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Effect of permeate flux and tangential flow on membrane fouling for wastewater treatment

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Abstract

Well-controlled membrane filtration experiments were performed to systematically investigate the effect of permeate flux and tangential flow (crossflow) on membrane fouling. Results were analyzed by the resistance-in-series model where the reason for flux decline was subdivided into adsorption, concentration polarization, and reversible and irreversible fouling. A synthesized paper mill wastewater with mainly lignin and 2-chlorophenol, biological suspension (activated sludge), and their mixture were used as feed solutions for ultrafiltration (30 000 Da) and microfiltration (0.3 μm) at different concentrations. The filtration experiments demonstrated that permeate flux declined faster with increasing feed concentration and membrane pore size and with decreasing tangential flow. The biological suspension rather than wastewater quality was a major cause for permeate flux decline in membrane bioreactors. In the absence of permeate flux, filtration resistance by foulants adsorption was negligible, as compared to total filtration resistance in the presence of permeate flux. It was also shown that tangential flow had almost no effect on the decline rate of permeate flux at pseudo steady state. Membrane cleaning results revealed that, in the absence of tangential flow, permeate flux decline was dominantly caused by reversible fouling. On the other hand, tangential flow caused slightly higher irreversible fouling due to higher permeation drag, as compared to the case of absence of tangential flow. Autopsy of fouled membranes suggested that the irreversible fouling layer was initially formed by pore blocking of small particles followed by strong interaction of fouling layer with mainly dissolved materials and by fouling layer compaction due to permeation drag.

Keywords: Fouling; Permeate flux; Tangential flow; Filtration resistance; Resistance-in-series model; Membrane bioreactor; Autopsy

1. Introduction

Membrane separation technologies for the removal of all suspended solids including microorganisms and a fraction of dissolved solids from wastewater are becoming more and more promising [1]. There has been a great degree of advancement in the development of membrane separation technologies. Porous membranes, like ultrafiltration (UF) and microfiltration (MF) membranes, present other operational advantages such as lower driving force and a smaller space requirement due to high packing density. However, there is no doubt that membrane fouling is one of the most serious problems of this technology [2,3]. Decrease in performance of membrane filtration due to fouling has hindered the widespread application of membrane separation processes for wastewater treatment. In fact, fouling has many adverse effects on the membrane system including flux decline, significant requirement for increase in transmembrane pressure (TMP), biodegradation of membrane materials and system failure [4]. Thus, the primary disadvantages of membrane bioreactors (MBRs) for the treatment of wastewater include high capital costs for the membrane system itself and operating costs associated with routine membrane cleaning due to fouling [5,6].

To prevent or reduce membrane fouling, several research studies have focused on modification and development of membrane materials [7–11]. According to these research results, hydrophilic, electrically neutral and smooth surfaces were generally the least susceptible to fouling. In order to investigate the fouling tendency of such modified or developed membrane materials, an adsorption test is usually

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performed, using certain experimental methods and devices such as the disc assay method [7,12] and the rotating annular reactor (Roto-Torque) [9,13] without permeate flux through the membrane.

However, it is clearly expected that water permeation through the membrane would cause rapid formation of a fouling layer due to compulsive transport of foulants into the membrane surface by the drag force of permeate flow, resulting in clogging membrane pores and building up the fouling layer. It is well-known that permeation drag is a dominant force affecting the initial attachment of feed components onto the membrane surface. By conducting comparative experiments with and without permeate flux, Ognier et al. [14] concluded that the presence of permeate flux caused highly irreversible fouling and that filtration resistance by foulants adsorption in the absence of permeate flux was very small. As a result, because such an adsorption test without water permeation might not represent the true fouling tendency of membranes in real applications, it is required to investigate the role of the presence of permeate flux on membrane fouling. A reasonable procedure is also needed for distinguishing between various filtration resistances including adsorption, concentration polarization, and reversible and irreversible fouling. Moreover, there have been only few research studies addressing the effect of operational conditions such as permeate flux and tangential flow (i.e., crossflow) as well as the influent properties such as feed composition and strength on fouling in terms of those subdivided filtration resistances.

Consequently, this paper deals with: (1) definition and measurement of various filtration resistances, (2) assumptions used to reduce complexities of the resistance-in-series model, (3) the effect of permeate flux, tangential flow, feed composition and strength, and pore size of MF and UF membranes on various filtration resistances, and (4) autopsy of fouled membranes.

2. Background and approach

2.1. Resistance-in-series model

The typical variation of permeate flux over time is an initial sharp decrease for a few minutes followed by gradual decrease due to fouling and concentration polarization, and then finally steady state due to the equilibrium of foulant attachment with its detachment between membrane surface and feed solution. The basic model used for determining filtration resistance occurring during permeate transport through porous membranes is Darcy's law:

$$J = \Delta P/(\mu R_t) \quad (1)$$

where J is the permeate flux (l/m^2 h), ΔP the TMP (Pa), μ the viscosity of permeate (Pa s), and R_t the total filtration resistance (m^{-1}). Generally, the driving force and filtration resistance can be changed due to fouling and concentration polarization over time, resulting in a decrease of permeate flux. Many models describing permeate flux decline have been used with various theories.

Ko and Pellegrino [15] explained that the filtration resistance caused by concentration polarization accounted for the reduction of the effective TMP by increased osmotic pressure. However, in order to explain permeate flux decline with various filtration resistances including concentration polarization, the resistance-in-series model is usually used [16–18]:

$$R_t = R_m + R_{cp} + R_f \quad (2)$$

where the total filtration resistance R_t is composed of each filtration resistance caused by the membrane itself, R_m, concentration polarization, R_{cp}, and fouling, R_f. The effect of R_{cp} on overall resistance R_t can be removed by replacing the feed solution with clean water [19].

The most important factor for flux decline is fouling resistance, R_f, which can be reduced by proper methods such as crossflow filtration. The fouling can be divided into reversible and irreversible fouling according to the attachment strength of foulants to the membrane surface. For example, reversible fouling resistance R_{rf} caused by loosely attached foulants is easily removed by a strong shear force or backwashing. On the other hand, irreversible fouling resistance R_{if} caused by strong attachment of foulants such as pore blocking, cake, gel and biofilm is difficult to remove by such physical control methods. A schematic description of the resistance-in-series model used in this study is shown in Fig. 1. During filtration, particles are transported to the membrane surface by permeation drag. Concentration of particles on the membrane surface reaches its maximum value after a short initial filtration and a gel and cake layer starts to form. Moreover, an initial reversible fouling layer might be transformed into an irreversible fouling layer due to formation of a strong matrix of fouling layer with dissolved materials and to compaction

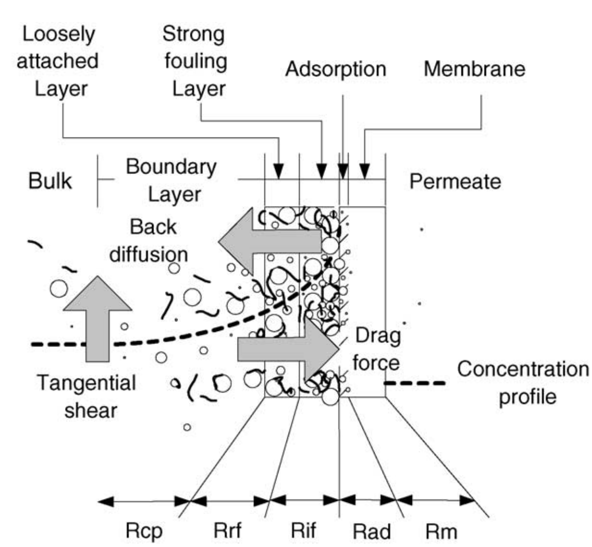

Fig. 1. Schematic description of the resistance-in-series model for explaining the causes for permeate flux decline with various filtration resistances.