II-415 The effect of mass transfer on the performance of anaerobic biofilm reactors

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1. Introduction.- Recently, the potential of utilization of microbial films in wastewater treatment processes has been increasingly investigated. Understanding of substrate decomposition and growth kinetics and comprehension of transport phenomena within and out of microbial films is essential for the design and optimization of processes such as anaerobic filters, fluidized beds, expanded beds, etc. This study deals with the effect of a liquid layer mass transfer resistance on the performance of both complete-mixed and plug-flow biofilm reactors.

2. Biofilm Model.- The model assumes a plane microbial film of uniform density and thickness in which substrate decomposition according to Monod kinetics and molecular diffusion occur simultaneously. These phenomena can be represented by the differential equation:

$$D_s \cdot \frac{d^2S}{dy^2} = \frac{\mu_{max} \cdot \rho \cdot \alpha_s}{K_s + S} \cdot S \qquad (1)$$

in which, D_s= effective diffusivity of substrate within the biofilm; K_s= Monod half velocity coefficient; ρ= biofilm density; α_s= ratio of substrate decomposer in total bacteria; μ_{max}= maximum specific utilization rate of substrate; S= substrate concentration in biofilm; and y= length dimension normal to the biofilm surface.

A stagnant liquid layer covers the biofilm and substrate is transported from the bulk liquid to the biofilm-liquid interface by molecular diffusion. The boundary conditions are:

$$N_s = D_s \cdot \frac{dS}{dy}\Big|_{y=Lf} = k_l \cdot (S_b - S_s) \quad (2) \qquad D_s \cdot \frac{dS}{dy}\Big|_{y=0} = 0 \quad (3)$$

Equations (1)-(3) can be normalized as follows:

$$\frac{d^2S^*}{dY^{*2}} = \frac{Ms^2 \cdot S^*}{1 + Bsf \cdot S^*} \quad (4); \qquad \frac{dS^*}{dY^*}\Big|_{Y^*=1} = Bi \cdot (S_b^* - S_s^*) \quad (5); \qquad \frac{dS^*}{dY^*}\Big|_{Y^*=0} = 0 \quad (6)$$

where, $S^*=S/S_{bf}$; $Sb^*=S_b/S_{bf}$; $S_s^*=S_s/S_{bf}$; $Bsf=S_{bf}/K_s$; $Y^*=y/L_f$; $Bi=k_l.L_f/D_s$; $Ms=L_f \cdot (\mu_{max} \cdot \rho \cdot \alpha_s/K_s \cdot D_s)^{1/2}$. Here, S_{bf}= bulk substrate inlet conc.; Ms= modified Thiele modulus; Bi= Biot number; S_b= bulk substrate conc.; S_s= biofilm surface substrate conc.; k_l=mass transfer coefficient; and Ns= substrate flux.

3. Complete Mixed Biofilm Reactor.- A mass balance for the substrate yields:

$$S_{bf} - S_b - a \cdot \theta \cdot N_s = 0 \qquad (7)$$

Equation (7)in dimensionless form becomes:

$$Pes \cdot (1 - S_b^*) = \frac{dS^*}{dY^*}\Big|_{Y^*=1} (8) \quad \text{or} \qquad S_b^* = \frac{Pes + Bi \cdot S_s^*}{Pes + Bi} \quad (9)$$

where, $Pes=Lf/a.\theta.Ds$, a=specific surface area, and θ= hydraulic retention time.

4. Piston Flow Biofilm Reactor.- A material balance for substrate yields:

$$\frac{F}{A} \cdot \frac{dS_b}{dz} = a \cdot N_s \qquad (10)$$

in which, F= flow rate of liquid; A= reactor's cross sectional area; z= axial dimension along the biofilm. Using the term $Z^*=z/H$, where H=reactor length, Eq.(10) becomes:

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$$\mathrm{Pes.}\ \frac{dS_b^*}{dZ^*} = \left(\frac{dS^*}{dY^*}\Big|_{Y^*=1}\right)_{Z^*} = \mathrm{Bi.}(S_b^* - S_s^*)\Big|_{Z^*} \quad (11)$$

5. Results and Discussion.- Calculations where carried out for various values of Ms,Bsf, Bi and Ms^2/Pes in order to compare the performances of the two types of reactors.

Fig.1 shows the relation between the dimensionless flux term N_s^* (Ns/Nsmax) and the dimensionless bulk sustrate concentration Bs (Bsf・Sb*), for various values of Bi ranging from 0.1 to ∞ at Ms=4.0. As the Biot number decreases, Ns* decreases remarkably for low values of Bs.

Fig.2 shows the relationship between volume ratio of a complete mixed reactor and a piston flow reactor and conversion, calculated at various values of Bi, for the case of Ms=4 and Bsf=50. As Bi decreases, the ratio Vcm/Vp increases in order to obtain the same conversion.

Figs. 3 and 4 show the relationship between Vcm/Vp with conversion, at Ms=4 and Bi=1-0.1 using Bsf as a parameter. From the figures, it follows that as Bsf decreases the ratio Vcm/Vp increases to obtain a certain conversion. However,it must be noticed that when Bi=1, the lower limit of Bsf lies around 10, and when Bsf=500 or more, in order to obtain a 90% conversion it is indistinct to use a complete mixed or a plug flow reactor.

At Bi=0.1, the lower limit of Bsf increases to about 100 and when Bsf=2000 the ratio Vcm/Vp approximates 1 at a 90% conversion.

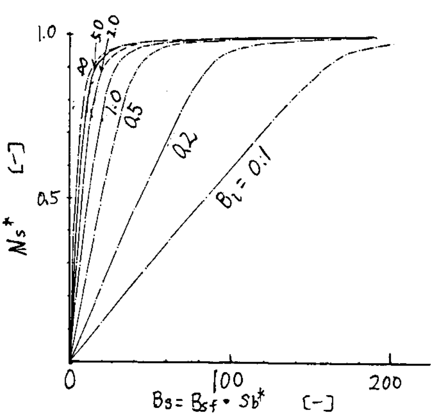

Fig. 1 .- Dimensionless Substrate Flux vs. Dimensionless Bulk Concentration.

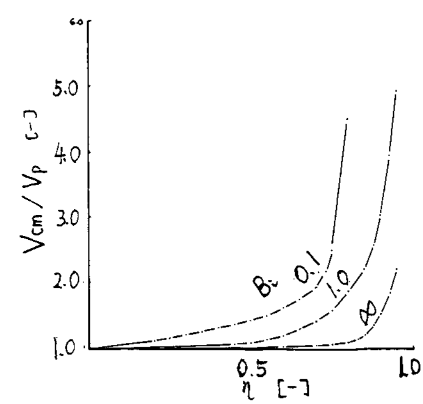

Fig. 2 .- Relationship between Vcm/Vp and Conversion, at different values of Bi.

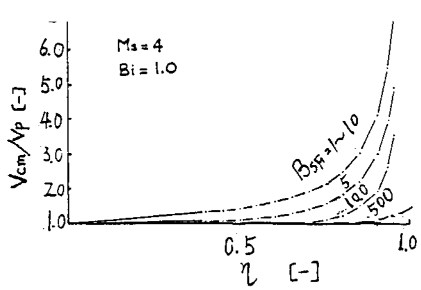

Fig. 3. Relationship between Vcm/Vp and Conversion for Bi=1.0 at different Bsf.

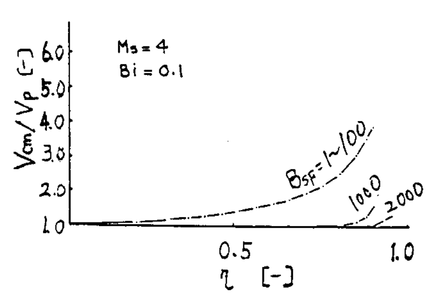

Fig. 4. Relationship between Vcm/Vp and Conversion for Bi=0.1 at different Bsf.