SWIM and Horizon 2020 Support Mechanism

Working for a Sustainable Mediterranean, Caring for our Future

SWIM-H2020 SM Regional Activities 14

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SWIM and Horizon 2020 SM REG-14: Refugee Emergency: Fast track project Design of wastewater

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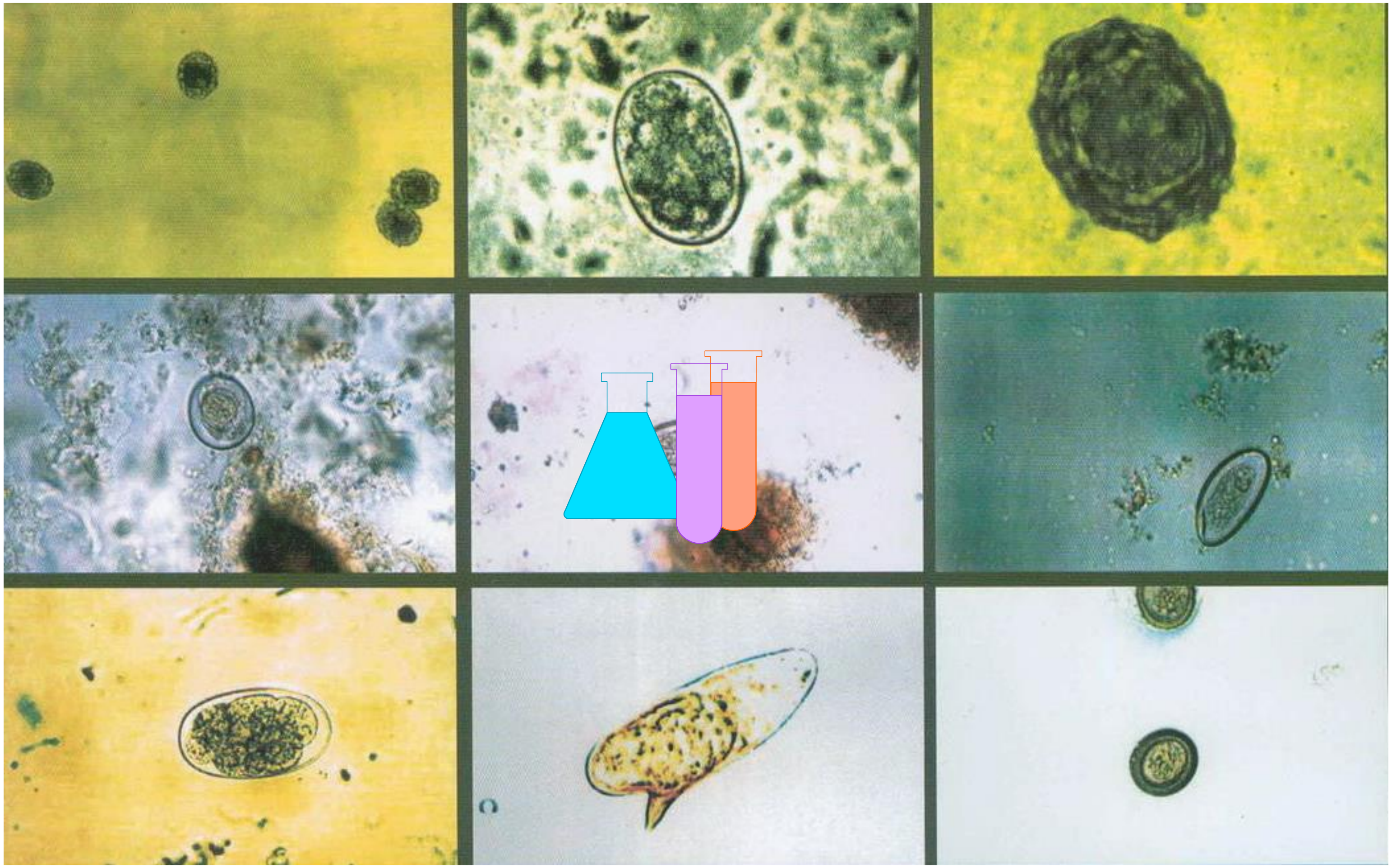
SESSION -1 PART 2

MICROORGANISMS



MICROORGANISMS
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8. Activated sludge kinetic coefficients for Nitrifying bacteria

PURPOSE OF WASTEWATER TREATMENT

IS TO…

Transform

Particulate & Dissolved Organics

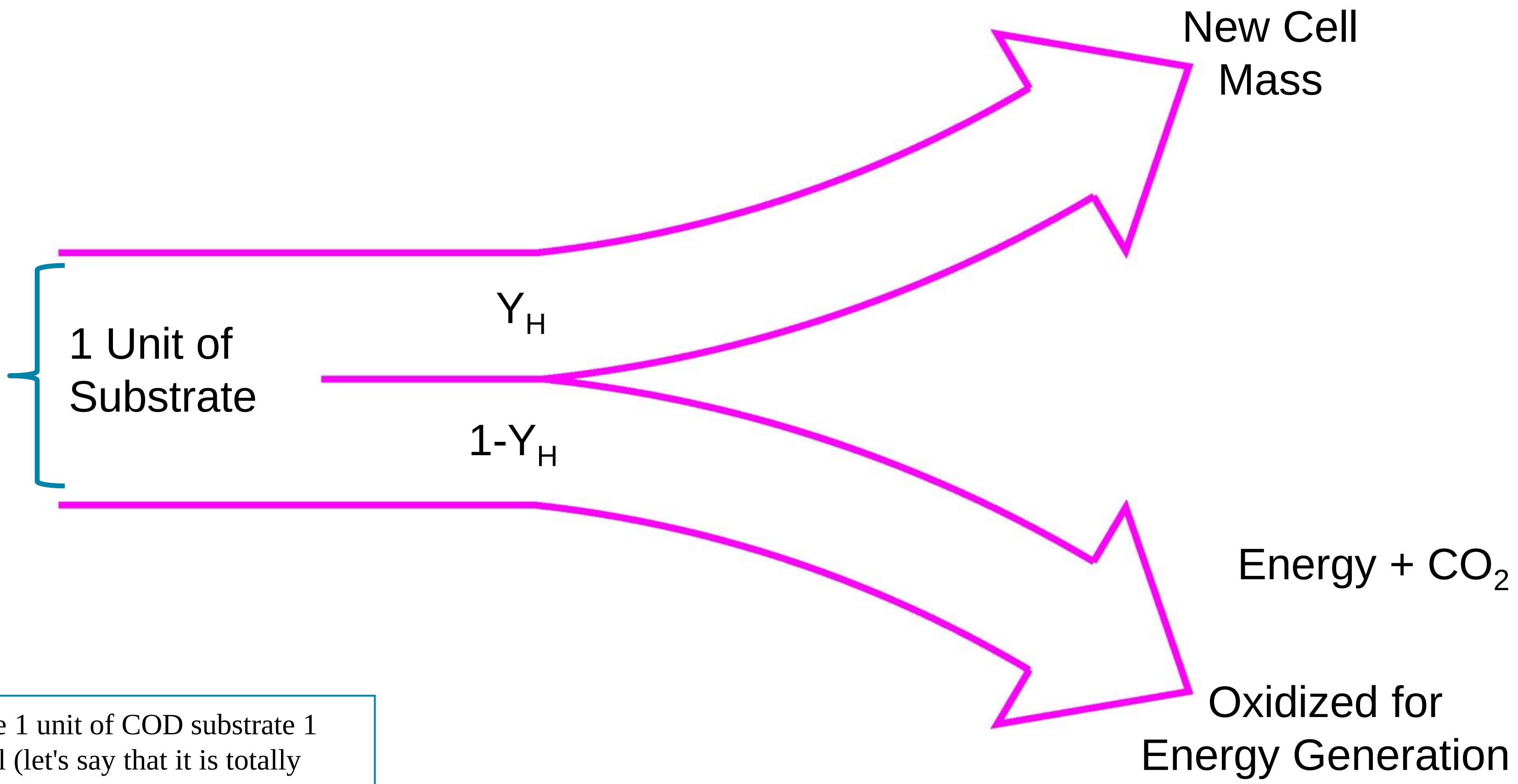
INTO

Biomass (Primarily Bacterial Bodies)

Why?

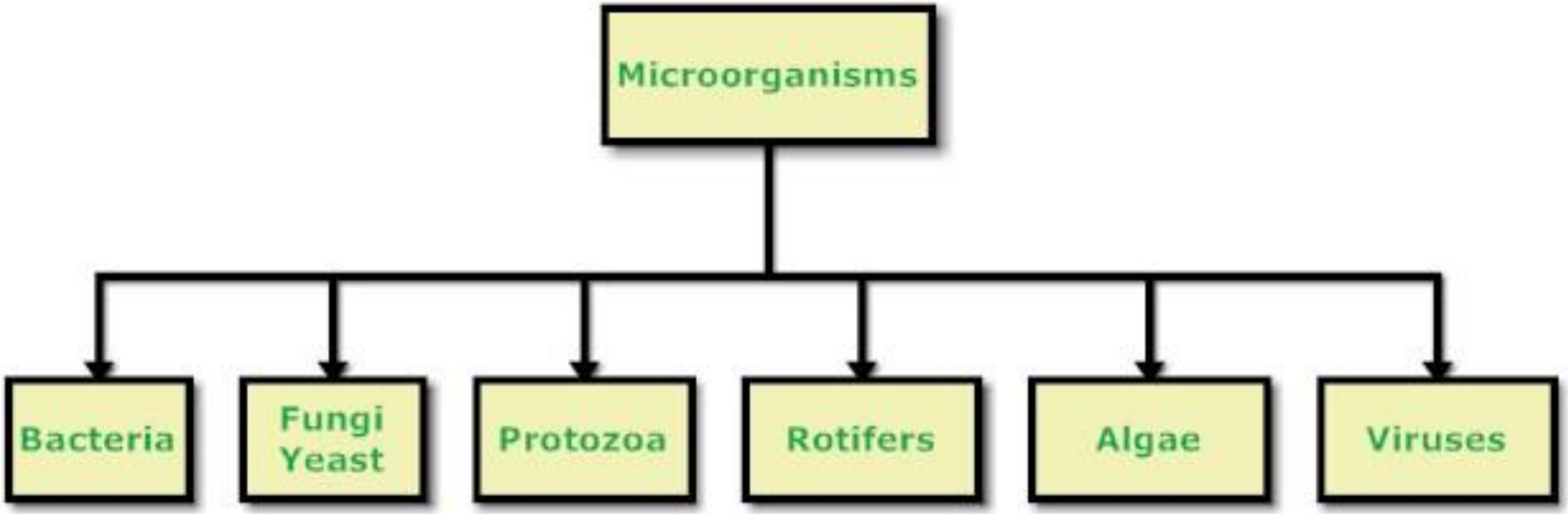
Because Bacteria Settle & Dissolved Solids Don’t

UTILIZATION OF SUBSTRATE BY HETERETROPHIC ORGANISMS



If we have 1 unit of COD substrate 1 mg COD/l (let's say that it is totally biodegradable), then we will grow Y units of cell mass, and 1-Y will be oxidized for energy.

TYPICAL MICROORGANISMS IN WASTEWATER



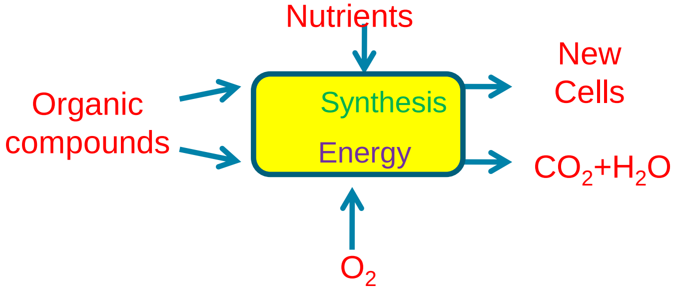
CLASSIFICATION OF BACTERIA BASED ON NUTRITIONAL REQUIREMENTS

Item	Hetrotrophic Bacteria	Autrotrophic Bacteria
Energy Source	Organic compounds	Inorganic Compounds
Carbon Source	Organic compounds	CO_2
Types	Aerobic Bacteria	Nitrifying Bacteria
	Anaerobic Bacteria	Nitrosomonas
	Facultative Bacteria	Nitrobacter
		Sulfur Bacteria

METABOLISM OF HETEROTROPHIC BACTERIA

- Organic matter is the substrate(food) used as energy source.
- The majority of organic matter in wastewater is in the form of large molecules which can't penetrate the bacteria cell membrane.
- Therefore large molecules are hydrolyzed into diffusible reactions for assimilation into their cells. The first biochemical reactions are hydrolysis of:
  - Complex carbohydrates sugar units
  - Proteins amino acids
  - Insoluble fats fatty acids
- Under aerobic conditions the reduced soluble organics compounds are oxidized to end products of CO2 and water.

$$Organics(Aerobic) + O_2 \rightarrow CO_2 + H_2O + energy$$



- Under anaerobic conditions , soluble organics are decomposed to intermediate end products(H_2S,organic acids) along with production of CO2 water.

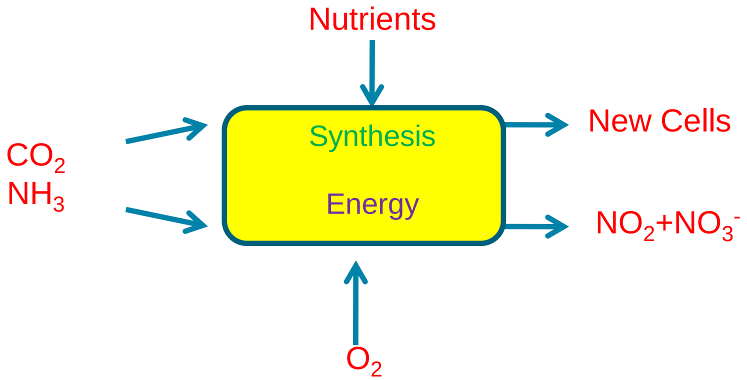
$$Organics(Anaerobic) \rightarrow Intermediates + CO_2 + H_2O + energy$$

METABOLISM OF AUTOTROPHIC BACTERIA

- Autotrophic bacteria use CO2 as a carbon source and oxidize inorganic compounds for energy.
- **Nitrifying Bacteria**

$$NH_3 + O_2 \xrightarrow{Nirosomonas} NO_2^- + energy$$

$$NO_2^- + O_2 \xrightarrow{Nitrobacter} NO_3^- + energy$$



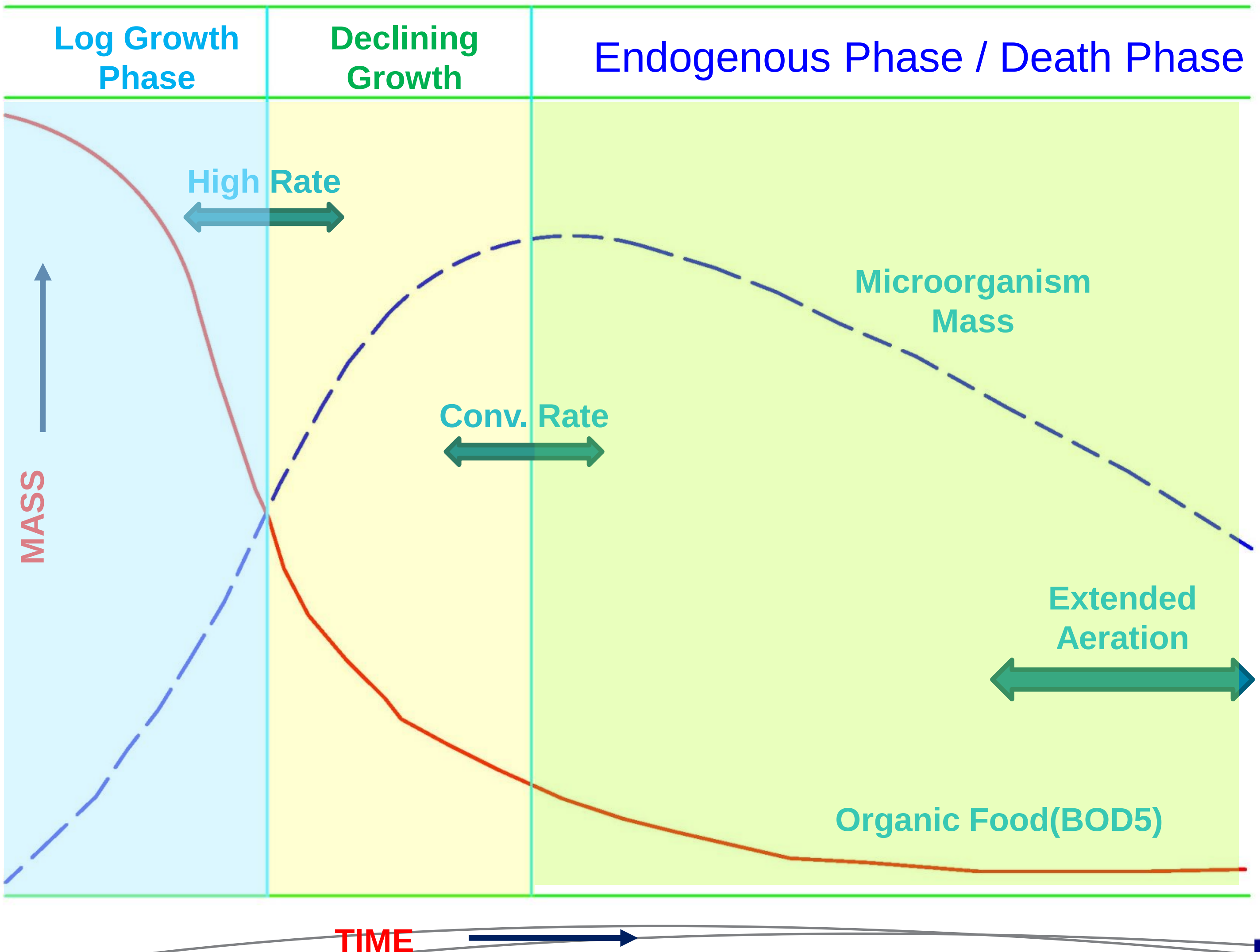
- **Sulfur Bacteria**

$$H_2S + O_2 \rightarrow H_2SO_4 + energy$$

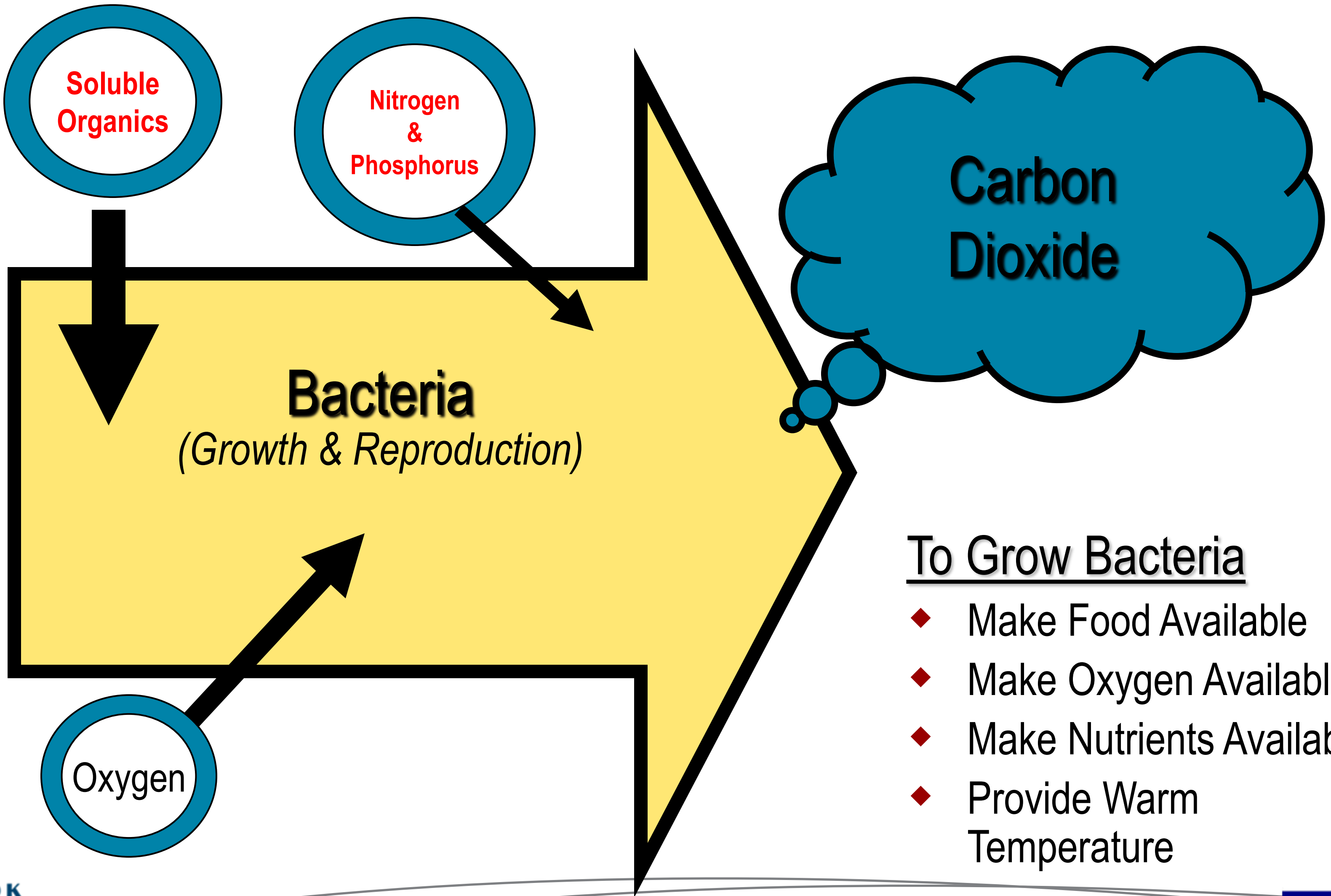
- **Iron Bacteria**

$$Fe^{2+} + O_2 \rightarrow Fe^{3+} + energy$$

BACTERIAL GROWTH PATTERNS



HETEROTROPHIC BACTERIAL GROWTH



To Grow Bacteria

- Make Food Available
- Make Oxygen Available
- Make Nutrients Available
- Provide Warm Temperature

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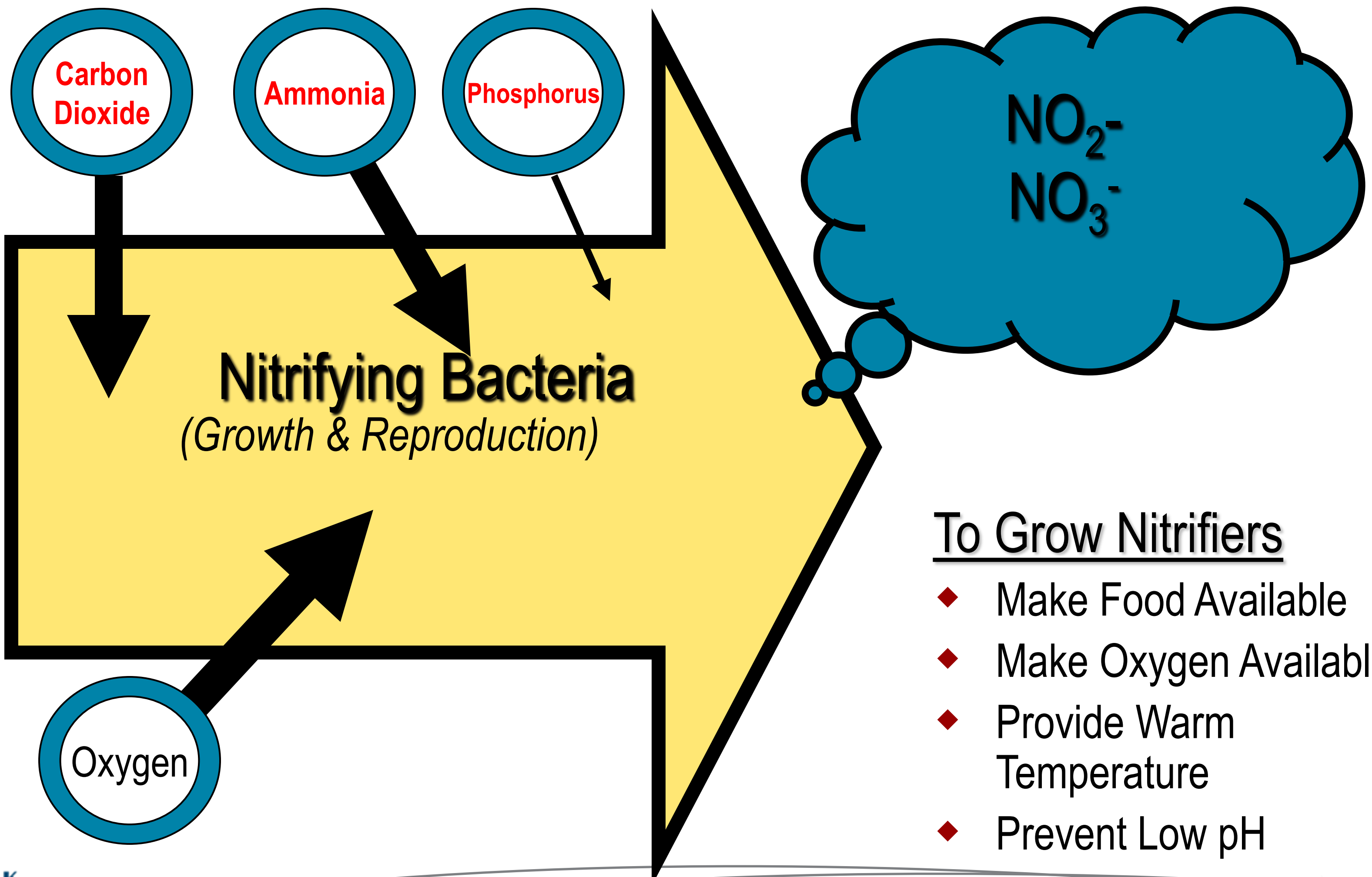
NITRIFIRES GROWTH



To Grow Nitrifiers

- Make Food Available
- Make Oxygen Available
- Provide Warm Temperature
- Prevent Low pH

DEFINITIONS & TERMINOLOGY

- **Substrate**
  - Carbon source (organic and inorganic)

- **Heterotrophs**
  - Organisms that use organic carbon to produce new cells.
    - e.g. most organisms used in aerobic treatment of wastewater

- **Autotrophs**
  - Organisms that use CO_2 to produce new cells.
    - e.g. Nitrifying bacteria

- **Nutrients**
  - Essential For Growth and Maintenance Of Micro-organisms
- e.g. Macro nutrients (N and P). Micro nutrients (Metals such as Fe, Ca, Mg, K, Mo, Zn, Co)

Definitions & Terminology

- **Mixed Liquor(ML) & Mixed Liquor Suspended Solids(MLSS)**
  - ❑ ML ,Mixture of wastewater and microorganisms(bugs) in the aeration tank.
  - ❑ MLSS ,concentration of bugs in the mixed liquor.

- **Microorganisms(Bugs)**
  - ❑ Microscopic living objects which require energy, carbon and small amount of inorganic elements to grow and multiply. They get these requirements from the wastewater and the sun and in doing so help to remove the pollutant from wastewater

- **Nitrification**
  - ❑ Nitrification is the biological oxidation of ammonia with oxygen into nitrite followed with the oxidation of these nitrites into nitrates.

- **Denitrification**
  - ❑ The reduction of nitrate or nitrite to gaseous products such as nitrogen, nitrous oxide, and nitric oxide; brought about by denitrifying bacteria.
- **Lysis**
  - ❑ To separate, breakdown of a cell often by viral, enzymic or osmotic by rupture of the cells wall.

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MICROBIAL GROWTH KINETICS

BACTERIAL METABOLISM

- The metabolic activity of bacteria is the primary means of removing pollutants in a bioreactor. Estimating production of biomass is a key step in the analysis and design of activated sludge system in general and bioreactor in particular and involve two aspects:
  - Kinetics, which deals with rates of bacterial growth and decay reactions(how fast the reactions will occur)
  - Stoichiometry, which deals with reactions and relationships between the masses of reactants and products involved in the reactions.
- Reactions affecting biomass production are:
  - Bacterial growth from uptake of substrate.
  - Bacterial loss from decay or endogenous respiration.

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STOICHIOMETRY
SYNTHESIS (TRUE) YIELD

- Synthesis or true yield(Y,) is a stoichiometric parameter that is generally defined as the mass of biomass produced per unit mass of biodegradable substrate consumed. This represents the “true yield”, applies only to the biodegradable fraction of the substrate and active biomass produced, and doesn’t account for the effect of biomass decay.

$$Y = \frac{Biomass\_Produced}{Substrate\_Removed} = \frac{\mu_{\max}}{k}$$

Where
Y = synthesis or true yield.
k = maximum specific substrate utilization rate.
μmax = maximum specific growth rate,1/d

k

Kinetic Coefficients

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NET BIOMASS YIELD

The net biomass yield(Y_{net} or Y_{bio}) is different than the "true yield", it is defined as the ratio of net biomass growth rate to the substrate utilization rate. It includes biomass decay. It is used to estimate the amount of active microorganisms in the system.

$$Y_{net} = \frac{Net\_bio\_mass\_production\_rate}{substrate\_utilization\_rate}$$

$$Y_{net} = \frac{-r_g}{r_{su}}$$

$$Y_{net} = \frac{production\_rate - decay\_rate}{substrate\_utilization\_rate}$$

$$Y_{net} = \frac{Y}{1 + k_d \times SRT}$$

Where

Y_{net} = net biomass yield, g biomass (AVSS)/ g substrate used.

OBSERVED YIELD

The observed yield Y_{obs} is based on the actual measurement of the amount of solids production relative to the substrate removal.

$$Y_{obs} = \frac{Total\_MLVSS\_Production\_Rate}{Substrate\_removal\_Rate}$$

$$Y_{obs} = \frac{P_{X,VSS}}{Q(S_o - S)}$$

$$Y_{obs} = \frac{P_{X,TSS}}{Q(S_o - S)}$$

Where

Y_{obs} = observed yield, g VSS produced/g substrate removed.
g TSS produced/g substrare removed.

$P_{X,VSS}$ = net waste activated sludge produced, kg VSS/day.

$P_{X,TSS}$ = net waste activated sludge produced, kg TSS/day.

Q = Average influent flow

S_0 = influent substrate concentration (mg/l)

S = effluent substrate concentration (mg/l)

STOICHIOMETRY

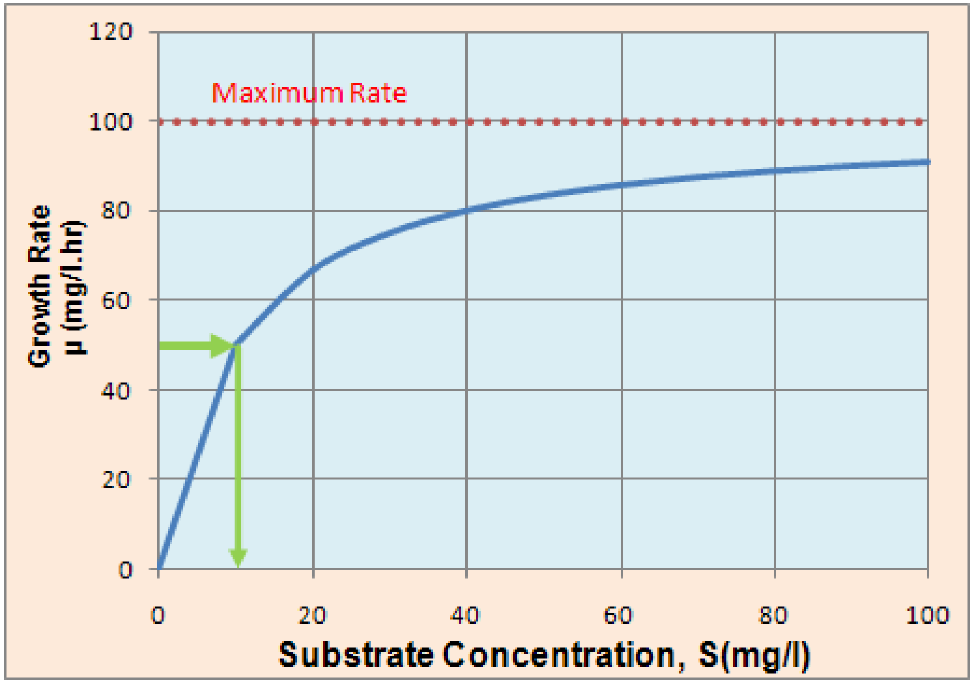
- Most simulation models base all calculations of organic material(including biomass) on COD.
- For practical purposes biomass has to be expressed as suspended solids.
- It is estimated that 1 gram of volatile suspended solids is equal to 1.42 gram of COD. This is based on the assumption that the composition of a typical bacterial cell(biomass) can be characterized as $C_5H_7NO_2$.

$$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3$$

- This implies that 160 g of oxygen are required(COD) to completely oxidize 113 g of biomass(VSS). Thus the COD/VSS ratio is 160/113=1.42

HALF-VELOCITY CONSTANT (K_S)

- The half-velocity constant is the value of the soluble substrate concentration at an one-half the maximum specific substrate utilization rate..



- The relationship developed by Monod(1949) forms basis for bacterial growth kinetics.
- Rate of bacterial growth and substrate utilization is a function of the concentration of the limiting substrate(e.g. BOD or NH3) surrounding the bacteria and the concentration of active bacteria.

Kinetic Coefficients

EFFECT OF TEMPERATURE ON KINETIC COEFFICIENTS

$$k_T = k_{20} \times \theta^{(T-20)}$$

Where

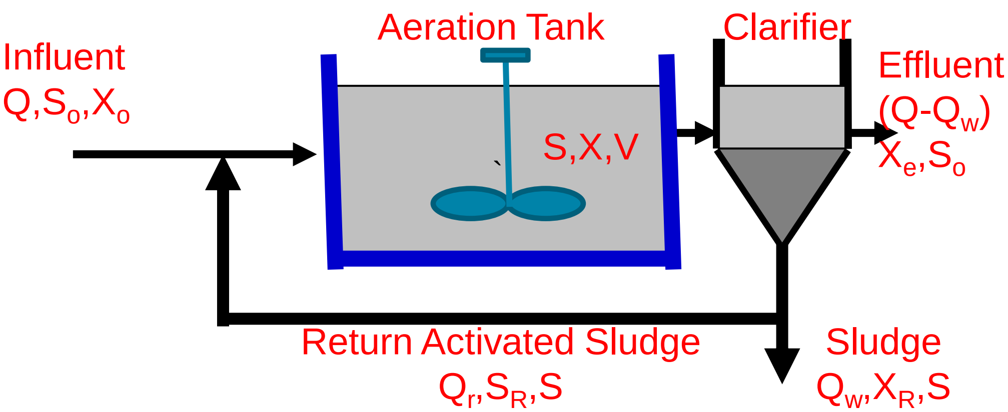
k_T = reaction rate coefficient at temperature T, ^oC.

k_{20} = reaction rate coefficient at 20 ^oC.

θ = temperature coefficient(1.02-1.25).

T = temperature, ^oC.

EFFLUENT DISSOLVED SUBSTRATE CONCENTRATION



$$S = \frac{K_S[1 + k_d SRT]}{SRT(Yk - k_d) - 1}$$

$$\mu_m = kY$$

$$S = \frac{K_S[1 + k_d SRT]}{SRT(\mu_m - k_d) - 1}$$

S

- The effluent soluble substare concentration for a complete mix activated sludge process is only a function of the SRT and kinetic coefficients for growth and decay.
- The effluent substrate concentration is not related to the influent soluble substrate concentration.
- The influent concentration affects the biomass concentration.

Where:
S : effluent soluble substrate concentration g BOD or bsCOD/m3
SRT : sludge age
μ_m = maximum specific growth rate,1/d.
K_S : Half-velocity constant
k_d : endogenous decay coefficient, g VSS/gVSS.d
Y : True yield heteretrophs.
k : Maximum specific substrate utilization rate

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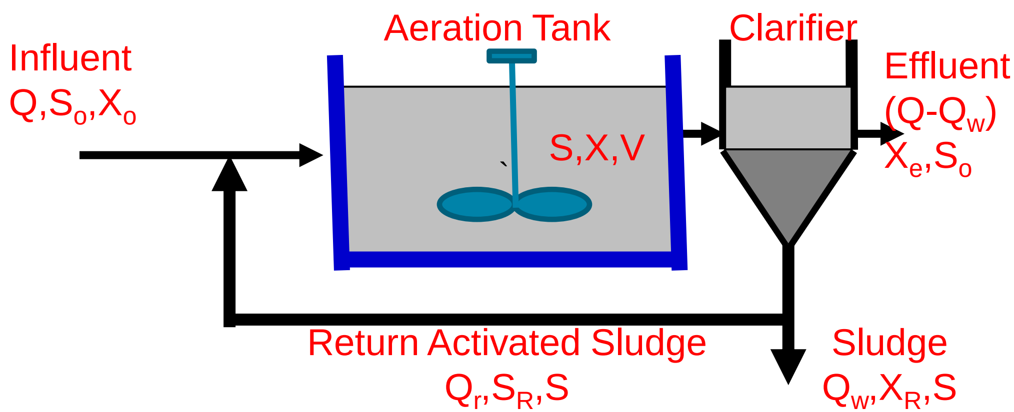
BIOMASS CONCENTRATION IN THE AERATION TANK



$$X = \left(\frac{SRT}{\tau}\right)\left[\frac{Y(S_o - S)}{1 + k_d SRT}\right]$$

$$\tau = \frac{V}{Q}$$

$$X = \left(\frac{SRT}{V}\right)\left[\frac{YQ(S_o - S)}{1 + k_d SRT}\right]$$

The reactor biomass concentration is function of:

- SRT
- Aerobic detention time.
- Yield coefficient
- Amount of substrate removed($S-S_o$).

Where:

X : Biomass concentration , g/m3
SRT : sludge age
k_d : endogenous decay coefficient, g VSS/gVSS.d
Y : True yield heterotrophs, mg VSS/mg BOD or COD
S_o : Influent soluble substare concentration g BOD or bsCOD/m3
S : Effluent soluble substarte concentration, BOD or bsCOD/m3.
τ : hydraulic detention time, V/Q, day.

AVSS Calculator

DECAY (LOSS OF BIOMASS)

CELL DEBRIS(ENDOGENOUS PRODUCTS)

- VSS in the bioreactors include:
  - Active biomass.
  - nbVSS in the influent wastewater.
  - Cell debris.
- Cell debris
  - The remaining non-biodegradable material after cell death and lysis.
  - Cell wall is non-biodegradable and contribute to the cell debris.
  - Cell debris represents about 10 to 15 percent of the original cell weight.
- The rate of production of cell debris is directly proportional to the endogenous decay rate.

$$r_{XD} = f_d \times k_d \times X$$

Where:
r_{XD} = rate of cell debris production, g VSS/m3.d
f_d = fraction of biomass that remains as cell debris(0.10-0.15 g VSS/g VSS)
k_d : endogenous decay rate, g VSS/gVSS.d
X = Active biomass concentration mg/l

Cell Debris Calculator

TOTAL VOLATILE SUSPENDED SOLIDS

Total Volatile suspended solids = Biomass production

+ nbVSS from cell debris

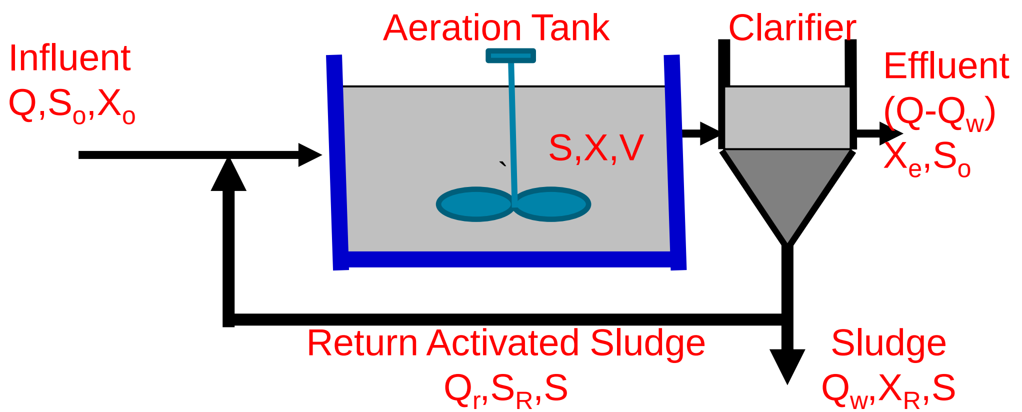
+ nbVSS in influent

ACTIVE BIOMASS(AVSS) FRACTION

$$F_{AVSS} = \frac{Net\_Biomass\_Production(growth - decay)}{MLVSS}$$

MODELLING SUSPENDED GROWTH TREATMENT PROCESSES
BIOMASS MASS BALANCE

Rate of accumulation of microorganisms within the system = Rate of flow of microorganisms into the system − Rate of flow of microorganisms out of the system + Net growth of microorganisms



GROWTH KINETICS FOR NITRIFICATIONS

$$\mu_n = \mu_{nm} \times \frac{N}{K_N + N} - k_{dn}$$

Assuming excess DO is available

$$\mu_n = \mu_{nm} \times \frac{N}{K_N + N} \times \frac{DO}{K_O + DO} - k_{dn}$$

Accounts for DO concentration

Where

μ_n = specific growth rate of nitrifying bacteria, g new cells/g cells.d

μ_{nm} = maximum specific growth rate of nitrifying bacteria, g new cells/g cells.d

N = nitrogen concentration, g/m3.

K_n = half-velocity constant for ammonia concentration, substrate concentration at one half the maximum specific substrate utilization rate, g/m3.

k_{dn} = endogenous decay coefficient for nitrifying organisms, g VSS/g VSS.d.

DO = DO concentration

K_O = half-velocity constant for DO concentration

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For further information

Website

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Thank you for your attention.

This Project is funded by the European Union

Appendix

MAXIMUM RATE OF SOLUBLE SUBSTRATE UTILIZATION (*k*)

- This coefficient is used for designing a complete-mix activated-sludge system and has to do with the biomass growth process. Substrate in biological processes used for wastewater treatment, referrers to the organic matter or nutrients in wastewater, that are converted during biological treatment or that may be limiting in biological treatment.
- In specific circumstances, there will be a certain rate with which the soluble substrate will be depleted by bacteria. At a high substrate concentration, the utilization rate will be high and will be practically even to the maximum rate of soluble substrate utilization

$$\mu_m = kY$$

ACTIVATED SLUDGE KINETIC COEFFICIENTS FOR HETEROTROPHIC BACTERIA-METCALF & EDDY FOURTH EDITION

Coefficient		Unit	Value @ 20 °C		Temp. Correction (θ Value)	
			Range	Typical	Range	Typical
Maximum specific bacterial growth rate	μ_m	gVSS/g VSS.d	3-13.2	6	1.03-1.08	1.07
Half-velocity constant	K_s	mg BOD/l	25-100	60	1	1
		mg bsCOD/l	10-60	40	1	1
		mg bCOD/l	5-40	20	1	1
True yield /Synthesis yield coefficient)	Y	mgVSS/mg BOD	0.4-0.8	0.6		
		mgVSS/mg bCOD	0.3-0.5	0.4		
Endogenous decay coefficient	k_d	g VSS/g VSS.day	0.06-0.2	0.12	1.03-1.08	1.04
Cell debris fraction	f_d	Unitless	0.08-0.2	0.15		

Source: Tale 8-10 Metcalf & Eddy, page 705.

COMPARISION OF TYPICAL KNETIC COEFFICIENTS FOR AEROBIC OXIDATION OF BOD

Parameter		Unit	Metcalf & Eddy/AECOM Fifth Edition		Metcalf & Eddy Fourth Edition	
			Range	Typical	Range	Typical
Maximum specific substrate utilization rate	k	b bsCOD/g VSS.d	4-12	6	2-10	5
Half-velocity constant	Ks	mg/l BOD	20-60	30	25-100	60
		mg/l bsCOD	5-30	15	10-60	40
True yield /Synthesis yield coefficient)	Y	mg VSS/mg BOD	0.4-0.8	0.6	0.4-0.8	0.6
		mg VSS/mg COD	0.4-0.6	0.45	0.3-0.6	0.4
Endogenous decay coefficient	b,kd	g VSS/g VSS.d	0.06-0.15	0.1	0.06-0.15	0.1

ACTIVATED SLUDGE KINETIC COEFFICIENTS FOR NITRIFYING BACTERIA

Coefficient		Unit	Value @ 20 °C		Temp. Correction (θ Value)	
			Range	Typical	Range	Typical
Maximum specific growth rate of nitrifying bacteria	μ_{mn}	gVSS/g VSS.d	0.2-0.9	0.75	1.06-1.123	1.07
Half-velocity constant for ammonia concentration	K_n	mg NH4-N/l	0.5-1	0.74	1.06-1.123	1.053
Biomass true yield /Synthesis yield coefficient)	Y_n	mgVSS/mg NH4-N	0.1-0.15	0.12		
Endogenous decay coefficient for nitrifying organisms	k_{dn}	g VSS/g VSS.day	0.05-0.15	0.08	1.03-1.08	1.04
Half-velocity constant for dissolved -oxygen concentration	K_o	mg/l	0.40-0.60	0.5		

Ks

Y

Source: Tale 8-11 Metcalf & Eddy, page 705.