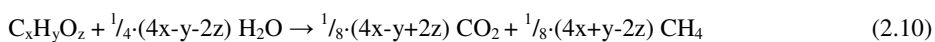


2.3.3 Anaerobic digestion.

In the preceding sections some aspects of aerobic (or oxic) metabolism have been discussed. However, there are also micro-organisms that can metabolise organic material even in the absence of an oxidant, a process that is called fermentation. It results in a rearrangement of the electrons in molecules of the metabolised compound in such a fashion that at least two new molecules are formed. Sometimes only one particular type of molecule is formed, but in general different types of molecules are produced, one being more oxidised and the other one being more reduced than the original molecule.

Fermentations are of very great importance in the food industry (e.g. for the production of cheese, yoghurt and beer). In sanitary engineering, the fermentation of particular interest is anaerobic digestion. This fermentation is characterised by the fact that the end products are methane and carbon dioxide. The particularity is that methane cannot be further reduced and carbon dioxide cannot be further oxidised, so that anaerobic digestion is the most complete of all fermentation processes. For a compound $C_xH_yO_z$ the anaerobic digestion process can be written as:



Example 2.7

What is the theoretical composition of biogas generated by the fermentation of ethanol ?

Solution:

For ethanol one has $x = 2$, $y = 6$ and $z = 1$, thus per mol digested $C_xH_yO_z$ an amount of $\frac{1}{8} \cdot (4 \cdot 2 - 6 + 2 \cdot 1) = \frac{1}{2}$ mol CO_2 and $\frac{1}{8} \cdot (4 \cdot 2 + 6 - 2 \cdot 1) = 1 \frac{1}{2}$ mol CH_4 are formed. Hence, the theoretical biogas composition will be 75 percent methane and 25 percent carbon dioxide. In practice, the gas will be richer in methane, because of the higher solubility of carbon dioxide in water, so less will escape to the gas phase.

As in the anaerobic digestion process there is no oxidation of organic material (no oxidant is available), the electron transfer capacity does not change and will end up in the formed methane, which has a chemical oxygen demand of $4 \text{ g COD} \cdot \text{g}^{-1} CH_4$. It can be concluded that in order to produce 1 gram of methane, the mass of organic material to be digested is equal to 4 gram COD. Therefore the mass of generated methane will be $\frac{1}{4}$ th of the digested COD mass.

An aspect of great importance concerns the energy involved in anaerobic digestion. Different from the oxidative catabolism that results in the destruction of organic material, fermentation only converts the organic material and a large proportion of the chemical energy is transferred to the formed methane. It was shown in Section 2.3 that the free energy release upon oxidation of "normal" organic material is approximately $13.7 \text{ kJ} \cdot \text{g}^{-1} \text{ COD}$ (see Fig 2.2). Furthermore, in the same figure, it can be seen that the free energy release for the oxidation of methane is $12.4 \text{ kJ} \cdot \text{g}^{-1} \text{ COD}$. Thus, it can be concluded that the anaerobic digestion of organic material results in a free energy release of only $13.7 - 12.4 = 1.3 \text{ kJ} \cdot \text{g}^{-1} \text{ COD}$. Hence, the free energy release of the anaerobic digestion process is much smaller (about $\frac{1}{10}$ th) of the energy release from the oxidation of organic material.

The consequence of this small energy release is that more organic material must be converted into methane for the bacteria to obtain the same amount of energy required for anabolism.

This leads to the conclusion that the proportion of catabolised material to anabolised material will be much larger in the case of anaerobic digestion than in the case of aerobic metabolism. In practice 90 to 95 percent of the digested organic material is transformed into methane and only 5 to 10 percent is synthesized. In contrast, in aerobic metabolism only 33 percent of the organic material is catabolised and 67 percent is synthesized. In the activated sludge process anaerobic digestion can be applied to reduce the mass of excess sludge produced and/or as a pre-treatment process to reduce the organic load to the activated sludge process. These applications of anaerobic digestion are discussed in Chapters 8 and 9.