while for CO_2 the maximum yield is

$$Y_{CO_2/S} = \frac{2(44)}{180} = 0.49 \text{ g ethanol/g glucose}$$

In practice, these maximal yields are not obtained. The product yields are about 90% to 95% of the maximal values, because the glucose is converted into biomass and other metabolic by-products (e.g., glycerol or acetate).

7.5. SUMMARY

Simple methods to determine the reaction stoichiometry for bioreactors are reviewed. These methods lead to the possibility of predicting yield coefficients for various fermentations using a variety of substrates. By coupling these equations to experimentally measurable parameters, such as the respiratory quotient, we can infer a great deal about the progress of a fermentation. Such calculations can also assist in initial process design equations by allowing the prediction of the amount of oxygen required (and consequently heat generated) for a certain conversion of a particular substrate. The prediction of yield coefficients is not exact, because unknown or unaccounted for metabolic pathways and products are present. Nonetheless, such calculations provide useful first estimates of such parameters.

SUGGESTIONS FOR FURTHER READING

ATKINSON, B., AND F. MAVITUNA, *Biochemical Engineering and Biotechnology Handbook*, Macmillan, Inc., New York, 1983.

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ERICKSON, L. E., AND D. Y.-C. FUNG, *Handbook on Anerobic Fermentations*, Marcel Dekker, Inc., New York, 1988. (Five chapters deal with bioenergetics, stoichiometry, and yields.)

———, I. G. MINKEVICH, AND V. K. EROSHIN, Application of Mass and Energy Balance Regularities in Fermentation, *Biotechnol. Bioeng. 20*:1595, 1978.

MINKEVICH, I. G., Mass and Energy Balance for Microbial Product Synthesis: Biochemical and Cultural Aspects, *Biotechnol. Bioeng. 25*:1267, 1983.

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PROBLEMS

7.1. Determine the amount of $(NH_4)_2SO_4$ to be supplied in a fermentation medium where the final cell concentration is 30 g/l in a 10^3 l culture volume. Assume that the cells are 12% nitrogen by weight and $(NH_4)_2SO_4$ is the only nitrogen source.

7.2. The growth of baker's yeast (*S. cerevisiae*) on glucose may be simply described by the following equation:

$$C_6H_{12}O_6 + 3\ O_2 + 0.48\ NH_3 \longrightarrow \underset{\text{yeast}}{0.48\ C_6H_{10}NO_3} + 4.32\ H_2O + 3.12\ CO_2$$

In a batch reactor of volume 10^5 l, the final desired yeast concentration is 50 gdw/l.

Using the above reaction stoichiometry:

a. Determine the concentration and total amount of glucose and $(NH_4)_2SO_4$ in the nutrient medium.

b. Determine the yield coefficients $Y_{X/S}$ (biomass/glucose) and Y_{X/O_2} (biomass/oxygen).

c. Determine the total amount of oxygen required.

d. If the rate of growth at exponential phase is $r_x = 0.7$ gdw/l-h, determine the rate of oxygen consumption (g O_2/l-h).

e. Calculate the heat-removal requirements for the reactor (recall eq. 6.26).

7.3. The growth of *S. cerevisiae* on glucose under anaerobic conditions can be described by the following overall reaction:

$$C_6H_{12}O_6 + \beta\ NH_3 \longrightarrow 0.59\ CH_{1.74}N_{0.2}O_{0.45}\ \text{(biomass)} + 0.43\ C_3H_8O_3 + 1.54\ CO_2 + 1.3\ C_2H_5OH + 0.036\ H_2O$$

a. Determine the biomass yield coefficient $Y_{X/S}$.

b. Determine the product yield coefficients $Y_{EtOH/S}$, $Y_{CO_2/S}$, $Y_{C_3H_2O/S}$.

c. Determine the coefficient β.

7.4. Aerobic growth of *S. cerevisiae* on ethanol is simply described by the following overall reaction:

$$C_2H_5OH + a\ O_2 + b\ NH_3 \longrightarrow c\ CH_{1.704}N_{0.149}O_{0.408} + d\ CO_2 + e\ H_2O$$

a. Determine the coefficients a, b, c, and d, where RQ = 0.66.

b. Determine the biomass yield coefficient, $Y_{X/S}$, and oxygen yield coefficient, Y_{X/O_2} (gdw/g O_2).

7.5. Aerobic degradation of benzoic acid by a mixed culture of microorganisms can be represented by the following reaction.

$$\underset{\text{(substrate)}}{C_6H_5COOH} + a\ O_2 + b\ NH_3 \longrightarrow \underset{\text{(bacteria)}}{c\ C_5H_7NO_2} + d\ H_2O + e\ CO_2$$

a. Determine a, b, c, d, and e if RQ = 0.9.

b. Determine the yield coefficients, $Y_{X/S}$ and Y_{X/O_2}.

c. Determine degree of reduction for the substrate and bacteria.

7.6. Aerobic degradation of an organic compound by a mixed culture of organisms in waste water can be represented by the following reaction.

$$C_3H_6O_3 + a\ O_2 + b\ NH_3 \rightarrow c\ C_5H_7NO_2 + d\ H_2O + e\ CO_2$$

a. Determine a, b, c, d, and e, if $Y_{X/S} = 0.4$ g X/g S.

b. Determine the yield coefficients Y_{X/O_2} and Y_{X/NH_3}.

c. Determine the degree of reductions for the substrate, bacteria, and RQ for the organisms.