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Reduction and control of flux decline in cross-flow membrane processes modeled by artificial neural networks and hybrid systems

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Abstract

The aim of the present paper is the development of a hybrid system to model the behavior of membrane units operating in pulsating conditions. In two previous papers the authors already showed how efficiently advanced models based on artificial neural networks (ANN) could be used to predict the behavior of unsteady-state membrane processes. Nevertheless, a ''pure'' neural model does not make use of any equation that could help to determine, on the basis of fundamental principles, the mutual relationships existing between the inputs and the outputs. A hybrid system represents an alternative method that may allow predicting the behavior of complex systems, in a more efficient way. Hybrid model predictions are given as a combination of both a theoretical and a neural network approach, together concurring to the obtainment of system responses. In this way, some well-assessed phenomena can be described by a fundamental theoretical approach; some others, being very difficult to interpret, can be analyzed by means of rather simple ''cause-effect'' models, based on ANN.

Keywords: Ultrafiltration; Modeling; Transport phenomena; Hybrid models

1. Introduction

In a previous work [1], the authors of the present paper developed an artificial neural network (ANN) model capable to analyze the behavior of membrane systems operating in pulsating conditions. The network was trained through a selected set of experimental data collected during the ultrafiltration of aqueous BSA solutions through PES membranes. All the experiments were performed in a lab-scale flat sheet membrane module equipped with a device that generated periodic and repeated pulses of both the applied trans-membrane pressure (TMP) and the feed flow rate (Q). During each pulse, operating

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TMP abruptly decreased from the operating value to about zero, whereas Q had, on average, a twofold increase with respect to its actual value. The generation of negative pulses for TMP and of positive pulses for Q was attained according to a square-wave-like profile. Two different effects were achieved by this continuous alternation of process variables: the periodic disruption of concentration polarization layer and the formation of a less consolidated cake (as compared to traditional membrane processes) on the active membrane side. It was shown that UF system behavior was strongly dependent on the duration of each upstream pressure release, i.e. the pulse time, identified as t_{pul}, and on the duration of each upstream operating pressure restoration, i.e. the operating time, t_{op}. The developed neural network model was capable of offering very accurate predictions when it was tested within the range used for training, but also when the inputs combination was never exploited during learning phase. The observed reliability of neural network prediction suggested an optimal control application of ANN aimed at searching a pulsation frequency profile that could maximize the normalized permeate flux [2]. The obtained results showed that t_{op} had to be changed continuously in order to attain a significant improvement of membrane performance.

In spite of the very promising results presented in [1] and in [2], the ''pure'' ANN approach poses some problems. The main criticism concerns the fact that ANN model did not make use of any equation that could have helped to determine, on the basis of fundamental principles, the mutual relationships between the output, i.e. the permeate flow rate, and the external disturbances or manipulated variables. If no fundamental equation is adopted, the resulting ANN model can be rather complicated, as shown in [1], since it requires a large number of connections and, therefore, a larger number of parameters with respect to a ''traditional'' one-hidden-layer neural architecture. The possibility to combine even a simple fundamental model to an ANN may lead to improve the model capability to generalize to new situations and to reduce the number of experimental data that are actually needed to build a proper neural network. The previous considerations are, actually, the basis for the development of a hybrid model, i.e. a model whose predictions are given as a combination of both a fundamental and a ''pure'' neural network approach, together concurring to the obtainment of system responses. Moreover, ultrafiltration of BSA solutions is one of the most common systems that was theoretically modeled by several authors [3–5], even though no reference about the utilization of pulsating conditions is currently available.

The aim of the present paper is to develop a hybrid model predicting the behavior of BSA ultrafiltration performed in pulsating conditions. The hybrid system actually consists of two different parts: a theoretical model describing the unsteady-state transport of both momentum and mass in the module channel and through the membrane, and a rather simple neural model. The theoretical model, described by a system of partial differential equations solved by Finite Elements Method (FEM), allows predicting the time evolution of concentration polarization and of permeate flux decay as a function of process input variables. The neural model, instead, is used to determine, in a wide range of operating conditions, the complex functional relationship existing between the concentration of BSA adsorbed on the membrane surface and the additional resistance due to membrane fouling.

2. Theory

To develop this theoretical analysis, the lab-scale membrane unit already used to build the ANN model [1] has been exactly reproduced and represented as a 2D straight rectangular channel, 27 cm long and 2.5 mm thick; the membrane,