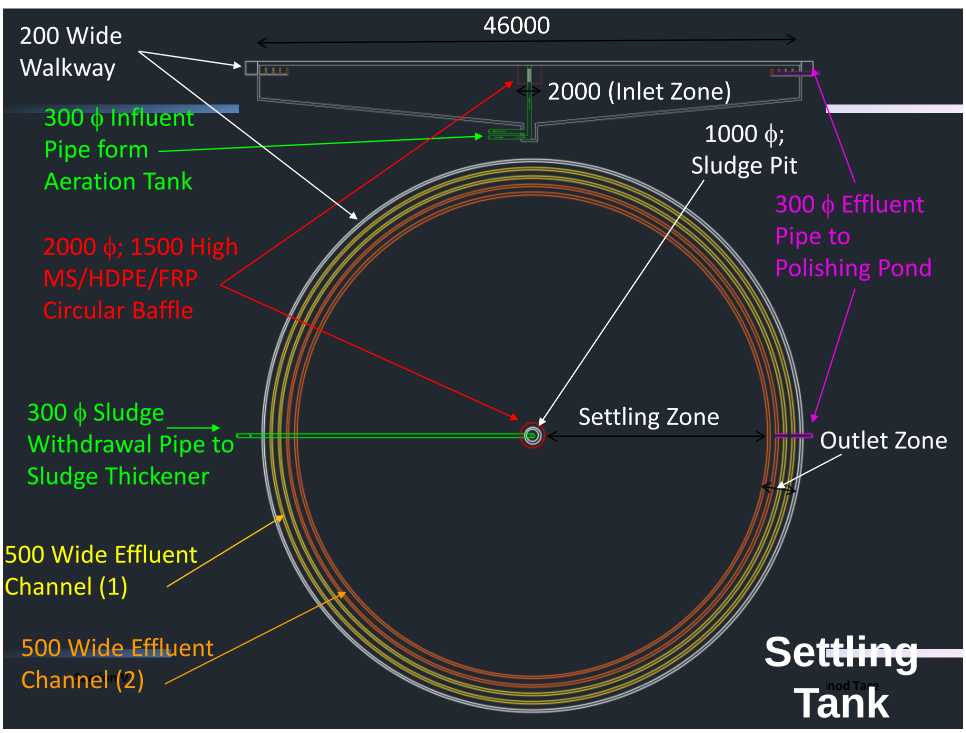
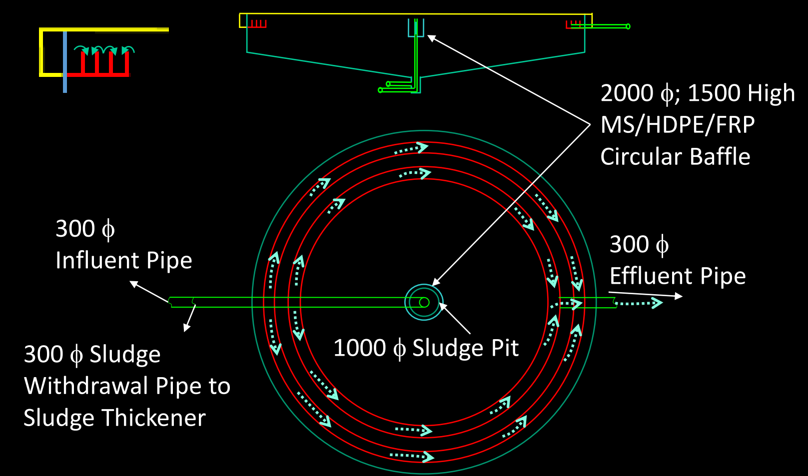

CE412A:
2022-23 II
Design of Water Treatment &
Waste Disposal Systems
Instructor : Dr Vinod Tare,
Emeritus Professor, IIT Kanpur
Rivers
Pipes and pumps
Urban
Sewage treatment plant
Crops Irrigation
ural
Sediment


46000
200 Wide Walkway
2000 (Inlet Zone)
300 ϕ Influent Pipe form Aeration Tank
1000 ϕ; Sludge Pit
300 ϕ Effluent Pipe to Polishing Pond
2000 ϕ; 1500 High MS/HDPE/FRP Circular Baffle
300 ϕ Sludge Withdrawal Pipe to Sludge Thickener
Settling Zone
Outlet Zone
500 Wide Effluent Channel (1)
500 Wide Effluent Channel (2)
Settling Tank

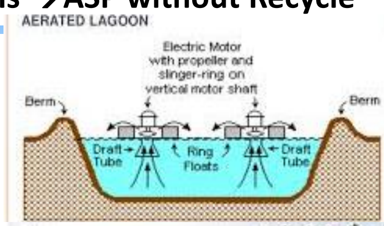


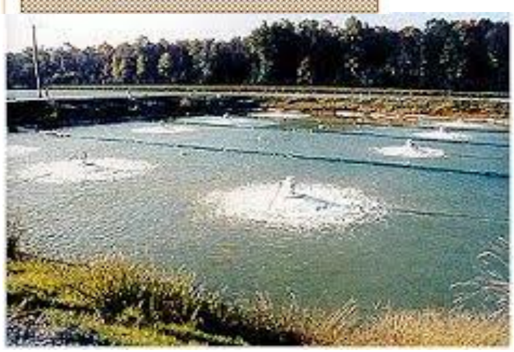
Settling Tank

ASP Variants: Aerated Lagoons →ASP without Recycle

Aerated lagoon:

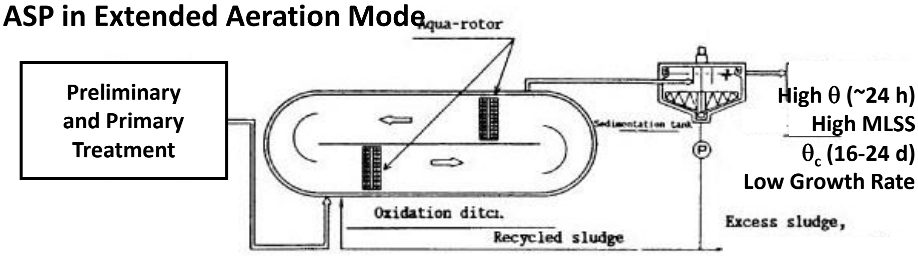
- High F/M Ratio → Low θ_c →High Growth Rate
- Poor Flocculation → Poor Settling → Poor Effluent Quality
- Higher Biomass Production → Higher Nutrient Requirement/Higher N & P Removal





ASP Variants: Oxidation Ditch → ASP with high Recycle

ASP in Extended Aeration Mode



Pond Systems → Following Natural Processes for Wastewater Management

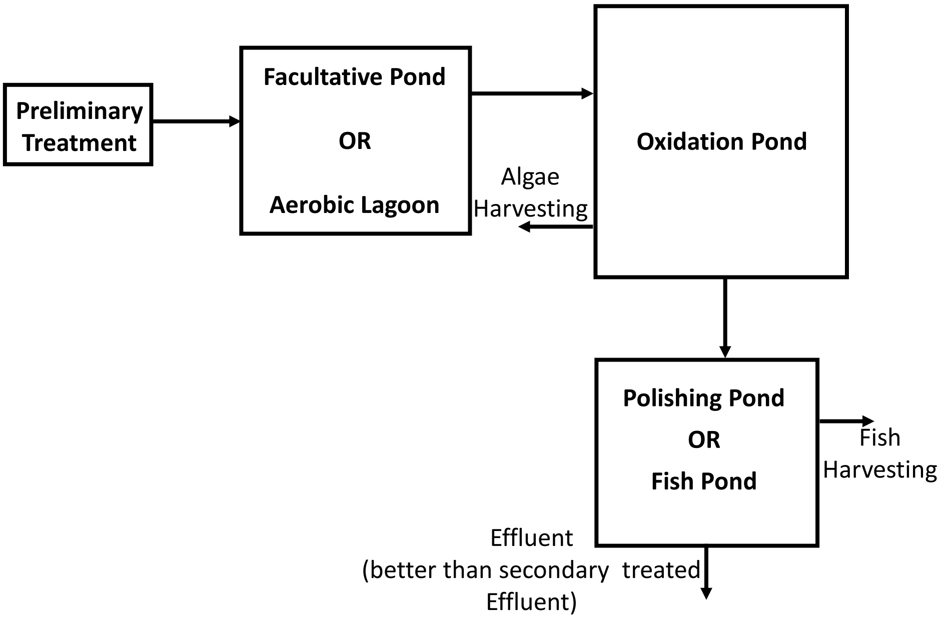
These treatment technologies try to mimic BOD and nutrient removal processes in nature. When properly designed and operated, such treatment methods can produce treated effluent similar to secondary treated effluent in other engineered systems. In some cases, the effluent quality is even better, i.e., closer to that produced by tertiary treatment in engineered systems. However, such treatment processes require large land area and hence are only feasible in places where relatively cheap land is available, i.e., in rural areas.

Pond Systems for Wastewater Treatment

Sewage after preliminary treatment is passed through a series of ponds for treatment. Various types of ponds are possible,

1. Anaerobic Ponds
2. Facultative Ponds
3. Oxidation Ponds
4. Polishing Ponds
5. Fish Pond

Pond Systems for Wastewater Treatment



Pond Systems for Wastewater Treatment

Facultative Pond: Deep Pond (3-4 m). Solids settle to the bottom and are degraded anaerobically. Top part of the pond is aerobic due to algal photosynthesis. Some aerobic biodegradation of BOD takes place on the top part. Hydraulic retention time is ~ 2 days.

Aerobic Lagoon: Natural aeration in a facultative pond may be enhanced through the provision of surface aerators. Such a system is known as an Aerobic Lagoon. Hydraulic retention time is ~ 12-24 hours.

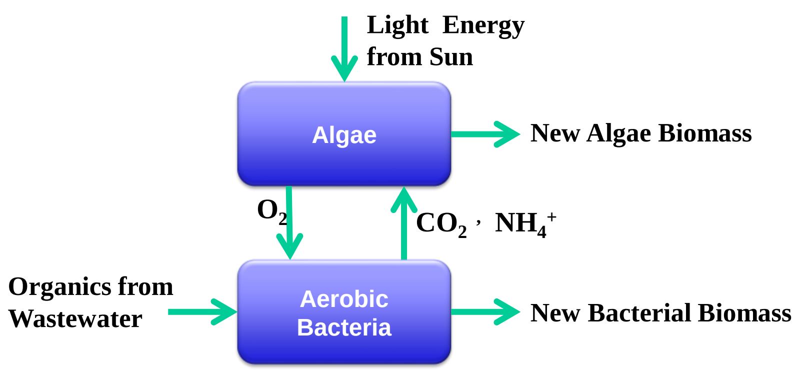
Oxidation Pond: Shallow Pond (< 1 m deep). Completely aerobic. Oxygen provided for aerobic biodegradation of BOD through algal photosynthesis. Both BOD and nutrient removal occur. Hydraulic retention time is ~ 4-5 days.

Polishing Pond: Shallow Pond. Completely aerobic. Fish cultivation with algae and bacteria as fish food. Fish harvesting is possible. Hydraulic retention time is ~ 1-2 days.

Treated Effluent: Treated effluent is low in both BOD and nutrients, but may contain some suspended particulate matter.

Oxidation Pond

Algae/Bacteria Symbiotic Relationship in an Aerobic Pond



Oxidation Pond

$$\boldsymbol{hW_a = ES_RA} \quad \textbf{Eq 01}$$

$h = unit\ heat\ of\ combustion\ of\ algae\ cells, \frac{cal}{g}$
$W_a = algal\ biomass\ produced, g/day$
$E = efficiency\ of\ energy\ conversion, fraction$
$S_R = solar\ radiation\ incident\ on\ the\ pond\ surface, \frac{cal}{cm^2} - day, or\ langleys$
$A = surface\ area\ of\ pond, cm^2$

Oxygen production and algal growth are related by the expression

$$\boldsymbol{W_{O_2} = pW_a} \quad \textbf{Eq 02}$$

$W_{O_2} = oxygen\ production\ as\ a\ result\ of\ photosynthesis, g/day$
$p = oxygenation\ factor\ representing$
$the\ oxygen\ produced\ per\ day\ per\ unit\ of\ biomass\ synthesized$

An expression for the surface area of the pond can be obtained by substituting from Equation 02 for the $\boldsymbol{W_a}$ term in Equation 01 and solving for *A*.

$$\boldsymbol{A = \frac{hW_{O_2}}{pES_R}} \quad \textbf{Eq 03}$$

The unit heat of combustion of algal cells is a variable term since it depends upon cell composition which is affected by numerous environmental factors. Oswald and Gotaas (1957) related the heat content of algal cells to an R-value:

Oxidation Pond

$$\boldsymbol{R = (100)\frac{(\%carbon)(2.66) + (\%hydrogen)(7.94) - (\%oxygen)}{398.9}} \quad \textbf{Eq 04}$$

Jewell and McCarty (1968) and Foree and McCarty (1968) have reported mean, minimum, maximum values for the major elements found algae cells. These values, expressed in percentage ash-free dry weight are: carbon, 53, 42.9,70.2; hydrogen, 8,6.0,10.5; oxygen, 31, 17.8, 34.0; nitrogen 8, 0.6, 16.0; and phosphorus, 2.0, 0.16, 5.0. Growth conditions in the system affect each of these values.

$$\boldsymbol{aCO_2 + (05.b - 1.5d)H_2O + dNH_3 \rightarrow C_aH_bO_cN_d + (a + 0.25b - 0.75d - 0.5c)O_2} \quad \textbf{Eq 05}$$

$$\boldsymbol{7.6CO_2 + 2.5H_2O + NH_3 \rightarrow \underset{153.3}{C_{7.6}H_{8.1}O_{2.5}N} + \underset{(7.6 \times 32)}{7.60_2}} \quad \textbf{Eq 06}$$

The oxygenation factor depends on the composition of the algal biomass (organic Material) synthesized during the photosynthesis Process.

Oxidation Pond

As an example, Oswald and Gotaas (1957) assume that for a particular culture, the algae have the following cellular composition on an ash-free dry weight basis: 59.3% carbon, 5.24% hydrogen, 26.3% oxygen, and 9.1% nitrogen. The cell formula is determined by first dividing each percentage by the corresponding atomic weight. Therefore,

C = 59.3/12 = 4.94; H = 5.24/1 = 5.24; O = 26.3/16 = 1.64; N = 9.1/14 = 0.65

To avoid elemental fractions less than unity, each fraction is multiplied by 1.54 to increase the nitrogen fractional weight to 1.0.

C = (4.94)(1.54) = 7.6
H = (5.24)(1.54) = 8.1
O = (1.64)(1.54) = 2.5
N = (0.65)(1.54) = 1.0

The corresponding cellular structure is given by $C_{7.6}H_{8.1}O_{2.5}N$. Assuming that water, ammonia, and carbon dioxide are the sources of oxygen, nitrogen, and carbon, respectively, the overall photosynthetic process may be represented by the general expression

Oxidation Pond

Correction for elevation up to 10,000 ft:

$$(\boldsymbol{S_R})_{\boldsymbol{c}} = (\boldsymbol{S_R})_{\boldsymbol{min}} + \boldsymbol{r}[(\boldsymbol{S_R})_{\boldsymbol{max}} - (\boldsymbol{S_R})_{\boldsymbol{min}}] \quad \textbf{Eq 07}$$

$$(\boldsymbol{S_R})_{\boldsymbol{design}} = (\boldsymbol{S_R})_{\boldsymbol{c}}(\boldsymbol{1} + \boldsymbol{0.001e}) \quad \textbf{Eq 08}$$

$$\mathrm{f} = \frac{I_s}{I_0}\left[ln\left(\frac{I_0}{I_s}\right) + 1\right] \quad \textbf{Eq 09}$$

r → fraction of time the weather is clear = Uncloudy daylight hours/total daylight hours
e → elevation above see level in ft

$$where\ f = fraction\ of\ available\ light\ utilised$$
$$I_0 = light\ intensity\ at\ the\ pond\ surface$$
$$I_s = saturation\ intensity$$

$$(BOD_u)_r = \frac{32.808\ \ln(\frac{I_0}{24})}{d} \quad \textbf{Eq 10}$$

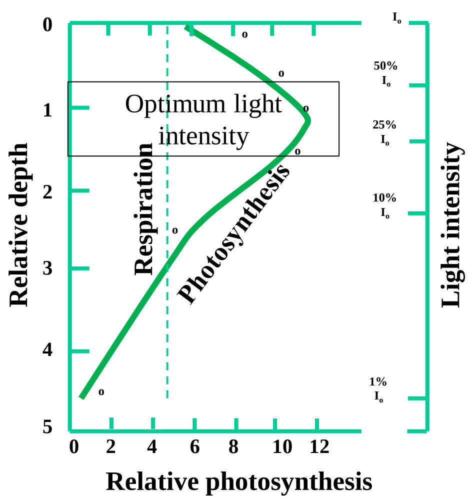
$where\ (BOD_u)_r = \text{ultimate BOD removed, mg/l}$
$\text{d} = \text{aerobic depth or depth of aerobic pond, ft}$
$I_0 = \text{light intensity at pond surface, ft} - \text{C}$

Oxidation Pond

North Latitude		Month																							
Degree	Range	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
		V	T	V	T	V	T	V	T	V	T	V	T	V	T	V	T	V	T	V	T	V	T	V	T
0	max																								
	min																								
2	max																								
	min																								
4	max																								
	min																								
6	max																								
	min																								
8	max																								
	min																								
10	max																								
	min																								
…	max																								
	min																								
…	max																								
	min																								
60	max																								
	min																								

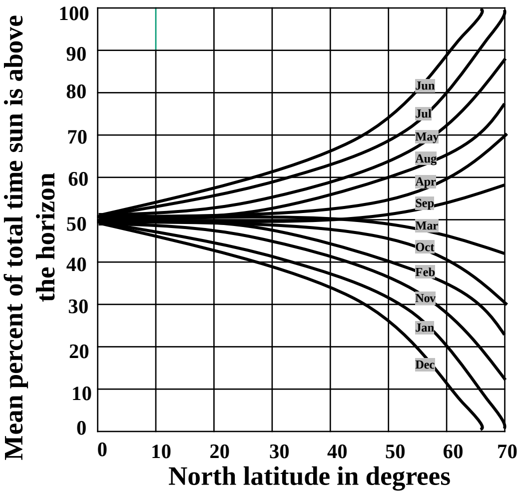
Oxidation Pond

Relative Photosynthesis from Surface to Depth of Penetration of 1% Surface Light **(After Bartsch, 1961)**



Oxidation Pond

Mean Percent of Total Time Sun is Above the Horizon at a Specified Latitude. (After Oswald and Gotaas, 1957)



Oxidation Pond

Design of an Oxidation Pond:
1 MLD of wastewater to be treated in an oxidation pond. The influent BOD_5 (S_o) in an oxidation pond is 80 mg/L. Desired effluent BOD_5 (S) is 5 mg/L.

For Oxidation Pond:
K = 0.1 L/mg/d, where K is the first order microbial substrate utilization rate ($K = q_m/K_s$), (i.e.., assuming K_s >> S)
Y_T = 0.5 mg/mg; K_d = 0.05 /d (based on BOD_5)

Formula for microbial biomass:	$C_{60}H_{87}O_{23}N_{12}P$
Average intensity of solar radiation:	150 calories/cm^2/d
Solar energy utilization efficiency for algae:	6 percent
Energy requirement of algal bio-mass:	6000 calories/g algae

Equation for algal photosynthesis:

$$106CO_2 + 16NO_3^- + HPO_4^{--} + 122H_2O + 18H^+ \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138O_2$$

Section V
CE412A
Design of Water Treatment and Waste Disposal Systems
Dr Vinod Tare

Oxidation Pond

Solution:
$q = K.S = 0.1.(5) = 0.5$ /d; $\mu = Y_T.*q - k_d = 0.5*0.5 – 0.05 = 0.20$ /d;
$\theta = \theta_c = 1/\mu = 1/0.2 = 5$ d
$X = (S_o – S)/(q.\theta) = (80 - 5)/(0.5)(5) = 30$ mg/L;
Sludge Production $(\Delta X) = Q.X = (1.0 * 10^6 /1000) * 30 (10^3/10^6) = 30$ kg/d

Oxygen Requirement = **1.5**$.Q.(S_o –S) - 1.42.(\Delta X) = 69.9$ kg/d; $V = \theta.Q = 5000$ m^3
Assuming depth = 0.5 m; Surface Area (A) = 10000 m^2
Algae Production = $(150).(10^4)(0.06)/6000 = 15$ g/m^2/d;
Total algae production = 150 kg/d

from, Photosynthesis Equation, 1.3 kg oxygen production / kg algae production
Oxygen Production = 1.3.(150) = 195 kg/d

Assuming 50 percent of the algal oxygen produced is available for microbial respiration, Oxygen available = 97.5 kg/d >> 69.9 kg/d (oxygen required)

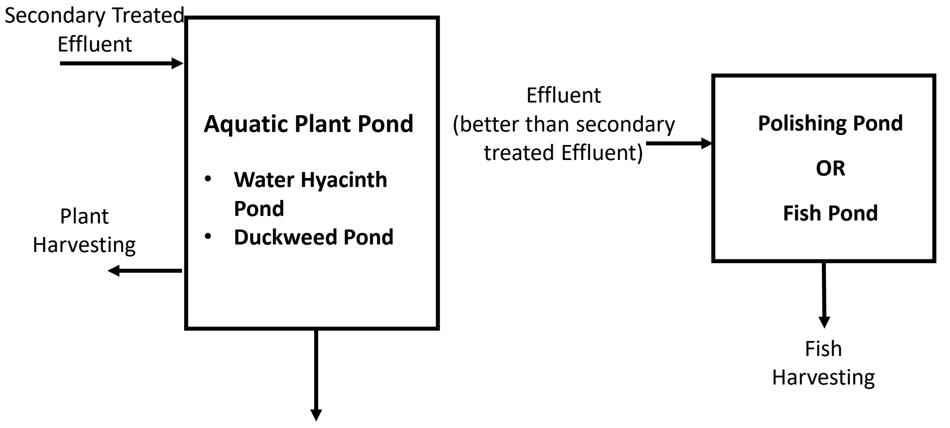
Aquatic Plant Ponds for Nutrient Removal

Aquatic Plant Pond:
Aquatic plants take nutrient from the water and carbon dioxide from air. They release oxygen directly into air. Hence DO levels are generally low in aquatic plant ponds. Such ponds are however, good for nutrient removal from water. Depth is generally 3-4 m. HRT is 1-2 days. Regular harvesting of plants is essential.

Polishing Pond:
Algal and bacterial action in this pond, along with the presence of fish result in removal of residual BOD, nutrients and solids for the effluent.

Effluent is almost equivalent to tertiary treated effluent from an engineered process. The effluent may still have some solids.

Aquatic Plant Ponds for Nutrient Removal



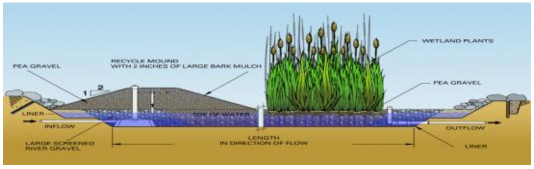
Constructed Wetlands

Sewage after preliminary treatment is allowed to flow through a constructed wetland. Various natural processes in the wetland, i.e., sedimentation, filtration, aerobic and anaerobic biodegradation, nitrification, denitrification, algal growth, etc. combine to treatment the influent sewage to almost tertiary level.

Constructed wetlands can be used as stand-alone treatment systems or in conjunction with pond systems (as a replacement for polishing ponds). Also, constructed wetlands may be used for tertiary treatment of secondary treated effluent, mainly for nutrients removal and filtration.

As with other natural treatment systems, the HRT (~ 5-10 days) is high requiring large land area.

Wetlands (Marshy Land/Areas) Constructed Wetlands

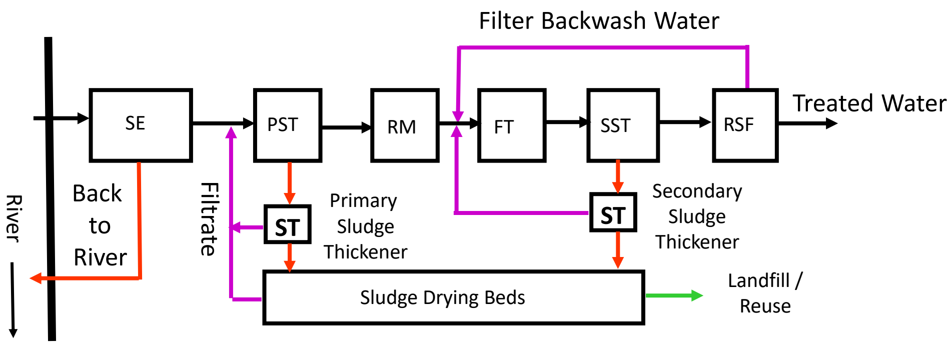


Subsurface Flow

Subsurface + Overland Flow

Actual picture of a constructed Wetland actually in Operation

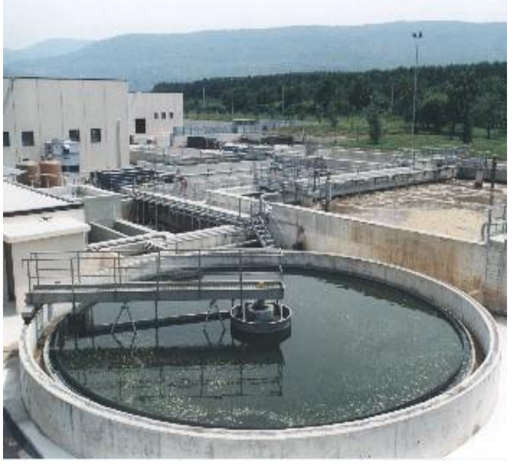
Sludge Management in Water Treatment



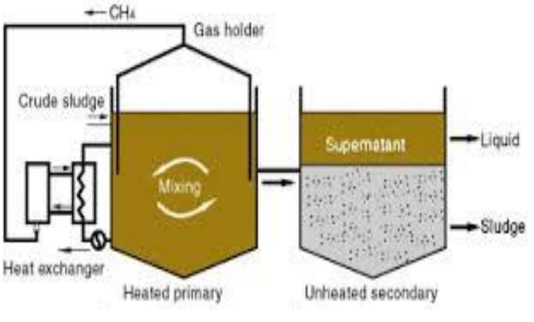
ST - Sludge Thickener

Similar to a sedimentation tank. Influent is either primary or secondary sludge (solids content 1-2 percent. Effluent is the thickened sludge (solids content ~ 4 percent).

Thickening occurs by Type IV settling, i.e., compression settling, where the mechanism of settling is the forcing out of water from the solids due to compressive force of solids on top.



Anaerobic Sludge Digestion



Anaerobic Sludge Digestion Process

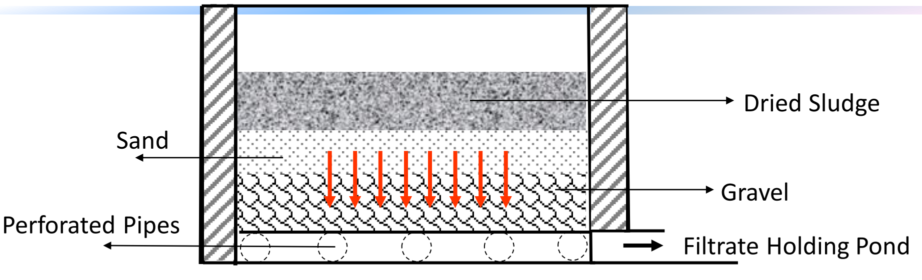
Gas Dome

Anaerobic Sludge Digestion

Anaerobic Sludge Digester

Gas Storage

Sludge Drying Beds



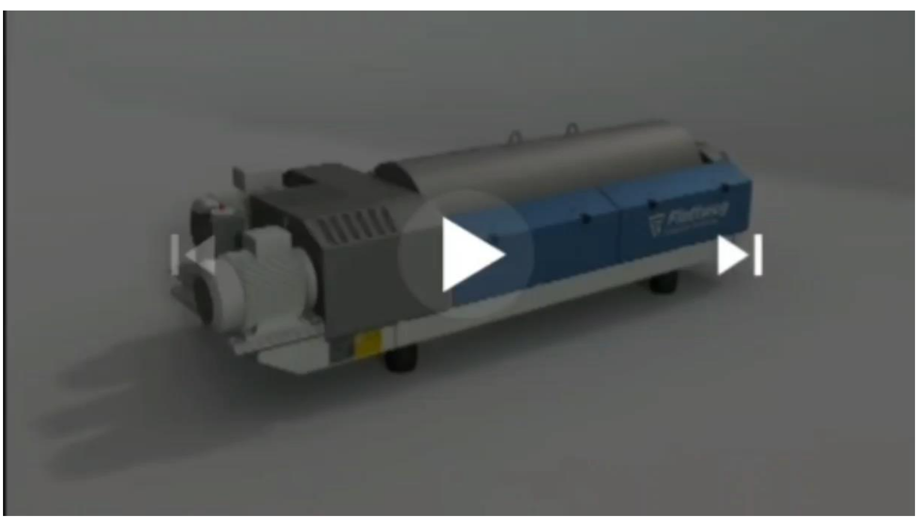
The solids content of the sludge influent to sludge drying bed = ~ 4 percent
Solids loading to sludge drying bed = 1.5 kg solids (dry basis) /m^2 / cycle
The solids content of the dried sludge is ~ 30 - 40 percent.
Drying time ~ 2 weeks
Dried primary sludge can be used for land application
Dried secondary sludge must be disposed in a land fill

Alternatives to Sludge Drying Beds: Centrifuge

Sludge Inlet

Feed and Polymer Inlet

Alternatives to Sludge Drying Beds: Centrifuge



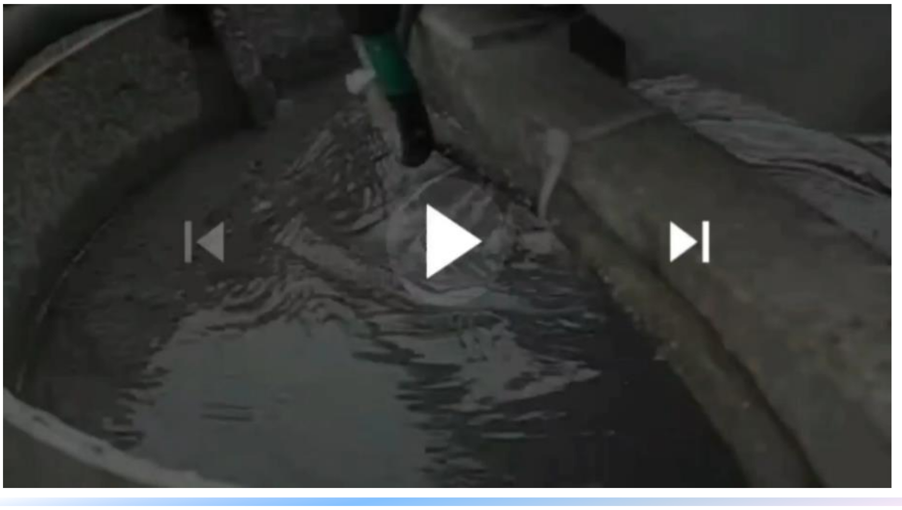
Alternatives to Sludge Drying Beds: Belt Filter Press

Actual Machine

Dewatered Sludge (~40 percent solids)

The sludge is put between two fabric filters and passed through rollers. Water in the sludge is squeezed out and the dried sludge is collected.

Alternatives to Sludge Drying Beds: Centrifuge



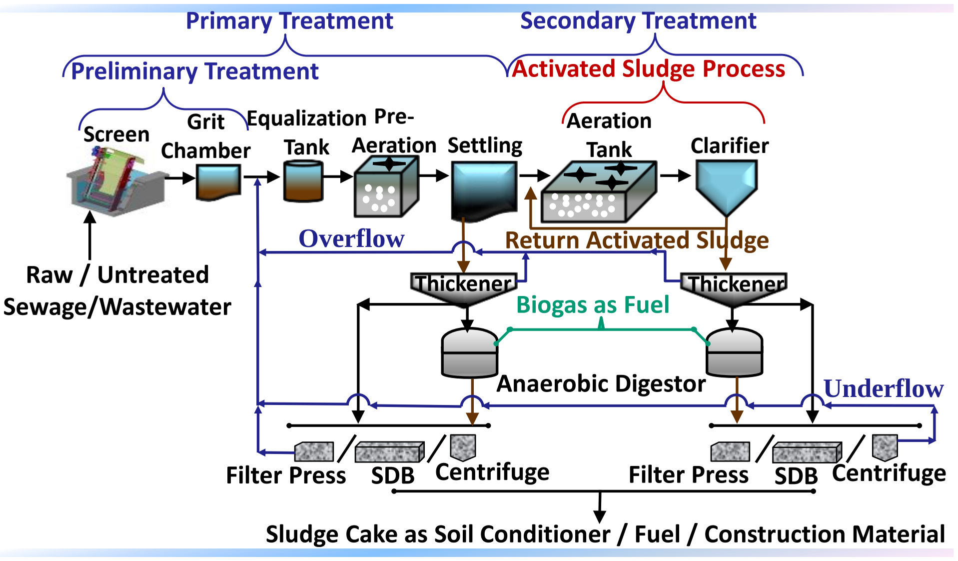
Sludge Management in Wastewater Treatment

SD: Anaerobic Sludge Digestion

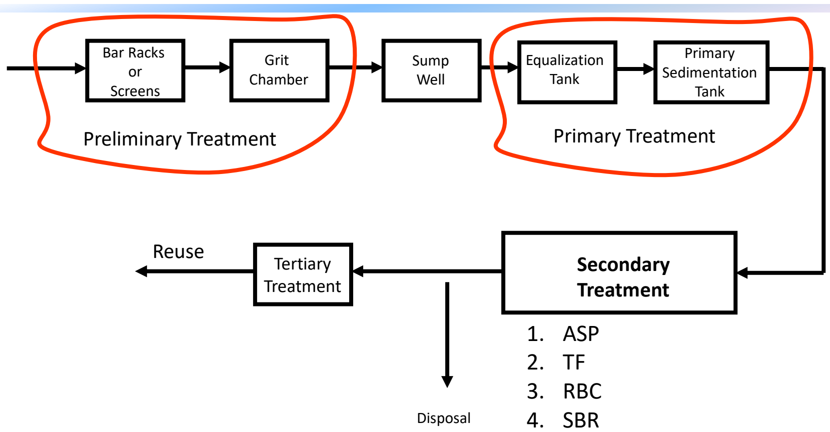
Anaerobic sludge digestion is useful only for organic sludge obtained (from PST and SST) during wastewater treatment. Anaerobic sludge digestion is a suspended growth anaerobic biodegradation process with no sludge recycle.

The objective is to reduce solids concentration in thickened sludge so that the load on sludge drying beds / centrifuge / belt filter press is reduced. The methane gas obtained as a product from the sludge digestion process may have economic value.

Sewage Treatment Plant (STP) Flow Sheet



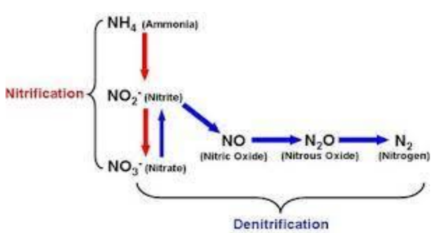
Tertiary Wastewater Treatment for Reuse/Recycling



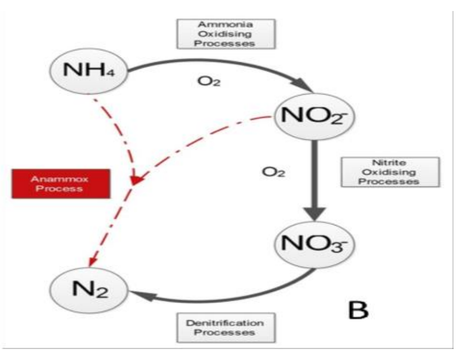
1. ASP
2. TF
3. RBC
4. SBR
5. MBBR
6. MBR
7. UASB + Polishing Treatment
8. Natural Systems (Ponds / Wetlands)

Tertiary Treatment of Sewage: Nitrogen Removal

Denitrification:



Anamox

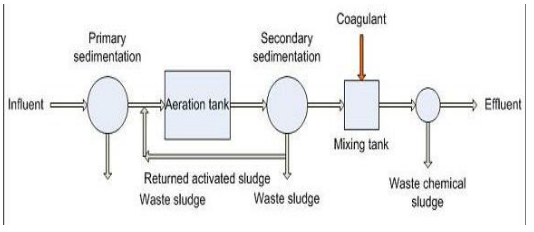


Algal Uptake:

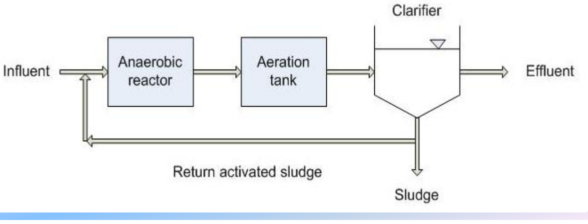
Algal growth is initiated in the effluent containing ammonia or nitrate leading to nitrogen uptake by incorporation into algal biomass.

Tertiary Treatment of Sewage: Phosphorus Removal Removal

Precipitation as Calcium Phosphate



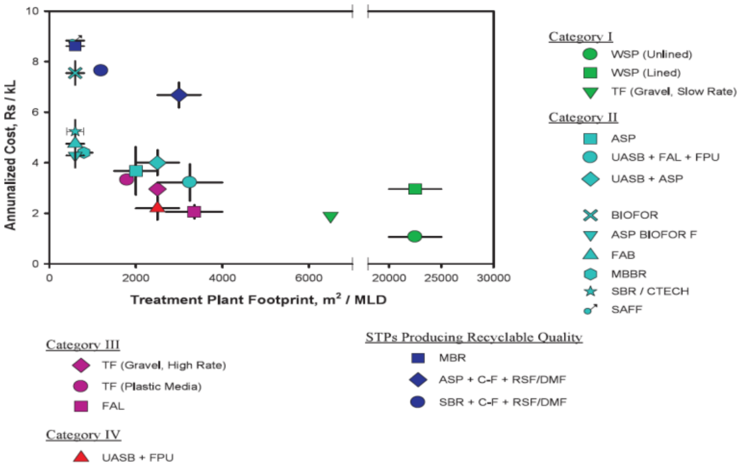
Biological Phosphate Removal



Tertiary Treatment of Sewage: Other Processes

1. Suspended Solids Removal
    a. Rapid Sand Filtration/Pressure Filtration
    b. Membrane Filtration: Microfiltration
2. Micro-pollutants Removal
    a. Ozonation/other Advanced Oxidation processes (AOPs)
    b. Activated Carbon Adsorption
3. Dissolved Inorganic Solids Removal
    a. Ion Exchange
    b. Reverse Osmosis
4. Disinfection
    a. Chlorination/other disinfectants
    b. UV disinfection

Treatment Cost vs Land Area Requirement



Annualized Cost (as in 2008) of Treatment and Corresponding Land Requirement for Various Technologies