Application of a diffusion-reaction model to biofouling in heat exchangers

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Modelling the processes that take place inside biofilms under known operating conditions is crucial, since the results obtained may be used to predict biofilm behaviour in other circumstances. The processes related with substrate consumption that take place inside a biofilm can be adequately described by the diffusion-reaction model developed for the heterogeneous catalysis. In fact, the overall "observable" or apparent reaction rate in a biofilm system comprises the transport of the reactants outside and inside the biological matrix and the biochemical reaction involving the immobilised microorganisms. Assuming that the reaction inside the biofilm is well described by the Monod kinetics, the mass balance for the substrate is:

$$D_A \frac{d^2C_A}{dz^2} - \frac{k_1 C_A}{k_{s1} + C_A} = 0 \, ,$$

with the following boundary conditions: $z= L$ $C_A= C_{As}$ and for $z= 0$ $dC_A/dz= 0$,
where L is the biofilm thickness, C_A the substrate concentration in the biofilm, C_{As} the substrate concentration at the biofilm surface, and k_1 and k_{s1} are the Monod kinetic constants.
The diffusion coefficient inside the biofilm (D_A), can be regarded as an average "effective diffusivity", and replaced by a mass transfer coefficient that takes into account all the mechanisms of mass transport in the matrix.

The aim of this communication is to present a methodology to solve the diffusion-reaction model without using any simplifications to solve it analytically. Therefore, there will be no restrictions on the reaction order (it may vary from zero to one, according to Monod). Also, the Monod kinetic constants in the biofilms are not considered to be equal to the ones in suspension. Finally, instead of theoretical "effective diffusivities" experimental values of mass transfer coefficients are introduced in the model equations.
The methodology, using experimental data of substrate consumption, biofilm thickness, mass transfer coefficients inside the biofilm, bulk substrate concentrations, for, at least, more than two different situations, involves modelling for parameter estimation (including least square parameter estimation and numerical integration). The solution of the model will be the concentration profiles inside the biofilms and the Monod kinetic constants. The proposed model was applied to biofilms formed under turbulent flow and low organic substrate concentrations in heat exchanger surfaces.