Tema 7 – Lodos Activados
Activated Sludge

CI7115 – Biotecnología Ambiental

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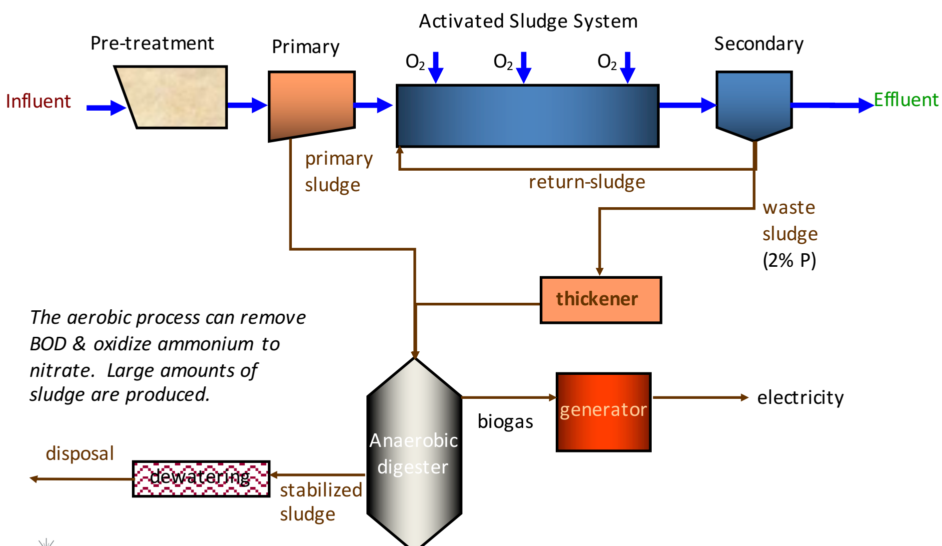
Tratamiento Convencional para ARes Municipal



The aerobic process can remove BOD & oxidize ammonium to nitrate. Large amounts of sludge are produced.

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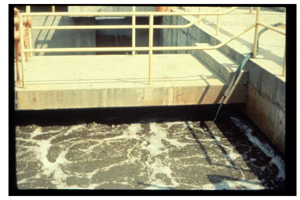
Lodos Activados

Aerobic dispersed growth treatment
Largest application of biotechnology in the world

Empty basin showing aeration manifold

Michigan, USA



Mixed liquor under aeration

Hyperion WWTP, Playa Del Rey, CA

For aquaculture

Consideraciones

- Nutrient and oxygen requirements
- Oxygen transfer and mixing
  - Diffused aeration/mixing vs mechanical aeration/mixing
- θ_x - Solids retention time (sludge age)
- Sludge settling and bulking
  - Recycle Ratio ($R = Q^r / Q^o$) (range: 0-3, typically <1)
  - Sludge Volume Index (SVI)
    - Volume occupied by one gram of SS after settling for 30 min (ml/gSS)
    - <50 (very good settling), 100 (typical), >200 (poor settling, bulking)

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Consideraciones

- <u>Volumetric loading</u>

  kg BOD or COD applied per day per volume of aeration tank (i.e., mass loading normalized to reactor volume) (e.g., kg BOD_5/m^3-d)

  Volumetric loading = $Q^{\circ}S^{\circ} / V$

- <u>Food-to-microorganism ratio (F/M)</u>

  kg BOD or COD applied per day per kg of <u>suspended solids</u> in the aeration tank (e.g., kg BOD_5/kg X_v-d)

  $F/M = Q^{\circ}S^{\circ} / VX$ (for TSS)

  $F/M_v = Q^{\circ}S^{\circ} / VX_v$ (for VSS)

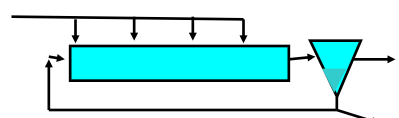
  See pp 324-326 in text

  Typical range: 0.25 to 0.5 kg BOD_5/kg X_v-d

Activated sludge process configurations

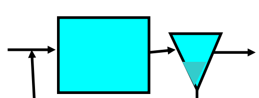
Plug-Flow (conventional) Activated Sludge

Advantage: High efficiency,
Disadvantages: uneven O_2 demand, Si>>Se, perhaps causing toxicity



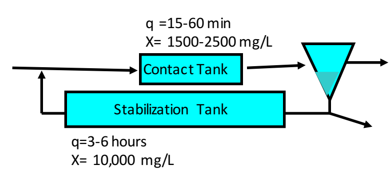
Step-Aeration Activated Sludge

Advantages: reduces max concentration in tank, evens out O_2 demand



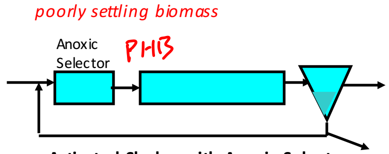
Complete-Mix Activated Sludge

Advantage: S<<S° for toxic wastes
Disadvantage: reduced efficiency, selects for poorly settling biomass



Contact-Stabilization Activated Sludge

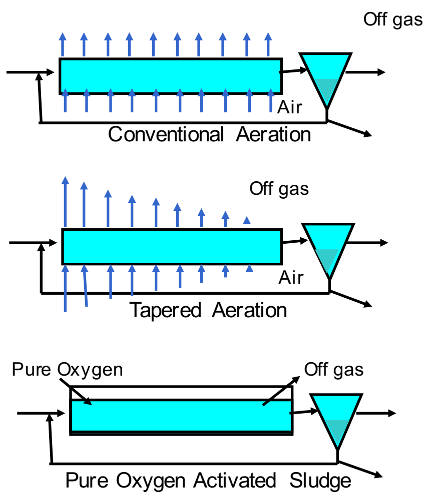
Advantage: Reduced tank volume for a given q_x



Activated Sludge with Anoxic Selector

Advantage: High efficiency, selects flocculant biomass that settles well

Activated sludge modifications to aeration



Pure Oxygen Activated Sludge

- *Results in biomass that settles well.*
- *Economics have recently become more favorable.*
- *pH control becomes more important because P_{CO2} is high in the headspace*

Ex: Howard F. Curren Advanced Wastewater Treatment Plant
https://www.tampagov.net/wastewater/info/advanced-wastewater-treatment-plant

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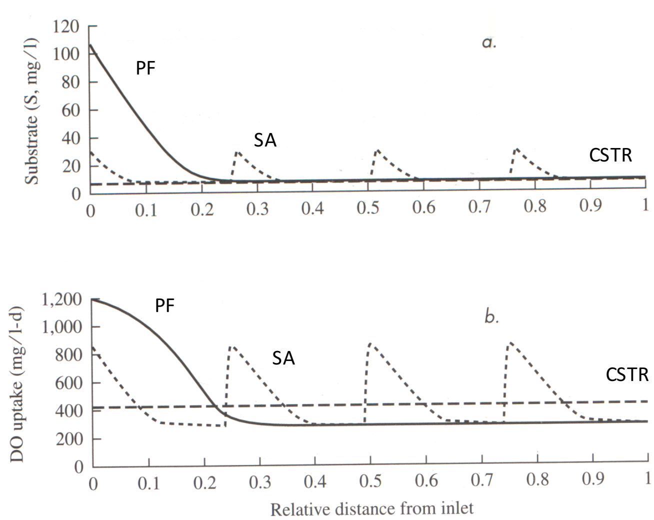

Figure 6.2 Changes in contaminant (substrate) concentration and oxygen (DO) uptake rate along the reactor length for plug flow (PF, solid lines), step aeration (SA, small-dash lines), and continuous-stirred tank (CSTR, large-dash lines) reactors for a typical loading with a dilute wastewater.

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Mean Cell residence time (sludge age) and loading rates for different activated sludge systems

Process	Typical θ_x^d days	Safety factor	Volumetric loading kg BOD_5/m^3-d	F/M kg BOD_5/kg X_v-d	Typical BOD_5 removal efficiency
Extended aeration	>14	>70	0.3	0.05-0.2	85-95
Conventional	4-14	20-70	0.6	0.2-0.5	95
Tapered Aeration	4-14	20-70	0.6	0.2-0.5	95
Step Aeration	4-14	20-70	0.8	0.2-0.5	95
Contact Stabilization	4-14	20-70	1.0	0.2-0.5	90
Modified Aeration	0.8-4	4-20	1.5-6	0.5-3.5	60-85

Check table 6.2 of your book for more details

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Soluble Microbial Products (SMP)

Definition: dissolved substances resulting from

- cell lysis
- leaking cell membranes
- excretion

Molecular weight range: 100s to 1000s

Significance

- metal complexation (ex: siderophores)
- cell-cell signaling (ex: homoserine lactones)
- ecological warfare (ex: antibiotics, toxins)
- fouling of membranes
- color
- foaming (ex: biosurfactants)

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SMP = UAP + BAP

Utilization Associated Products (UAP) = released during growth

k_1 in units of (COD_p/COD_s), is a fraction of substrate that becomes UAP

Specific rate of formation $= k_1 q$

$$\text{Specific rate of degradation} = q_{UAP} = \frac{\hat{q}_{UAP} UAP}{K_{UAP} + UAP}$$

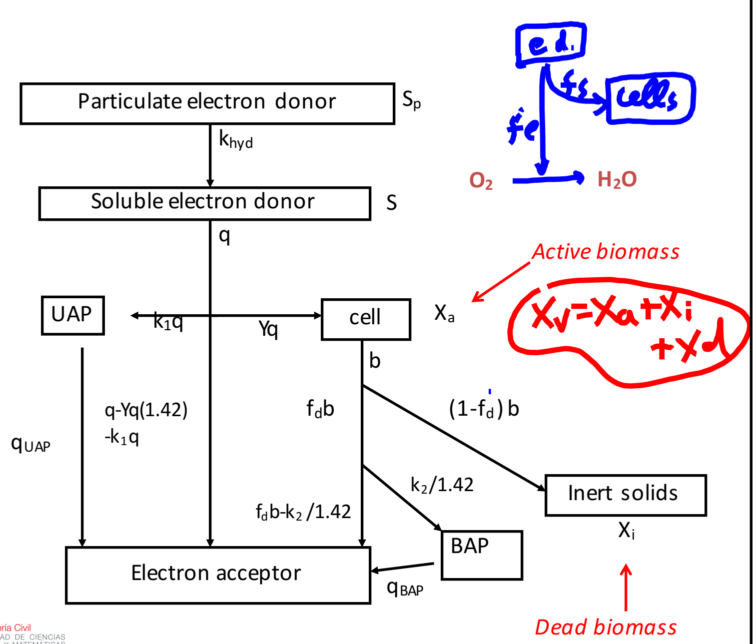
Biomass Associated Products (BAP) = released during decay

k_2 has units of ($gCOD_p$/ gVSS -d), need to divide by 1.42 gCOD/gVSS to result in same units as **b** (1/d)

Specific rate of formation $= k_2$

$$\text{Specific rate of degradation} = q_{BAP} = \frac{\hat{q}_{BAP} BAP}{K_{BAP} + BAP}$$

Adding structure: accounting for more of what we see (p. 176-178 in text)



SMP = UAP + BAP

Parameter estimates - see p. 178 in text

UAP

Aerobic (product (UAP); substrate)

$k_1 = 0.12$ g COD_p/gCOD_s

$\hat{q}_{UAP}$=1.8 g COD_p/g vss-d

K_{UAP}=100 mg/L

$$\frac{\hat{q}_{UAP}}{K_{UAP}} = 18 \text{ L/g vss-d}$$

BAP

Aerobic (product (BAP); biomass)

k_2=0.09 gCOD_p/g vss-d

$\hat{q}_{BAP}$=0.1 g COD_p/g vss-d

K_{BAP}=85 mg/L

$$\frac{q_{BAP}}{K_{BAP}} = 1.2 \text{ L/g vss-d}$$

UAP – Methanogenic

$k_1 = 0.21$ g COD_p/gCOD_s

$$\frac{\hat{q}_{UAP}}{K_{UAP}} = 2.4 \text{ L/g vss-d}$$

BAP – Methanogenic

$k_2 = 0.035$ g COD_p/g vss-d

$$\frac{\hat{q}_{BAP}}{K_{BAP}} = 0.31 \text{ L/g vss-d}$$

Key points

- Significant fraction of COD becomes released as UAP (12% for aerobes and 21% for methanogen) rather than EA or biomass
- Formation of BAP is a significant fraction of biomass loss (b)
- UAP is degraded faster than BAP (18:1.2 for aerobe and 2.4:0.31 for methanogen), resulting in accumulation of BAP.

SMP = UAP + BAP

Utilization Associated Products (UAP) = released during growth

k_1 in units of (COD_p/COD_s), is a fraction of substrate that becomes UAP

Specific rate of formation $= k_1 q$

Specific rate of degradation $= q_{UAP} = \dfrac{\hat{q}_{UAP} UAP}{K_{UAP} + UAP}$

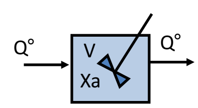
Biomass Associated Products (BAP) = released during decay

k_2 has units of ($gCOD_p$/ gVSS -d), need to divide by 1.42 gCOD/gVSS to result in same units as **b** (1/d)

Specific rate of formation $= k_2$

Specific rate of degradation $= q_{BAP} = \dfrac{\hat{q}_{BAP} BAP}{K_{BAP} + BAP}$

Steady state CSTR mass balances on UAP and BAP



	source	sink	out
UAP	$0 = k_1 qXaV$	$- \dfrac{\hat{q}_{UAP}(UAP)X_aV}{K_{UAP}+UAP}$	$- Q°(UAP)$
BAP	$0 = k_2 XaV$	$- \dfrac{\hat{q}_{BAP}(BAP)X_aV}{K_{BAP}+BAP}$	$- Q°(BAP)$

The above equations can be solved for UAP and BAP.
Solutions are available in the text (ch. 8)

Ecuaciones de SMP para el cálculo de UAP and BAP

SMP = UAP + BAP

$$\mathrm{UAP} = \frac{-(\hat{q}_{\mathrm{UAP}}\mathrm{X}_a\theta + K_{\mathrm{UAP}} - K_1 q\mathrm{X}_a\theta)}{2} + \sqrt{\frac{(\hat{q}_{\mathrm{UAP}}\mathrm{X}_a\theta + K_{\mathrm{UAP}} - K_1 q\mathrm{X}_a\theta)^2 + 4K_{\mathrm{UAP}}K_1 q\mathrm{X}_a\theta}{2}}$$

$$\mathrm{BAP} = \frac{-[K_{\mathrm{BAP}} + (\hat{q}_{\mathrm{BAP}}\mathrm{X}_a - k_{\mathrm{hyd}}(\mathrm{EPS})\theta]}{2} + \sqrt{\frac{-[K_{\mathrm{BAP}} + (\hat{q}_{\mathrm{BAP}}\mathrm{X}_a - k_{\mathrm{hyd}}(\mathrm{EPS})\theta)^2 + 4K_{\mathrm{BAP}}k_{\mathrm{hyd}}(\mathrm{EPS})\theta]}{2}}$$

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Parámetros SMP

Information to define the SMP kinetic parameters is sparse. Noguera (1991) analyzed aerobic data and obtained the following best-fit values:

$$k_1 = 0.12 \text{ g COD}_p/\text{g COD}_s$$
$$k_2 = 0.09 \text{ g COD}_p/\text{g VSS}_a\text{-d}$$
$$\hat{q}_{\mathrm{UAP}} = 1.8 \text{ g COD}_p/\text{g VSS}_a\text{-d}$$
$$K_{\mathrm{UAP}} = 100 \text{ mg COD}_p/\text{l}$$
$$\hat{q}_{\mathrm{UAP}}/K_{\mathrm{UAP}} = 18 \text{ l/g VSS}_a\text{-d}$$
$$\hat{q}_{\mathrm{BAP}} = 0.1 \text{ g COD}_p/\text{g VSS}_a\text{-d}$$
$$K_{\mathrm{BAP}} = 85 \text{ mg COD}_p/\text{l}$$
$$\hat{q}_{\mathrm{BAP}}/K_{\mathrm{BAP}} = 1.2 \text{ l/g VSS}_a\text{-d}$$

While these values can be considered only provisional, they do point out several key features of SMP. First, a significant fraction of substrate COD is shunted to UAP formation; $k_1 = 0.12$ g COD_p/mg COD_s means that 12 percent of the substrate "utilized" is neither sent to the electron acceptor nor converted to biomass, but is released as UAP. Second, the formation of BAP constitutes a significant fraction of biomass loss; $k_2 = 0.09$ g COD_p/g VSS_a-d converts to a first-order "decay" rate of approximately 0.06/d. Third, UAP is biodegraded considerably faster than is BAP; thus, we should expect to see preferential buildup of BAP in most situations.

Noguera et al. (1994) estimated SMP parameters for a methanogenic system:

$$k_1 = 0.21 \text{ g COD}_p/\text{g COD}_s$$
$$k_2 = 0.035 \text{ g COD}_p/\text{g VSS}_a\text{-d}$$
$$\hat{q}_{\mathrm{UAP}}/K_{\mathrm{UAP}} = 2.4 \text{ l/g VSS}_a\text{-d}$$
$$\hat{q}_{\mathrm{BAP}}/K_{\mathrm{BAP}} = 0.31 \text{ l/g VSS}_a\text{-d}$$

Most notable is the relatively slower degradation kinetics, compared to the aerobic system.

Since k_2 can be a significant fraction of b, we shall assume that b implicitly includes BAP generation, as well as biomass oxidation and conversion to inert biomass. By differences, the portion of endogenous decay that results in direct biomass oxidation is $b - f_d b - k_2 = (1 - f_d)b - k_2$.

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Table 8.1 Estimates for EPS- and SMP-Related Production and Consumption Parameters

Parameter Name	Parameter Symbol	Units	Typical Value	All Microbial Types or Only Heterotrophs
EPS–formation fraction	k_{EPS}	g COD_{EPS}/g COD_S	0.18	All
UAP–formation fraction	k_1	g COD_{UAP}/g COD_S	0.05	All
Net biomass–formation fraction	$1 - k_{EPS} - k_1$	g COD_X/g COD_S	0.77	All
EPS–hydrolysis rate	k_{hyd}	1/d	0.17	Heterotrophs
UAP maximum specific utilization rate	qUAP	g COD_{UAP}/g COD_X-d	1.3	Heterotrophs
BAP maximum specific utilization rate	qBAP	g COD_{BAP}/g COD_X-d	0.35	Heterotrophs
UAP half-maximum-rate concentration	K_{UAP}	g COD_{UAP}/l	0.1	Heterotrophs
BAP half-maximum-rate concentration	K_{BAP}	g COD_{BAP}/l	0.085	Heterotrophs

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Table 8.2 Estimates for SMP- and EPS-Affected Parameter Values for Key Types of Microorganisms

Parameters and Units	Aerobic Heterotrophs	Denitrifying Heterotrophs	Denitrifying H_2-Oxidizing Autotrophs	Ammonium-Oxidizing Autotrophs	Acetate-Cleaving Methanogens
Y, g COD_{Xa}/g COD_S	0.64	0.50	0.20	0.14	0.04
Y', g COD_{Xa}/g COD_S	0.49	0.39	0.15	0.11	0.031
ˆqq^, g COD_S/g COD_X-d	7	7	5	5.6	8
ˆμ,1/dμ^, 1/d	4.5	3.5	1.0	0.78	0.32
ˆμ′,1/dμ^′, 1/d	3.4	2.7	0.77	0.68	0.25
b, 1/d	0.3	0.15	0.05	0.05	0.03
K, mg COD_S/l	10	10	0.6	0.5	30
[θminx]′lim[θxmin]lim′, d	0.32	0.39	1.4	1.8	4.5
S′min,mgCODS/lS′min, mgCODS/l	0.96	0.59	0.04	0.045	4.4

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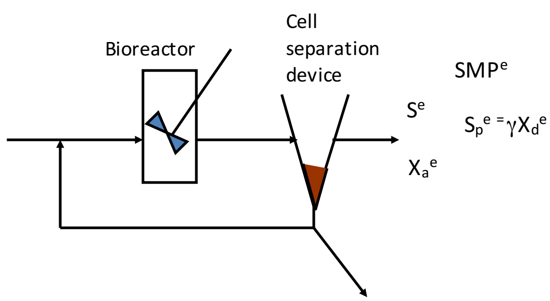
Cálculo de la BOD_L efluente



Soluble $BOD_L = S^e + SMP^e$ (assumes all biodegradable SMP)

Total BOD_L = Soluble $BOD_L + 1.42\ f_d\ X_a^e + S_p^e$

BOD_L from particulate fraction

Note: 1.42 g COD/ g VSS

Typically, $S < SMP^e < 1.42\ f_d\ X_a^e$

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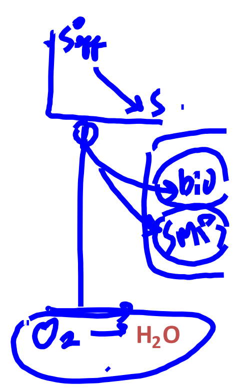
Rough estimate of effluent BOD_5^e

$BOD_t^e = S^e(1\text{-}e^{-kt}) + SMP^e(1\text{-}e^{-k_{smp}t}) + 1.42 f_d X_a^e(1\text{-}e^{-bt}) + S_p^e(1\text{-}e^{-k_{hyd}t})$

when t = 5 days, $BOD_t^e = BOD_5^e$

Refer to Example 3.3 in the text



O_2 UTILIZATION RATE ADJUSTED FOR SMP

O_2 utilization rate = $Q°(S°_{eff}\text{-}S)$ - $Q°(SMP)$ - 1.42(cell production rate)

= $Q°(S°_{eff}\text{-}S)f_e\text{-}Q°(SMP)$

= Σ O_2 equivalent input
– ΣO_2 equivalent output (biomass+SMP)

Note: the value of S_p^e depends upon the removal efficiency of the separation device. $S_p^e = \gamma\ (X_d/X_v)X_v^e$, where X_v^e is obtained from a knowledge of clarifier performance and $X_d = (\theta_x^d/\theta)[X_d°/(1+k_{hyd}\theta_x^d)]$. SMP values are calculated using equations 3.38-3.40 in the text.

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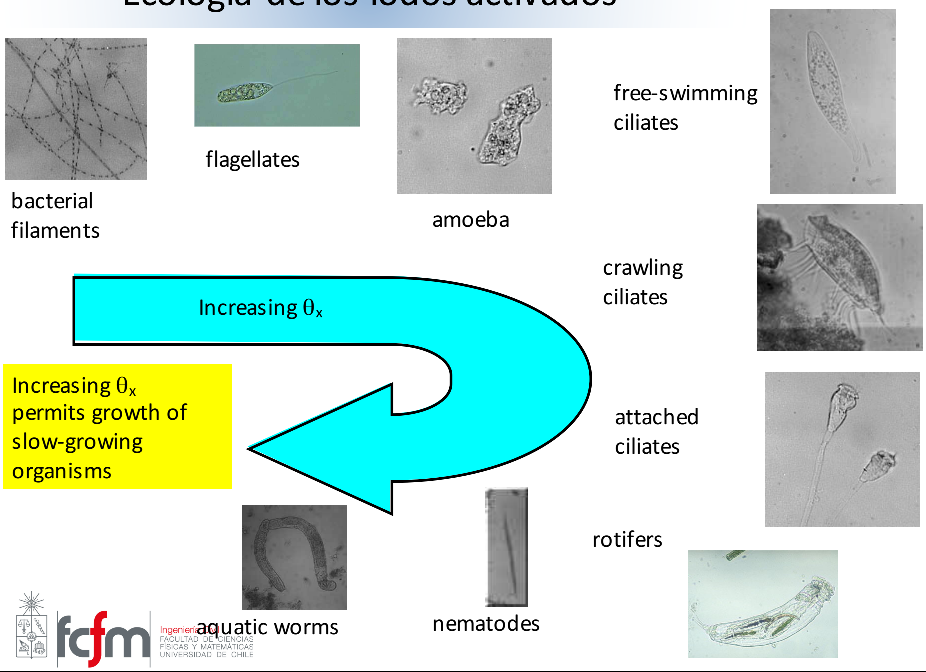
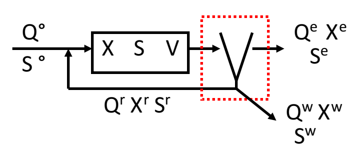
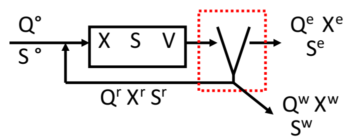
Ecología de los lodos activados



Tanques de Sedimentación



Tanques de Sedimentación



Solids balance around clarifier.

$$(Q^{\circ}+Q^{r})X = Q^{r}X^{r} + Q^{e}X^{e}$$

$$X=\frac{Q^{r}X^{r}}{Q^{\circ}+Q^{r}}=\frac{X^{r}}{\frac{Q^{\circ}}{Q^{r}}+1}$$

$$R=\frac{Q^{r}}{Q^{\circ}} \quad \text{so that} \quad X=\frac{X^{r}}{\frac{1}{R}+1}$$

R	X/X^r	X Normal compaction (X^r = 10,000 mg/L)
0.1	0.09	900
0.25	0.2	2,000
0.5	0.33	3,300
1	0.5	5,000
2	0.67	6,700

Settling tank criteria – X^r_{max}

Normal – 10,000 mg/L (1%)
Good – 20,000 mg/L (2%)
Poor < 5,000 mg/L (0.5%)

As R increases X approaches X^r, R must increase if compaction is bad to maintain adequate solids in the reactor.

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Problemas con la separación de biosólidos lodos

Biosolids Separation Problem	Cause of Problem	Effect of Problem
Bulking	Filamentous organisms extend from flocs into the bulk solution and interfere with compaction and settling	High SVI with clear supernatant. Overflow of sludge blanket can occur. Solids handling processes become hydraulically overloaded
Viscous bulking or nonfilamentous bulking	Microorganisms present in large amounts of exocellular slime. In severe cases, the slime imparts a jelly-like consistency	Reduced settling and compaction rates. Can result in overflow of sludge blanket from secondary clarifier or formation of a viscous foam
Dispersed growth	Microorganisms do not form flocs, but are dispersed, forming only small clumps or single cells	Turbid effluent. No zone settling of sludge
Pin floc or pinpoint floc	Small, compact, weak, roughly spherical flocs. Larger aggregates settle rapidly, smaller ones slowly	Low SVI and cloudy turbid effluent
Foaming/Scum formation	Caused by (i) nondegradable surfactants or (ii) the presence of Nocardia sp. and/or Microthrix parvicella	Foams float large amounts of biosolids to surface of treatment units. Causes solids overflow into secondary effluent and onto walkways. Anaerobic-digestor foaming also can result
Rising sludge	Denitrification in the settler releases poorly soluble N_2 gas which attaches to activated sludge flocs and floats them to the clarifier surface	"Chunks" of activated sludge collect on the surface of the settler and may result in turbid effluent

Source: Jenkins (1992), Jenkins et al. (2004), Wanner and Grau (1989).

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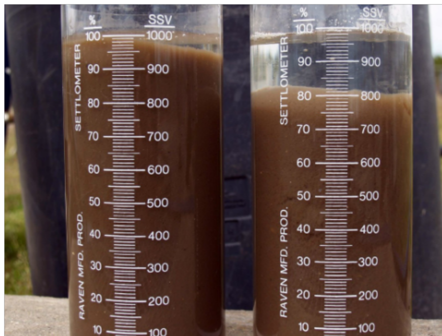
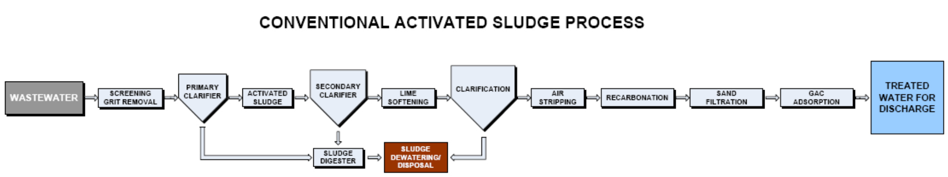
Problemas con la separación de biosólidos lodos

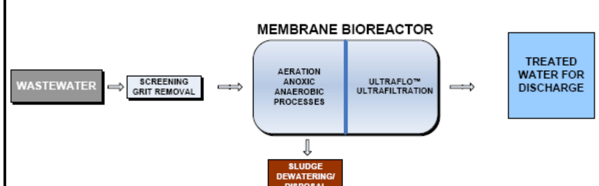


SVI TEST

27

Reactores de Membrana o Membrane Bioreactors (MBRs)





- Particle-free effluent
- Absolute barrier for retention of biomass
- Decoupling of HRT and SRT
- Remote-monitoring and control appropriate

But...

Energy + maintenance

Comparison between CAS and MBR space and process requirement (adapted from Ultra-Flo, 2007)

Ventajas de los MBR

- Particle free effluent
  - Removal of pathogenic protozoa, bacteria, viruses
- Higher biomass concentration (5 to 10 x)
  - More compact
  - May permit direct anaerobic treatment of dilute waste (e.g., sewage) at cooler temperatures
- Solids separation
  - Independent from sludge settling
  - Reduced operator attention: remote monitoring and control may be possible (distributed systems?)

Tecnología compacta de lodos activados

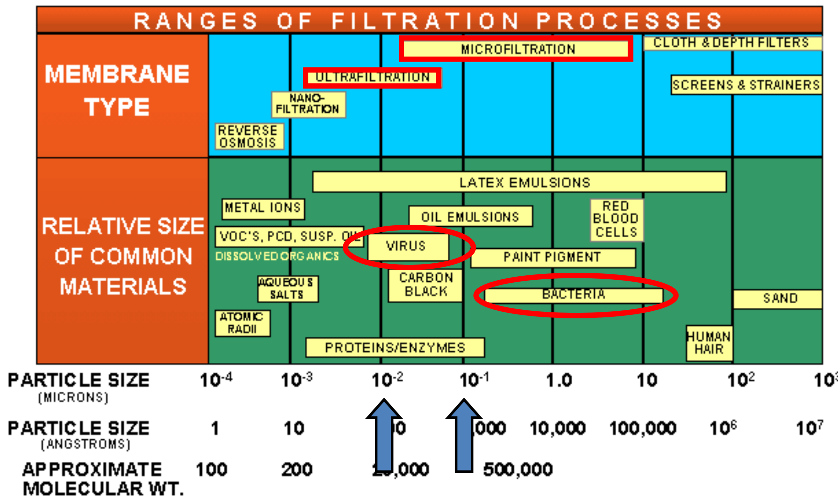
- Largely developed in Japan in the 1990's
- Used all over the world in municipal and industrial applications

https://www.thembrsite.com/largest-membrane-bioreactor-plants-worldwide/

Two major types:
- submerged
- crossflow

Membrane flux ranges from 5-300 L/m^2-h, depending on:
- membrane material (surface characteristics, pore size)
- extent of fouling
- transmembrane pressure
- mode of operation
- module arrangement

Membrane separation

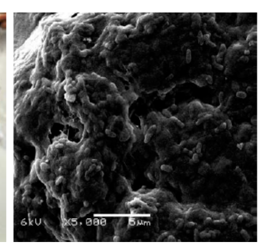


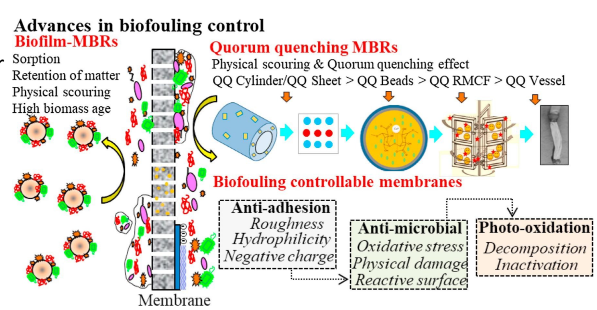
MBR concerns

The major concern is biofouling

Strategies to combat biofouling:

- periodic cleaning of membranes
- backwash
- highly turbulent aeration
  - high energy needed to shear biomass (2-10 kWh-m^3) for crossflow applications, but is reportedly 10 times lower for submerged membranes.





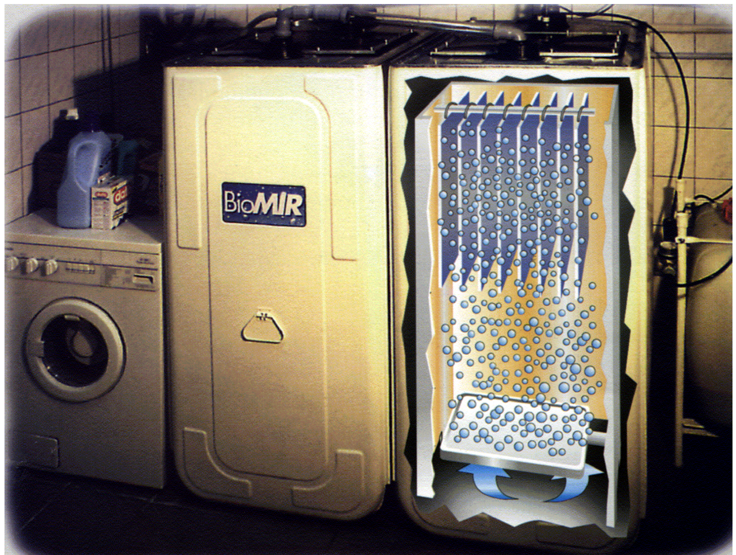
Aslam et al., 2018, Recent developments in biofouling control in membrane bioreactors for domestic wastewater treatment, Separation and Purification Technology, 206, 297-315, U.S. Filter membranes

Source: http://www.usfilter.com

U.S. Hollow Fiber membranes

Source: http://www.zenon.com/

Submerged plate and frame membrane modules
(KUBOTA, license VA Tech WABAG, Germany)



Source: http://www.busse-is.de

Design Example 1: Activated Sludge (Example 6.2 in the text, pages 347-352):

1. Determine waste characteristics and effluent requirements:

$Q° = 1000\ m^3/d$
$S° = 500$ mg/L
$S_p° = 0$ (not typical of sewage)
$X_i° = 50$ mg/L
$X_{in}° = 20$ mg/L
$S^e_{max} = 20$ mg/L
Nonbiodegradable COD = 0

2. Select coefficients and design factors.

$Y = 0.4$ mg vss/mg BOD_L
$\hat{q} = 10$ mg BOD_L/mg vs-d
$b = 0.1\ d^{-1}$
$K = 10$ mg BOD_L/d
$f_d = 0.8$
S.F. = 20
X_v (if recycle) = 2500 mg/L
$X_v^e = 15$ mg/L (expected performance of clarifier)

3. Calculate $\left[\theta_x^{min}\right]_{lim}$ **=** 1/[(0.4)(10)-0.1] = **0.26 d**

4. Select $\theta_x^d = S.F. \bullet \left[\theta_x^m\right]_{lim}$ **=** (20)(0.26) = **5.2 days**

5. Solve $S^e = \dfrac{K\left(1 + b\theta_x^d\right)}{\theta_x^d\left(Y\hat{q} - b\right) - 1} = \dfrac{10\,[1 + (0.1)(5.2)]}{5[(0.4)(10) - 0.1] - 1} = 0.81\ \text{mg/L}$

$S^e_{max} = 20$ mg/L which is >>0.81 , so we are OK.

6. Use the expression:

0 (no Sp^{o})

$$X_v = \frac{\theta_x}{\theta}\left[X_i^o + \frac{X_d^o}{1+k_{hyd}\theta_x} + \frac{Y\left(S_{eff}^o - S^e\right)\left(1+0.2b\theta_x\right)}{1+b\theta_x}\right] =$$

$$\frac{\theta_x}{\theta}\left[\overline{X_i^o} + \overline{X_a} + \overline{X_{i,syn}}\right] = \frac{\theta_x}{\theta}\left[\overline{X_v}\right]$$

Activated sludge systems are designed for recycle, so we rearrange the above equation to solve for θ using a design value for Xv of 2,500 mg/L. This value is a chosen based on the expected settleability of the activated sludge.

In this example, $X_d^{\circ} = 0$, so the second term inside the parenthesis drops out, and $S^{\circ}_{eff} = S^{\circ}$:

$$\theta = \frac{\theta_x}{X_v}\left[X_i^o + \frac{Y\left(S_{eff}^o - S^e\right)\left(1+0.2b\theta_x\right)}{1+b\theta_x}\right] = \frac{5}{2500}\left[50 + \frac{0.4(500-0.8)(1+0.2(0.1)(5))}{1+(0.1)(5)}\right]$$

$$= \frac{5}{2500}\left[50+133+13\right] = \frac{5}{2500}\left[196\right] = 0.39 \text{ d} = 9.4 \text{ h}$$

7. Solve V=Q°θ

$V = (1000 \text{ m}^3/\text{d})(0.39 \text{ d}) = 390 \text{ m}^3$

8. Solve for waste sludge production and biomass production rate:

$$X_v \text{ production rate} = \frac{X_v V}{\theta_x^d} = \left(\frac{\left(2500 \text{ g/m}^3\right)\left(390 \text{ m}^3\right)}{5 \text{ d}}\right)\left(\frac{\text{kg}}{1000 \text{ g}}\right) = 196 \text{ kg/d}$$

Alternatively, X_v production rate = $Q\overline{X_v}$ = (1000 m^3/d)(196 g/m^3)(kg/1000 g) = 196 kg/d

The wasting rate of volatile suspended solids is obtained by subtracting out solids that are accidentally lost from the system in the clarifier effluent (=Q° X_v^e)

Wasting rate = production rate - accidental loss rate = 198-(1000)(15)/1000=181 kg vss/d

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8. Continued

X_{in} removal rate = rate at which X_{in} enters system = $Q°X_{in}$= (1000)(20)/1000 = 20 kg ss/d

Some X_{in} is also generated as Xv is produced because MLVSS is 90% organic and 10% inorganic (ash). For that ratio, the additional inorganic solids produced = (196)(10/90) = 22 kg/d.

Suspended solids (organic + inorganic) production rate = 196 + 20 + 22 = 238 kg/d

What is the biological suspended solids production rate?

$$\overline{X_{syn}} = \overline{X_a} + \overline{X_{i,syn}} = 133 + 13 = 146 \ \ g/m^3$$

Biological solids production rate = $Q\overline{X_{syn}}$ = (1000 m^3/d)(146 g/m^3)(kg/1000 g) = 146 kg/d

9. Stoichiometry and materials balance:

Substrate removal rate = Q°(S°-S) = 1000(500-0.81)/1000 = 499 kg BOD_L/d

Volumetric BOD_L removal rate = 499/390 = 1.28 kg BOD_L/m^3-d

N requirement = 0.124 x Cell production rate = (0.124)(146) = 18 kg N/d

P requirement = 0.025 x Cell production rate = (0.025)(146) = 3.6 kg P/d

10. Computation of SMP - use equation 3.38 and 3.39 and coefficients in the book

UAP = f(volumetric BOD_L removal rate, X_a, θ) = 4.8 mg/L
BAP = f(X_a, θ) = 39 mg/L
SMP = 4.8 + 39 = 43.8 mg COD/L

11. Estimate effluent quality:

How much COD is in the effluent?

Effluent COD = Se + (1.42)(X_v^e) + SMP = 0.8 + 21.3 + 44 = 66 mg COD/L

How much BOD_L is in the effluent?

Assume $X_a^e = X_v^e(X_a/X_v) = 15(133/196) = 10.2$ mg vss/L
Since $f_d = 0.8$,
Effluent $BOD_L = S^e + (1.42)(0.8)(X_a^e)$ + SMP = 0.8 + 11.6 + 44 = 56 mg BOD_L/L

How much BOD_5 is in the effluent?

For this we need to know the first order decay rates for the BOD test, the decay rates of the cells, and the decay rate of SMP.

Assume k = 0.23 d^{-1}
b = 0.1 d^{-1}
$b_{smp} = 0.03\ d^{-1}$

$BOD_5^e = S^e(1-e^{-5k}) + f_d(1.42)X_a^e(1-e^{-5b}) + SMP(1-e^{-5ksmp}) =$
$S^e(0.68) + 0.8(1.42)X_a^e(0.4) + SMP(0.14) = 0.5+4.6+6.1 = 11.2$ mg/L

12. Estimate O_2 use rate:

Oxygen equivalents entering system:

Substrate: Q°S° = (1000)(500)/1000 = 500 kg/d
VSS: 1.42 Q°X_i° = (1.42)(1000)(50)/1000 = 71 kg/d

(Note: Since X_i does not exert an O_2 demand, it could be omitted from the oxygen equivalents balance, but if X_i is not separated out in the computation of oxygen equivalents leaving the system, then it must be included here and multiplied by 1.42, so that it cancels out X_i leaving the system that is of nonbiological origin).

Sum: 500 + 71 = 571 kg/d

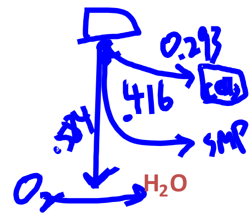
Oxygen equivalents leaving system:

Substrate: Q°S^e = (1000)(0.81)/1000 = 0.8 kg/d
SMP: Q°SMP° = (1000)(43.8)/1000 = 43.8 kg/d
VSS discharged in effluent or wasted = (1.42)(196)=278 kg/d (Note that this value includes X_i° that has passed through the system undegraded)

Sum: 0.8 + 43.8 +278 = 323 kg/d

O_2 uptake rate = Oxygen equivalents entering system - Oxygen equivalents leaving system

O_2 uptake rate = 571 – 323 = 248 kg O_2/d



Alternative method:

$$Y_{eff} = \frac{Y(1+0.2b\theta_x)}{1+b\theta_x} = \frac{(0.4)(1+0.2(0.1)(15))}{1+(0.1)(15)} = 0.293 \text{ g vss/g BOD}_L$$

f_s = 1.42Y = (0.293)(1.42) = 0.416

f_e = 1- f_s = 1-0.41 = 0.584

O_2 use if there were no SMP in the effluent = (0.584)(499) = 291 kg/d

O_2 use corrected for SMP in the effluent = 291-43.8 = 248 kg/d

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