IB01x - 3.3 - Energy consuming and energy producing products

In the previous unit it has been shown that all q-values depend only on cs, when we design the nutrient supply such that substrate is limiting. Also all q-values are flux coupled to each other which makes qp, µ and all other q-rates only dependent on cs. This is the basis of black box models. Also we already mentioned 2 product classes. When the synthesis of product costs energy the process must be aerobic because substrate needs to be oxidized which will supply energy for the product reaction. When the product makes energy an anaerobic process is possible because oxidation of substrate is not needed anymore. Now we will have a better look at these two product classes from the point of view of setting up a black box model.

For both product classes substrate is taken up by a transporter, following a hyperbolic function in cs as discussed in the previous unit. This function has 2 parameters qs,max and Ks. Both parameters are assumed to be constant for a given organism-substrate combination and a defined T and pH and needs to be determined. Whether you are working with an energy consuming or energy producing product, both follow the same kinetic format for substrate uptake.

All microorganisms have to maintain their structure integrity against constant leakage of molecules over membranes and degradation of cellular polymers. To counteract these degrading processes like pumping out leaked molecules and repair of degraded molecules, the cells must spent energy at a continuous rate, which requires substrate catabolism at a maintenance rate ms. This already shows that part of the substrate taken up is used for maintenance. Also important is to realize that aerobic ms-values are about a factor 10 lower then anaerobic mss values because the energy produced per mol glucose is aerobically roughly tenfold higher.

Having discussed the common aspects, hyperbolic substrate uptake and maintenance, we must now engage in the differences for the 2 product categories. Let us first discuss energy consuming products such as the current PDO process. The substrate taken up is distributed over 3 network processes: formation of biomass with rate µ and consumption of a mol substrate per produced mol x, leading to a partials substrate consumption rate for growth equal to a*µ, formation of product with rate qp and consumption of b mol substrate for each mol produced product leading to a partial substrate consumption rate for product equal to b*qp and finally maintenance with a substrate consumption rate ms. Please note that each of the 3 processes requires energy making the aerobic process necessary. We can put our insight into an equation where we can trace back where our substrate is going to as shown in the image. This is the Herbert-Pirt substrate distribution relation with 3 terms. Moreover the cell has a branch point where substrate goes either to biomass or to product. We call this kinetic coupling where qp and µ are coupled to each other in a non-linear way.

So let us now construct a black box aerobic model for PDO. The glucose uptake rate qs is a hyperbolic relation in cs as shown. The Herbert-Pirt relation is also given. Finally we have a nonlinear qp(μ) relation. By combining these equations you can see that we have three equations and four variables which are cs, qs, qp and μ. Therefore we have one free variable. This free variable can be cs where we recall the substrate limiting conditions. Another practical choice of the free variable is μ because one can manipulate this in a chemostat as shown last week.

From an economic point of view the ratio qs/qp is relevant because it gives mol glucose consumed per mol product PDO for your process. The Herbert-Pirt substrate distribution relation and the qp(μ) relation can be combined to show this qs/qp ratio which is only a function of the free variable μ.

The graph shows you that there is an optimal growth rate where the consumed glucose per mol PDO is the lowest. Calculation show that the optimal growth rate is at 0.0245h-1. At this optimal μ-value you can calculate the optimal production rate qp, opt and the optimal substrate uptake rate qs, opt finding that 1 mol PDO requires minimally 1.29 mol glucose. This is higher than the value of 0.80 mol glucose per mol PDO found in the Herbert-Pirt relation, because in the process glucose is also used for making biomass and is oxidized to provide energy for maintenance.

By using the Herbert-Pirt relation, we can also calculate how at μopt=0.0245, the consumed glucose is distributed over growth, production and maintenance. We see that 62% of glucose is used for making PDO, 17% is used for maintenance and 21% for growth.

Let us now consider the black box model for an energy producing product, for example ethanol from glucose. The cell now has only 2 processes, namely biomass formation and maintenance. In the biomass formation process substrate is used with a mols for 1 mol biomass, leading to a partial substrate consumption rate a*μ. Maintenance has a partial substrate consumption rate ms. Both processes require energy which is expressed by stoichiometric coupling to the production of energy generating ethanol in both processes. This leads to a Herbert-Pirt relation of only 2 terms and a linear qp(μ) relation as you can see.

We can now summarize our insight in black box models for the 2 product categories and we see that these are partly similar, like the substrate uptake, and partly different, like the qp(μ) relation (non linear or linear) and the Herbert-Pirt relation (3 terms or 2 terms).

Next time we will focus on the parameterization of the black box models.