Electrochimica Acta 176 (2015) 463–471

Contents lists available at ScienceDirect

Electrochimica Acta

journal homepage: www.elsevier.com/locate/electacta

Study of the influence of boundary conditions, non ideal stimulus and dynamics of sensors on the evaluation of residence time distributions

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ARTICLE INFO

Article history:
Received 16 May 2015
Received in revised form 17 June 2015
Accepted 3 July 2015
Available online 10 July 2015

Keywords:
Dispersion model
Electrochemical reactors
Hydrodynamic behaviour
Dynamic response
Non-ideal behaviour
Stimulus-response method

ABSTRACT

The study of the residence time distribution is usually made in order to diagnose the hydrodynamic behaviour of the equipment. This paper reports on the residence time distribution according to six combinations of the open and closed boundary conditions, which are compared in order to determine an appropriate equation to fit experimental data from the stimulus-response method. The residence time distribution under laminar flow is analysed and the mathematical modelling of the pure convection regime, zone of axial dispersion and intermediate case is discussed. The disturbances in the residence time distribution produced by a non-ideal impulse and also by the dynamic behaviour of the sensor are quantified and the errors in its evaluation are given.

1. Introduction

The design of an electrochemical reactor requires knowledge of its hydrodynamics, which can be studied by using the stimulus-response method in order to determine the residence time distribution, RTD, of the flow inside the equipment [1]. Thus, an inert tracer is injected into the vessel inlet and its concentration in the effluent stream is measured versus time. Several signals can be used as a stimulus function, but the most common one is an instantaneous impulse in concentration at the vessel inlet, mathematically described as a Dirac delta function. The shape of the response at the vessel outlet allows to determine irregularities in the flow conditions and their correction by means of geometric changes in the equipment [2]. The response function can be processed in order to obtain characteristic parameters of the model proposed to represent the hydrodynamic behaviour of the reactor.

The implementation of the stimulus-response method, data acquisition, modelling, and ways to derive the model parameters from the residence time distribution are properly summarized in [3,4].

The effect of the injection time of the stimulus on the RTD is scarcely treated in the literature. Richardson and Peacock [5] commented that the deviation of the stimulus from the ideal pulse is irrelevant in the frequent practical cases. However, in reactors operated at high volumetric flow rates or filled with turbulence promoters the space time can be small increasing the importance of the non-ideal behaviour of the stimulus on the response of the system. Westerterp et al. [3] and Levenspiel et al. [6,7] recommended that the injection time must be lower than the reactor space time as a basic criterion for an ideal stimulus. Likewise, Levenspiel and Smith [8] show that when a stimulus is not well represented by an impulse function it is necessary to measure the RTD at the inlet and at the reactor outlet subtracting both variances. But, the measurement of the RTD at the inlet can introduce high errors because the time constant of the sensor could be in the same order of magnitude as the injection time of the tracer, which demands that the response of the system must be processed taking into account the dynamic behaviour of the sensor.

The aim of this paper is to compare different boundary conditions, earlier-presented [8–12], in order to identify the best choice to fit experimental data, including turbulent and laminar flow conditions. Also, the influence of the dynamic response of sensors and the non-ideal behaviour of the stimulus on the RTD are discussed.

2. Fundamental equations of the dispersion model

The temporal behaviour of an electrochemical reactor without reaction according to the axial dispersion model is given by [13,14]

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http://dx.doi.org/10.1016/j.electacta.2015.07.019
0013-4686/

$$\frac{\partial c(T,Y)}{\partial T} = \frac{1}{\mathrm{Pe}}\frac{\partial^2 c(T,Y)}{\partial Y^2} - \frac{\partial c(T,Y)}{\partial Y} \quad (1)$$

where

$$T = \frac{t}{\tau} \quad (2)$$

$$\tau = \frac{\varepsilon L}{u} \quad (3)$$

$$\mathrm{Pe} = \frac{uL}{\varepsilon D_{\mathrm{L}}} \quad (4)$$

and

$$Y = \frac{y}{L} \quad (5)$$

being c concentration, Pe Peclet number, t time, τ space time, T dimensionless time, L electrode length, u mean superficial fluid velocity, ε porosity, D_{L} dispersion coefficient, y axial coordinate along the electrode length and Y normalized axial coordinate. However, the adoption of the initial and boundary conditions represent a controversial subject. To solve Eq. (1) the following initial condition is proposed

$$T = 0 \quad c(0,Y) = \mathrm{f}(Y) \quad (6)$$

and for the boundary conditions some of the more common proposals are:

(i) At the reactor inlet and $T>0$:for an open system

$$\frac{c(T,0)}{2} - \frac{1}{\mathrm{Pe}}\frac{\partial c(T,Y)}{\partial Y}\Big|_{Y=0} = \mathrm{g}(T) \quad (7)$$

for a closed system with dispersion at the reactor inlet

$$c(T,0) - \frac{1}{\mathrm{Pe}}\frac{\partial c(T,Y)}{\partial Y}\Big|_{Y=0} = \mathrm{g}(T) \quad (8)$$

for a closed system without dispersion at the reactor inlet

$$c(T,0) = \mathrm{g}(T) \quad (9)$$

(ii) At the reactor outlet and $T>0$:
for an open system

$$c(T,\infty) = 0 \quad (10)$$

and for a closed system

$$\frac{\partial c(T,Y)}{\partial Y}\Big|_{Y=1} = 0 \quad (11)$$

The boundary condition given by Eq. (7) considers that only half of the tracer enters into the reactor because in an open system it can diffuse in both positive and negative directions due to the initial concentration gradients [15]. Consequently, a portion of the tracer diffuses on the contrary direction to the convection flow giving that its mean residence time is lower than the space time of the reactor. Likewise, Eq. (9) means that the dispersion is neglected at the reactor inlet. Eq. (10) assumes that at a long distance from the injection point the system is not disturbed retaining the initial condition given by Eq. (6); whereas Eq. (11) neglects the dispersion at the outlet.

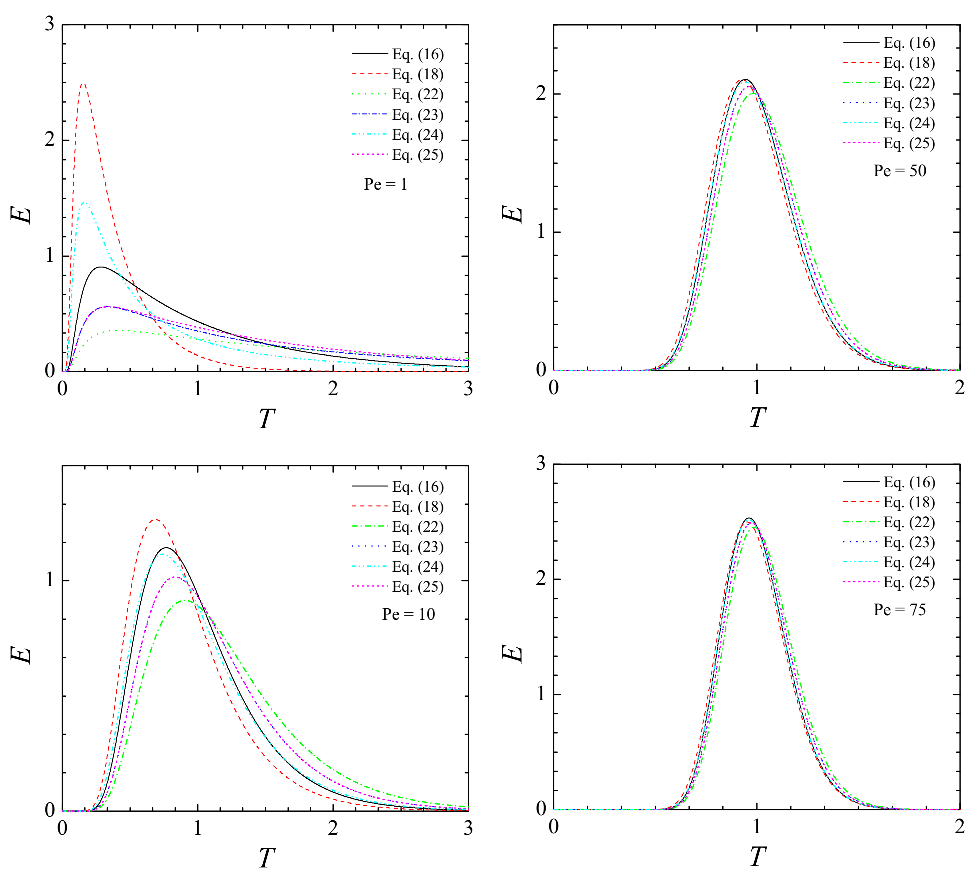

Fig. 1. Comparison of the response according to Eqs. (16),(18), (22), (23), (24) and (25) at different Peclet numbers.