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Biofouling of spiral-wound nanofiltration and reverse osmosis membranes: A feed spacer problem

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ABSTRACT

Biofouling was studied in full-scale and pilot-scale installations, test-rigs and membrane fouling monitors by conventional methods as well as Magnetic Resonance Imaging (MRI). Independent of permeate production, the feed spacer channel pressure drop and biomass concentration increased similarly in a nanofiltration pilot installation. In the presence of a feed spacer the absolute feed channel pressure drop increase caused by biomass accumulation was much higher than when a feed spacer was absent: in both spiral-wound nanofiltration and reverse osmosis systems biofouling is dominantly a feed spacer problem. This conclusion is based on (i) in-situ visual observations of the fouling accumulation, (ii) in-situ non-destructive observations of the fouling accumulation and velocity distribution profiles using MRI, and (iii) differences in pressure drop and biomass development in monitors with and without feed spacer. MRI studies showed that even a restricted biofilm accumulation on the feed channel spacer influenced the velocity distribution profile strongly. Biofouling control should be focused on the development of low fouling feed spacers and hydrodynamic conditions to restrict the impact of biomass accumulation on the feed channel pressure drop increase.

1. Introduction

Biofouling – excessive growth of biomass, i.e. biofilms – is the major fouling type in spiral-wound nanofiltration (NF) and reverse osmosis (RO) systems, resulting in a pressure drop increase (Characklis and Marshall, 1990; Ridgway and Flemming, 1996; Patching and Fleming, 2003). In NF/RO membranes, pressure drop occurs over the feed spacer channel and membrane (Flemming et al., 1994; Patching and Fleming, 2003). Autopsies on membrane modules from full-scale and pilot installations show biofouling of the spacer, located in the feed channel (Fig. 1).

In the late 1990s, two strategies were strongly proposed to prevent and control membrane biofouling: (i) physical removal of bacteria from the feed water of membrane systems (for example by microfiltration or ultrafiltration pretreatment), and (ii) metabolic inactivation of bacteria by applying biocide dosage or UV irradiation (Ridgway, 1997). At present,

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Nomenclature

ATP	adenosine triphosphate (measure for active biomass) [pg ATP cm^{-2}]
FCP	feed channel pressure drop [bar]
ΔFCP	feed channel pressure drop increase [bar or %]
MFS	Membrane Fouling Simulator [–]
MRI	Magnetic Resonance Imaging [–]
MTC	normalized flux (mass transfer coefficient) [m s^{-1} Pa^{-1}]
NMR	Nuclear Magnetic Resonance [–]
NF	nanofiltration [–]
RO	reverse osmosis [–]
S-MFS	small MFS (plastic) used for NMR studies [–]
TMP	trans-membrane pressure drop [bar]

the focus is on nutrient removal by biological pretreatment (e.g. sand filtration) and modification of membranes (disinfectant resistant and low fouling). Already in 1997, Ridgway was the first author to point out that adaptation of hydrodynamics and feed channel spacers may be an approach to control membrane biofouling. Nevertheless, since then research to control biofouling was predominantly focused on development of low fouling membranes and not on feed channel and spacer modification. The number of publications in journals satisfying the search criteria "biofouling" and "modified and/or adapted membrane" in the article title, abstract and keywords in the scopus database of March 2008 amounted 59. The search criteria "biofouling" and "modified and/or adapted spacer" yielded no references at all. At the North American Membrane Society (NAMS) conference 2007, to control biofouling membrane modification was addressed in 6 presentations while feed spacer modification was addressed in 1 presentation only. Evidently, until now biofouling control was considered a membrane problem and not a feed channel problem.

The main items of this study were as follows:

1. an overview of biofouling problems in practice,
2. the effect of biofouling on the feed channel pressure drop and trans-membrane pressure drop and
3. the role of the feed spacer on the development of feed channel pressure drop caused by biofouling.

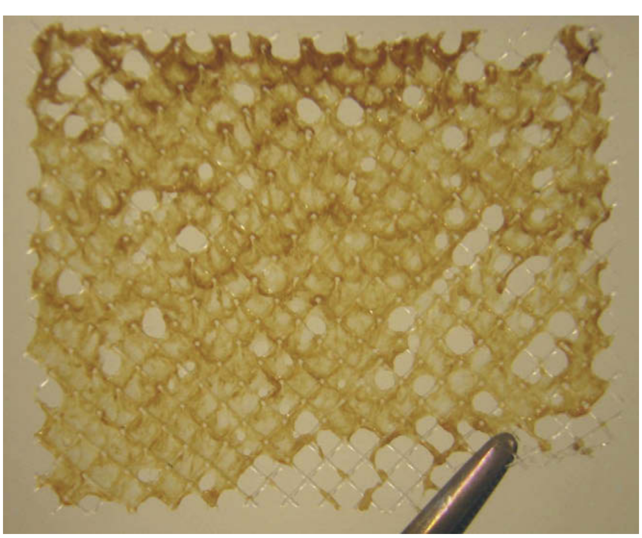

Fig. 1 – Feed spacer taken during autopsy of spiral-wound membrane module from a full-scale installation suffering from a prolonged elevated feed channel pressure drop.

2. Materials and methods

2.1. Terminology

Biofouling – excessive growth of biomass, i.e. biofilms – is the major fouling type in nanofiltration and reverse osmosis systems after extended pretreatment with for example ultrafiltration. Biofouling increases the pressure drop (Characklis and Marshall, 1990), thereby increasing the process costs (Ridgway, 2003). In spiral-wound membrane modules, two types of pressure drop can be discriminated: the trans-membrane pressure drop (TMP) and the feed channel pressure drop (FCP, Fig. 2; Flemming et al., 1994). The TMP is the differential pressure between feed and permeate lines, caused by the frictional resistance over the membrane. The TMP is related to the membrane flux. When the TMP is increased by biofouling, the membrane flux is declined. The definition of flux is the water volume passing a membrane per unit area and time (L m^{-2} h^{-1}). The flux normalized for temperature and pressure, the Mass Transfer Coefficient (MTC), is expressed in m s^{-1} Pa^{-1}. The FCP is the pressure drop between feed and brine lines.

2.2. Experimental set-up

In this study, the development of biofouling in the feed channel was investigated using (i) full-scale installations, (ii) a nanofiltration pilot plant, (iii) test-rigs and (iv) MFS's with and without feed spacer. In-situ visual observations on fouling accumulation using the Membrane Fouling Simulator (MFS)

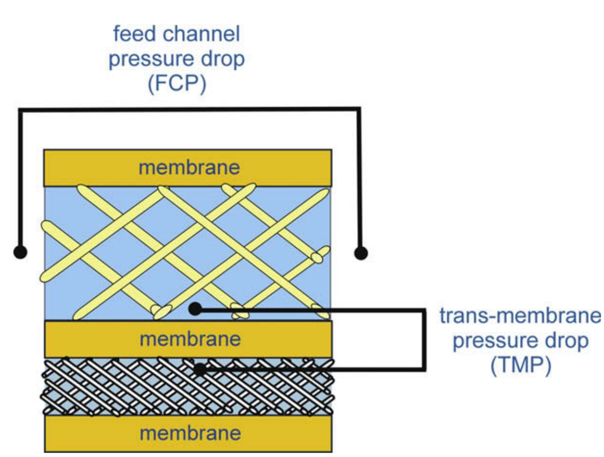

Fig. 2 – Scheme of pressure drops in membrane sheets showing feed channel pressure drop (FCP) and trans-membrane pressure drop (TMP).