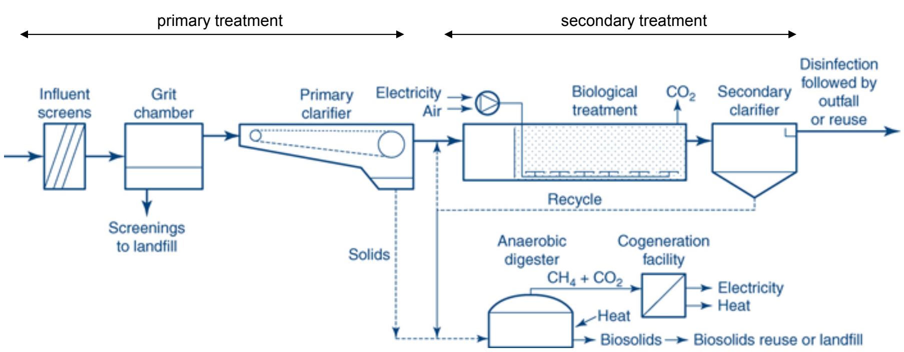
Biological Wastewater Treatment

(Nazaroff & Alvarez-Cohen, Section 6.E – slightly augmented)

Aerial View of the Water Reclamation Plant in Hanover, NH

(http://www.hanovernh.org/Pages/HanoverNH_PublicWorks/WaterRecl/Index)

Wastewater Treatment Plant (WWTP) – System Overview



Primary treatment = PHYSICAL
Secondary treatment = BIOLOGICAL

(Mihelcic & Zimmerman, Figure 11.4)
(See also Nazaroff & Alvarez-Cohen, Figure 6.B.2)

Primary treatment: Physical removal

Example of bar screen
as first step in primary treatment

http://photos.innersource.com/

filtered water

Example of grit chamber
as second step in primary treatment

http://www.vsfcd.com/primary.htm

water

grit to landfill

Example of
primary clarifier
as third step
in primary treatment

www.takamotobiogas.com/tag/missoula/

floating grease to incineration or disposal

bottom sludge to anaerobic treatment

water to secondary treatment

Secondary Treatment: Activated Sludge

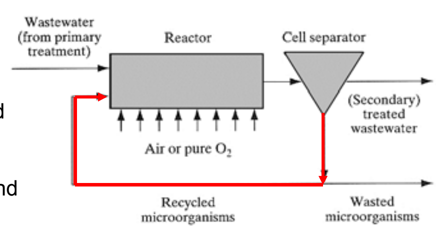
(Nazaroff & Alvarez-Cohen, Section 6.E.1)

An activated-sludge reactor is a system in which pre-treated sewage (*i.e.* having passed through primary treatment) is aerated to promote the growth of bacteria (cells) that gradually consume the organics in the sewage.

The result is the development of cells acclimated to the particular mix of substances present in the sewage and a significant consumption of the organic material. The effluent is a mixture of water with suspended cells and drastically reduced BOD content.

This mixture is then passed through a clarifier (settling tank) where the solids (mostly cells, called sludge at this stage) are separated from the water. The system is commonly operated in continuous mode (as opposed to batch mode).

The system is properly speaking an *activated-sludge* system when a portion of the sludge (cells) collected from the bottom of the clarifier is returned to the aerator. Not only are these cells already acclimated to the sewage, but by the time they are collected from the clarifier, they are also starved and really "hungry" for another meal!



(Nazaroff & Alvarez-Cohen, Figure 6.E.1)

Alternative 1: <u>Trickling Filter</u>

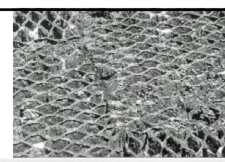
A trickling filter consists of a substrate (rocks or other material) on which cells can grow and over which the pre-treated sewage is sprayed. The spraying action creates contact between BOD in sewage, oxygen in the air and cells on the substrate. Cells grow and degrade the sewage. Excess cells (slime) need to be periodically removed from the substrate.

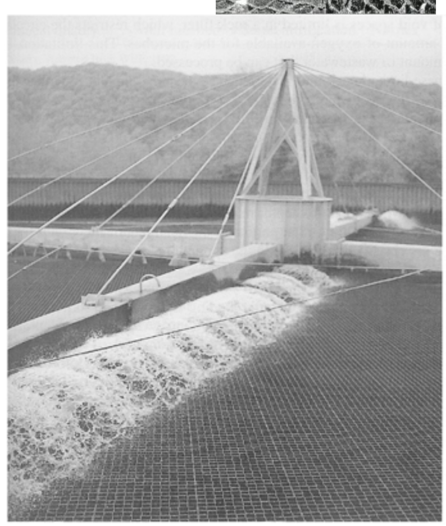
en.wikivisual.com

http://www.thecityofportland.net/wastewater

A trickling filter in action at the wastewater treatment plant in Portland, Indiana.

www.training.gpa.unep.org



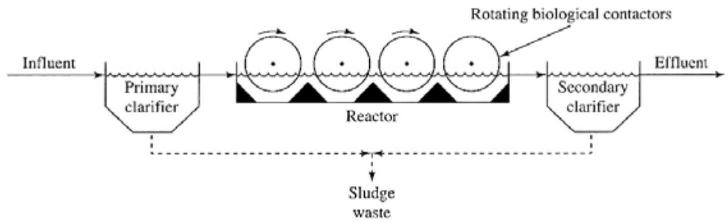


Trickling filters: over rocks (left) and over synthetic media (right)

(From Davis & Cornwell, 2008)

Alternative 2: <u>Rotating Biological Contactors</u>

Sincero & Sincero, 1996



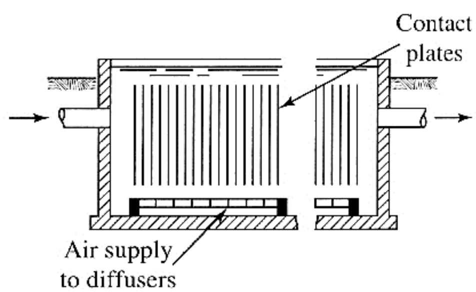
(c)

In this process, cells are attached to disks that rotate in the vertical plane. Cells are then alternatively exposed to sewage (their food) and air (their oxygen supply).

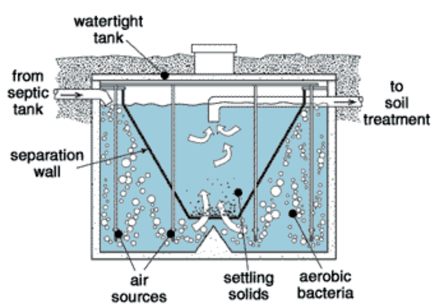
www.mayglothlingwaste.co.uk/treat_plant.php

Alternative 3: <u>Fixed-film Reactors</u>

In this process, cells are attached to vertical plates that are immersed by the flowing sewage and air is injected from the bottom to provide the oxygen.

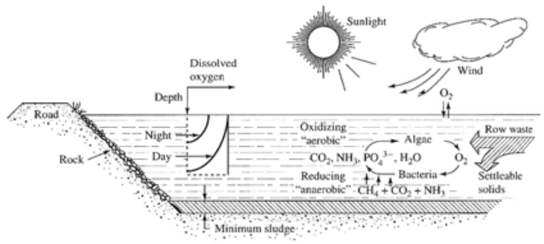


Sincero & Sincero, 1996



www.extension.umn.edu/distribution/naturalresources/

Alternative 4: Aerated Lagoons and Stabilization Ponds



In this process, nature is essentially left to run its course, with or without a little help from aeration.

The system looks less technological and is thus better integrated in the landscape, but it occupies much more real estate. Odor may also be a nuisance.

http://www.lagoonsonline.com/technote5.htm

http://www.lagoonsonline.com

Alternative 5: Eco-machine (John Todd Ecological Design)

www.toddecological.com/

inside

Rest area and welcome center along Interstate 89 in Sharon, Vermont.

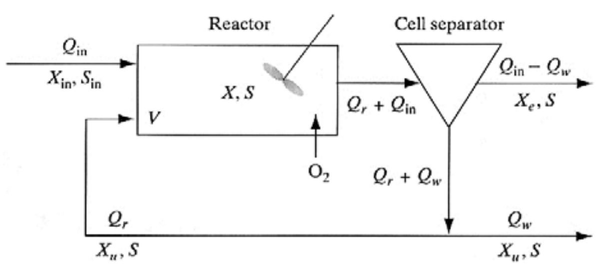
The wastewater from the toilets is treated on site by an eco-machine designed by John Todd.

Comparative summary of biological wastewater treatment technologies

Technology	Applications	Advantages	Disadvantages
Activated sludge	Low concentration organics Some inorganics	Removal of dissolved constituents Low maintenance Destruction process Relatively safe Low capital costs Relatively easy to operate	Volatile emissions Waste sludge disposal High energy costs Susceptible to shock and toxins Susceptible to seasonal changes
Trickling filters, Fixed-film reactors	Low concentration organics Some inorganics	Removal of dissolved constituents Low maintenance Destruction process Relatively safe Reduced sludge generation	Volatile emissions Susceptible to shocks and toxins Susceptible to seasonal changes Relatively high capital costs Relatively high operating costs
Aerated lagoons, Stabilization ponds	Low concentration organics Some inorganics	Removal of dissolved constituents Low maintenance Destruction process Relatively safe Low capital costs Low energy costs Easy to operate Infrequent waste sludge	Volatile emissions Susceptible to shocks and toxins Susceptible to seasonal changes High land requirement No operational control
Anaerobic degradation (septic systems)	Low concentration organics Chlorinated organics Inorganics	Removal of dissolved constituents Destruction process Treatment of chlorinated wastes Methane generation (= fuel) Reduced sludge generation	Susceptible to shocks and toxins Susceptible to seasonal changes Relatively high capital costs Relatively high operating costs

Activated-sludge system

The activated sludge system consists of two components, an aerator, where cells (*X*) consume the sewage (*S*), and a clarifier, where cells are then removed from the treated water.



(Nazaroff & Alvarez-Cohen, Figure 6.E.2)

Because cells need oxygen for their metabolism, air is injected from the bottom of the aerator. Rising bubbles agitate the water well and create good contact between the three ingredients: cells, sewage and oxygen.

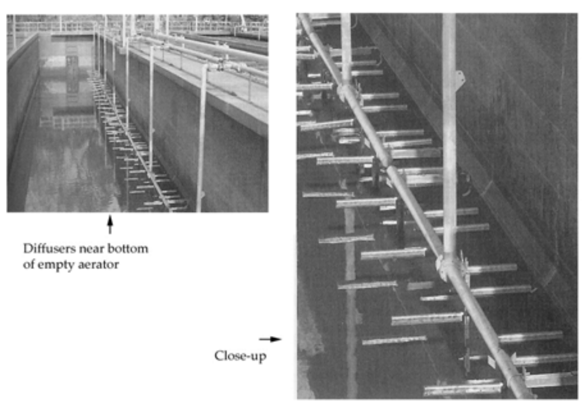
Activated-sludge aerators are well agitated by mechanical stirring from the top or injection of air from the bottom.

An *activated sludge* reactor with surface mechanical aeration / oxygen supply at the Stickney Water Reclamation Plant in Chicago

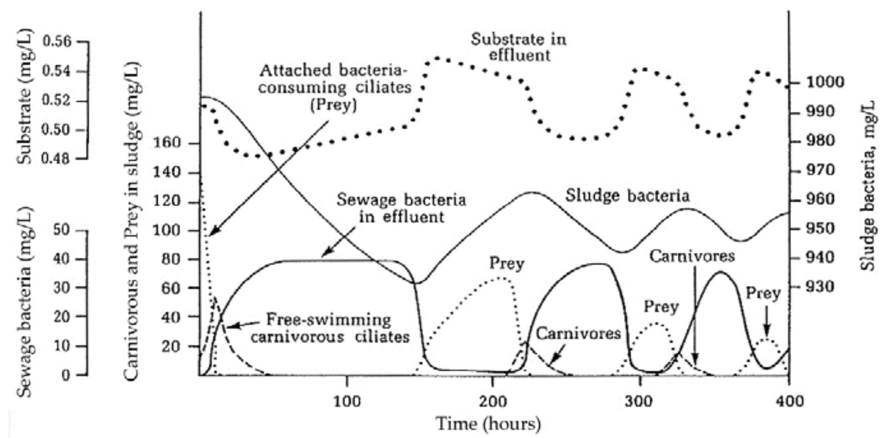
Complete mix aeration system for activated sludge process at the Eastman Kodak Company manufacturing facility in Rochester, NY .

(http://www.nywea.org/Clearwaters/pre02fall/302090.html)

Activated-sludge aerator in Lansing, Michigan



(*Source*: Davis & Cornwell, McGraw-Hill, 2008)



(From Davis & Cornwell, 2008; their source: Curds, 1973)

Different organisms grow and decay depending on the nature of the sewage and its rate of flow. Note that biological processes take many hours to adjust to a changed "ecosystem".

Note: Cells = bacteria = micro-organisms are interchangeable words here.

Kinetics of cell growth and waste utilization:

In an activated-sludge reactor, there are two fundamental variables:
the amount of organic waste, denoted by S (as in Substrate), and
the concentration of bacterial cells, denoted by X.

Both are measured in mg/L.

The quantity S is also directly related to the BOD.
The higher the BOD in the sewage, the more food for the cells.

To determine their magnitudes, which may be functions of time, $S(t)$ and $X(t)$, we need to know their rate of growth and decay.

Location	TSS (mg/L)	BOD (mg/L)
Influent to plant	220	220
Effluent from primary, influent to secondary	95	140
Effluent from activated sludge unit	15	20

(Metcalf & Eddy, 1991 – as taken from Nazaroff & Alvarez-Cohen – Table 6.E.1)

Let us define:

r_S = rate of substrate consumption = decay rate of waste
[in mg of substrate/(L.day)]

r_X = rate of cell formation = growth rate – decay rate [in mg of cells/(L.day)]
= $r_g - r_d$

Empirical observation #1: The rate of cell growth r_g is proportional to the substrate consumption rate r_S, because the substrate is consumed by the cells to make more cells.

The coefficient of proportionality is defined as the yield and denoted by Y (no units).

Thus,

$$r_g = Y\, r_S$$

Typically, the value of Y is 0.6 or less because cells emit carbon dioxide and therefore put on as weight only a fraction of their food consumption.

Empirical observation #2:

The cell growth rate r_g is proportional to the cell concentration X, when all other variables are held unchanged, because the more cells there are, the more new cells can be manufactured.

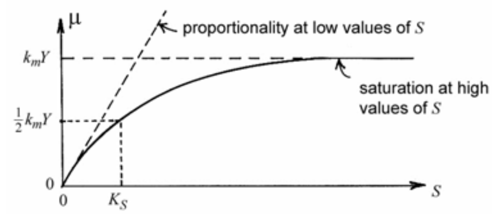
Thus,

$$r_g = \mu\, X$$

where the coefficient μ depends on other variables, such as the amount of substrate present, S.

Empirical observation #3: (Mihelcic & Zimmerman, pages 171-174; Mines & Lackey, pages 67-69)

The coefficient μ of proportionality depends on the substrate concentration as follows:
- At low S values, μ increases in proportion to increasing S, because the more food is available, the faster the cells multiply;
- At high S values, μ reaches a constant maximum value, because there is then a superabundance of food and cells cannot consume all of it right away.



This bimodal behavior is well captured by the so-called Monod kinetics:

$$\mu = \frac{k_m YS}{K_S + S}$$

where k_m is the growth constant (in /day), Y is the yield rate (ratio of cellular material generated per amount of substrate consumed), and K_S is called the half-saturation constant (in mg/L) because when $S = K_S$, $\mu = k_m/2$, which is at half of its maximum value. Put together, we have:

$$r_g = \frac{k_m SYX}{K_S + S} \qquad r_S = \frac{1}{Y} r_g = \frac{k_m SX}{K_S + S}$$

Empirical observation #4:

The death rate r_d of cells is proportional to the cell concentration X, because cells die in proportion to their number.

Thus,

$$r_d = k_d X$$

Recycling

To promote growth of the cells already adapted to the nature of the sewage, some fraction of the sludge collected at the bottom of the clarifier is recycled into the aerator.

Let us denote by Q_r the volumetric flow rate of sludge added to the inflowing rate of sewage Q_{in}, and by X_u the cell concentration inside the sludge collected at the bottom of the clarifier.

It goes without saying that X_u is expected to be significantly larger than the concentration X of cells in the aerator.

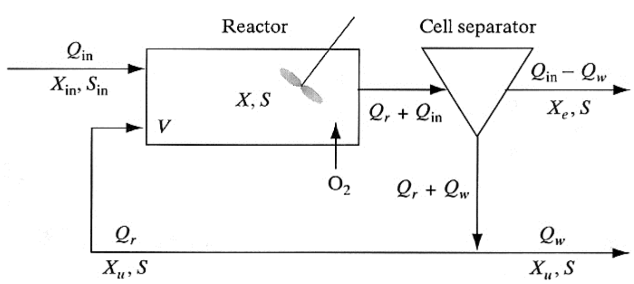
Table 6.E.2 Parameter Values for Conventional Activated Sludge Systems Using a Completely Mixed Flow Reactor

Parameter	Typical range	Typical value
Microbial parameters		
k_m (mg BOD_5 per mg VSS per day)	2–10	5
K_s (mg BOD_5 per L)	25–100	60
Y (mg VSS per mg BOD_5)	0.4–0.8	0.6
k_d (d^{-1})	0.025–0.075	0.06
Operational parameters		
Mean cell residence time, Θ_c (d)	5–15	
F/M (mg BOD_5 per mg VSS per day)	0.2–0.6	
Loading (kg BOD_5 m^{-3} d^{-1})	0.8–1.9	
Total suspended solids (kg m^{-3})	2.5–6.5	
Hydraulic detention time, Θ (h)	3–5	
Recycle ratio, $R = Q_r/Q_{in}$	0.25–1	
BOD removal efficiency (%)	85–95	

Source: Metcalf & Eddy, 1991.

(Nazaroff & Alvarez-Cohen, page 351)

Notation of fluxes and variables at several points in the system:



In continuous operation, where wastewater is constantly added and some of the mixture is constantly removed, the budgets of S and X are those of a continuously-stirred tank reactor (CSTR). If the reactor's volume is V (in m^3) and the volumetric flow rate is Q_0 (in m^3/day), the budgets are:

Substrate:

$$V\frac{dS}{dt} = Q_{in}S_{in} + \cancel{Q_r}S - (Q_{in} + \cancel{Q_r})S - V\left(\frac{k_m SX}{K_S + S}\right)$$

Cells:

$$V\frac{dX}{dt} = Q_{in}\cancel{X_{in}} + Q_r X_u - (Q_{in} + Q_r)X + V\left(\frac{k_m YSX}{K_S + S} - k_d X\right)$$

The entering wastewater has a known substrate concentration S_{in} and contains almost no cells, and we may assume $X_{in} = 0$.

Finally, the substrate concentration coming from the clarifier is indistinguishable from that entering it ($S_u = S$) because settling of cellular material does not affect the substrate concentration.

Equations reduce to:

$$V\frac{dS}{dt} = Q_{in}S_{in} - Q_{in}S - \frac{k_m VSX}{K_S + S}$$

$$V\frac{dX}{dt} = Q_r X_u - (Q_{in} + Q_r)X + \frac{k_m VYSX}{K_S + S} - k_d VX$$

Dividing these equations by the volume V and defining the *hydraulic residence time* θ in the reactor (in days) as

$$\theta = \frac{V}{Q_{in}}$$

and the dimensionless *recycle ratio* R

$$R = \frac{Q_r}{Q_{in}}$$

we obtain:

$$\frac{dS}{dt} = \frac{1}{\theta}(S_{in} - S) - \frac{k_m SX}{K_S + S}$$

$$\frac{dX}{dt} = \frac{RX_u - (1+R)X}{\theta} + \frac{k_m YSX}{K_S + S} - k_d X$$

steady state

Summary of budget equations

Substrate/Sewage:

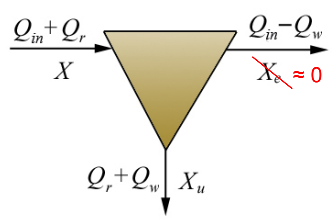
$$\frac{1}{\theta}\left(S_{in}-S\right)=\frac{k_m SX}{K_S+S} \qquad (1)$$

Cells/Bacteria:

$$\left(\frac{1+R}{\theta}+k_d\right)X = Y\frac{k_m SX}{K_S+S}+\frac{R}{\theta}X_u \qquad (2)$$

The first equation expresses that the difference between the entering and exiting substrate is due to the consumption by cells, while the second equation states that the amount of cells exiting the aerator plus those that have died inside is equal to the amount of cells grown on the substrate plus those added by the recycling flow.

Writing the steady-state budget for the cells in the clarifier, we have:



$$(Q_r+Q_w)X_u = (Q_{in}+Q_r)X$$

in which we have assumed that the concentration of cells in the clarified water (X_e) is virtually nil because most cells have settled to the bottom.

Then, introducing the *wastage ratio* W

$$W=\frac{Q_w}{Q_{in}}$$

we can express X_u in terms of X:

$$X_u=\frac{1+R}{W+R}X$$

and eliminate X_u from Equation (2), which then becomes:

$$\left(\frac{W(1+R)}{\theta(W+R)}+k_d\right)X = Y\frac{k_m SX}{K_S+S} \qquad (3)$$

So, we have two equations, one for S, the amount of substrate (sewage), and the other for X, the amount of cells, both in the aerator and both expressed in mg/L:

$$\frac{1}{\theta}(S_{in} - S) = \frac{k_m S X}{K_S + S} \qquad (1)$$

$$\left(\frac{W(1+R)}{\theta(W+R)} + k_d\right) X = Y \frac{k_m S X}{K_S + S} \qquad (3)$$

The first equation expresses that the loss of substrate ($S_{in} - S_{out}$) per time (division by residence time θ) is equal to the amount eaten by the cells.

The second equation states that the amount of cells that leave and die per time is equal to the rate of growth.

The equations contain four biological-type parameters:

k_m = cell growth constant = BOD degradation rate (in mg of substrate per mg of cells per day)
K_S = half-saturation constant of cell growth (in mg of substrate per L)
Y = yield rate = ratio of cell growth to substrate consumption (dimensionless)
k_d = cell death constant (in 1/day)

Determination of the biological parameters:

In any operation, it is important to know the value of the various 'constants', for these not only vary significantly with temperature but also with the nature of the sewage. Different mixes of organic material in different sewages (or in the sewage of the same town at different time periods) grow different cells at different rates.

To determine these 'constants', plant operators proceed as follows.

The system is operated several times in continuous mode and without recycling ($R = 0$) and with different values of the input parameters S_{in} and θ, and the exiting S and X concentrations are measured each time. The result is a set of (S_{in}, S, θ, X) data.

Eliminating the k_m fraction between the preceding two equations, we obtain

$$\frac{1}{\theta}(S_{in} - S) = \frac{1}{Y}\left(\frac{1}{\theta} + k_d\right) X$$

which can be rewritten as:

$$\frac{S_{in} - S}{X} = \frac{k_d}{Y}\theta + \frac{1}{Y}$$

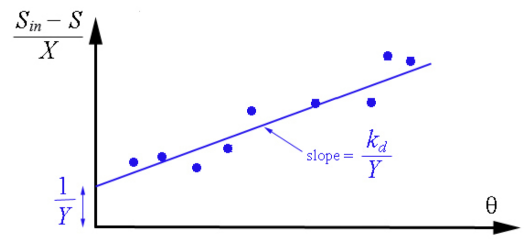
This equation,

$$\frac{S_{in} - S}{X} = \frac{k_d}{Y}\theta + \frac{1}{Y}$$

is a linear relationship between the known variables $(S_{in} - S)/X$ and θ. Therefore, plotting one of these variables against the other should produce a set of points falling more or less along a straight line.

Fitting a straight line through the set of points provides the two coefficients, namely the slope k_d/Y and the intercept $1/Y$.

From these, the constants k_d and Y can be separately determined.



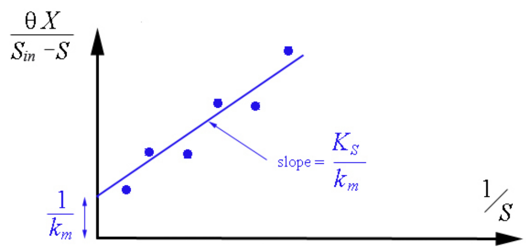
To determine the remaining constants k_m and K_S, we flip Equation (1) upside-down and multiply it by X, to obtain:

$$\frac{\theta X}{S_{in} - S} = \frac{K_S}{k_m}\frac{1}{S} + \frac{1}{k_m}$$

which is another linear relationship between known variables, this time $\theta X/(S_{in} - S)$ and $1/S$.

A plot should enable a fit by a straight line, which then yields values for K_S/k_m and $1/k_m$.

From these, we can extract the values of k_m and K_S.



Typical values of the biological parameters

(Nazaroff & Alvarez, top of Table 6.E.2)

Parameter	Typical range	Typical value	Units
k_m	2 – 10	5	mg of substrate / (mg of cells x day)
K_S	25 – 100	60	mg of substrate / L
Y	0.4 – 0.8	0.6	(dimensionless)
k_d	0.025 – 0.075	0.06	1 / day

Wash-out time

A crucial design parameter is the so-called *wash-out time*.

If the residence time θ is less than a critical value, denoted θ_{min}, then the sewage flow is too fast at steady state for bacteria to grow, existing cells are flushed out faster than they can multiply, and the result is the absence of cells, namely $X = 0$. When this happens, the sewage is not consumed and the exiting sewage shows no reduction in BOD, namely $S = S_{in}$.

Mathematically, a trivial solution of Equation (3) is $X = 0$ with accompanying solution $S = S_{in}$ from Equation (1). To avoid such state of affairs, we obviously need to have $X > 0$. Dividing Equation (3) by X then provides:

$$\text{Eq.}(3): \quad \left(\frac{W(1+R)}{\theta(W+R)} + k_d \right) X = Y \frac{k_m S X}{K_S + S} \quad \Rightarrow \quad \frac{W(1+R)}{\theta(W+R)} + k_d = Y \frac{k_m S}{K_S + S}$$

(Funny! The X-equation no longer depends on X. So, we'll use it to determine S instead and use the S-equation to get X afterwards.)

$$\frac{W(1+R)}{\theta(W+R)} + k_d = Y \frac{k_m S}{K_S + S}$$

This equation is a relationship between S and θ when cells are present (X not zero).

According to this relationship, S goes to infinity as the residence time θ is decreased. Obviously, S cannot exceed S_{in}, the entering concentration.

Therefore, the range of θ values has a lower bound, with the minimum being the value that corresponds to $S = S_{in}$:

$$\frac{W(1+R)}{\theta_{\min}(W+R)} + k_d = Y \frac{k_m S_{in}}{K_S + S_{in}}$$

of which the solution is:

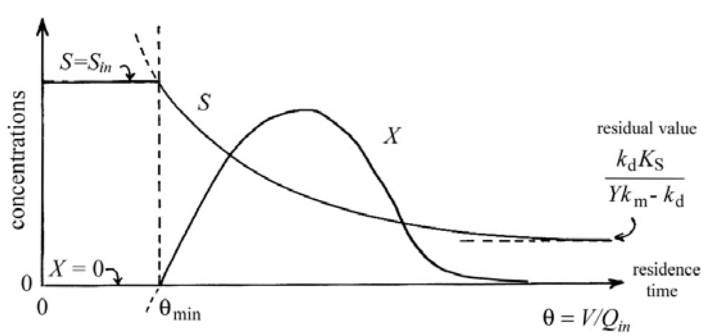
$$\theta_{\min} = \frac{W(1+R)}{W+R} \times \frac{K_S + S_{in}}{(Yk_m - k_d)S_{in} - k_d K_S}$$

This minimum value is called the *wash-out time*, because if θ falls below it, $S = S_{in}$ and there is no substrate reduction taking place, *i.e.* no treatment.
The system is a complete failure!

Solving now for S as a function of θ and then for X by using the remaining equation, we obtain:

$$S = \frac{(W+R)k_d\theta + W(1+R)}{(W+R)(Yk_m - k_d)\theta - W(1+R)} K_S$$

$$X = Y(W+R)\left[\frac{S_{in}}{(W+R)k_d\theta + W(1+R)} - \frac{K_S}{(W+R)(Yk_m - k_d)\theta - W(1+R)}\right]$$



We note that S decreases as θ increases, which is intuitively correct since more time spent in the aerator means more consumption of waste.

The amount of cells first increases as more time spent in the system gives them more time to feed, but decreases for longer residence times as substrate becomes depleted and death of old cells becomes the dominant effect.

Note that there is an ultimate S value below which the system cannot reach:

$$S_{\min} = \frac{k_d K_S}{Y k_m - k_d}$$

It is fairly small because k_d, the death decay rate of cells, is a small parameter.

Because the rate k_d of cell decay is slow compared to the growth rate k_m, the preceding two expressions for S and X can be approximated as:

$$S \cong \frac{W(1+R)}{(W+R)Yk_m\theta - W(1+R)} K_S \qquad X \cong Y \frac{W+R}{W(1+R)} (S_{in} - S)$$

for a wide range of θ values above but not too far from the wash-out time.

Note concerning the choice of residence time

Since our goal is to reduce the BOD of the sewage, we may first think that we should operate the aerator at long residence times (because high θ values yield low S values).

However, long residence times demand large tank volumes and create enormous costs. Therefore, there is an economic incentive to operate the system with moderate values of the residence time.

Also, a larger tank increases the hydraulic residence time and, with it, the cell's residence time in the system. Older cells perform less well than younger cells. (Sounds familiar?)

an old cell

In the tendency toward lower values of the residence time, close attention must be paid to the wash-out time, in order to avoid failure. Because the values of the coefficients that make up the expression for $\theta_{\min}$ vary with both temperature and the nature of the sewage mix, a generous margin of safety must be included.

The benefit of sludge recycling

In the early attempts of biological wastewater treatment, no recycling of cells was performed. In other words, no activated sludge was used to promote biological degradation.

Aside from the obvious disadvantage of not seeding the aerator with pre-adapted cells to make the work more effective, these systems suffered also from having to be excessively large.

We now quantify the benefits of recycling sludge by contrasting the quantities in the absence of recycling (setting the R ratio to zero).

With $R = 0$, the wash-out time becomes

$$\theta_{\min} = \frac{K_S + S_{in}}{(Yk_m - k_d)S_{in} - k_d K_S}$$

which is related to the original value by

$$\theta_{\text{min with recycling}} = \frac{W(1+R)}{W+R}\,\theta_{\text{min with no recycling}}$$

$$\theta_{\text{min with recycling}} = \frac{W(1+R)}{W+R}\,\theta_{\text{min with no recycling}}$$

Since W must be less than 1 by definition, the ratio

$$\frac{W(1+R)}{W+R}$$

will always fall below unity, and the minimum required residence time is lowered because of recycling.

The gain is very significant. For example, with typical values $R = 0.25$ and $W = 0.003$, the ratio equals 0.015, which leads to a reduction in residency time by 98.5%, with a concomitant 98.5% reduction in aerator volume, or about $1/67$ of the size required without recycling.

Mean cell residence time = Solids retention time (SRT)

(Nazaroff & Alvarez-Cohen, page 351)

Operators of activated-sludge systems need to be concerned by the age of the cells.

Indeed, an old cell population has the disadvantages of a higher death rate and of acclimatization to older sewage. Vice versa, a young cell population may be insufficiently acclimatized to the nature of the sewage.

The average cell age, also called the mean cell residence time and noted SRT or θ_c , is defined as the amount of cells in the aerator divided by the cell exit rate from the system:

$$SRT = \theta_c = \frac{VX}{Q_w X_u} = \frac{W + R}{W(1+R)}\theta$$

While the typical hydraulic residence time θ (average time spent by water in the aerator) is on the order of 3 to 5 hours, the average cell age SRT is typically on the order of 5 to 15 days (2 to 30 days as outer values).

Here, we see again the advantage of recycling some of the cells: $R \neq 0$ permits a decoupling between the water residence time (θ), on the order of a few hours and the average cell age (SRT) in a sensible biological range of days to weeks.

Like the hydraulic residence time θ, the cell residence time SRT may not fall below a minimum value, which is

$$SRT_{\min} = \frac{K_S + S_{in}}{(Yk_m - k_d)S_{in} - k_d K_S}$$

which is the same value as $\theta_{\min}$ in the absence of recycling.

In terms of the SRT, the S and X quantities are:

$$S = \frac{1 + k_d\, SRT}{(Yk_m - k_d)\, SRT - 1} K_S$$

$$X = \frac{Y(W+R)}{W(1+R)}\left[\frac{S_{in}}{k_d\, SRT + 1} - \frac{K_S}{(Yk_m - k_d)\, SRT - 1}\right]$$

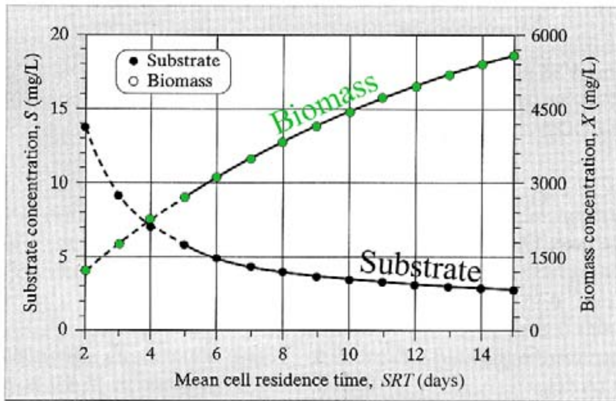


Figure 6.E.4 Theoretical performance of a conventional activated sludge unit with a completely mixed flow reactor.

(Nazaroff & Alvarez-Cohen, page 352)

Food-to-microorganism ratio
(Nazaroff & Alvarez-Cohen, page 353)

Another commonly reported characteristic of an activated-sludge system is the food-to-microorganism ratio, defined as the rate at which sewage (BOD) is supplied, $Q_{in} S_{in}$, divided by the amount of cells in the aerator, $V X$:

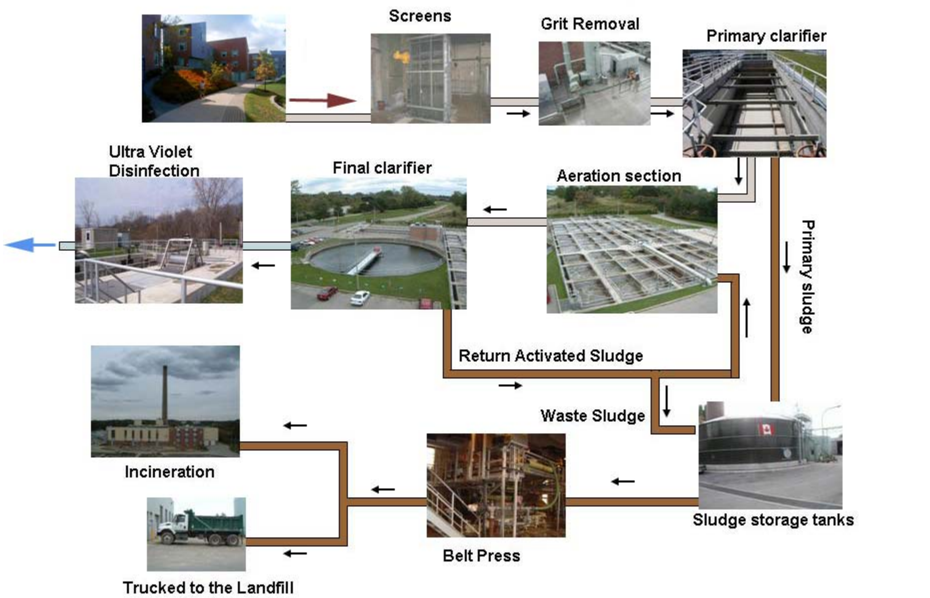
$$F / M = \frac{Q_{\text{in}} S_{\text{in}}}{VX} = \frac{S_{in}}{\theta X} = \frac{S_{\text{in}}}{S_{\text{in}} - S} \frac{1 + k_d \, SRT}{Y \, SRT}$$

With a 90% removal rate [$(S_{in} - S)/S_{in} = 0.10$], k_d = 0.06/day, $Y = 0.6$ and SRT = 10 days, this ratio is 2.7 per day.

Put another way, it means that at any one time, the system contains enough food to feed the cells for the next 1/2.7 = 0.37 days ≈ 9 hours. Should the flow of sewage be interrupted (*ex*. because of nighttime), the cells can only feed for another 9 hours before they starve and begin to die at an accelerated rate. Think of the F/M ratio as a feeding rate.

SRT	*F/M*
5 to 7 days	0.3 to 0.5 per day
7 to 20 days	0.08 to 0.4 per day
20 to 30 days	0.05 to 0.10 per day

And, then what happens to the collected sludge?



http://www.london.ca/Sewer_and_Wastewater/images/Activated_Sludge_Process_feb08.jpg