Dynamic Energy Budgets – Tele-course 2005

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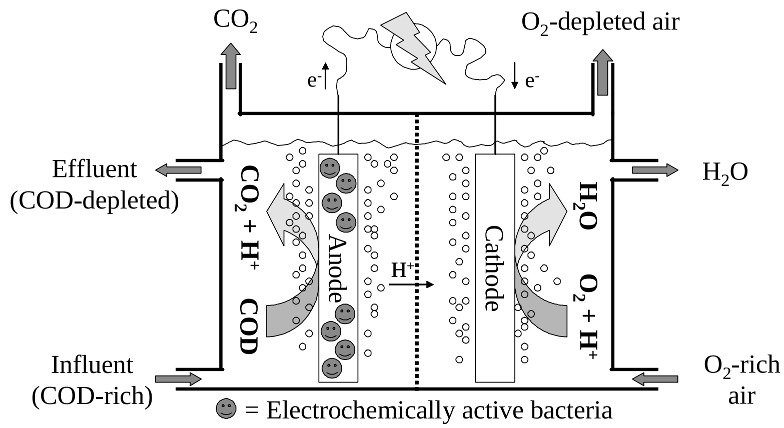
Subprogram: Population Dynamics

General Paragraph

My main interest is in the field of environmental biotechnology, especially wastewater treatment technology. In my daily work I therefore do a lot with the application of micro-organisms (especially mixed cultures of bacteria). Because of my education in this field I am used to applying Monod type relationships that do not include reserves in the calculations. For most applications these Monod type relationships function adequately, but there are several practical wastewater treatment processes that are based on the formation of reserves (e.g. biological phosphate removal, bioplastic production, etc.). Furthermore, I can imagine that reserve formation by micro-organisms can be an important feature for developing new wastewater treatment technologies. It might seem straightforward, but the inclusion of reserves in the DEB model is therefore one of the most important benefits for me. Next, it was also very good for me to learn that asexually propagating unicellular organisms (like bacteria) can be treated as juveniles through the whole DEB model. This eliminates the complete kappa rule for my application and makes things much simpler mathematically. From this perspective it was also good to learn that bacteria can be regarded as V1-morphs under most circumstances, so that the DEB model behaves identically on the individual and the population level. Also this makes the application much simpler. This simplicity is actually something that is of ultimate importance for me. This is because I hope that the DEB model will proof to be a predictive tool to me, next to being a descriptive tool. Besides using the DEB model in combination with measured data, I hope I can use the DEB model to make predictions without measured data, but with the aid of parameter estimations based on thermodynamics (e.g. J.J. Heijnen, Bioenergetics of Microbial Growth, Encyclopedia of Bioprocess Technology: Fermentation, Biocatalysis, and Bioseparation, John Wiley & Sons, Inc, 267-291 (1999)). This is especially important when working with mixed populations of bacteria (as in wastewater treatment), where specific reactor conditions and process design will determine the outcome of the process. In these systems natural selection plays a most important role, which can be understood to some extend by looking at the thermodynamics and kinetics of the involved reactions. More and more wastewater engineers are focussing on trying to make products (e.g. hydrogen) from wastewaters, instead of just oxidizing all organic pollutants to carbon dioxide. DEB could play an important role for predicting this product formation. Whether, it will be possible to make these kind of predictions, I couldn't really get from the DEB book. In the DEB book parameters are almost solely estimated from data fitting. Maybe the combination of DEB with parameter estimation from thermodynamics could be a new field for future DEB research.

Specific Paragraph

At the moment I am doing a PhD study on microbial fuel cells. A microbial fuel cell is an electrochemical device that is capable of converting organic pollutants (i.e. COD) in wastewaters to electricity. This is achieved by using electrochemically active micro-organisms that attach to an electrode surface. Schematically a microbial fuel cell can be depicted as follows:



The system consists of two compartments (anode and cathode), that are separated by a proton exchange membrane. Organic pollutants (COD) in wastewater enter the anode compartment of the electrochemical cell and are converted to carbon dioxide, protons and electrons by the electrochemically active micro-organisms on the anode. At a certain energy level these electrons are then transferred by the micro-organisms to the electrode surface and are transported to the cathode via the electrical circuit (current!!!). At the same time protons travel through the electrolyte (the aqueous medium and the membrane) from the anode to the cathode. From the cathode the electrons are subsequently transferred to oxygen (the electron acceptor). Together with the protons, water is then formed at the cathode. Overall, one can say the organic pollutants in the wastewater are combusted with oxygen. However, instead of only producing heat, also electricity is produced. Depending on the potential at which the electrons are released and the rate at which they flow, a certain amount of electrical power is generated.

Because this technology is relatively new, many aspects have not yet been investigated thoroughly. One of these aspects is the biological anode itself, which is covered with the electrochemically active micro-organisms. Up till now, people dealt with the anode more or less as a black box. Now it is time to go into more detail. This is where I hope DEB can help me.

From thermodynamics it is quite easy to calculate the maximally possible anode potential (i.e. highest possible energy level of the released electrons) from a certain substrate. However, because the micro-organisms need some energy themselves, the practically found anode potential is always lower than this calculated value. Using DEB I hope we will be able to understand this better and maybe find a way of predicting the potential. A bottleneck for this could be that we solely work with mixed cultures of bacteria. All these different species of micro-organisms probably behave quite differently. Furthermore, we work with mixed substrates (wastewater!).

My modelling strategy would be to start with a simple model that is completely directed towards maintenance (i.e no growth). In practise, wastewater treatment systems are commonly operated as close to the "pure maintenance" case as possible. In those cases you allow just enough growth to keep the microbial population viable. This is done, because excess sludge is expensive to dispose of.

In a later modelling stage, some growth might be allowed, but then some difficulties come in with respect to the choice of the correct morphology. In the case that the electrode surface is still not completely covered, twice as much bacteria, gives twice as much electroactive surface area. In that case V1 morphology would suffice. However, in the case the electrode surface is already completely covered and growth still occurs, twice as much bacteria does not give twice as much electroactive surface area… Another thing we still not sure of, is whether the anode operates as a monolayer of bacteria or if multilayer systems are also possible, i.e. do these electrochemically active micro-organisms conduct the electrons themselves as well. Still a lot of questions; hopefully DEB can help with the answers.