

## A Numerical Simulation of Amperometric Biosensor Effect of Enzyme Loading and Stirring Strength on Biosensor's Performance

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### 1. Introduction

Biosensors are defined as analytical devices incorporating a physicochemical transducer (or transducing system) and biologically active material integrated with it. The amperometric biosensor is one of the types of biosensors which typically rely on an enzyme system that catalytically converts an electrochemically non-active analyte into products that can be oxidized or reduced at a working electrode. Modelling of biosensors is of crucial importance in order to understand their behaviour, which began with the work of Gough et al., [1], G. Jobst et al., [2] and S.D. Caras et al., [3,4,5]. S. Bacha et al. [6,7] developed a model that takes into account a variety of configuration designs.

In the present work, we have developed a mathematical model in order to describe and evaluate the performance of amperometric biosensors. The chosen configuration is the one most used nowadays in the design of enzymatic biosensors such as the polymeric matrices as enzyme supports and the mass production of biosensors by the screen-printing technique.

### 2. Main Results

The sensors considered consist of a metallic electrode surface, a membrane held against the surface electrode and a diffusion layer adjacent to the outer surface of the membrane. In the enzyme membrane, the substrate  $S$  is converted to an electroactive product  $P$  which is detected. Coupling the enzyme catalysed reaction in enzyme layer with the one-dimensional-in-space diffusion, described by Fick's second law, leads to the following equation:

$$\frac{\partial [C]}{\partial t} = D_c \frac{\partial^2 [C]}{\partial x^2} \pm \frac{v_{\max}^v [C]}{k_s + [C]_c}$$

where  $C$  may be  $S$  or  $P$ .

The current density is calculated by estimating the gradient of the electroactive species at the surface of electrode.

The above equation as well as initial and boundary conditions are integrated over controlled volumes according to Finite Volume Method (FVM) and the set of algebraic equation are solved numerically by Thomas algorithm. The algorithm is written in Visual Fortran and run on a Pentium III PC (733 kHz) processor. The model is applied to simulate the response of the biosensors versus many parameters such as the amount of the immobilized enzyme, the membrane thickness and the thickness of the diffusion.

### 3. Influence of the internal resistance on the signal magnitude

To study the effect of the internal resistance, a diffusion layer thickness is taken deliberately equal to 0. This leads to a value of  $Bi = \infty$ . One can see that the maximal magnitude of the biosensor, which corresponds to the steady state current, increases with an increase in the quantity of enzyme. Another interesting feature is that the maximum current density does not exceed a limit of  $11.56 \mu\text{A}/\text{cm}^2$  regardless of the amount of immobilized enzyme. The maximum dimensionless current density  $\Psi_{\max}$  versus Thiele modulus is linear up to a value of  $\Phi=2$ . No further increase of  $\Psi_{\max}$  is obtained beyond this value whatever is the Thiele's modulus value.

### 4. Effect of external resistance to mass transfer

To study the effect of external resistance to mass transfer, values of  $\Phi=7$  and  $\Phi=1$  are taken to perform the simulation. The diffusion layer thickness  $\delta_e$  is chosen to ensure value of  $Bi$  from 0.5 to 50 (i.e. for diffusion layer thickness  $\delta_e$  varying from 200 to  $2\mu\text{m}$ ). Results show that the magnitude of the response increase with the decrease of the diffusion layer thickness, but one should highlight that for  $Bi=1$  and  $Bi=0.5$ , there is a peak of  $6.6 \mu\text{A}/\text{cm}^2$  approximately at  $t=4\text{s}$ . The maximum current density at  $Bi$  value equal to 50

(well stirred solutions) is 1.8 times its value at  $Bi$  value equal to 1 (weak stirred ones).

### 5. Conclusion

The described model has shown interesting features in investigating amperometric biosensor performance. It is useful to explain the sensing mechanism and provide a basis for an interpretation of the response in order to incorporate further improvements in amperometric biosensor design. Numerical results demonstrate that best performances are obtained when the biosensor operate under internal diffusion control. High loading membrane with enzyme will provide, in addition to a maximal and fast signal for a given substrate concentration, a wide range of linearity and may keep somewhat a regular biosensor signal during the storing of the biosensor as long as the biosensor is under diffusion control.

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