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New configuration of immobilized *A. succinogenes* bed for succinic acid production

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Fermentative production of succinic acid from renewable resources (wood hydrolysates, whey, cane molasses) using microorganism as: *A. succinogenes*, modified *E. coli*, *A. succiniciproducens*, *M. succiniciproducens* proved to be cost effective compared with other methods. The use of immobilized microorganisms offers the advantages of the increase of number of the repeated biosynthesis cycles re-using the same particles of biocatalysts, increase of the thermal, chemical and to shear forces resistance of the biocatalysts. However, the bioreactor design and operating conditions influence the efficiency of the biosynthesis process.

OBJECTIVE

This work studies the external and internal mass transfer of glucose, under substrate and product inhibition limitations, in succinic acid production by immobilized *A. succinogenes*, using a stationary basket bioreactor.

Materials and Method

- bioreactor 10L, type Fermac 360 Electrolab, UK
- cylindrical bed of basket type having the inner diameter of 100 mm, height of 100 mm and the bed thickness of 10 mm
- impeller rotation speed: 250 rpm
- immobilized cells of *A. succinogenes ATCC 55617* (particle diameters: 3.0, 3.6 and 4.2 mm)
- fermentation media

The biocatalyst particles size and position inside the basket bed exhibit significant influences on: Biot number, Bi, (represents the ratio between the resistance to the diffusion in the boundary layer surrounding the particle), Thiele modulus, φ, and effectiveness factor λ: the increase of the particle diameter led to the decrease of Bi number, to the increase of Thiele modulus and, implicitly, to the decrease of factor λ in the particle center. From the inner surface of basket bed to the outer one, the glucose consumption rate decreased for about 8.9 to 10.8 times, depending on the biocatalyst particles diameters.

RESULTS

❑ The glucose concentration profiles inside the biocatalyst particle (C_{SP}) and at the particle surface (C_{Si}):

$$C_{SP} = \frac{Bi \cdot (C_{SL} - C_{Si}) \cdot \cosh(3\varphi \cdot R_p)}{R_P^{\,2}} \cdot \left[\frac{3\varphi}{R_p} - R_p \cdot \tanh(3\varphi \cdot R_p)\right] \cdot \frac{\sinh(3\varphi \cdot r)}{r}$$

$$C_{Si} = \frac{Bi \cdot C_{SL} \cdot \cosh(3\varphi \cdot R_p) \cdot \left[3\varphi - R_p^{\,2} \cdot \tanh(3\varphi \cdot R_p)\right] \cdot \sinh(3\varphi) - C_{SL} \cdot R_p^{\,4}}{Bi \cdot \cosh(3\varphi \cdot R_p) \cdot \left[3\varphi - R_p^{\,2} \cdot \tanh(3\varphi \cdot R_p)\right]}$$

C_{SL} - substrate concentration in liquid phase, kg/m^3
R_P - biocatalyst particle radius, m

❑ The internal and external glucose mass flows:

$$n_L = k_L \cdot (C_{SL} - C_{Si})$$

$$n_p = D_{Se} \cdot \frac{Bi \cdot (C_{SL} - C_{Si}) \cdot \cosh(3\varphi \cdot R_p)}{R_P^{\,3}} \cdot \left[3\varphi - R_p^{\,2} \cdot \tanh(3\varphi \cdot R_p)\right] \cdot \left[\frac{3\varphi \cdot \cosh\left(\frac{3\varphi \cdot r}{R_p}\right)}{R_p \cdot r} - \frac{\sinh\left(\frac{3\varphi \cdot r}{R_p}\right)}{r^2}\right]$$

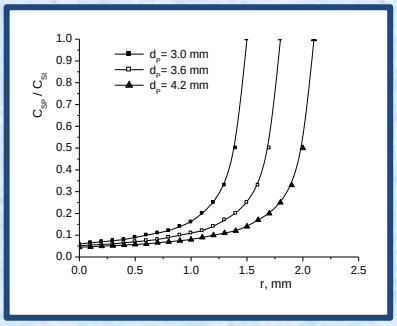
D_{Se} - effective diffusivity, m^2/s

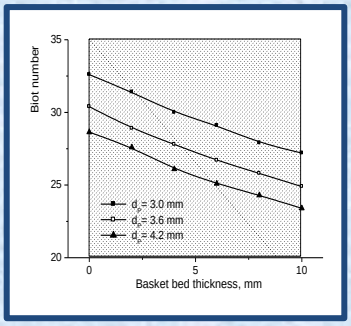
❑ The effectiveness factor **λ,** defined as the ratio between the rates of the biochemical reaction in heterogeneous system and in homogeneous one, that it is used for describing more accurately the effect of the internal diffusion on the rate of glucose consumption during the succinic fermentation:

$$\lambda = \frac{3 \cdot k_L \cdot (C_L - C_{Si}) \cdot \cosh(3\varphi \cdot Rp) \cdot \left(\frac{3\varphi}{Rp} - Rp \cdot \tanh(3\varphi \cdot Rp)\right) \cdot \cosh(3\varphi) \cdot [3\varphi - \tanh(3\varphi)]}{R_p^4 \cdot V \cdot C_C \cdot \left(\frac{K_{iS}}{K_{iS} + CS}\right) \cdot \left(\frac{K_{iP}}{K_{iP} + Y_{P/S} \cdot C_S}\right)}$$

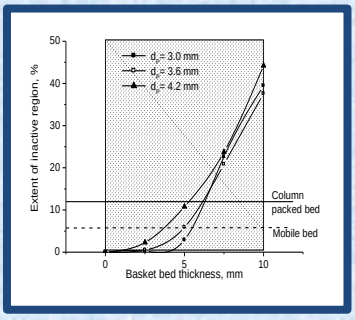
K_{iP} - product inhibition constant, kg/m^3
K_{iS} - substrate inhibition constant, kg/m^3
V - maximum biochemical reaction rate, kg/kg.s
$Y_{P/S}$ - yield of substrate conversion to product, kg/kg

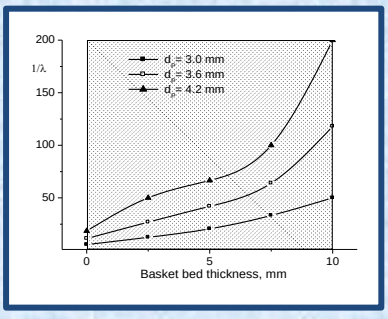
The experiments for succinic acid fermentation indicated that it is possible to reach very low values of glucose internal mass flow near the particle center, this central region being considered a "biological inactive region", whose extent varies from 0.24 to 44% from the overall volume of each biocatalyst particle, the highest values being recorded for the largest particles at the outer surface of basket bed.





By using the fixed bed of basket conformation containing immobilized *A. succinogenes* cells the rate of the biochemical conversion of glucose conversion is considerably reduced for 1/λ, but the magnitude of this effect has to be correlated with the size and position inside the bed of the biocatalyst particles.





CONCLUSIONS

➢ The studies on the glucose external and internal mass transfer and, implicitly, on the influence of the internal diffusion on the transfer and biochemical processes rates showed that the basket bioreactor is more efficient for the biocatalyst particles with 3 mm diameter and basket bed thickness up to 5 mm.

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