

2.3.1 Oxidative metabolism

First the metabolism of heterotrophs in an aerobic environment will be considered. In this case the catabolic process will be the oxidation of organic material by oxygen, also called aerobic respiration. The anabolic process will be the synthesis of cellular material from organic material. It is concluded that the organic material represents both an energy source and a material source for the micro-organisms. Fig. 2.3 schematically displays the metabolism of organic material by heterotrophic bacteria in an aerobic environment.

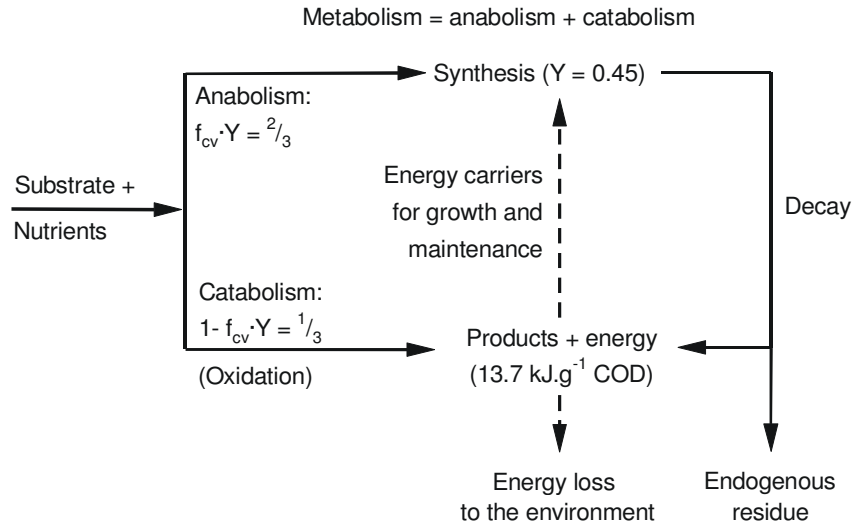


Figure 2.3 Metabolism of organic material in an aerobic environment

The processes of catabolism and anabolism are interdependent: without anabolism it is not possible to maintain a living micro-organism mass and consequently metabolism itself would be impossible. On the other hand, anabolism is an energy demanding process and the micro-organisms obtain this energy from the catabolic activity. Hence anabolism is necessary for catabolism and vice-versa.

The processes of catabolism and anabolism result in measurable phenomena. Oxidation of organic material leads to consumption of dissolved oxygen and this consumption can be measured by respirometric techniques (Spanjers et al, 1996). Furthermore the generated microbiological mass can be detected by the increase in (volatile) suspended solids content (gram VSS). This parameter can be determined as the difference between the weight of a dried sample at 103°C (total suspended solids, TSS) and the weight of the same sample after combustion of the organic material at a temperature of 550°C (fixed of inorganic suspended solids, FSS) The mass difference is equal to the mass of volatile suspended organic material. Experimental details of the determination of volatile solids can be found for example in Standard Methods (2002).

Experimental results indicate that the production of bacterial mass is in the range of 0.35 g to 0.52 g VSS per gram of metabolised COD, while an average value of $0.45 \text{ g VSS.g}^{-1} \text{ COD}$ is often reported and will be adopted in this text. The proportion between the synthesised microbial mass and the metabolised COD mass is called the yield coefficient Y .

To determine which fraction of the metabolised COD is used for anabolism, the COD value of a unit mass of micro-organisms (f_{cv}) must be determined. Several researchers suggested empirical structural formulae and calculated on that basis experimental values of f_{cv} as shown in Table 2.5. Marais and Ekama (1976) found an average value of 1.48 mg COD.mg⁻¹ VSS in a very extensive research project. Another investigation in Brazil led to a f_{cv} value of 1.50 mg COD.mg⁻¹ VSS for micro-organisms generated from raw sewage (Dias, 1981).

Table 2.5 Calculated values of the f_{cv} ratio for different empirical formulas of microbial composition (McCarty 1964)

Structural formula	Molar weight	COD per gram	Reference
C ₅ H ₇ O ₂ N	113	1.42	Hoover and Porges (1952)
C ₅ H ₉ O ₃ N	131	1.22	Speece and McCarty (1964)
C ₇ H ₁₀ O ₃ N	156	1.48	Sawyer (1956)
C ₅ H ₈ O ₂ N	114	1.47	Symons and McKinney (1958)

Accepting the sludge mass parameters $Y = 0.45$ mg VSS.mg⁻¹ COD and $f_{cv} = 1.48$ mg COD.mg⁻¹ VSS, the fraction of organic material that is anabolised in the aerobic environment can now be calculated. Upon metabolism of 1 gram of COD, the obtained micro-organism mass is Y gram with a COD mass of $f_{cv} \cdot Y$ gram. Hence, the remainder $(1 - f_{cv} \cdot Y)$ g COD will be catabolised. Per definition, the required oxygen mass for this catabolism is equal to $(1 - f_{cv} \cdot Y)$. Numerically one has $f_{cv} \cdot Y = 1.48 \cdot 0.45 = 0.67$ and $(1 - f_{cv} \cdot Y) = 0.33$. It is concluded that in an aerobic environment a fraction of 0.67 or $\frac{2}{3}^{rd}$ of the metabolised organic material is anabolised, whereas a fraction of 0.33 or $\frac{1}{3}^{rd}$ is oxidised.

Figure 2.3 shows an aspect of metabolism that has not yet been discussed. The cellular mass itself contains biodegradable organic material and can be oxidised, at least partially. The oxygen consumption due to oxidation of the cellular material is called endogenous respiration, to distinguish it from the consumption for oxidation of extra-cellular material denominated exogenous respiration.

In Fig. 2.3 it is indicated that only a part of the cellular mass is oxidised. The remaining non biodegradable solids, called the endogenous residue, are a fraction $f = 0.2$ of the decayed micro-organism mass. In Chapters 3 and 8 the stoichiometric and kinetic aspects of the degradation of cellular mass and the consequential oxygen consumption and endogenous residue generation are discussed in detail.

Example 2.5

Calculate the ultimate BOD value of a solution that contains a theoretical COD concentration of 1 g.l^{-1} , composed of biodegradable organic material.

Solution:

During the metabolism of 1 g COD.l^{-1} of biodegradable organic material, there is a synthesis of microbial mass of $Y = 0.45 \text{ g VSS}$. After endogenous respiration, an endogenous residue of $f \cdot Y = 0.2 \cdot 0.45 = 0.09 \text{ g VSS}$ will remain. This residue will have a COD mass of $f_{cv} \cdot f \cdot Y = 1.5 \cdot 0.2 \cdot 0.45 = 0.135 \text{ g COD}$, so that $1 - 0.135 = 0.865 \text{ g COD}$ was oxidised. For this oxidation an oxygen mass of 0.865 g O_2 was required.

It is concluded that in a solution with 1 g.l^{-1} of biodegradable organic material (present as COD), the oxygen consumption after completing endogenous respiration is 0.865 g.l^{-1} or equivalently, the BOD is 0.865 g.l^{-1} or 865 mg.l^{-1} . Hence, even in the case that all the biological oxygen demand of biodegradable organic material is satisfied, theoretically the oxygen consumption will only be 86.5 percent of the chemical oxygen demand.