Oxygen transfer rates and requirements in oxidative biocatalysis

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Oxygen transfer rates and requirements in oxidative biocatalysis

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Biocatalytic oxidation reactions offer several important benefits such as regio- and stereoselectivity, avoiding the use of toxic metal based catalysts and replacing oxidizing reagents by allowing the use of oxygen. However, the development of biocatalytic oxidation processes is a complex task which requires simultaneous consideration of several issues regarding the process design and operation.

In this work, the oxygen requirements are analysed for different process scenarios, considering different biocatalyst formats and variation of the desired productivity. Also, the applicability of bubble-bubbling and membrane aeration investigated. Hollow fibre membrane contactors present an interesting alternative for reactor aeration, creating large specific areas (area/volume) of the gas/liquid interface. The modular design of membrane contactors, scaling-up is relatively straightforward (Gabelman and Hwang, 1999), and membrane contactors are implemented for various industrial applications (Klaassen et al., 2005).

Oxygen requirements

Figure 1 illustrates the overall metabolic processes of a cell catalysing a biocatalytic reaction. By combining these catalytic reaction with the anabolic reaction for biomass synthesis (Eq. 1) a model for the oxygen consumption can be derived (Eq. 2) (Villadsen et al., 2011).

\[ \text{Eq. 1} \]

\[ (1 - a)\Delta H_0 + Y_{\text{RED}} \text{NADH} + Y_{\text{ATP}} \text{ATP} \rightarrow X + a\text{CO}_2 + Y_{\text{RED}} \text{NADH} \]

\[ \text{Eq. 2} \]

\[ A = \frac{V_{\text{ATP}} - V_{\text{RED}} P/O}{P/O - 1} \quad \beta = \frac{m_{\text{ATP}}}{\text{ATP}} \quad \gamma = \frac{1}{2} \quad \text{OTR limit at industrial scale} \]

Membrane aeration

Because enzymes can be inactivated by gas/liquid interfaces (Bommarius & Karau, 2005), bubble-less aeration through membranes may improve the operational stability of the enzyme. Figure 2 shows the estimated specific membrane areas necessary in order to reach given productivities using different forms of the biocatalyst.

Conclusions

- The maximum achievable productivity is greatly influenced by the oxygen requirement set by the biocatalyst.
- Maximum productivities of 3.5 and 5.0 g L⁻¹ h⁻¹ were estimated for growing and resting cells respectively, using conventional bubble aeration.
- Membrane aeration is limited in terms of maximum oxygen flux. Thus, the use of pure oxygen may be necessary in order to support the desired productivity.
- Bubble-less aeration would be particularly relevant to systems using sensitive enzymes. It may also be beneficial in order to minimize the evaporation of volatile components.

References


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