ENVE 302

Environmental Engineering Unit Processes

CHAPTER: 13

TRICKLING FILTERS

ROTATING BILOGICAL CONTACTORS (RBC)

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TRICKLING FILTERS

- Non-submerged fixed film biological reactor

- A reactor in which randomly packed solid (rock or plastic) provide surface area for biofilm growth

Ideal filter packing:

High surface area per unit volume

Low in cost

High durability

High enough porosity

Rock

- low cost

- Low void volume limits the space available for airflow and increases the potential for plugging and flow short-circuiting

Plastic Packing

- High hydraulic capacity
- High void ratio
- Resistance to plugging
- Require less area due to ability to use higher organic loadings and taller trickling filters

Ref: Metcalf & Eddy

PACKING MATERIALS

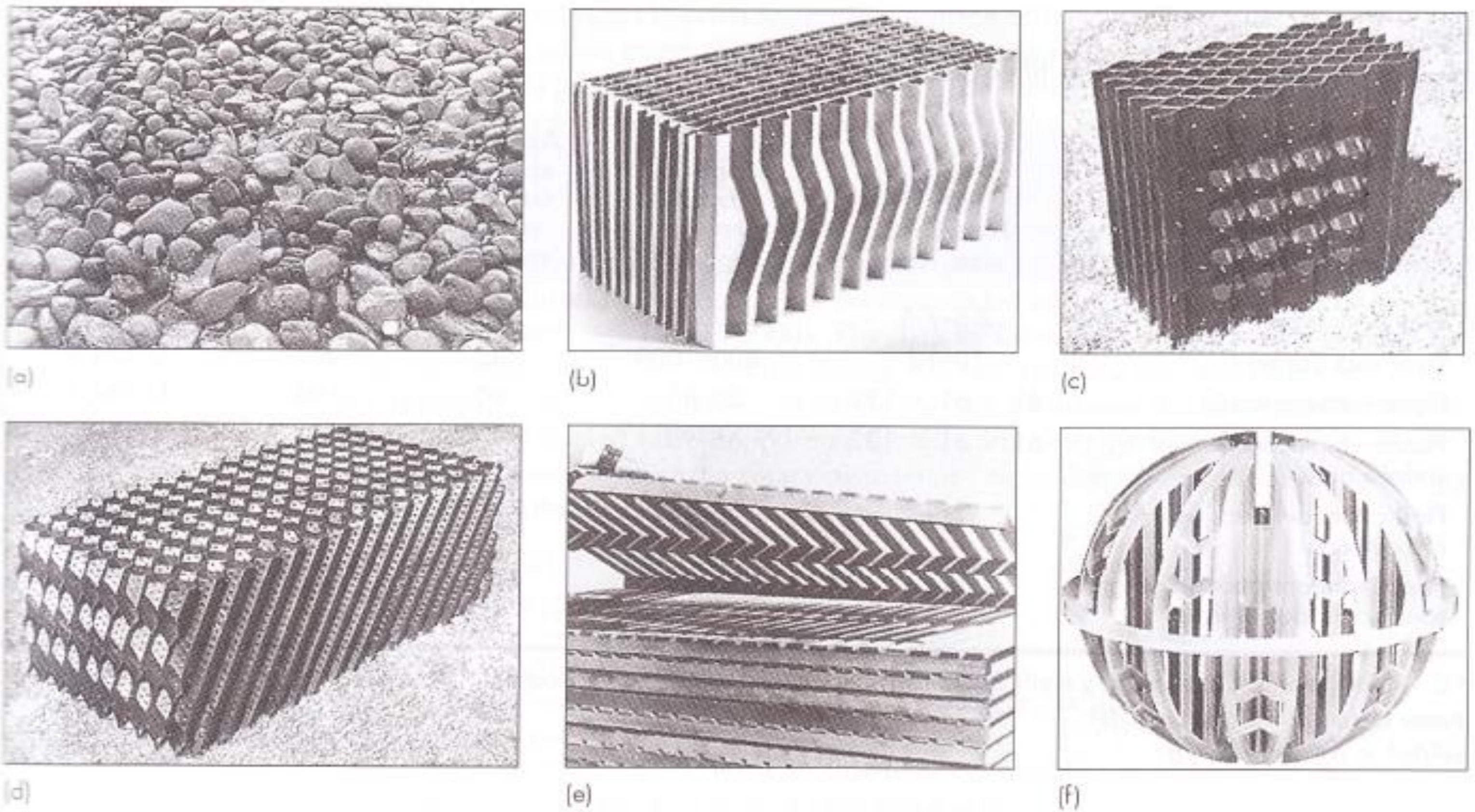


Figure 9–3

Typical packing material for trickling filters: (*a*) rock, (*b*) and (*c*) plastic vertical-flow, (*d*) plastic cross-flow, (*e*) redwood horizontal, and (*f*) random pack. *[Figs. (c) and (d) from American Surfpac Corp., (e) from Neptune Microfloc, and (f) from Jaeger Products, Inc.]* Note: the random pack material is often used in air stripping towers.

Distribution Systems

- The application of wastewater onto the medium is accomplished by a rotating distribution system

- 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

- The arms are hollow and contain nozzles through which the wastewater is discharged over the filter bed

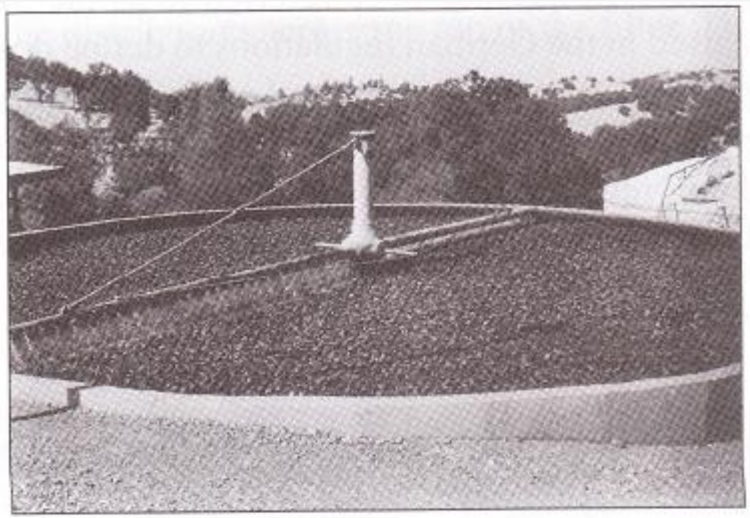
- Nozzles are spaced unevenly so that greater flow per unit of length is achieved near the periphery of the filter than at the center

- For uniform distribution over the area of the filter, the flowrate per unit length should be proportional to the radius from the center

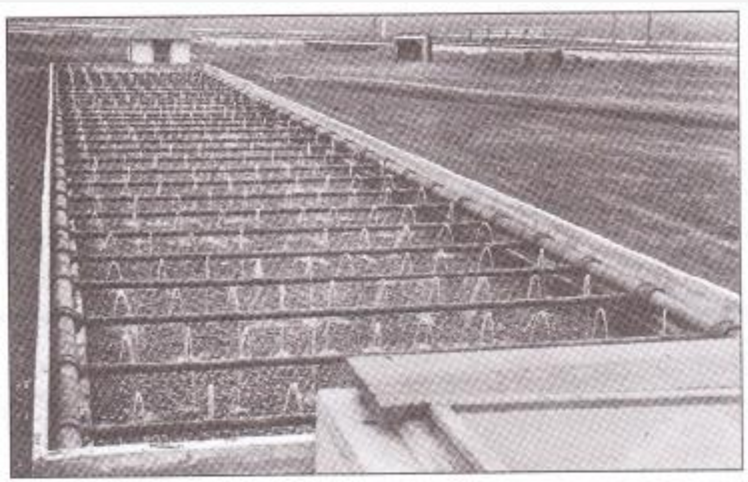
DISTRIBUTION SYSTEMS

Figure 9-4

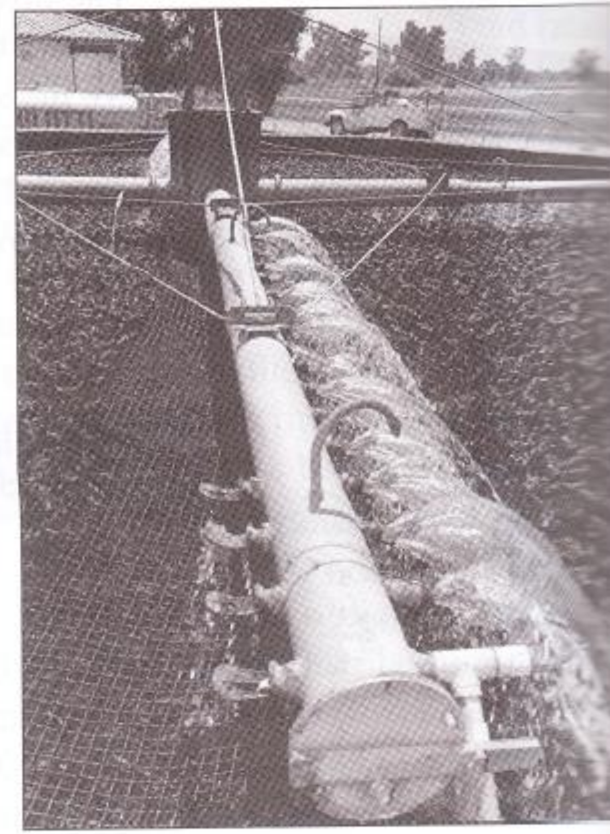
Typical distributers used to apply wastewater to trickling filter packing: (a) view of conventional rock filter (b) view of early rock filter with a fixed distribution system (c) view of top of tower trickling filter with four-arm rotary distributor



(a)



(b)



(c)

UNDERDRAIN

- To catch the filtered wastewater and solids discharged from the filter packing for conveyence to the final sedimentation tank

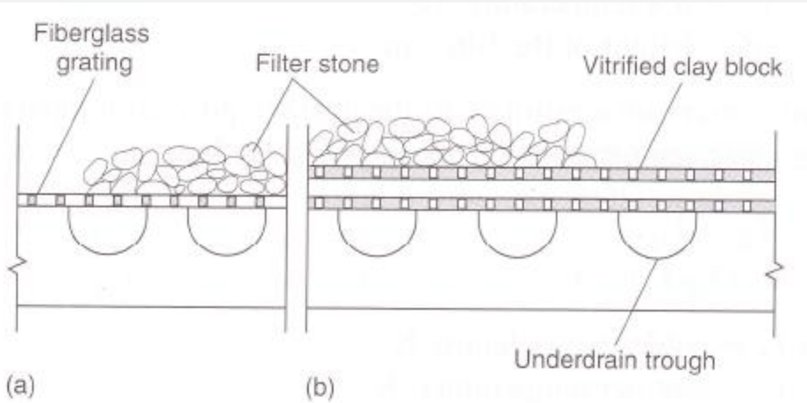
- Precast blocks of vitrified clay

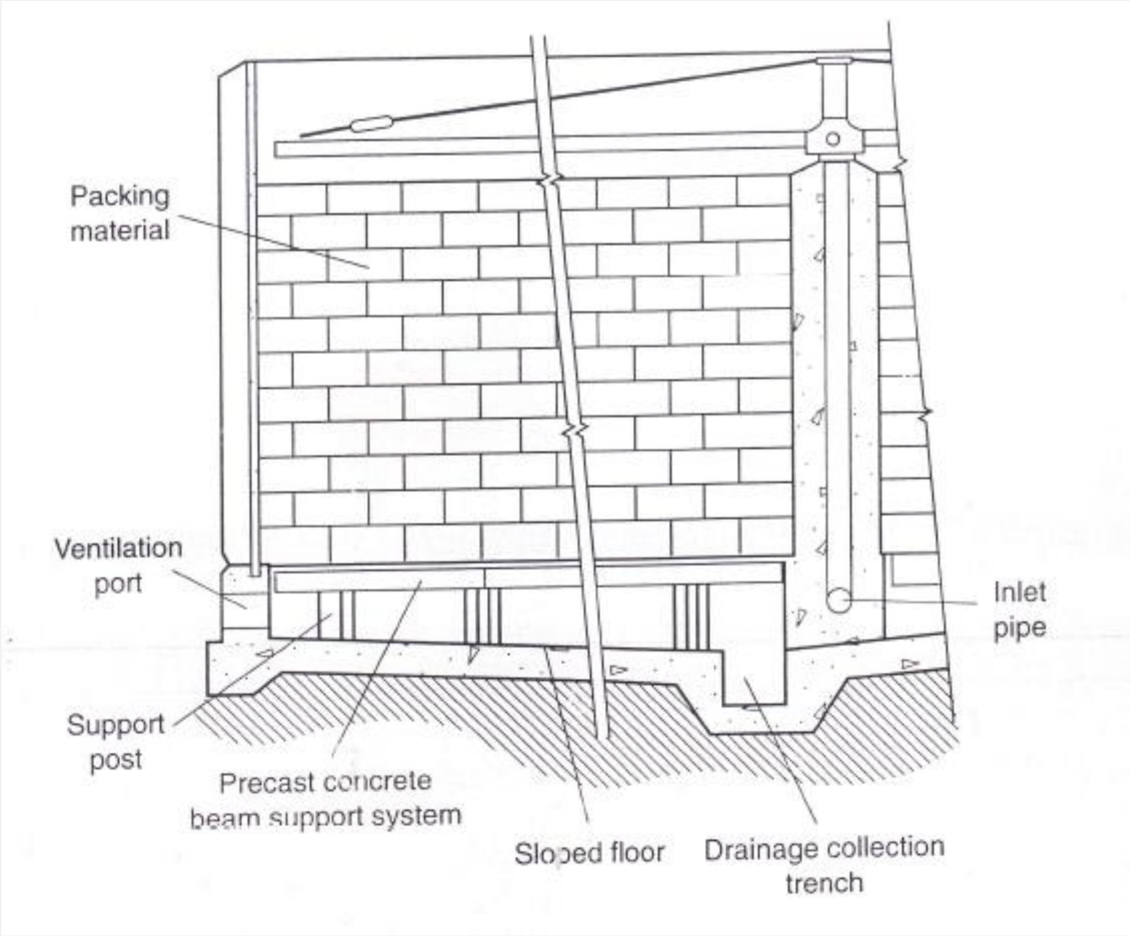
  Fiberglass grating laid on a reinforced concrete subfloor

- The floor and underdrains must have sufficient strength to suport the packing, slime growth and the wastewater

Figure 9–5

Typical underdrain for rock filter: (*a*) fiberglass grating and (*b*) vitrified clay block.





Packing material
Ventilation port
Support post
Precast concrete beam support system
Sloped floor
Drainage collection trench
Inlet pipe

- Underdrains may be open at both ends (so that they may be inspected easily and flushed out if they become plugged)
- The underdrains also allow ventilation of the filter, providing the air for microorganisms
- All underdrain systems should be designed so that forced air ventilation can be added at a later date

AIRFLOW

An adequate air flow is of fundemental importanc to successful opertaion of a trickling filter to provide efficient treatment and to prevent odor

Natural draft

Forced ventilation using low-pressure fans

In case of natural ir draft driving force for airflow:

temperature difference between the ambient air and air inside the pores

If wastewater is colder than the ambient air → the pore air will be cold

direction of airflow will be downward

If the ambient air is colder than wastewater→ direction of air flow will be upward

Solids Seperation Facilities for Trickling Filters

- differ from activated-sludge settling tanks
- has a much lower SS content
- sludge recirculation is not necessary

Effluent Recirculation

- To dilute strong influent wastewater and supplement weak wastewater
- To bring the filter effluent back in contact with the biological population for further treatment
- Almost always included in high-rate trickling filter systems
- improves distribution over the surface of filters
- Reduces the clogging tendency
- If sufficiently high, aids in the control of filter flies
- the increase in applied total flow increases wetting efficiency, thus reducing short circuiting

Trickling Filters

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

Classification of Trickling 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 (m3/m2.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

Ref: Metcalf & Eddy

Table 9–1
Historical classification of trickling filters applications[a]

Design characteristics	Low or standard rate	Intermediate rate	High rate	High rate	Roughing
Type of packing	Rock	Rock	Rock	Plastic	Rock/plastic
Hydraulic loading, $m^3/m^2 \cdot d$	1–4	4–10	10–40	10–75	40–200
Organic loading, kg $BOD/m^3 \cdot d$	0.07–0.22	0.24–0.48	0.4–2.4	0.6–3.2	>1.5
Recirculation ratio	0	0–1	1–2	1–2	0–2
Filter flies	Many	Varies	Few	Few	Few
Sloughing	Intermittent	Intermittent	Continuous	Continuous	Continuous
Depth, m	1.8–2.4	1.8–2.4	1.8–2.4	3.0–12.2	0.9–6
BOD removal efficiency, %	80–90	50–80	50–90	60–90	40–70
Effluent quality	Well nitrified	Some nitrification	No nitrification	No nitrification	No nitrification
Power, $kW/10^3\ m^3$	2–4	2–8	6–10	6–10	10–20

[a] Adapted from Metcalf & Eddy, Inc. (1979) and WEF (2000).

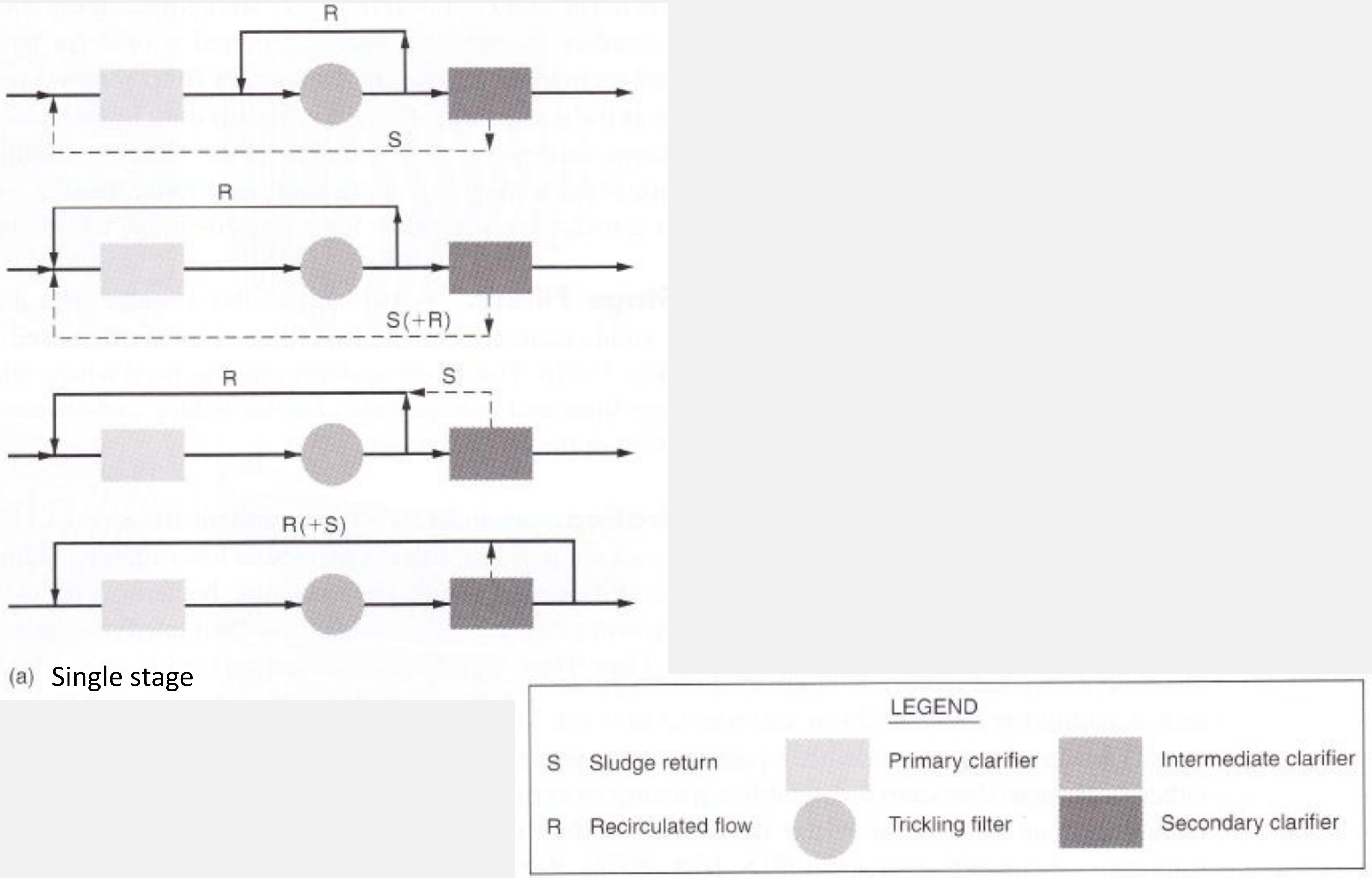
Note: $m^3/m^2 \cdot d \times 24.5424 = gal/ft^2 \cdot d$.

$kg/m^3 \cdot d \times 62.4280 = lb/10^3\ ft^3 \cdot d$.

$kW/10^3\ m^3 \times 5.0763 = hp/10^3\ gal$.

Figure 9-2

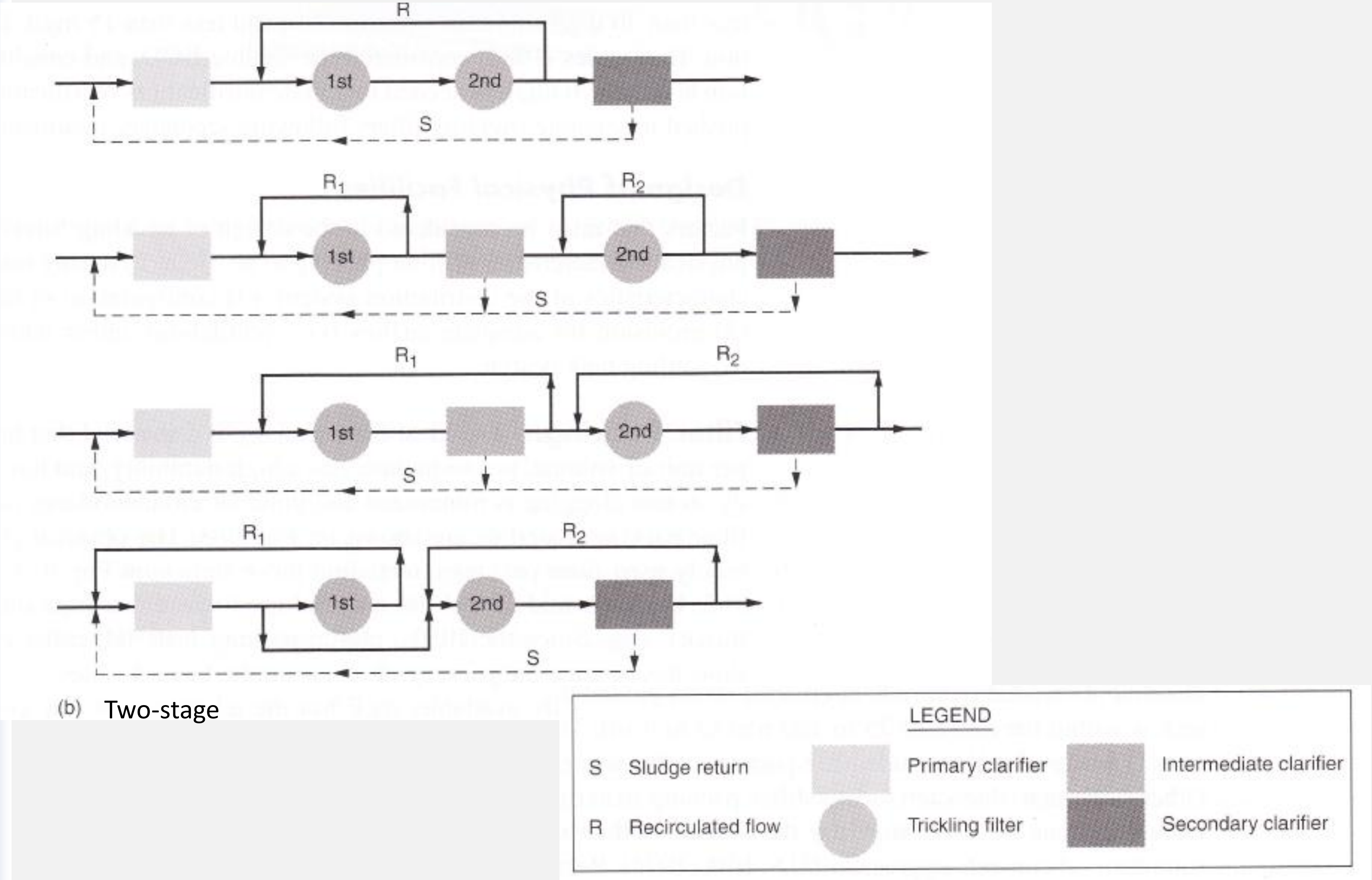
Typical trickling filter process flow diagrams. Where used, the most common flow diagrams are the first two of each series



(a) Single stage

Figure 9-2 (continued)

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



Two-stage

Design of Trickling Filters

A) Single stage or two stage rock filters

NRC (National Research Coancil) design model

For a single stage or 1st stage rock filter:

$$E_1 = \frac{100}{1 + 0.4432\sqrt{\frac{W_1}{VF}}}$$

$$F = \frac{1+R}{(1+R/10)^2}$$

E_1= BOD removal eff. for 1st stage filter at 20^{0}C including recirculation (%)

W_1= BOD loading to filter (kg/d) (not including recycle)

V= volume of filter packing m^3

F= recirculation factor

F= recycle ratio

F→represents the ave number of passes of the influent organic matter through the filter

The factor R/10 accounts for the fact that the benefits of recirculation decreases as the number of passes increase.

$R=0\text{-}2 = Q_R/Q$

Removal Efficiency of 2nd Stage for Two-stage Rock Filter

$$E_2 = \frac{100}{1 + \frac{0.4432}{1 - E_1}\sqrt{\frac{W_2}{VF}}}$$

E_2=BOD removal efficieny for the 2nd stage at 20^{0}C (%)

E_1=fraction of BOD removal in the 1st stage filter (%)

W_2=BOD loading applied to the second stage filter kg/d (not including recycyle)

The effect of ww temperature on the BOD removal efficiency:

$$E_T = E_{20}(1.035)^{T-20}$$

Example: Trickling filter sizing using NRC equation

A municipal ww having a BOD of 250 g/m^3 is to be treated by a two-stage trickling filter. The desired effluent quality is 25 g/m^3 of BOD. If both of the filter depths are to be 1.83 m and the recirculation ratio is 2:1 find the required filter diameters.

Q= 7570 m^3/d

ww temp=20^{0}C

Bioremoval in primary sedimentation tank =20%

E_1=E_2

B) Trickling filters with Plastic Packing

for trickling filters w/plastic packing → BOD removal is related to the hydraulic application rate

$$\frac{S_e}{S_o} = e^{\left(-kD/q^n\right)}$$

GERMAIN eqn

S_e= BOD conc of settled filter effluent (mg/L)

S_o= influent BOD conc (mg/L)

k= ww treatability and packing coeff $(L/s)^{0.5}/m^2$ (based on n=0.5)

D=packing depth, m

Q=hydraulic application rate of primary effluent, excluding recirculation (L/m^2sec)

n= characteristic of packing used

n→ normally assumed to be 0.5

Temp correction for k → $k_T = k_{20}(1.035)^{T-20}$

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

k_2= normalized value of k for the site specific packing depth and influent BOD conc

k_1= k value at depth of 6.1m and influent BOD of 150 mg/L $(L/s)^{0.5}/m^2$

Table 9.6 (Metcalf & Eddy, 2004) → k_1 values at 20^0C from pilot plant studies for different vastewaters

S_1= 150 mg/L

S_2= site-specific influent BOD conc (mg/L)

D_1=6.1m packing depth (m)

D_2= site-specific packing depth (m)

Another Approach (Modified eqn)

Includes a factor for the specific surface area of packing & for recirculation flow

$$S_e = \frac{S_o}{(R+1)\exp\left\{\dfrac{k_{20}A_s D Q^{T-20}}{[q(R+1)]^n}\right\}}$$

S_o= influent BOD (mg/L)

S_e= effluent BOD (mg/L)

R= recirculation ratio (Q_R/Q)

k_{20}= filter treatability constant at 20^0C $(L/s)^{0.5}/m^2$

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

D= packing depth, m

Q= temp correction factor (1.035)

q= hydraulic application rate (L/m^2s)

n= constant characteristic of packing used

Example: Design of trickling filter with plastic packing

Given the following design flowrates and primary effluent wastewater characteristics, determine the following design parameters for a trickling filter design assuming 2 towers at 6.1m depth, cross flow plastic packing with a specific surface area of $90 m^2/m^3$, a packing coefficient n value of 0.5

The required min wetting rate = $0.5\ L/m^2$ sec

Q= $15140\ m^3/d$

BOD_{inf}= 125 mg/L BOD_{eff}= 20 mg/L

Min temp=14^0C

a) Diameter of tower trickling filter , m?

b) Volume of packing required , m^3

c) Recirculation rate required , if any

Major Operational Problems of Trickling Filters

Cold weather operation

- Freezing may cause partial plugging of the filter medium

Filter flies

- High hydraulic loading rates and maintanance of a thin biological film asist in washing the fly larvae from fitler 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 probabaly not harmfull 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 anaeorobic activity within the slime layer

- is reduced by high recirculation rates which thin the film and supply additional oxygen

ROTATING BIOLOGICAL REACTORS (RBCs)

- consists of a series closely spaced circular disks of polystyrene or polyvinyl chloride that are submerged in wastewater and rotated through it

- the cylindrical plastic disks are attached to a horizontal shaft and are provided at standard unit sizes of approx. 3.5 m in diameter and 7.5 m in length

- The RBC unit is partially submerged (typically %40) in a tank containing the wastewater
- Disc rotatiom → slow (1-1.6 rpm)

- As the RBC disks rotate out of the wastewater, aeration is accomplished by exposure to the atmosphere

- seperate baffled basins are needed to develop the benefits of a staged biological reactor design

- Staging→ compartmentalization of the RBC disks to form a series independent cells

- 2-4 stages → for BOD removal

6-more stages → for nitrification

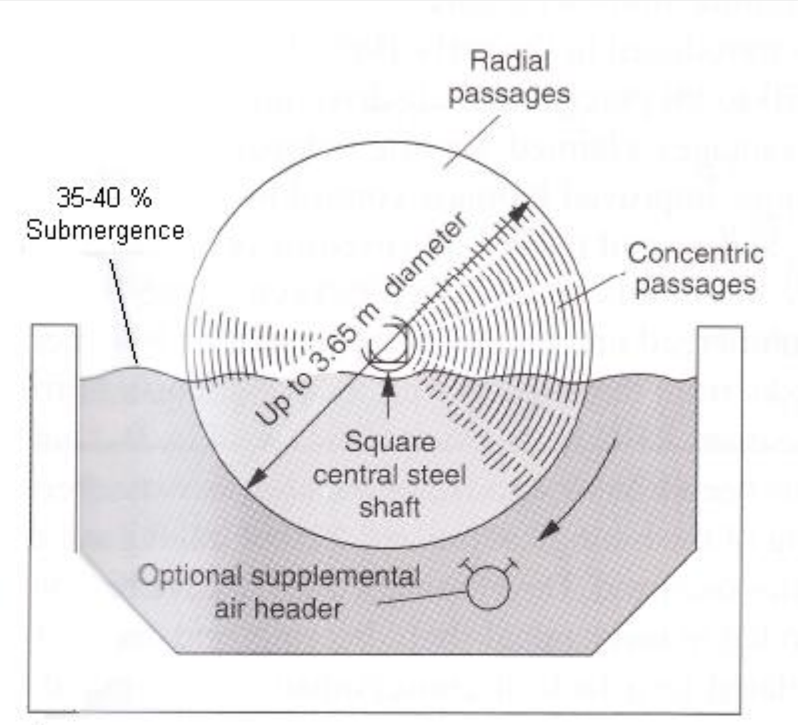
- stages can be accomplished

  by using baffles in a single tank

  by using seperate tanks in series

- the complexity in the physical and hydrodynamic characteristics require that;

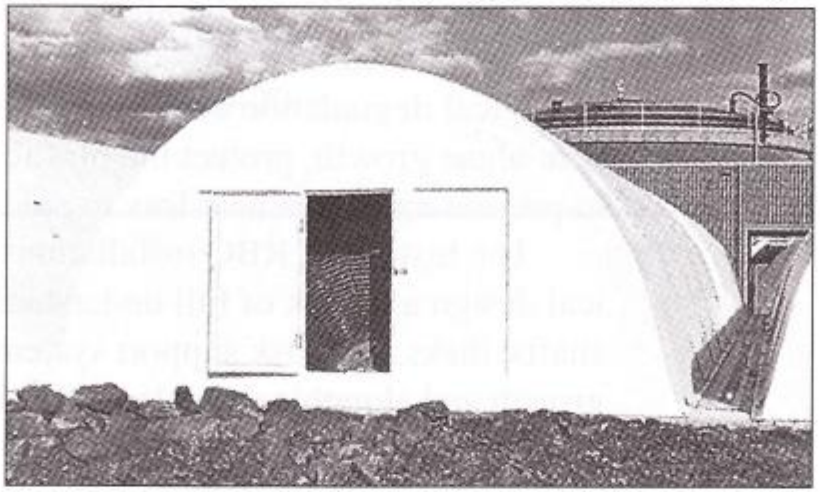
design of the RBC process is based on fundemental information from pilot-plant and field installations



a)

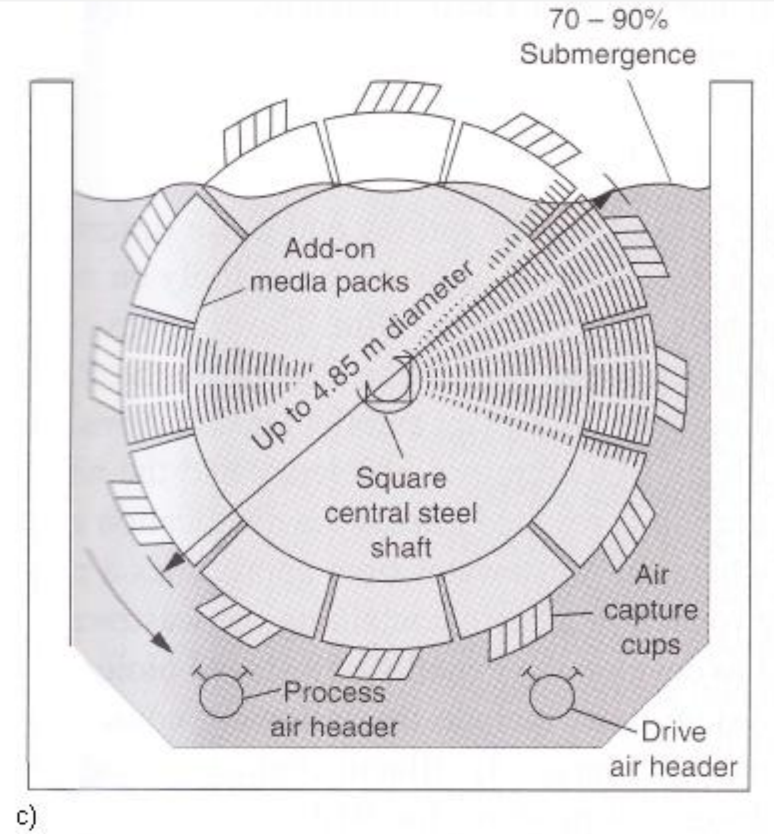
Conventional RBC with mechanical drive

and optional air input



(b) Conventional RBC in enclosed reactor

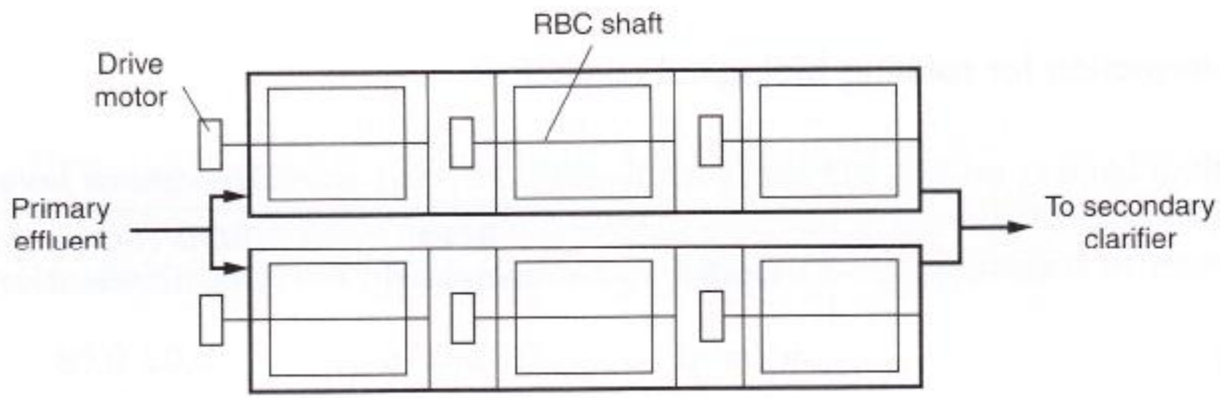
Figure 9-11. Typical RBC units (Ref: Metcalf & Eddy, 2004)



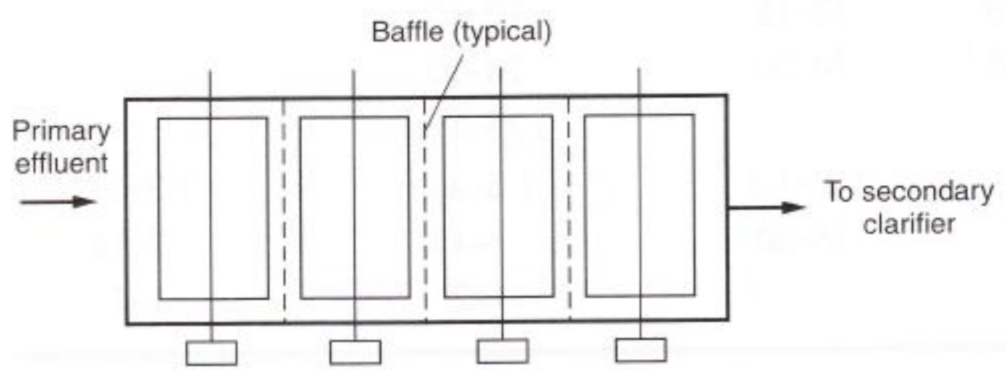
Submerged-type RBC equipped with air capture cups (air is used both to rotate and to aerate the biodisks)

Typical submerged RBC equipped with air capture cups

Figure 9-11. Typical RBC units (Ref: Metcalf & Eddy, 2004)



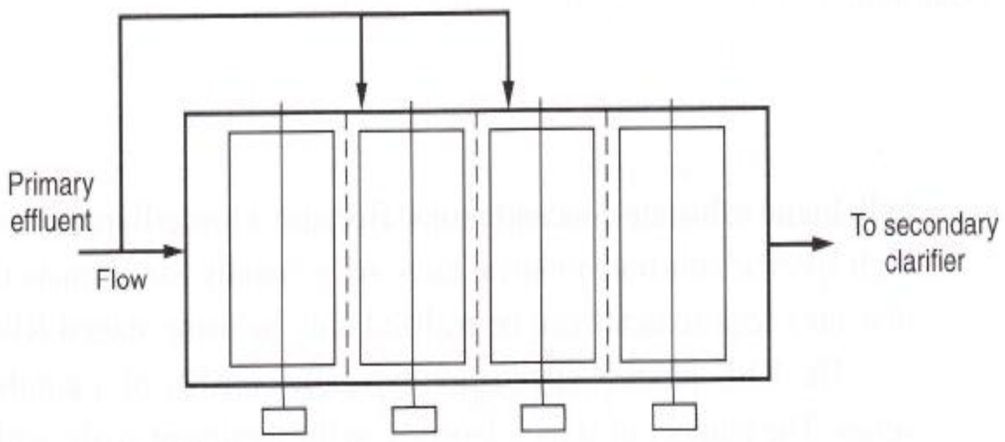
(a) Flow parallel to shaft



(b) Flow perpendicular to shaft

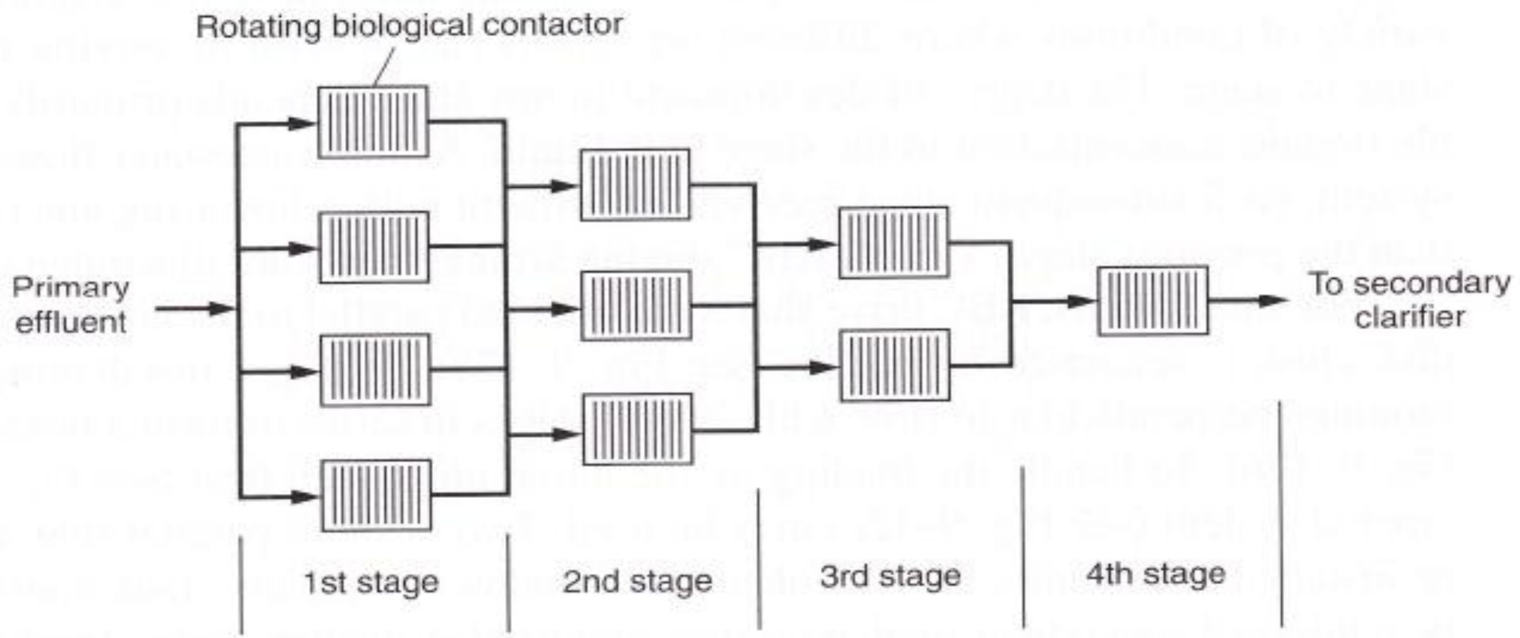
Figure 9-12. Typical RBC arrangements (Ref: Metcalf & Eddy, 2004)

(c) View of RBCs with flow perpendicular to shaft



(d) Step-feed flow

Figure 9-12 (continued) . Typical RBC staging arrangements



(e) Tapered feed flow parallel to shaft

Figure 9-12 (continued). Typical RBC staging arrangements

RBC disks :

- high density polyethylene
- corrugated pattern (to increase available surface area)
- partially submerged in wastewater (typically 40%)
- disk rotation → slow (about 1-1.6 rpm)

Drive System:

- Most RBC units are rotated by direct mechanical drive units attached directly to the central shaft

Tank Dimensions:

- Typical sidewater depth : 1.5 m

Enclosure:

- In some cases, units have been housed in a building
- protection against cold weather
- aesthetic reasons

Table 9-8
Typical design information for rotating biological contactors Ref: Metcalf & Eddy

Parameter	Unit	Treatment level[a]		
		BOD removal	BOD removal and nitrification	Separate nitrification
Hydraulic loading	$m^3/m^2 \cdot d$	0.08–0.16	0.03–0.08	0.04–0.10
Organic loading	g $sBOD/m^2 \cdot d$	4–10	2.5–8	0.5–1.0
	g $BOD/m^2 \cdot d$	8–20	5–16	1–2
Maximum 1st-stage organic loading	g $sBOD/m^2 \cdot d$	12–15	12–15	
	g $BOD/m^2 \cdot d$	24–30	24–30	
NH_3 loading	g $N/m^2 \cdot d$		0.75–1.5	
Hydraulic retention time	h	0.7–1.5	1.5–4	1.2–3
Effluent BOD	mg/L	15–30	7–15	7–15
Effluent NH_4-N	mg/L		<2	1–2

[a] Wastewater temperature above 13°C (55°F).
Note: $g/m^2 \cdot d \times 0.204 = lb/10^3\ ft^2 \cdot d$.
$m^3/m^2 \cdot d \times 24.5424 = gal/ft^2 \cdot d$.