employed at times when flow is not enough to turn the rotary distributor (night time)
- Usually single-stage
- BOD_5 removal = 90 to 95 %
- Effluent BOD_5 = 12 to 25 mg/l
- Can achieve better nitrification than high-rate filters
- Media volume is much greater than high-rate filters

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Intermediate-rate Filters

- Organic loading = 0.24 to 0.48 kg BOD_5/m^3-day
- Unit liquid loading = 4 to 10 m^3/m^2-day
- Bed depth = 1.2 to 2.4 m
- Recycle may or may not be employed on continuous basis, it is employed at times when flow is not enough to turn the rotary distributor (night time)
- May be single-stage or two-stage
- BOD_5 removal = 85 to 90 %
- Effluent BOD_5 = 20 to 30 mg/l

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High-rate Filters

- Organic loading = 0.32 to 1.0 kg BOD_5/m^3-day
- Unit liquid loading = 10 to 40 m^3/m^2-day
- Bed depth = 1 to 2 m
- Recycle is employed continuously
- May be single-stage or two-stage
- BOD_5 removal
  - Single-stage = 75 to 80 %
  - Two-stage = 85 to 90 %
- Effluent BOD_5
  - Single-stage = 40 to 50 mg/l
  - Two-stage = 20 to 30 mg/l
- Can not achieve a highly nitrified effluent

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Super-rate Filters

- Organic loading = 0.80 to 6.0 kg BOD_5/m^3-day
- Unit liquid loading = 40 to 200 m^3/m^2-day
- Bed depth = 4.5 to 12 m
- Recycle is continuous
- Medium is always synthetic plastic (most common) or redwood
- Plastic media has a specific surface area (surface area per unit volume) that is from 2 to 5 time that for stone media
- Microbial growth is proportional to surface area
- Can achieve a nitrified effluent at low loadings

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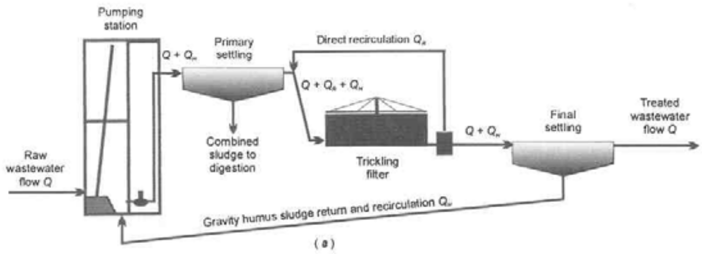
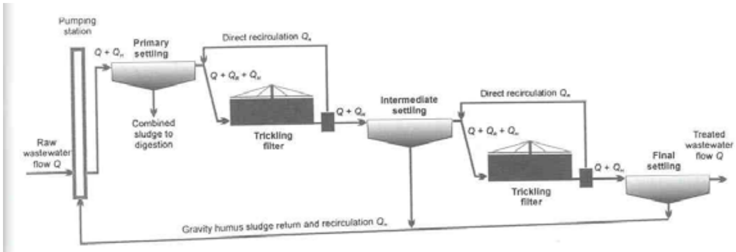


Single Stage Trickling Filter



Two Stage Trickling Filter

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Trickling Filters

- Energy cost per mass of BOD_5 removed is less than that of activated sludge
- Super-rate filters can be used ahead of activated sludge (for high-strength wastewater)
  - To reduce the BOD loading for the activated sludge process.
- Single-stage and two-stage trickling filters are upgraded by adding activated sludge process or a shallow polishing pond downstream

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Mechanisms in Biological Filtration

- Tank is filled with solid media (Rocks or Plastic)
- Bacteria grow on surface of media
- Wastewater is trickled over media, at top of tank
- As water trickles through media, bacteria degrade BOD
- Bacteria eventually die, fall off of media surface
- Filter is open to atmosphere, air flows naturally through media
- Treated water leaves bottom of tank, flows into secondary clarifier
- Bacterial cells settle, removed from clarifier as sludge
- Some water is recycled to the filter, to maintain moist conditions

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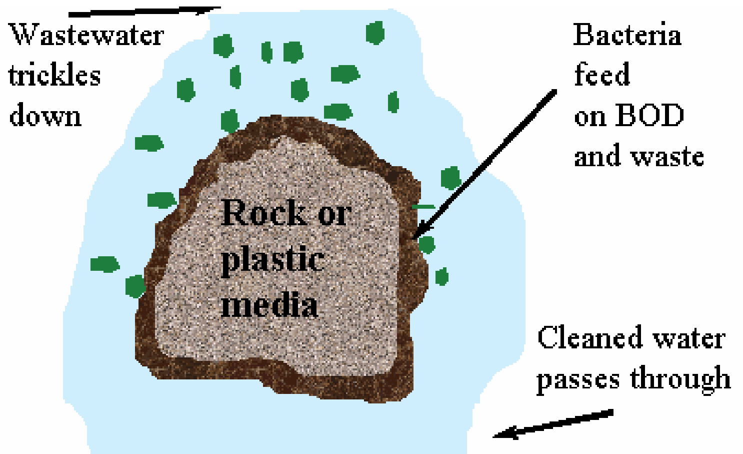
Trickling Filter Process



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Bacteria Removal

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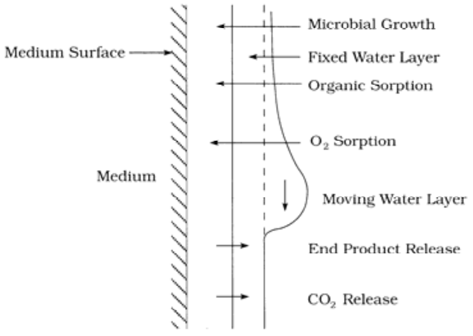

FIGURE 17.4
Biological Action of a Trickling Filter

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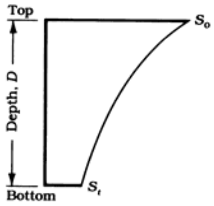

FIGURE 17.5 *Organic Concentration in the Wastewater versus Filter Depth*

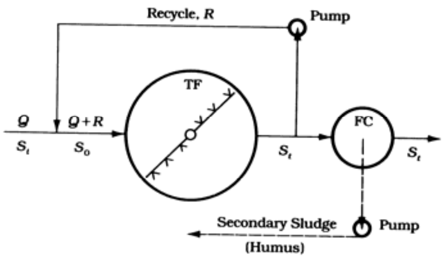

FIGURE 17.6 *Flowsheet of a Trickling Filter*

Filter Performance

- Kinetic Equations
  - The rate of organic removal per interval of depth is proportional to the remaining concentration of removable organic matter:
    - $- dL/dD = kL$
      - dL is an increment of remaining organic concentration
      - dD is an increment of depth
      - L is the remaining removable organic concentration (BOD)
    - Integrating above equation gives:
    - $(L_D / L) = 10^{-kD}$
      - L_D = removable ultimate first-stage BOD concentration at depth D
      - L = removable ultimate fist-stage BOD concentration applied to the bed
      - k = rate constant
      - D = depth of bed, ft (m)

Kinetic Equations

- For low-rate filters and flow of 1.88 to 5.61 m^3/m^2-day
  - k = 0.574
  - Removable fraction = 90%
- For high-rate filters operated at flow 18.8 m^3/m^2-day
  - k = 0.494
  - Removable fraction = 78.4%
- The following equation was developed for temperature correction:
  - $k_2 = k_{20} \cdot 1.047^{(T_2 - 20)}$
  - k_2 is rate at T_2 ; k_{20} is the rate at 20° C

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Kinetic Equations

- Another performance equation was developed based on the specific rate of substrate removal
  - $(-1/X)(dS/dt) = kS$
    - (1/X)(dS/dt) = specific rate of substrate utilization, mass/(mass microbes)(time)
    - (dS/dt) = rate of substrate utilization, mass/(volume)(time)
    - k = rate constant, volume/(mass microbes)(time)
    - S = substrate concentration, mass/volume

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Kinetic Equations

- Re-arrange and integrate
  - $(S_t/S_0) = e^{-k\bar{X}t}$
    - k = rate constant
    - $\bar{X}$ = average cell mass concentration, mass/volume
    - S_t = substrate concentration after the contact time t, mass/volume
    - S_0 = substrate concentration applied to the filter, mass/volume
  - $\bar{X}$ is proportional to the specific surface area of the packing, A_s (m^2 of the surface per bulk m^3 of the volume)
  - $\bar{X} \sim A_s$

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Kinetic Equations

- The mean contact time, t, for a filter is given by:

$$t = \frac{CD}{Q_L^n}$$

- t = mean contact time
- D = depth of filter
- Q_L = unit liquid loading or surface loading
- C, n = experimental constants

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Kinetic Equations

- From the previous equations

$$\frac{S_t}{S_0} = e^{-KA_s^m D / Q_L^n}$$

- – S_t = substrate concentration in the filter effluent, mass/volume
- – S_0 = substrate concentration applied to the filter, mass/volume
- – K = rate constant
- – A_s = specific surface area of the packing, area/volume
- – D = filter depth
- – Q_L = unit liquid loading or surface loading
- – m, n = experimental constants

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Kinetic Equations

- Value of n
  - – Depends of the flow characteristics through the packing
  - – Usually between 0.5 to 0.67
- The equation can be further simplified by combing KA_s^m

$$\frac{S_t}{S_0} = e^{-KD / Q_L^n}$$

- – K is the new rate constant
- – K is between 0.01 and 0.1
- – K can be obtained from pilot-scale plant

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Kinetic Equations

- To correct K for temperature

$$K_T = K_{20} \times 1.035^{(T-20)}$$

- K_T = rate constant at temperature T, ° C
- K_{20} = rte constant at 20 ° C
- T = temperature, ° C

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Kinetic Equations

- A more common kinetic equation for filter with stone media is:

$$\frac{S_t}{S_0} = \frac{1}{1 + C\left(\frac{D^{0.67}}{Q_L^{0.50}}\right)}$$

- S_t = BOD_5 in the filter effluent, mg/l
- S_0 = BOD_5 in the wastewater discharged on the filter bed, mg/l
- C = 2.5 for USCS units and 5.358 for SI units
- D = filter depth, ft (m)
- Q_L = unit liquid loading, MG/acre-day (m^3/m^2-day)

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Study Examples 17.1, 17.2, and 17.3

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Flowsheets for Intermediate- and High-Rate Trickling Filter Plants

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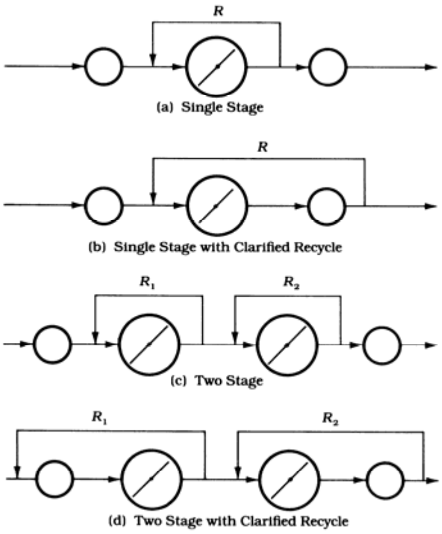

FIGURE 17.7 *Flowsheets for Intermediate- and High-Rate Trickling Filter Plants*

Operational Problems

- Less problems than activated sludge processes
- Problems
  - Floating sludge may be encountered if anaerobic conditions occur within the settled sludge
  - Presence of fly that breed in the filter
    - Can be controlled by allowing the medium to stay submerged
  - Odor when low-rate filters are employed and wastewater is stale when it reaches the plant