Transient Convection, Diffusion, and Adsorption in Surface-Based Biosensors

This paper presents a theoretical and computational investigation of convection, diffusion, and adsorption in surface-based biosensors. In particular, we study the transport dynamics in a model geometry of a surface plasmon resonance (SPR) sensor. The work, however, is equally relevant for other microfluidic surface-based biosensors, operating under flow conditions. A widely adopted approximate quasi-steady theory to capture convective and diffusive mass transport is reviewed, and an analytical solution is presented. An expression of the Damköhler number is derived in terms of the nondimensional adsorption coefficient (Biot number), the nondimensional flow rate (Péclet number), and the model geometry. Transient dynamics is investigated, and we quantify the error of using the quasi-steady-state assumption for experimental data fitting in both kinetically limited and convection-diffusion-limited regimes for irreversible adsorption, in specific. The results clarify the conditions under which the quasi-steady theory is reliable or not. In extension to the well-known fact that the range of validity is altered under convection-diffusion-limited conditions, we show how also the ratio of the inlet concentration to the maximum surface capacity is critical for reliable use of the quasi-steady theory. Finally, our results provide users of surface-based biosensors with a tool for correcting experimentally obtained adsorption rate constants.

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