Classes of Nitrogen Removal Processes

Total N removal consists of nitrification and denitrification. To achieve both you must include an anoxic zone. Processes are defined as single sludge or two sludge. The single sludge system has only 1 clarifier while the two sludge system has two clarifiers.

The design of these systems is based on playing with the recycle of wastewater and solids flow to the different zones of a single reactor (Figure 8-21 overhead). Your text goes over the steps for designing these processes as well as several designs for different reactor and aeration configurations. You should go over this information on your own and use it for your homework and project.
Table 8-22 (overhead) provides some typical design parameters.

Phosphorous Removal

There are two types of phosphorous removal processes. mainstream (already discussed) Figure 8-29 (overhead) and sidestream Figure 8-30 overhead).

In the sidestream process the aerobic sludge which is high in phosphorous due to accumulation by *Acinetobacter* is settled out and the sludge is treated in a sidestream process. This process puts the sludge through an anaerobic reactor/thickener where it releases the phosphorous back into the aqueous phase. The sludge is settled again and the solids recycled to the aerobic reactor to return the cells to the aerobic stage to bind more phosphorous. The aqueous phase from the anaerobic settler contains high concentrations of phosphorous and can be used as fertilizer or chemically treated to remove the phosphorus.

The end result of the sidestream process is that the phosphate is stripped from the bulk of the flow and released in a smaller volume of water. This saves chemicals because the concentration of phosphates is higher so better kinetics are realized and it saves volume if the sidestream is to be disposed of in another way.

Sequencing Batch Reactors

Intermittent flow stirred tank reactor
everything happens in one tank
add waste to sludge mix with air and is an STR, turn air off, things settle out, let water go, waste some sludge and add new waste to start off next cycle.
More technically termed 1) Fill, 2) React, 3) Settle, 4) Decant and 5) Idle.
Usually run several of these so you can always handle the inflow. Stagger the flow so it goes from one to the next and then by the time you are back at number one it is ready again.
Illustrated in figure 8-16 (overhead)
No set time dedicated to wasting but, depending on the influent wastewater characteristics, sludge must be wasted periodically. This is usually done during the decant step so a uniform wasting can be obtained.

SBR Kinetics

Because each reactor is a batch process, batch kinetics will apply. The usual kinetic equations will apply, but since Q is taken as 0 during the react phase, there is no influent in the mass balance. Therefore the mass balance equations are rewritten:

$$K_S \ln\frac{S_o}{S_t} + (S_o - S_t) = X\left(\frac{\mu_m}{Y}\right)t \quad \text{text equation 8-38}$$

and

$$K_N \ln\frac{N_o}{N_t} + (N_o - N_t) = X_n\left(\frac{\mu_{mn}}{Y_n}\right)\left(\frac{DO}{K_o + DO}\right)t \quad \text{text equation 8-40.}$$

Because of the many design variables in an SBR the design requires an iterative approach. The key design criteria are:

1. The fraction of contents that are removed during the decant phase (this depends a lot on the settle ability of the sludge)
2. The settle decant and reaction times.

The design steps are presented in Table 8-14 (overhead). Example 8-3 (overheads) presents an example process design.

Your text presents many example design applications for the design of many of the alternate processes. You should go over these on your own and use them as examples for homework and your project.

Aeration System Selection and Design

An important consideration in aerobic treatment systems is the requirement for oxygen of the system. For plug flow this is very difficult at the head or beginning of the reactor, due to the high requirements of oxygen to metabolize the high concentrations of substrate and subsequent high growth of microorganisms.

Air supply must be adequate to

1. satisfy the BOD of the waste
2. satisfy endogenous respiration
3. Satisfy nitrification Oxygen demands
4. provide adequate mixing
5. maintain a minimum DO of 1 to 2 mg/L throughout the aeration tank.

Oxygen Transfer

Section 5-11 Text page 425 introduces oxygen transfer to water.

The SOTE (standard oxygen transfer efficiency) is determined by analyzing data collected during reaeration of a water using the aeration device of choice. The K_La values are determined at each measurement point and used to determine SOTE after conversion to standard conditions, which are tap water, 68°F, at 14.7 $lb._f/in^2$, initial dissolved $O_2 = 0$. This value will increase with depth of the reactor. For oxygen transfer in a wastewater one must also include the uptake of the bacteria as well so the K_La can be determined as:

$$K_L a = \left(\frac{r_m}{C_S - C} \right)$$

The oxygen transfer rate is a function of temperature, intensity of mixing, and constituents of the water.

Aeration Methods:

1. Submerged
2. Surface

Table 5-25 (overhead) lists commonly used devices/

1. Submerged

a) diffused-air aeration Table 5-26 (overhead)

blowers take in air through filter and blow through piping systems to diffusers submerged in the reactor.

diffusers - porous or fine pore
- non porous

porous,
figure 5-56 (Overhead)
costly to install and difficult to maintain
Must filter air so diffusers don't get clogged with grit and dust
Better aeration efficiency

non-porous.
Figure 5-59 (Overhead)
Lower aeration efficiency, lower cost, less maintenance. don't have to filter air

Other aerators:
jet, many versions (Figure 5-60), U-tube (figure 5-61) good transfer because of pressures at great depth, good for high strength wastes.

Performance (Table 5-27) Overhead.

Fouling - decrease in efficiency due to pore plugging and/or biological growth on diffusers relates to how often maintenance must be performed.

Blowers - how the air gets in the pipes
Centrifugal - capacity >15,000 ft^3/min of free air, not too good below this
rotary lobe displacement - high pressure, capacity < 15000 ft^3/min.
inlet guide vane variable diffuser – version of centrifugal that can accommodate capacity between 3,000 to 60,000 ft^3/min. High initial cost and sophisticated computer control are disadvantages.

Mechanical aerators

1. vertical axis - impellers mounted on floats or fixed. Agitate water, thus entraining air. (Figures 5-65, 5-66)
2. horizontal axis - brushes rotated horizontally over the surface, or disks (Figure 5-67).

When these are on the surface they mix the water with air thus entrapping the atmospheric air.
When submerged they disperse air bubbles pumped down to them into the water.

O_2.supply

1. Atmospheric Oxygen from air.
2. High purity oxygen
    a) pressure swing adsorption
    b) cryogenic air separation
3. Dissolution of commercial oxygen
    a) down flow bubble contactor
    b) U-tube contactor
    c) conventional diffused aeration

Aeration Tanks (Section 8-7)

This is the reactor where the aeration will take place. Usually are rectangular for space considerations but I have seen round ones (CFSTR or SBR only). You would usually design at least two tanks to allow for redundancy and down time of one tank.

Tank depth should be 15-25 ft with an additional 1 to 2 ft above the water. The width to depth should be around 1.5/1 and for plug flow regimes the length of the channels should be at least 5 times the width. The diffuser spacing must be designed to avoid any dead spots (places where inadequate mixing would be achieved).

Settling of Activated Sludge

This Material is from Chapter 5, and 8 of your text.

Sedimentation – the process of separation of solids from water using gravity.

Four types of settling occur in sedimentation basin

1. discrete particle settling (only for larger particles)
2. flocculant settling
3. Zone settling
4. Compression settling

1. discrete particle settling

This occurs in waters with relatively low concentrations of large particles. They settle as individual particles and do not have any significant interaction with each other.

2. Flocculant settling

The particles are present as a dilute suspension and coalesce to form larger particles with an increased mass. The particles then settle faster.

3. Zone or Hindered settling

The particles are present in suspension in intermediate concentrations. Interparticulate forces are important. These forces increase the hindrance of settling for neighboring particles. The result is that the mass usually settles as a unit. This settling results in the appearance of a solid liquid interface at the top.

4. Compression settling

The solids are now present in high concentration and the mass becomes structured. Only the compression of the structure will allow further settling.

Only zone and compressive settling are important in applications of settling for activated sludge. The flocs are usually concentrated enough that the first two types of settling do not play important roles.

Design of sedimentation basins is based on the analysis of settling data from single batch tests or using the solids flux method.

The control of the RAS is very important

pumps - should have the capability to pump 50 - 100% of the wastewater flow rate (150 for small plants)

<u>flow rate calculation</u>s

1) settleability
    - RAS pumping rate is set to the percentage ratio of the volume occupied by the settleable solids from the aeration tank to the volume of the clarified liquid
    - e.g. 275 mL settleable solids in 1L = 275/725 = 38% therefore want to return 38% of total flow.
    - never go less than 15%

2)sludge-blanket control level
    - maintain optimum blanket of sludge in clarifiers
    - based on experience (0.3 to 0.9 m)
    - requires considerable operator attention

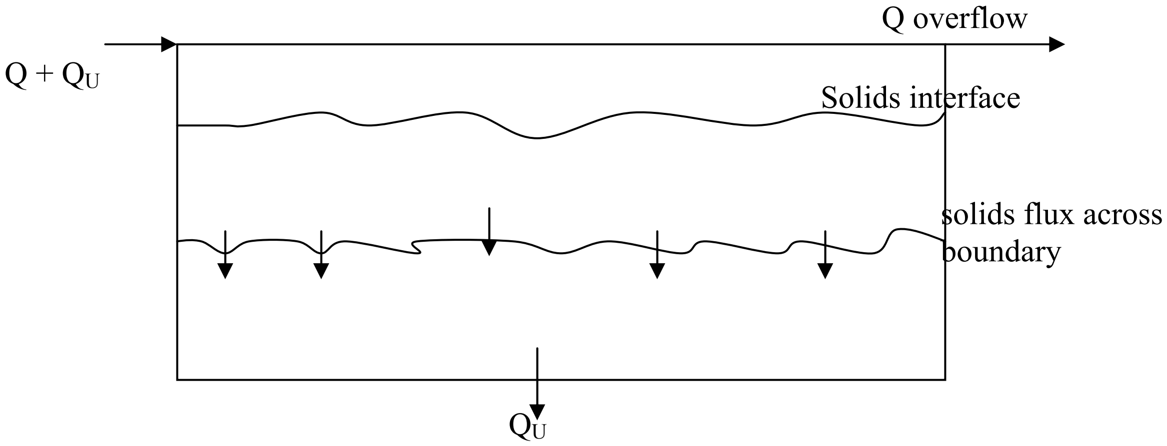
3) secondary clarifier mass balance (solids in must = solids out)
    - difference in concentrations accounts for differences in volumes or pumping rates

4) aeration tank mass balance
    - return enough solids to maintain constant concentration in aeration tank.

5) sludge quality
    - sludge settleability curves are generated and used as guidelines to determine return rates

Clarifier Area requirement based on solids flux analysis

There is a constant flux of solids down the sedimentation basin caused by gravity settling and transport out of the clarifier.



SF_x = solids flux due to gravity

$SF_g = kC_iV_i$

$k = 1/16030$
C_i = solids concentration at point in question
V_i = settling velocity at concentration C_i
$SF_U = kC_iU_b$
U_b = bulk downward velocity

$SF_T = SF_g + SF_U = k(C_iV_i + C_iU_b)$

Procedures
Develop a solids flux settling curve (overhead Figure 6.17)
    this is very similar to a microbial kinetic analysis
    Take the initial slope as the velocity for the settling of different concentrations of solids.
    Calculate V_iC_i plot vs C_1. This is solids flux due to gravity.
U_b =line with a slope that is a linear function of concentration

Total flux = Sum of these lines. (Overhead figure 6.18)
You will notice that an increase or decrease in the flow rate of the underflow will shift the total flux curve up or down.

Determination of area:

Two ways
One (Figure 8-36)
Draw a horizontal line tangent to the lowest point on the curve. The intersection of this with the y axis is the limiting flux (SF_L).
C_U = Underflow concentration at limiting flux. Drop a line from where the SF_L line crosses underflow line.

To make a thicker sludge reduce the slope of underflow flux, this reduces SF_L and increases area.

Two:
Figure 8-37
Draw line tangent to gravity flux curve passing through desired C_U
To make a thicker sludge choose a new C_U and draw a new line from C_U tangent to flux curve to Y axis – gives new SF_L

$$A = \frac{(Q + Q_U)C_o}{SF_L} \text{ x } 8.34 = \frac{(1+\alpha)QC_o}{SF_L} \text{ x } 8.34$$

$\alpha = Q_U/Q$
Q = flow over weir

See example 8-11. (overhead)

Typical Design Information for 2° Clarifier.

Table 10-12 in text.

	Overflow	Soilds	Depth
Activated sludge	400-800 gal/ft^2 d	0.8 – 1.2 lb/ft^2 h	12-20 ft

Extended aeration – more of the solids are removed so there is poorer settling. Need lower overflow rates for the same amount of water. Therefore a larger clarifier is required.

Solids Separation Facilities

- Circular or Rectangular tanks
- Circular
  - 3-60 m diameter more commonly 10-40 m
  - radius should not exceed 5x the sidewater depth
  - center feed or sidewall feed
  - sludge removal by rotating a scraper on the bottom, directs sludge either to a central hopper or through suction orifices along the tank bottom.
- Rectangular
  - Not as common due to problems of corners.
  - Maximum length not to exceed 10 x depth
  - Width 20 to 80 ft. (6 to 24 m)
  - Sludge collected with
    - traveling flights – a chain mechanism with buckets that scrape the bottom
    - traveling bridge – scraper or suction supported by overhead bridge
- Trays, tubes and lamella
  - More modern ways to clarify, they cost more $$ but take less land.
  - They are used where using conventional systems is a problem usually due to space.
  - They are often added in retrofits when a plant must be expanded.

ATTACHED GROWTH PROCESSES

General

Attached growth processes employ the use of stationary phases or media, which are very porous and allow the organisms a solid to attach to. The liquid waste flows over the media (trickling filter, packed columns) or the media turns through the wastewater (RBC) the organics bind to the cell mass and are metabolized. Excess growth is sloughed off and collected as sludge.

the main advantage of these is there is no need for aeration.

Trickling filter

General

Picture (Figure 9-1) mine overhead is a little different
bed of highly permeable medium
Aeration is supplied by allowing air to percolate through pore spaces in the medium
wastewater is distributed over filter material by a rotary distributor
under drain collects filtered water and sloughed sludge, this goes to clarifier, where the sludge settles out.
a portion of the liquid is returned to the filter to mix with the incoming wastewater, to act as a diluent and to keep up the necessary liquid content to keep the biofilm alive.

Microbiology

The usual types of aerobic bacteria, plus facultative bacteria. Algae will grow on the surface, and troublesome filamentous organisms in the lower parts of the filter where nutrients might become limiting.

Worms are very often a problem, but most filters that are subject to worms have a population of birds (land or sea gulls) that live off the biomass at the surface. These birds are not discouraged since they keep the worms, flies, snails etc. under control. The worms, flies, snails etc., help to keep the bacterial population on the surface low and constantly growing.

Process Models (Section 7-7)

The modeling of biofilms is still a very heated debate. The conceptual idea is that there is a thin film of microorganisms on the surface of the media, this film of microorganisms is kept moist by a film of water that should always be present on the surface of the biological film. (Figure 7-16). The waste water flows down through the filter on the surface of the biofilm. The soluble substrates must diffuse through the water layer into the biofilm before they can be acted on.

All models assume that all of the activity is occurring in the biofilm layer, and none in the sloughed organisms that are traveling with the wastewater flow down into the drains. I am not confident that this is the case. It makes it easier to model, but is probably not true. The conceptual models and mass flux equations are presented in the text, but we will deal more with design parameters than the conceptual models.

Filter Classification

Filters are classified by their Hydraulic or organic loading rates. These divide filters into classification as listed in Table 9-1 (overhead):

1) low rate
    - use rock or slag as media
    - dependable, simple, consistent
    - usually 6-8 ft. deep
    - don't usually use recirculation
    - use suction level pumps or dosing to give intermittent flow
    - top 2-4 feet is where the biofilm (slime) grows
    - provides good BOD removal and Nitrification
    - can use gravity flow
    - most have odors and flies (see note about birds)

2) intermediate and high rate
    - use rock or slag as media
    - use recirculation to allow higher organic loading
    - can use many recirculation schemes
    - flow is continuos
    - recirculation allows return of biological population and dilutes incoming waste so the filter doesn't get overgrown on top and form a pond
    - not as much odor or fly problems with these

3) super high rate
    - much higher organic loading
    - built as tall towers,
    - plastic media used so it won't be too heavy for base

4) Roughing
    - usually use plastic media and are usually a pretreatment to another secondary treatment process because they are run so fast they have poor BOD removal efficiency

5) Two stage
    - used for high strength wastewater or when nitrification is required
    - have two filters with a clarifier in the middle(most times) to remove solids from the first.
    - the first is usually for carbonaceous BOD removal
    - the second is usually for polishing carbonaceous BOD and removing NH_4^+ (nitrification)

Filter Media

want low cost, high SA/Vol, durable, does not clog easily.

Fig. 9-3 (overhead) has some pictures
Table 9-2 (overhead) has some physical properties of packing material.

Dosing

Need to have uniform growth and sloughing so must control the amount of water put on the filter
The dosing rate is the amount of water applied with each rotation of the distributor, and is calculated as inches per pass.
The required rate can be approximated by multiplying the organic loading rate (lb $BOD_5/1000ft^3$ by 0.12.
The rates are achieved by adjusting the speed of the distributor to meet the flow requirements.
equation

$$n = \frac{(1+R)(Q)(10^3\,mm/m)}{(A)(DR)(60\,\text{min/hr})}$$

where
n = rotational speed of distributor (rev/min)
Q = influent hydraulic loading rate (m^3/m^2 h)
R = recycle ratio
A = number of arms in rotary distributor assembly
DR = dosing rate (mm/pass)

Table 9-3 has some dosing rates that should be used for different BOD loading factors.

Distribution Systems

Rotary distributor is standard because of reliability and ease of maintenance
Two or more hollow tubes (or arms) with nozzles
Rotates horizontally over the filter bed.
Diameters of arms of larger units are tapered to maintain transport velocity
Nozzles are concentrated more towards the ends to allow greater flow per unit length at the periphery
Materials should be chosen for ease of cleaning, resistance to corrosion, ruggedness, and the ability to handle flow variations while maintaining a good rotational speed.
Very long arms have support wires hooked to a post in the middle for structural support
Can be driven by flow dynamics or a motor
Should have 6-9 inches of clearance above the bed.

Fixed distributors can also be used. (Figure 9-4) overhead.

Under Drains

vitrified clay or fiberglass grating on a reinforced concrete sub floor. Must be strong enough to support the media, biomass, and waste water.
slopes (1 to 5% grade) to central channel where effluent is collected
drain channels should provide 2 ft/s velocity at average flow rate
should be open at both ends to allow ease of inspection and flushing

also serve as ventilation chamber so must be open to air around the circumference Figures 9-5 and 9-6 show details. My overheads have the old edition figure numbers.

Air flow

depends on natural factors, wind and natural draft

Natural draft

temperature difference between ambient air and the air inside the pores.

For cold waste water, pore air will be colder than ambient air so the natural draft is downward and the well oxygenated air enters at the top.

For times when waste water is warmer than air, the draft will be upward, not as favorable but better than no draft at all.

Calculation

$$D_{air} = 353\left(\frac{1}{T_c} - \frac{1}{T_h}\right)Z$$

D_{air} = natural air draft, mm of water
T_c = cold temperature, °K
T_h = hot temperature, °K
Z = height of filter (m)

The log-mean temperature is used as a conservative estimate of average pore air temperature.

$$T_m = \frac{T_2 - T_1}{\ln(T_2 / T_1)}$$

Where T_1 is the warmer temperature and T_2 is the colder temperature in °K.

Precautions to ensure that natural draft will suffice to supply air.

1. never fill underdrains more than 1/2 full
2. have open grated venting manholes at both ends of the central collection channels
3. branch collecting channels with vent stacks at the periphery should be used for large diameter filters
4. open area of slots in the top of the underdrain blocks should not be less than 15% of the filter.
5. 1 ft^2 gross area of open grating in manholes and vent stacks should be provided for each 250 ft^2 of filter area..

Tower filters may require forced air aeration. Should provide 1 ft^3/ft^2 min in each direction (up and down)

See example 9-1 as an example of airflow requirement calculations.

Settling Tanks

Only for clarification, no RAS line, design similar to those for suspended phase treamten but can usually be a little smaller because there are less solids that settle well and compression settling is not necessary, although reducing the volume of sludge due to compressive settling is always a benefit.

Trickling Filter Design

The design of trickling filters is performed based on loading criteria developed form previous experience or on pilot plant studies.

Capacities

Filter type	Flow (Mgal/acre d)	Loading (lb BOD/1000 ft^3 d)
low rate filters	4	25
intermediate rate	10	30
high rate	40	60
super high rate	90	100
Roughing	200	500

low rate filters have the best removal efficiencies (~90%) while roughing have the worst (~65%)

Table 9-5 (overhead) lists some more general capacities for removing both BOD and nitrogen

Example 9-2 gives an example loading calculation

Rock

There are no universal equations that can be used for low rate filter design and sizing, but the NRC equation, which has been formulated from observation of trickling filter operation can be applied to single- and multi-stage rock systems, with varying recirculation rates.

$$E = \frac{100}{1 + 0.4432\sqrt{\frac{W}{VF}}}$$

Where

E = efficiency of BOD removal at 20°C, including recirculation and sedimentation (%)

W = BOD loading rate to filter (kg/day)

V = volume of filter media m^3

F = recirculation factor

F is calculated as follows

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

where

R= recirculation ratio (Q_r/Q)

For a second stage filter, the equation is modified to remove the waste degraded in the first stage

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

Where

E_2 = efficiency of BOD removal for second stage filter at 20°C, including recirculation and settling (%)

E_1 = fraction of BOD removed in first stage filter

W' = BOD loading applied to second stage filter (kg/day)

Temperature factors can be accounted for by using the same equation that we have always used, with $\theta = 10.35$

Example 9-3 (overhead) goes through an example calculation.

Plastic

A number of useful equations have been developed for plastic media, your book provides two. I will go over the Germain modification of the Schulze equation.

$$\frac{S_e}{S_o} = \exp[-kD/q^n]$$

Where

k = observed reaction rate constant for a given depth of filter (pilot plant studies) ($(L/s)^{0.5}/m^2$ id n=0.5)

D = filter depth (m)

S_e = BOD concentration of settled filter effluent

S_o = influent BOD concentration

q = hydraulic application rate of primary effluent exclusive of recirculation L/m^2 s (Q/A)

n = empirical constant characteristic of packing material.

The k must be corrected for temperature changes using θ of 1.035 and for differences of depth and substrate concentration using the following

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

where

D_1 and D_2 are the pilot plant and final depths, S_1 = 150g BOD/m^3 S_2 = site specific influent BOD conc. (g/m^3).

Pilot plant studies are almost always required because the coefficients are so dependent on local conditions.

Table 9-6 presents some normalized Germain k values, which range from .059 (refinery) to .351 (potato)

Example 9-4 applies this to removal of BOD only.

Example 9-5 applies this to removal of BOD and nitrate

Example 9-6 goes through design for nitrogen removal alone.

Typical Design Values

overhead from old text

Rotating Biological Contactors

General

Series of closely spaced disks of polystyrene or PVC submerged in wastewater and rotated slowly through it and out into the air and back into the wastewater. Microbial growth attaches to the disks and forms a biofilm on it. The rotation serves to aerate the biofilm, shear off excess cells and keep them in suspension so they can be carried into the clarifier.

Used mostly for CBOD removal but can be operated for nutrient removal

Designed on the basis of Pilot plant loading factors

Reliable

Withstands hydraulic and organic surges

Figure 9-11

Usually use staged series of reactors (Figure 9-12)

Shafts are about 3.5 m (12 ft) in diameter and 7.5 m in length (25 ft). The surface area for a standard density shaft is about 9300 m^2, but higher density shafts (up to 13,900 m^2) can be obtained. The media is typically 40% submerged.

Driven by mechanical, air, or the flow of the water

Shafts can be placed parallel (small systems) of perpendicular to flow (large systems).

Tanks should provide 0.005 m^3/m^2 of medium (0.12 gal/ft^2 of medium) optimal

therefore for initial stage 45 m^3 (12,000 gal) for 9,800 m^2 shaft, provides a hydraulic loading of 0.08 m^3/m^2 d (2 $gal/ft^2 \cdot d$), therefore have a detention time of 1.4 h.

usually have 40% submergence using a 1.5 m (5 ft) deep vessel.

Are usually enclosed to keep out the sun and bad temperatures.

The clarifiers are designed similary to those for trickling filters, i.e. there is no requirement for return sludge and the biosolids settle faster.

As mentioned for trickling filters, we still do not have a really good model yet, so the design is based on loading factors etc. There is one equation that has been developed that can be used to estimate BOD removal in each stage.

$$S_n = \frac{1-\sqrt{1+(4)(0.00974)(A_S/Q)S_{n-1}}}{(2)(0.00974)(A_S/Q)}$$ equation 9-27 in text.

Design Parameters

Table 9-8 (overhead) in text has typical design criteria that can be used for preliminary design .

Table 9-9 (overhead) provides a procedure for computational steps in the design and Example 9-7 (overhead) provides an example design.

The design parameters are usually derived from experience since there is not a readily acceptable model for fixed film growth yet.

Pilot scale tests should be performed on the wastewater in question in order to achieve the most optimal design.

The media design is based on the annual average design values unless variations are expected. Always check design to see if it can handle peaks.

Problems

Mechanical failures.

Excessive organic loading may cause overgrowth on the media and the shaft may collapse due to too much weight.

Media Breakage - the media is sensitive to heat and solvents, and does not withstand too much physical stress, i.e. when the axle breaks and the media falls it is usually destroyed.

Many of these problems occurred early in the implementation of the process and have since then been engineered out, mostly by improvements in materials for construction.