The IWA activated sludge models (ASM1, 2d and 3)

description of components and processes

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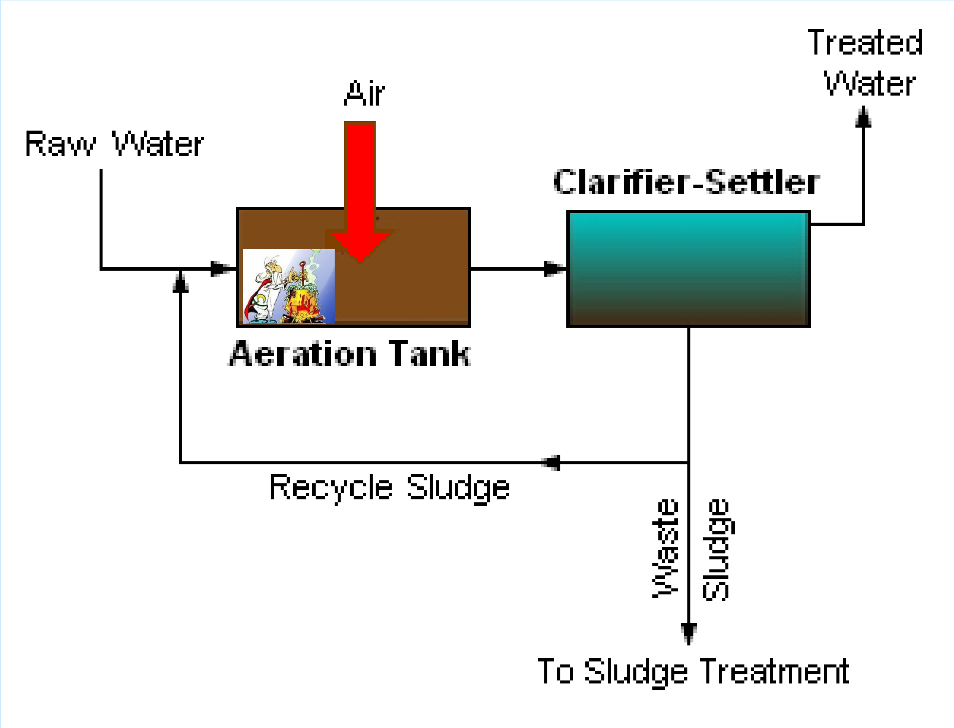
The activated sludge process

In the aeration tank, microorganisms aggregated in ‘flocks’ oxidize organic pollutants to CO_2 and synthesize new cells. Bacteria are separated from the treated water in the settling unit.

Excess sludge is removed and sent to the sludge treatment line



Microorganisms are the main actors in the system

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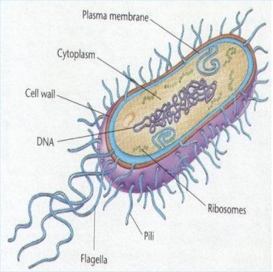


What microorganisms do?

Microorganisms, as humans, performe two kind of biochemical processes:

1) **Anabolisms** that is the process of building-up new biomass form elementar sources

C-source + N-source + P-source + H^+ *+* $CO_2 \rightarrow CH_hO_oN_n$ *(es:* $CH_{1.8}O_{1.2}N_{0.2}$*)* (by neglecting here micronutrients)

But this reaction has a positive ΔG → it does not proceed spontaneously in nature

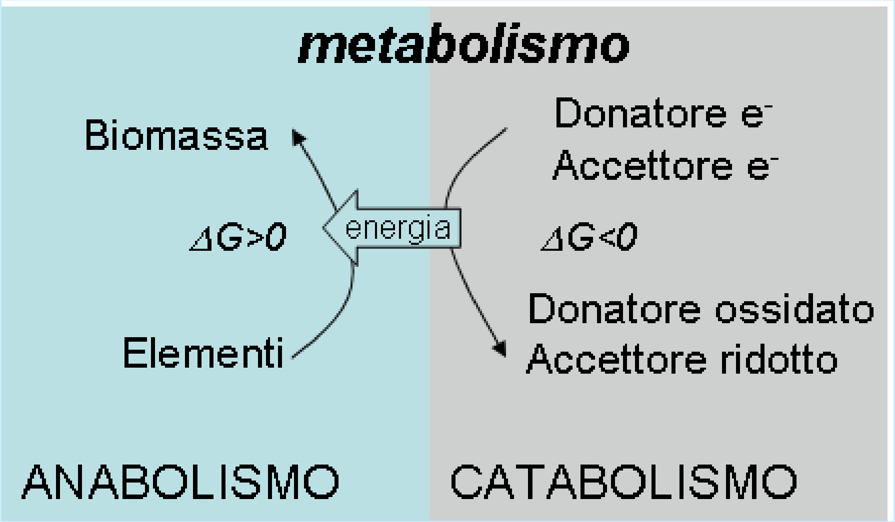
→ Anabolism has to be coupled to a negative ΔG process → catabolism

2) **Catabolism** is the process that furnishes the required energy to the bug to grow.

A typical catabolic process is a redox reaction

Electron donor + Electron acceptor → oxidised donor + reduced acceptor

What microorganisms do?



Microorganisms can be classified according to their ‘tastes’, i.e. according to what they select as:

- C-source: CO_2 (autotrophs), organic mater (heterotrophs);
- Energy source: light (phototrophs), chemical energy (chemotrophs);
- Electron donor: inorganic (lithotrophs), organic (organotrophs);
- Electron acceptor: (O_2, NO_3^-, $SO_4^=$, organic matter)

Metabolic stoichiometry

All this info are summarized in the stoichiometry of the methabolic bioreaction.

General formulation:

$$\alpha_1 \cdot (e - Don) + \alpha_2 \cdot (e - Acc) + \alpha_3 \cdot (N - source) + \alpha_4 \cdot (H_2O) + \alpha_5 \cdot (CO_2) + \alpha_6 \cdot (H^+) \rightarrow$$
$$\rightarrow 1 \cdot (Biomass) + \alpha_7 \cdot (red\text{ - }acc) + \alpha 8 \cdot (ox\text{ - }don)$$

To define it, we need to know:

-The chemical formula of bug-cells;

-What they like more as substrates

-At list one among the stoichiometric coefficients (by experimental determination) (usually α_1 *or* α_2).

All others α_i comes from the mass and charge balancing

Metabolic stoichiometry

Example: NITRIFIERS

Let us consider nitrifying bacteria = autotrophs, chemo-lithotrophs, aerobic

- Their e-acceptor = O_2 (dissolved oxygen)
- Their e-donor = ammoniacal nitrogen (that is also their preferential N-source) which is oxidized to nitrates
- Their biomass composition is: $C_5H_7O_2N$

↓

Substrates: CO_2 (*autotrophs*), O_2 (*aerobic*), NH_4^+ (e-donor & N-source), H^+ (for charge balance)

Products: biomass, rex-acc (H_2O), ox-donor (nitrate)

↓

$$\alpha_1 NH_4^+ + \alpha_2 O_2 + \alpha_3 H^+ + \alpha_4 CO_2 \rightarrow 1 C_5H_7O_2N + \alpha_5 H_2O + \alpha_6 NO_3^-$$

We have <u>*measured*</u> that for each mole of N that is oxidized, 0,1 mol of C can be converted into biomass

Metabolic stoichiometry

Example: NITRIFIERS

$$\alpha_1 NH_4^+ + \alpha_2 O_2 + \alpha_3 H^+ + \alpha_4 CO_2 \rightarrow 1 C_5H_7O_2N + \alpha_5 H_2O + \alpha_6 NO_3^-$$

We have

- –6 unknowns,
- –6 equations (1 experimental data + 4 mass balances + 1charge balance)

$$\begin{cases} \text{experimental measure}: \dfrac{\alpha_1}{5} = \dfrac{1}{0{,}1} \\ C: \quad \alpha_4 = 5 \\ H: \quad 4\alpha_1 + \alpha_3 = 7 + 2\alpha_5 \\ O: \quad 2\alpha_2 + 2\alpha_4 = 2 + \alpha_5 + 3\alpha_6 \\ N: \quad \alpha_1 = 1 + \alpha_6 \\ +/-: \quad \alpha_1 + \alpha_3 + \alpha_6 = 0 \end{cases}$$

By solving it: $\alpha_1 = 50; \alpha_2 = 93; \alpha_3 = -99; \alpha_4 = 5; \alpha_5 = 47; \alpha_6 = 49$

Metabolic stoichiometry

Example: NITRIFIERS

The final formulation is

$$50NH_4^+ + 93O_2 + 5CO_2 \rightarrow 1C_5H_7O_2N + 47H_2O + 49NO_3^- + 99H^+$$

NB: a negative coefficient for H^+ means that it has to be listed among the products

The same info can be rewritten with reference to the unit of oxidised ammonium:

$$NH_4^+ + 1{,}86O_2 + 0{,}1CO_2 \rightarrow 0{,}02C_5H_7O_2N + 0{,}98NO_3^- + 1{,}98H^+ + 0{,}94H_2O$$

Metabolic stoichiometry

Example: NITRIFIERS

In practical applications, moles are rarely used as a measuring unit. Widely applied measuring unit are:

- mgN/L for ammonia and nitrate
- mgCOD/L for biomass,
- mgO2/L for dissolved oxygen
- mmol/L for alkalinity

Moreover, some chemicals can be neglected for simplicity (water, gaseous products…)

→The bioreaction stoichiometry has to be rewritten according to these conventional measuring units and in view of the practical application

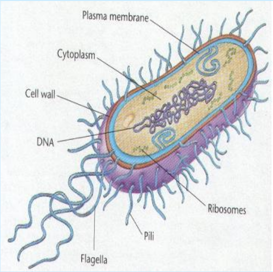
Converting units

From chemical formulas it is easily deducted that:

1 mol NH_4^+=14 gN
1 mol O_2 = 32 gO_2
1 mol NO_3^-=14 gN

But …

…. What is COD??



Converting units

When bioreactions involve organic substances, their concentration is often expressed in terms of

COD = chemical oxygen demand

that represents the oxygen request for the oxidation of the organic compounds to CO_2. The amount of oxygen requested is proportional to the amount of electrons that can be transferred and, thus, to the '*degree of reduction*' or '*chemical energy*' of this organic compound.

$O_2 + 4e^- + 4H^+ \rightarrow 2\ H_2O$ thus

4 moli e^- = 32 g O_2 → **1 mole e^- =** 8 g O_2 = **8 g COD**

Converting units

This ***oxygen request*** can be:

•theoretically quantified if the chemical formula of the organic substrate is known

•experimentally evaluated when the chemical composition is unknown (complex wastewaters)

•Example: Determination of the COD content of biomass ($C_5H_7O_2N$).

The complete oxidation of biomass to CO_2, and NO_3 has to be balanced:

$$C_5H_7O_2N + a \cdot O_2 \rightarrow b \cdot CO_2 + c \cdot H_2O + d \cdot NO_3^- + e \cdot H^+$$

Stoichiometric coefficients are calculated by mass and charge balances:

Mass balance for C:	b=5;
Mass balance for N:	d=1;
Charge balance:	e=1;
Mass balance for H:	c=3;
Mass balance for O:	a=7

Therefore: $C_5H_7O_2N + 7 \cdot O_2 \rightarrow 5 \cdot CO_2 + 3 \cdot H_2O + 1 \cdot NO_3^- + 1 \cdot H^+$

→ 1 mmol $C_5H_7O_2N$ = 7·32 mgCOD = 224 mgCOD.

Converting units

Example: Lets write the nitrification reaction stoichiometric coefficients:

$$NH_4^+ + 1{,}86O_2 + 0{,}1CO_2 \rightarrow 0{,}02C_5H_7O_2N + 0{,}98NO_3^- + 1{,}98H^+ + 0{,}94H_2O$$

according to different M.U.:

- mgN/L for ammonia and nitrate
- mgCOD/L for biomass, and other carbonaceous substrates
- mgO2/L for dissolved oxygen
- mmol/L for H^+ and alkalinity

Required conversion coefficients:

1 mmol $C_5H_7O_2N$ = 7·32 mgCOD = 224 mgCOD.

1 mmol O2 = 32 mg O_2

1 mmol H^+= -1mmol Alk.

CO_2 is a carbonaceous substrate but his COD = 0 (it cannot be further oxidized)

1 mmol CO_2 = 0 mgCOD

1 mol NH_4^+ = 14 mg N (from its chemical composition).

1 mol NO_3^- = 14 mg N (from its chemical composition).

Water is normally neglected

So the reaction stoichiometry can be expressed as:

(14 mgN/L) ammonium + (1,86x32) mg/L O_2 → (0,02x224) mgCOD/L biomass + (0,98x14) mgN/L NO_3^- - 1,98 mmolAlk/L

Converting units

$$NH_4^+ + 1{,}86O_2 + 0{,}1CO_2 \rightarrow 0{,}02C_5H_7O_2N + 0{,}98NO_3^- + 1{,}98H^+ + 0{,}94H_2O$$

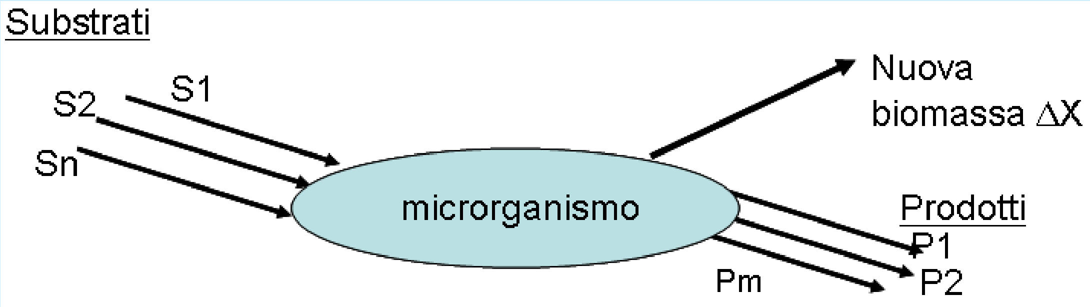
(14 mgN/L) ammonium + (1,86x32) mg/L O_2 → (0,02x224) mgCOD/L biomass + (0,98x14) mgN/L NO_3^- - 1,98 mmolAlk/L

We can refer stoichiometric coefficients with respect to the unit of new biomass that is formed, this is done by dividing all coefficient by (0,02x224):

(3,124 mgN/L) ammonium + (13,29) mg/L O_2 → (1) mgCOD/L biomass + (3,06) mgN/L NO_3^- - (0,44) mmolAlk/L

Metabolic stoichiometry

When considering heterotrophic microorganisms, the use of COD is very convenient, since the metabolic reaction can by synthetically expressed as:



$$S + (1-Y)\cdot O_2 \rightarrow Y\cdot X$$

- S = org. substrate (mgCOD)
- O_2 = oxygen (mgCOD)
- X = biomass (mgCOD)

This means that per unit of chemical energy in S:

- a fraction = Y (*growth yield*) is converted into new biomass
- a fraction = (1-Y) is ‘burned’ to get energy for the cell