A nanofiltration retention model for trace contaminants in drinking water sources

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Abstract

A diffusion–convection controlled mass transfer model was developed for predicting the retention behaviour of full-scale nanofiltration (NF) plants. The model is based upon a previous diffusion-only-controlled transport model and is described by an analytical equation in which the retention can be calculated as a function of the recovery. The three main parameters in the model are K_w, K_s, and K_c, respectively, the water transfer coefficient, solute transfer coefficient and the convective hindrance factor. These parameters can be determined experimentally for a given membrane and solute or can be taken from the literature for a given membrane and solute. Both laboratory-scale and bench-scale NF experiments were carried out with several trace organic contaminants using TriSep TS80 NF membranes. High retentions were found for trace organics with a molecular weight higher than the MWCO of the membrane. From these experiments K_w, K_s, and K_c were determined for $MgSO_4$ and atrazine in order to predict the retention behaviour of a full-scale NF process. Especially at higher recoveries, e.g., 0.6–0.95, the differences in predicted retentions are large compared to models using diffusion-only-controlled transport.

Keywords: Nanofiltration; Mass transfer model; Trace organic contaminants

1. Introduction

As a result of increasing industrialisation, the trace organic contaminant content in various drinking water sources has been increasing.

Groundwater, riverbank filtrate and surface water are increasingly polluted with trace organic contaminants such as pesticides and endocrine disrupting compounds. In many cases the concentration of these compounds exceeds existing drinking water standards, and hence needs to be

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eliminated. While for other compounds no drinking water standards exist, the need for their removal from drinking water sources still applies.

Nanofiltration (NF) and reverse osmosis (RO) are techniques used for the removal of dissolved trace organic contaminants for the production of drinking water. In particular, the NF retention of these compounds strongly depends on the feed water composition, the membrane properties, the properties of the components and the process conditions. Because of the wide variety of trace organic contaminants, a tool is under development to predict retention behaviour for full-scale installations using data from laboratory-scale experiments and a model for up-scaling to full-scale NF. This article describes a diffusion–convection controlled mass transfer model for predicting retention behaviour of full-scale NF plants.

2. Development of the retention model

To extrapolate the results of small-scale experiments to full scale, a model is required describing the mass transfer through the membrane of trace organic contaminants in one single (full-scale) NF membrane element. The development of the retention model is presented here.

2.1. Basic equations

In any pressure-driven membrane process for an aqueous system, the water flux equation is the product of the pressure gradient and the water transfer coefficient [1]. This pressure gradient depends on the transmembrane pressure and the effect of osmotic pressure, which is a function of the solute concentrations on both the feed and permeate side.

$$J_w = \frac{Q_p}{A} = K_w(\Delta P - \Delta \Pi) \qquad (1)$$

In a system only controlled by diffusion the solute mass transfer can be described by the solute flux equation, given by the product of the concentration difference and the solute mass transfer coefficient.

$$J_s = \frac{Q_p c_p}{A} = K_s \Delta c \qquad (2a)$$

Models based upon diffusion only give good predictions of full-scale mass transfer for rather dense RO osmosis membranes [2]. However, predictions of full-scale mass transfer of trace organic contaminants for NF membranes cannot accurately be described by a diffusion-controlled model. Mass transfer in NF membranes can be described more accurately by a combination of diffusion and convection [3,4]. The solute flux given by Eq. (2a) is extended with a convection term, which is the product of the feed concentration in the membrane element, the water flux and the term account for convective transport. The equation is:

$$J_s = \frac{Q_p c_p}{A} = K_s \Delta c + K_c c_b J_w \qquad (2b)$$

where c_b is the average feed concentration in a single membrane element given by $c_b = \frac{1}{2}(c_f + c_c)$. In the literature several authors have described mass transfer in NF by adding electromigration terms on top of diffusion and convection to account for charge effects between membrane and solutes [5]. This is, however, beyond the scope of this work.

For any single membrane element, water and solute mass balances can be given. Furthermore, the permeate recovery is defined as the ratio of the permeate flow and the feed flow. These equations are given by:

$$Q_f = Q_c + Q_p \qquad (3)$$