Improvements in Membrane Microfiltration Using Coagulation Pretreatment

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Introduction

An important consideration in water and wastewater treatment using low-pressure membrane filters is the potential for reductions in permeation rate due to the accumulation of colloidal and macromolecular materials on and within the membrane. One strategy for improving membrane performance has been proposed [1] in which colloids capable of entering membrane pores are coagulated to produce particles that are rejected by the membrane. Increasing the size of particles applied to membrane filtration units by coagulation may improve permeate flux by 1) reducing foulant penetration into pores, 2) forming a more porous cake on the membrane surface that may act as a dynamic membrane thereby protecting the membrane from long term fouling, and 3) decreasing the accumulation of foulants near the membrane due to particle size effects on particle transport. In this paper, a pilot study is reported in which metal coagulants were added to improve the permeate flux, fouling characteristics, and water quality produced by tubular ceramic microfiltration membranes with different nominal pore sizes.

Background

Reductions in the flux of permeate across a membrane may be categorized as being operationally reversible or irreversible. The irreversible loss in permeate flux due to accumulation of materials in and on the membrane is referred to as fouling. A reversible decrease in permeate flux is referred to as reversible fouling or sometimes as "colmatage" from the French word meaning clogging. The instantaneous flux of permeate across ultrafiltration (UF) and microfiltration (MF) membranes can be described using a modification of Darcy’s law in which permeate flux, \( J \), is assumed to be inversely proportional to a sum of resistances to the passage of permeate and proportional to the pressure drop across the membrane,

\[
J = \frac{\Delta P}{(R_m + R_f + R_c)}
\]

(1)

where \( R_m \) is the resistance to permeate flow associated with the clean membrane, \( R_f \) is the additional resistance due to membrane fouling, and \( R_c \) is
resistance due to membrane colmatage. The colmatage term, $R_c$ can be further
divided into the resistance due to the formation of a cake (or gel layer) on the
membrane that can be eliminated either hydrodynamically or chemically, the
resistance of a concentration polarization layer, and resistance due to reversible
obstruction of membrane pores. When a membrane is first placed into service,
the fouling and colmatage terms in Eq. (1) are zero, and permeate flux is lim-
ited by the resistance of the membrane. The accumulation of materials on (and
in) the membrane over time produces an increase in the relative importance of
$R_f$ and $R_c$ and these terms may eventually control permeate flux. In the case
where $R_c$ is dominated by the formation of a cake of constant resistance per
unit depth,

$$R_c = aL$$

where $a$ is the specific resistance of the cake (resistance per unit depth), and
$L$ is the depth of the cake. In many cases $a$ will increase over time as the
cake compacts and as smaller colloidal materials are "filtered" by the cake.
Cake growth at any time should be proportional to the rate at which materials
are carried to the membrane surface. However, as the cake depth increases,
shear-induced back-transport of deposited materials should occur at a greater
rate. These assumptions may be expressed in the following differential equation
describing the change in cake thickness with time:

$$\frac{\partial L}{\partial t} = k_1 J - k_2 L$$

The rate constant $k_1$ describes the transport of cake-forming materials to the
membrane and should increase with increasing feed concentration. Theoretical
consideration of particle trajectories in membrane elements indicates that
$k_1$ should decrease with increasing particle diameter and increasing crossflow
velocity due to the effects of inertial lift [2]. The constant $k_2$ indicates the
relative importance of back-transport mechanisms in removing materials from
the membrane and is also predicted to increase with increasing crossflow velo-
cy. If it is assumed that the cake is composed of a fluidized layer of particles,
a minimum in $k_2$ with respect to particle size is predicted for colloids near
0.1 μm in diameter based on the combined effects of Brownian diffusion and
shear-induced diffusivity [3].

Under the assumption of a constant membrane resistance, constant pres-
sure drop, colmatage resistance, $R_c$, dominated by cake growth, and a specific
resistance of the cake that is invariant with time, the time derivative of Eq. (1)
yields,

$$\frac{\partial J}{\partial t} = -Ja(k_1 J - k_2 L)/(R_m + aL)$$

During the early stages of cake formation, deposition of materials to the mem-
brane may be much greater than loss by fluid shear ($k_1 J > k_2 L$) and initial cake
resistance may be less than the resistance of the membrane ($R_m \geq aL$). Under
these assumptions, the time rate of change of permeate flux during the early
stages of filtration can be approximated as a pseudo-second order equation in
$J$: 