NOM Rejection by, and Fouling of, NF and UF Membranes [Project #390]

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OBJECTIVES:
The performance of spiral-wound nanofiltration (NF) and ultrafiltration (UF) membranes was investigated in terms of natural organic matter (NOM) rejection and associated NOM fouling. The study objectives focused on
• demonstrating the effects of both hydrophobic and electrostatic interactions between NOM components and the membrane surface
• determining influential factors (water quality and operational) in NOM rejection and flux-decline
• determining major foulant components of NOM
• developing NOM-rejection prediction equations and flux-decline (NOM adsorption) models

BACKGROUND:
NOM is recognized as both an important target solute for rejection as well as an important foulant in membrane treatment. However, little has been known about NOM rejection and fouling phenomena because of the complexity of NOM as a solute. Moreover, little is known about potential NOM-membrane interactions affecting rejection and fouling.

HIGHLIGHTS:
Detailed characterization of NOM in feed waters along with determination of important membrane properties, followed by membrane rejection and fouling tests, has provided revealing information on NOM rejection and fouling phenomena. While membrane properties are important, NOM characteristics and hydrodynamic operating conditions are even more influential.

APPROACH:
NOM characterization was performed to define size, structure, and functionality. Feed waters were characterized according to specific UV absorbance (for structure), molecular weight distribution (for size), humic content (for aromaticity/hydrophobicity), and XAD-8/-4 resin fractionation to describe the NOM distribution among various fractions (hydrophobic/hydrophilic acids, bases, and neutrals). Clean and NOM-fouled membranes were characterized in terms of molecular weight cut-off (MWCO) (for pore size), contact angle (for hydrophobicity), zeta potential (for surface charge), and Fourier transform infrared spectroscopy spectra for polymer (clean membranes) and foulant (fouled membranes) composition. NOM and membrane characterizations were evaluated in terms of several mechanisms and interactions that may influence NOM rejection and fouling, and flux-decline by membranes: steric (size) rejection, electrostatic (charge) rejection, and adsorption (fouling). Most of the work was based on a bench-scale, cross-flow filtration unit used for NOM rejection and fouling tests with a wide range of NF/UF membranes and various NOM source waters.

RESULTS/FINDINGS:
Results indicated that electrostatic repulsion between NOM acid components and the membrane surface was an influential factor in increasing NOM rejection and decreasing fouling and flux-decline. Hydrodynamic operating conditions, represented by an f/k ratio (the ratio of flux to back-diffusional transport of NOM molecules), were also influential in optimizing membrane performance, with NOM rejection decreasing and NOM fouling increasing with increasing f/k for a given combination of membrane and feed water. For a given feed water, different membranes exhibited similar flux decline trends at the same f/k condition. An optimum f/k value must also take into account system productivity as represented by the flux, f. Hydrophilic NOM (particularly hydrophilic neutrals such as polysaccharides) was found to be a major foulant for typical NOM source waters, as revealed by characterization of the foulant and fouled membranes. A concept of effective molecular weight cutoff, as opposed to manufacturer-specified MWCO, was derived to help explain the electrostatic rejection of NOM molecules (acids) with molecular weights smaller than the nominal MWCO. While both steric and electrostatic rejection mechanisms are important, electrostatic rejection is more important for UF while steric rejection is more important for NF. NOM rejection was significantly reduced by the presence of calcium ion (Ca^{2+}) while lower pH and higher ionic strength (I)
had a smaller adverse effect on rejection; over the ranges of conditions studied, higher Ca\(^{2+}\), lower pH, and higher I slightly increased fouling and flux decline. Effective cleaning and flux recovery was realized by caustic (NaOH) cleaning with citric acid, providing a minor additional benefit; cleaning with a surfactant had no effect. There was little difference in the fouling potential of polyamide versus polysulfone membranes, which are the dominant materials for spiral-wound UF and NF.

**IMPACT:**
It is recommended that a utility considering the implementation of NF or UF membranes make several decisions. The first decision is selection of NF versus UF, which is largely a function of treatment objectives. For UF, the primary goal is often microbial removal with modest NOM removal achievable while for NF, significant removal of NOM is generally the primary goal. The second decision is selection of a specific NF or UF membrane. Given the dominance of polyamide and polysulfone among spiral-wound NF and UF membranes, the main criteria should be MWCO and pure water permeability. The third decision is to select appropriate operational conditions. In this study, hydrodynamics represented by the \( f/k \) ratio are important; as \( f/k \) increases productivity increases, but fouling also increases while rejection decreases. The fourth decision is whether to adopt an effective cleaning strategy to ensure that most of the NOM-related fouling is reversible.

**PARTICIPATING UTILITIES:**
- Ten utilities and organizations located throughout the United States participated in the research for this project.