Effect of hydrodynamic conditions and bulk substrate concentration on biofilm efficiency at steady-state

Teixeira, F., Vieira, M.J., Lopes, F., Alves, C., Melo, L.F.
Centre of Biological Engineering, University of Minho, Portugal

1. Introduction

Water and wastewater biofilm reactors work under quite different substrate concentrations and hydrodynamic conditions. It is important to analyse how these factors can affect the activity of biofilms.

The work reported here presents results obtained with biofilms formed by *Pseudomonas fluorescens* suspensions carried out at different conditions: low and high fluid velocities; low and high bulk substrate concentrations.

2. Experimental work

Test Cells - The biofilm was grown on a plane surface, a 60 cm long perspex test cell, semi-circular, with an hydraulic diameter of 1.83 cm. The test cell included a removable 10 cm long mass transfer section, that permitted the measurement of mass transfer coefficients inside the biofilm, as described elsewhere (Vieira *et al.,* 1993).

Operating conditions - Pseudomonas fluorescens was used as a biofilm producer and the limiting substrate was glucose. Two sets of experiments were carried out:

a) With biofilms formed under high water velocity (0.23 to 0.61 m/s, turbulent flow) and low substrate concentration: 20 ppm

b) With biofilms formed under low water velocity (0.0028 to 0.0083m/s, laminar flow) and high bulk substrate concentration: 100 and 200 ppm

3: Results and discussion

The data obtained on mass transfer and diffusion limitations inside steady -state biofilms are presented on Table 1. The mass transfer coefficients inside the biofilms seem to be similar for the biofilms formed. Since the substrate concentration at the biofilm surface is low in all cases (between 8 and 40 ppm), a first-order reaction model (Harremöes, 1978) was fitted to the experimental data and the biofilm efficiency was estimated. The results obtained for the steady-state biofilms show that the biofilms formed at higher velocities and lower bulk substrate concentration are less efficient than the biofilms formed at lower velocities. Some of the biofilms formed under turbulent flow conditions were partially penetrated by the substrate, contrary to the biofilms formed at lower velocities.

Table 1 - Biofilm mass transfer coefficients and biofilm efficiencies

	Bulk substrate concentration (ppm)	Fluid velocity (m/s)	Biofilm mass transfer coefficients (m^2/s) x10^6	Biofilm efficiency
Thick biofilms	100	0.0028	1.37	0.86
		0.0056	1.39	0.87
		0.0083	1.39	0.88
	200	0.0028	1.36	0.83
		0.0056	1.34	0.84
		0.0083	1.33	0.86
Thin biofilms	20	0.23	1.66	0.15
		0.34	1.60	0.23
		0.46	1.87	0.40
		0.61	1.85	0.52

Probably, the differences pointed out between the biofilms are related to the internal structure of the biological layer. In fact, the biofilms formed under turbulent flow are thin (thicknesses ranging between 1200 μm and 460 μm, depending on the fluid velocity), with a dry biofilm density* around 14 to 21 kg/m^3 and have a high cohesive strength (Vieira *et al.*, 1993). On the contrary, the biofilms formed at higher substrate concentrations under laminar flow were composed by two different layers : one near the support, very thin (around 250 μm) with a density* similar to the one mentioned above, and firmly adherent to the support; while the other layer was very fluffy, and "floated" over the surface, and was not stable when subjected to slight variations on the hydrodynamic conditions. Therefore, it can be assumed that the main mass transfer resistance in these biofilms is located in the firmly adherent layer, which explains the similarity between the mass transfer coefficients in both type of biofilms. On the other hand, the significant differences in the values of biofilm efficiencies between thick and thin biofilms can be due to a much larger substrate consumption in the upper part of the thick biofilms. Additionally, substrate consumption rates were measured, in both types of biofilms, at different fluid velocities. The results showed that, although the substrate removal is dependent on bulk concentration, it is not dependent on fluid velocity, for thick fluffy biofilms. However, in the thin biofilms, the rate of substrate consumption decreases with increasing velocity. This means that when turbulent flow is used, changes in hydrodynamic conditions have a significant effect in the structure and behaviour of biofilms.

Furthermore, turbulence contributes to the formation of more rigid and compact films, avoiding the formation of an unstable "floating" biomass over the microbial film. Although biofilms subjected to high velocities may have lower efficiency factors, they allow a more stable reactor operation without substantial biomass wash-out.

Vieira, M.J., Melo, L.F., Pinheiro, M.M. (1993) " Biofilm formation - hydrodynamic effects on internal diffusion and structure", Biofouling, Volume 7, No 1, 67-80

Harremöes, P. (1978) "Biofilm Kinetics" in R. Mitchell (Eds) Water Pollution Microbiology, Vol2, John Wiley and Sons, New York, 82-109.

* Mass of dry biofilm per unit volume of wet biofilm