CHAPTER 4
Attached Growth Biological Treatment System

4.1 Introduction:

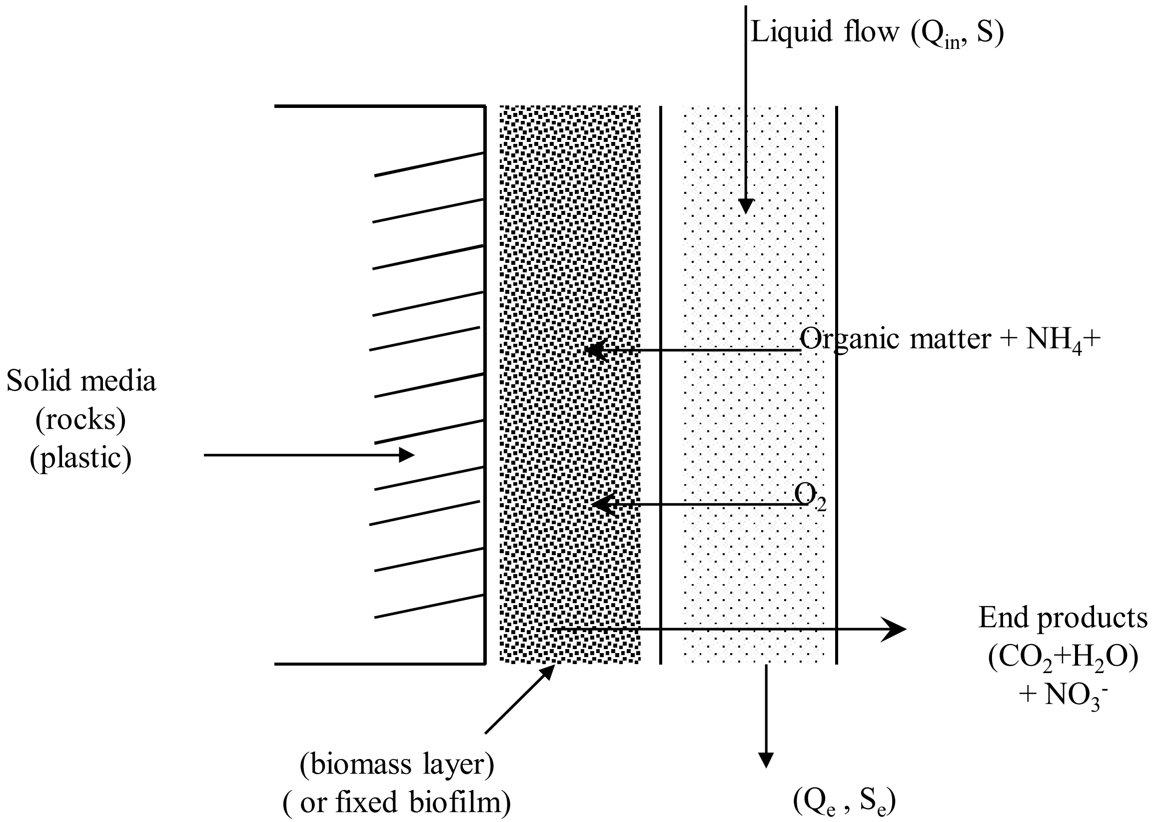
As mentioned previously, Attached Growth is a biological treatment process in which microorganisms responsible for conversion of organic matter or other constituents in wastewater are attached to some inert material such as: rocks, sand or specially ceramic or plastic materials. This process is also called fixed film process.

4.2 Examples of Attached growth system:

Many types of this system has been developed:

- Trickling filters(biological tower).
- Rotating biological contactors(RBC).
- Packed bed reactors
- Fluidized bed biofilm reactors.

4.3 Theory of attached growth treatment:



According to the figure shown, a biomass layer(bacteria) stick to the solid media and grow there. The liquid wastewater pass adjacent to the biomass layer forming a liquid layer. During the passage of the wastewater in the liquid layer and its contacts with the biofilm layer the organic matter, ammonia and dissolved oxygen in addition to other dissolved materials penetrate into the biomass layer by diffusion. The biochemical reactions such as organic matter oxidation, nitrification occur inside the biofilm layer. The end products such as CO_2, H_2O ,and NO_3^- Leave the biofilm layer back to the Liquid Layer and move out with the liquid flow to the effluent stream . Denitrification can be achieved in attached growth system in the lower parts of these systems where anoxic conditions exist . The bacteria in the biomass layer grow and some of it die . The dead bacteria lose its sticky characteristics and its removed from the biomass layer by the action of the moving liquid . The removed bacteria is then removed by sedimentation in a final sedimentation tank .

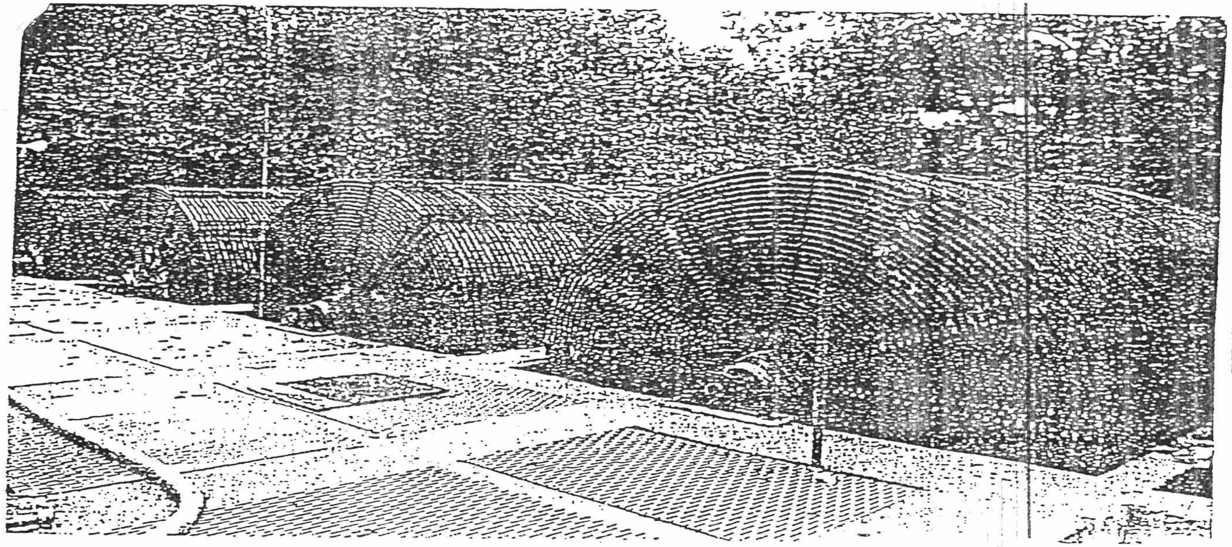
The biochemical reaction for BOD_5 removed nitrification and denitrification are the same of those in the suspended growth system.

4.4 applications of attached growth systems

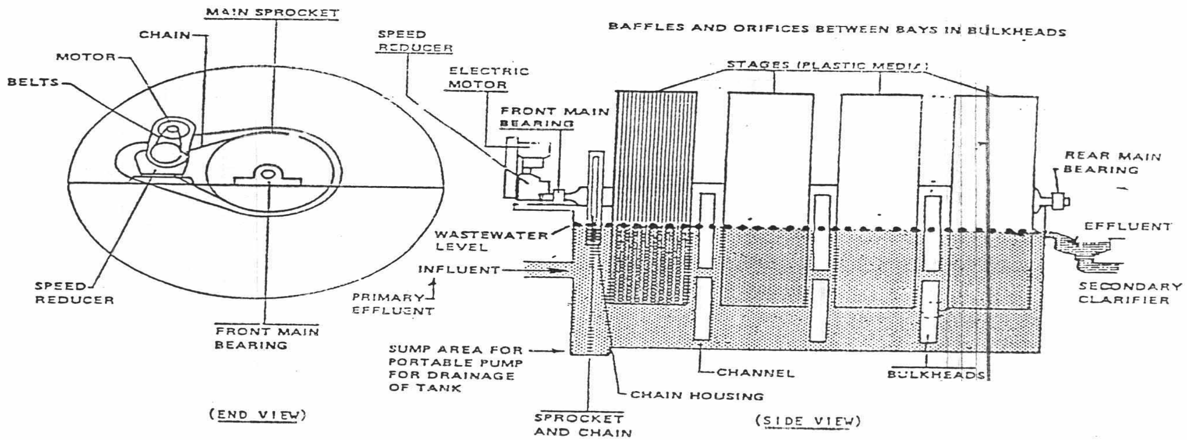
A rotating biological contactors{RBC}

4.4.1 Introduction

- Rotating biological contactors consist of a series of closely spaced circular disks of polyvinyl chloride (PVC) that are submerged in wastewater and rotated through it (see figure 1) .The cylindrical disk are attached to a horizontal shaft and are provided at standard unit sizes of approximately 3.5m in diameter and 7.5m in length . The surface area of disks for a standard unit is about $9300m^2$,and $13900m^2$ for high density units
- The RBC unit is partially submerged (typically 40%) in a tank containing wastewater , and the disks rotate slowly at about 1.0 to 1.6 revolutions per minute .
- As the RBC disks rotate out of the wastewater , aeration is accomplished by exposure to the atmosphere .



Fig(1) A full scale rotating biological contactor (Autotrol Corporation)



Equipment for inspection in a RBC unit.

4.4.2 RBC process design considerations:-

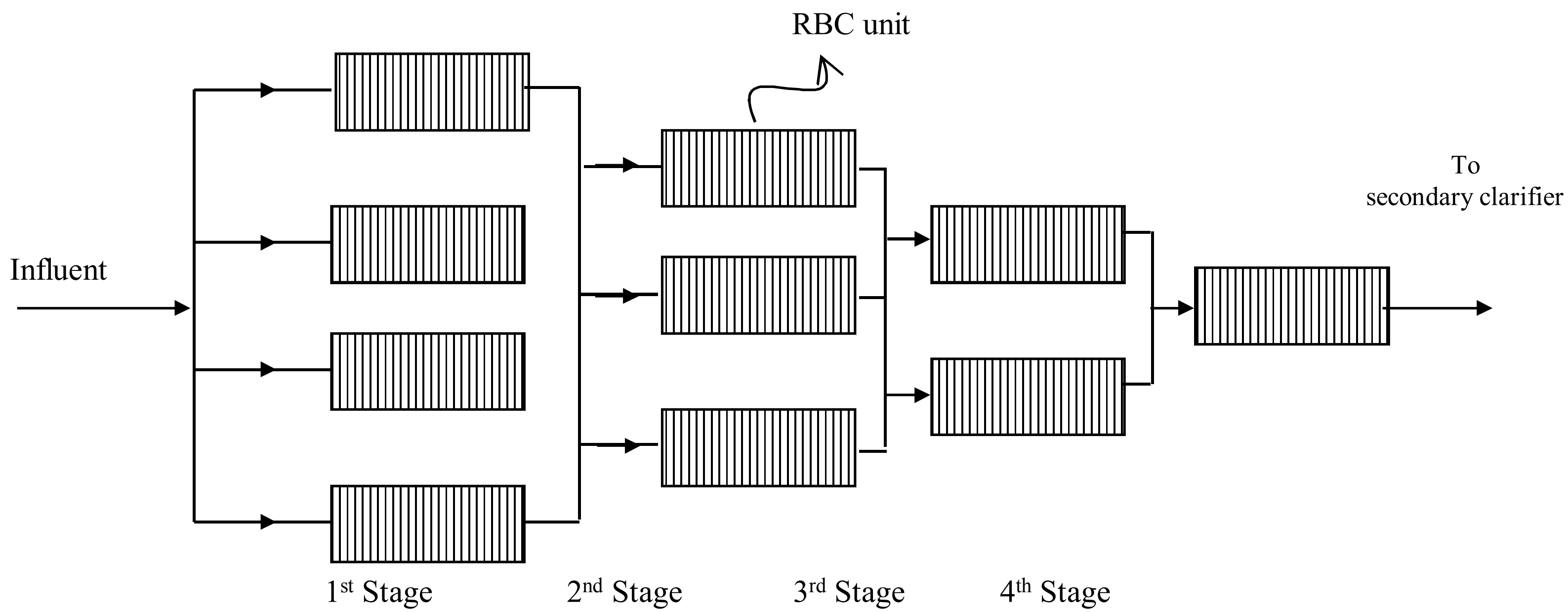
The following are the main design parameters needed to design the RBC System :-

1. Staging of the RBC units
2. Organic loading rate
3. Hydraulic loading rate

4.4.3 RBC staging:-

- The RBC process application typically consists of a number of units operated in series .
- For this purpose , RPC is divided in to stages . Number of stages depends on the treatment goals . For BOD removal " 2 " to " 4" stages are needed ,and " 6" or more stages for nitrification .

- NOTE :- the number of shafts in each stage depends on the treatment efficiency required .
- The separation between stages is accomplished by using baffles in a single tank or by a series of separate tanks .
- As the wastewater flow through the system , each subsequent stage receives an influent with a lower organic matter concentration than the previous stage.
- The RBC units may be arranged parallel or normal to the direction of wastewater flow.



4.4.4 Organic loading rate:

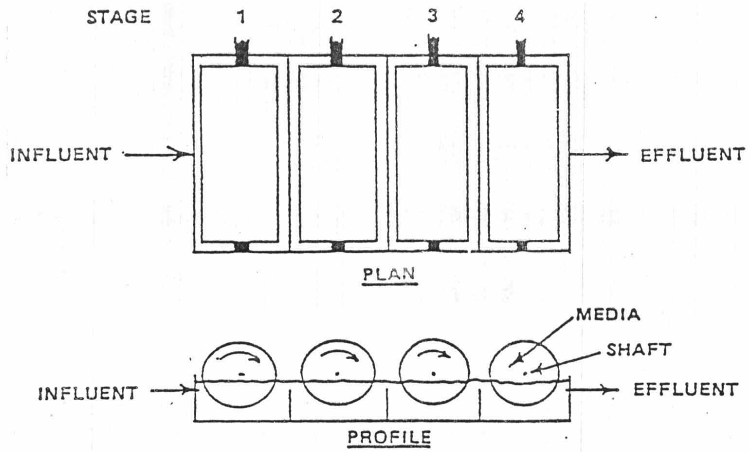
The organic loading rate for RBC in typically in the range 4-10 g(BOD) $\frac{soluble}{m^2 \bullet d}$ for BOD removal only. If both BOD removal and nitrification, the range is 2.5-4 $\frac{g(BOD_5)}{m^2 \bullet d}$

Nitrifying bacteria can not develop in RBC until(BOD_5) drops to less than 15mglL. The maximum nitrogen surface removal rate that has been observed to be about 1.5 $\frac{gN}{m^2 \bullet d}$

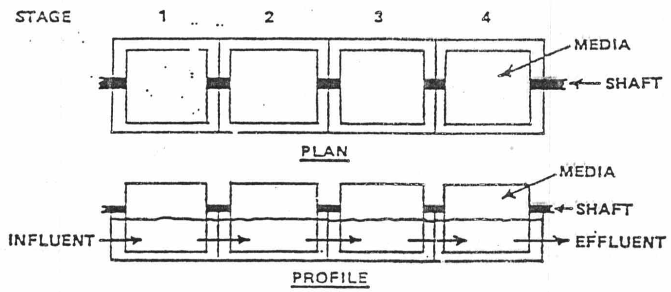
The maximum 1st stage organic loading is 12-15 $\frac{(BOD_5)_s}{m^2 \bullet d}$.

4.4.5 Hydraulic loading rate:

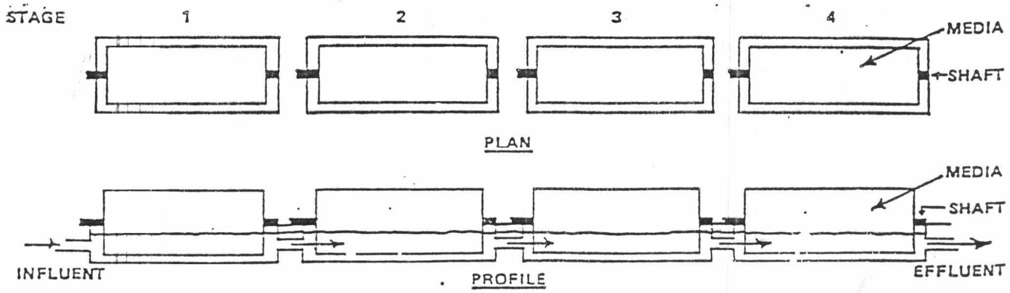
The typical hydraulic loading rate of $0.08\text{-}0.16\, m^3/m^2$ for BOD_5 removal and $0.03\text{-}0.08\, m^3/m^2$ for both BOD_5 removal and nitrification. The hydraulic detention time (θ) is 0.7-1.5hrs for BOD_5 removal and 1.5-4hrs for both BOD_5 removal and nitrification. The volume of RBC tank has been optimized at $0.0049\, m^3/m^2$ for one shaft of $9300\, m^2$.
A tank volume of 45 m^3 is needed. Based on this volume and a hydraulic loading rate of $0.08\, m^3/m^2.d$ the detention time is 1.44hrs. Atypical side wall depth is 1.5m to achieve 40% submergence.



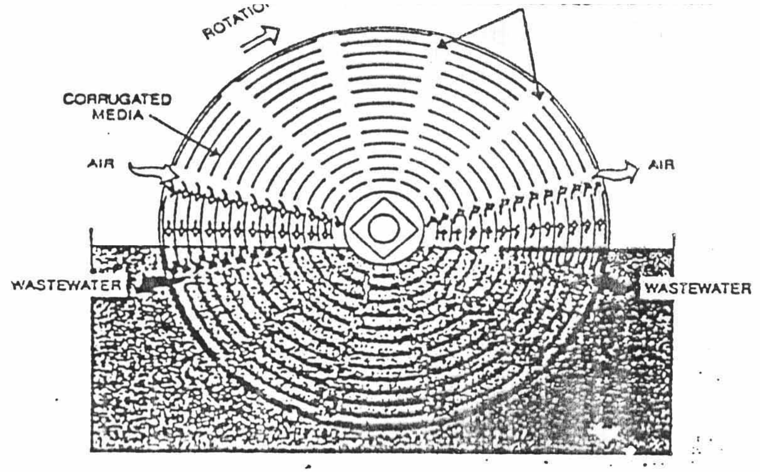
layout with flow perpendicular to shaft



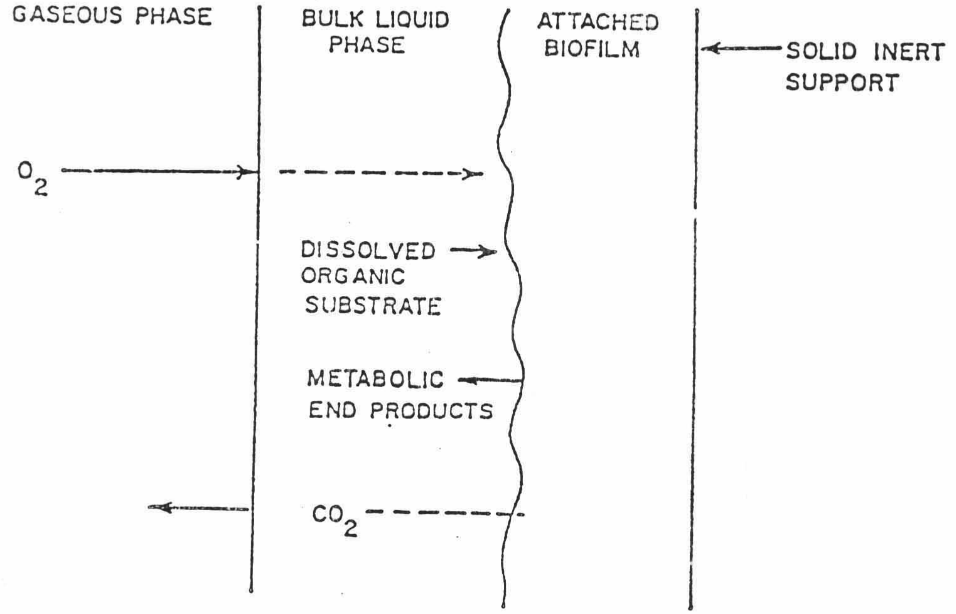
RBC with one shaft, flow parallel to shaft



RBC with four shaft, flow parallel to shaft

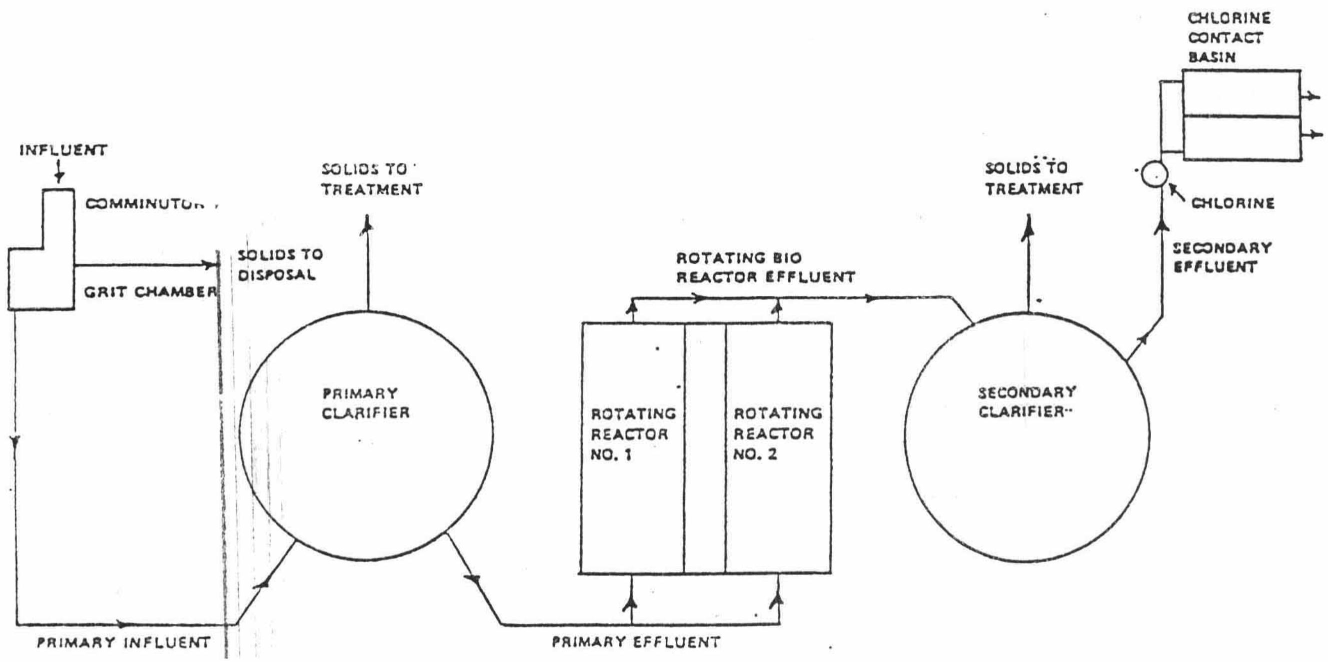


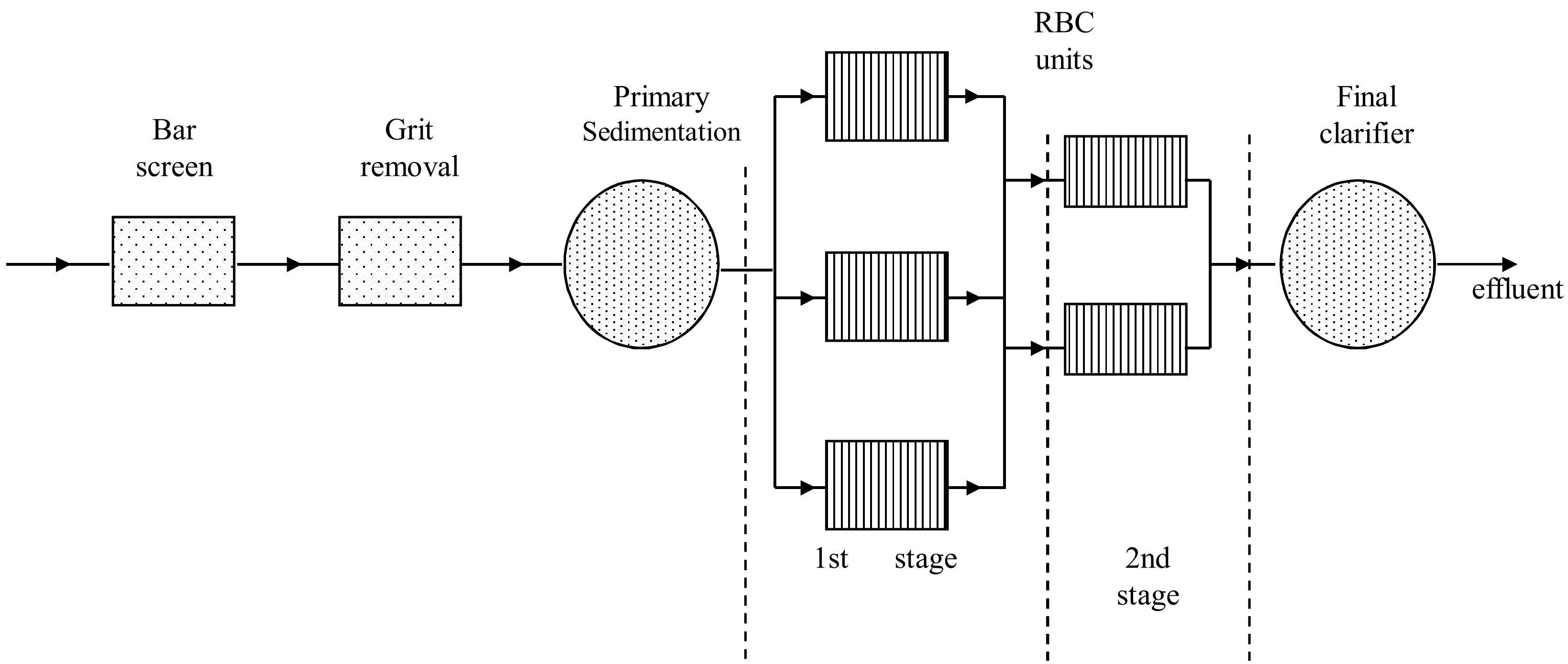
Schematic illustration of exchange of air and water in RBC reactor



Simplified model of biofilm

4.4.6 Typical treatment plan configuration:




Bar
screen
Grit
removal
Primary
Sedimentation
RBC
units
Final
clarifier
effluent
1st stage
2nd
stage

4.4.7 <u>Design equation of RBC:</u>

The following empirical equation developed by Optaken(US EPA,1985):

$$S_n = \frac{-1 + \sqrt{1 + 0.039(\frac{A_s}{Q})S_{n-1}}}{0.0195(\frac{A_s}{Q})}$$

Where S_n = soluble BOD_5 concentration in stage(n), (mg/L)

A_s = disk surface area on stage(n), m^2

Q= flow rate, m^3 / d

Example 4.1:

Design a rotating biological contractor to treat an influent soluble BOD_5 of 90 mg BOD_5/L.

The flow(Q)= 4000 m^3/d

Solution:

- Assume 1st stage (BOD_5) organic loading= 15g/ m^2 .d

BOD_5 (loading)= (BOD_5) $_{\text{concentration}}$ $\bullet Q_{in}$

$$=90\,\frac{mg}{L}\bullet 4000\,\frac{m^3}{d}\bullet\frac{10^3\,L}{m^3}\bullet\frac{g}{10^3\,mg}=360{,}000\,\frac{g}{d}$$

Disk area= $\dfrac{360{,}000\; g/d}{15\; g/m^2.d} = 2400\,m^2$ (first area stage)

Use $9300\,\dfrac{m^2}{shaft}$ so number of shafts needed for the first stage:

$$N=\frac{2400\,m^2}{9300\,m^2/shaft}\cong 2.6$$ say 3 shafts

- <u>Calculate $S_{1,}$ the BOD concentration after the first stage:</u>

$$S_n = \frac{-1+\sqrt{1+0.039(\frac{As}{Q})S_{n-1}}}{0.0195(As/Q)}$$

For the first stage n=1, $S_n = S_1$, $S_{n-1} = S_0$

$S_0 = 90$ mg/L, $A_S = 3 \times 9300 = 27900 \quad m^2, Q = 4000 \ m^3/d$

$$\frac{A_S}{Q} = \frac{27900\,m^2}{4000\,m^3/d} = 6.98\,d/m$$

$$S_1 = \frac{-1+\sqrt{1+0.039 \bullet 6.98 \bullet 90}}{0.0195 \bullet 6.98} = 29.75\frac{mg}{L} > 14\frac{mg}{L}$$

So we need one more stage.

- <u>Add another stage and calculate S_2:</u>

Assume two shafts in the second stage:

$A_S = 2 \times 9300 m^2 = 18600\, m^2$

$$\frac{A_S}{Q} = \frac{18600}{4000} = 4.65 \frac{m}{d}$$

$S_n = S_2$, $S_{n-1} = S_{2-1} = S_1 = 29.75$mg/L

$$S_2 = \frac{-1 + \sqrt{1 + 0.039 \bullet 4.65 \bullet 29.75}}{0.0195 \bullet 4.65} = 16.86 \frac{mg}{L} > 14 \frac{mg}{L}$$

So we need one more stage.

- <u>Add another stage and calculate S_3:</u>

Assume one shaft in the third stage:

$A_S = 1 \times 9300\, m^2 = 9300\, m^2$

$$\frac{A_S}{Q} = \frac{9300\ m^2}{4000\, \frac{m^3}{d}} = 2.33\, \frac{d}{m}$$

Follow Example 4.1:

$S_n=S_3, S_{n-1}=S_{3-1}=S_2=16.86mg/L$

$$S_3=\frac{-1+\sqrt{1+0.039\bullet 2.33\bullet 16.86}}{0.0195\bullet 2.33}\cong 13\frac{mg}{L}<14\frac{mg}{L}\quad \text{OK}$$

So three stages are enough.

- Check for the hydraulic loading:

$$HLR=\frac{Q}{total\ number\ of\ shafts\bullet Area\ of\ each\ shaft}$$

$N_{shafts}=3+2+1=6$ shafts

$$HLR=\frac{4000\,\frac{m^3}{d}}{6\times 9300}=0.072\,\frac{m^3}{m^2\bullet d},$$ typical range(0.08-0.16), which is a little bit lower than the range.

- <u>Is nitrification possible in any of the three stages?:</u>

*Nitrification is only possible when soluble BOD_5 loading is less than

10g $\frac{BOD}{m^2 \bullet d}$

- 1^{st} stage = $4000\frac{m^3}{d} \bullet 90\frac{g}{m^3} \bullet \frac{1}{3 \bullet 9300} = 12.9\frac{gBOD_5}{m^2 \bullet d}$ >10(no nitrification)
- 2^{nd} stage = $4000\frac{m^3}{d} \bullet 29.75\frac{g}{m^3} \bullet \frac{1}{2 \bullet 9300} = 6.4\frac{gBOD_5}{m^2 \bullet d}$ (nitrification occurs)
- 3^{rd} stage = $4000\frac{m^3}{d} \bullet 16.86\frac{g}{m^3} \bullet \frac{1}{1 \bullet 9300} = 7.25\frac{gBOD_5}{m^2 \bullet d}$ (nitrification occurs)

*Rate of nitrification is related to the soluble BOD_5 loading by the following equation:

$$r_n = 1.5[1 - 0.1(BOD_5)] \quad \frac{g\ N}{m^2 \bullet d}$$

* So for 2nd stage→ $r_n = 1.5[1 - 0.1 \bullet 6.4] = 0.54 \quad \frac{g\ N}{m^2 \bullet d}$

* And for 3rd stage→ $r_n = 1.5[1 - 0.1 \bullet 7.25] = 0.413 \quad \frac{g\ N}{m^2 \bullet d}$

*If the ammonia concentration in the influent to the 2nd stage is 30 mgN/L, find the effluent ammonia concentration.

$$r_n = 0.54 \quad \frac{g\ N}{m^2 \bullet d} \quad \text{for } 2^{nd} \text{ stage}$$

$$\text{Nitrogen removal} = 0.54 \quad \frac{g\ N}{m^2 \bullet d} \bullet (2 \bullet 9300 m^2) = 10044 \frac{g}{d}$$

$$\text{Concentration} = \frac{10044 g}{d} \bullet \frac{d}{4000 m^3} = 2.51 \frac{mg}{L}$$

So $\rightarrow N_2 = 30 - 2.51 \cong 27.5 \frac{mg}{L}$

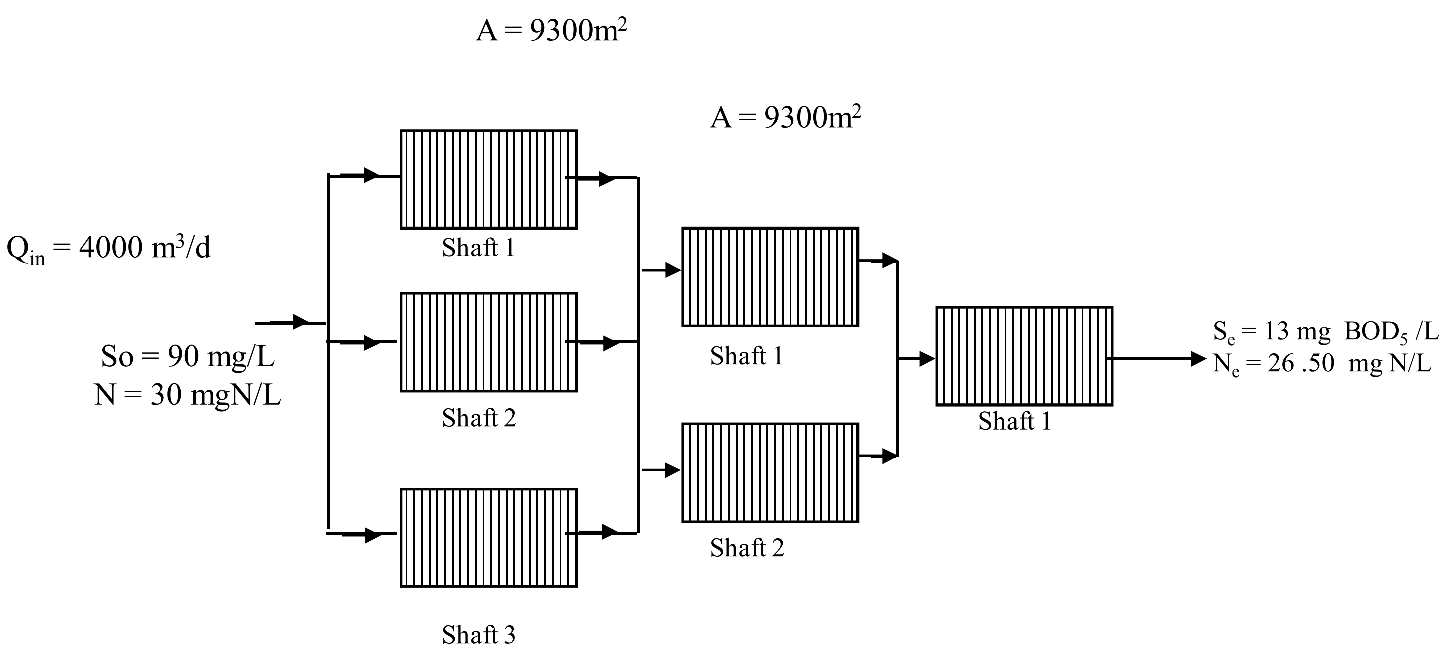
$\rightarrow r_n = 0.413 \ \frac{g\ N}{m^2 \bullet d}$ for 3^{rd} stage,

$$\text{Nitrogen removal} = 0.66 \ \frac{gN}{m^2 \bullet d} \times (1 \bullet 9300 m^2) = 3841 \frac{g}{d}$$

$$\text{Concentration} = 3841 \frac{g}{d} \bullet \frac{d}{4000 m^3} = 0.96 \frac{mg}{L}$$

So $\rightarrow N_3 = 27.5 \ \frac{mgN}{L} - 0.96 \cong 26.5 \frac{mgN}{L}$

If complete nitrification is needed a separate nitrification stage should be added after these stages.



Proposed design

Note: each shaft has a tank volume of 45m3.