Available online at www.sciencedirect.com
ScienceDirect
Journal of Membrane Science 284 (2006) 339–351
journal of MEMBRANE SCIENCE
www.elsevier.com/locate/memsci

Air sparging in capillary nanofiltration

J.Q.J.C. Verberk [a,*], J.C. van Dijk [a,b]

[a] *Section Sanitary Engineering, Department of Water Management, Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands*
[b] *Kiwa Water Research, Nieuwegein, P.O. Box 1072, 3430 BB Nieuwegein, The Netherlands*

Received 27 January 2006; received in revised form 18 July 2006; accepted 31 July 2006
Available online 11 August 2006

Abstract

Capillary nanofiltration offers the possibility to treat raw water to high quality (process) water in just one step. Surface water can be treated for drinking water production and effluent for water recycling. In capillary membranes no feed-side spacers are present and a high concentration polarization is thus observed, limiting the overall system performance. In this study, the effect of air sparging to limit concentration polarization is investigated. Experiments are carried out with synthetical water at different TMPs and superficial water and air velocities. As expected, air sparging decreases concentration polarization, resulting in an increase in permeate flux and retention. Moreover, air sparging uses less energy, so the industrial relevance is high.

Keywords: Nanofiltration; Air sparging; Concentration polarization; Capillary membranes

1. Introduction

1.1. Description of capillary nanofiltration

Capillary nanofiltration is a relatively new concept in membrane filtration. Capillary nanofiltration combines the advantages of nanofiltration membranes (good water quality) and capillary ultrafiltration membranes (good hydraulic cleaning possibility). Due to the high fluxes of capillary nanofiltration membranes, the system can be operated at moderate pressures, reducing operational costs significantly. Capillary nanofiltration offers the potential to treat (surface) water in one single step to high quality (process) water. In The Netherlands several feasibility studies with pilot plants have been performed with varying success. Effluent from a sewage treatment plant [1] and surface water have been treated [2,3].

In nanofiltration installations spiral wound membrane modules are most common. The specific membrane area (installed membrane area per volume) is large, resulting in low investment costs. However, unlike tubular and capillary micro- and ultrafiltration membranes, spiral wound membranes cannot be cleaned hydraulically by a back flush. To prevent fouling of the spiral wound nanofiltration membranes an extensive pretreatment, consisting of conventional drinking water processes or even ultrafiltration, is used. Furthermore, chemicals are necessary to prevent scaling and fouling and to clean the membrane surface [4].

Capillary membranes are commonly used in micro- and ultrafiltration applications. Micro- and ultrafiltration are mainly used to remove suspended material from the feed water. The removal of suspended material from water results in the build-up of a cake layer on the membrane. By means of hydraulic cleaning methods this cake layer can be removed. Several hydraulic cleaning methods are used, like for example back flush and forward flush [5–7].

The process of capillary nanofiltration can be compared to dead-end ultrafiltration. Concentrate is discharged periodically and a filtration and cleaning cycle can be distinguished. On the other hand, like in cross-flow systems, a cross-flow velocity is used to limit the concentration polarization. It depends on the system boundaries whether the process is called dead-end or cross-flow.

A direct capillary nanofiltration module is always placed vertically. During the filtration period permeate is produced, while no concentrate is discharged (Fig. 1, left). A feed pump provides the necessary feed pressure. The permeate flow is equal to the feed flow and the water in the system is concentrated over time. Therefore, problems with scaling, deteriorating permeate

* Corresponding author. Tel.: +31 152781585; fax: +31 152784918.
E-mail address: j.q.j.c.verberk@tudelft.nl (J.Q.J.C. Verberk).

0376-7388/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.memsci.2006.07.050

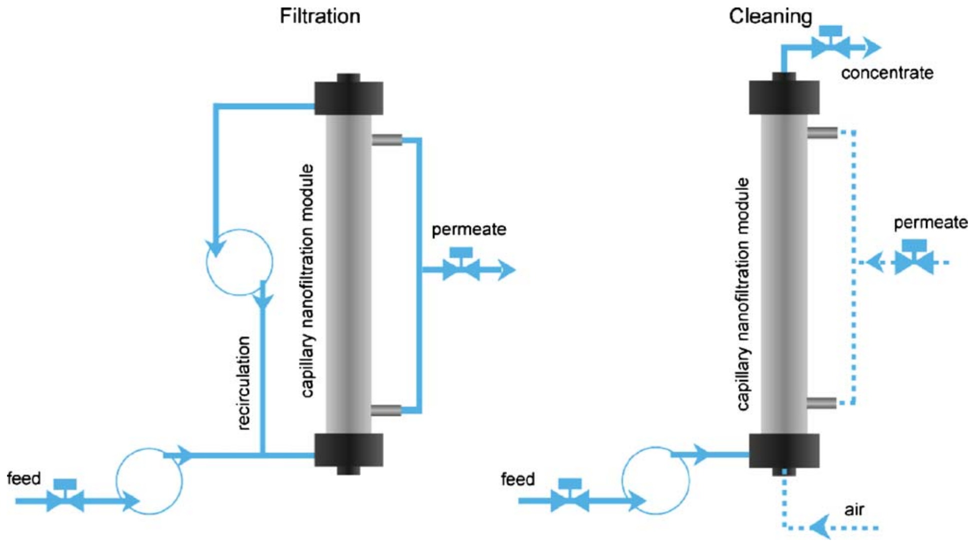

Fig. 1. Operation of direct capillary nanofiltration.

quality, decrease in flux due to higher osmotic pressure and fouling occur in capillary nanofiltration systems. To prevent these problems water is recirculated continuously (cross-flow) and the most effective system performance is obtained when the flow in the membranes is turbulent. The bulk flow emerges at the top of the membrane module with a pressure of about 0.2–0.5 bar less than the inlet pressure. This loss in pressure is compensated by a positive displacement pump in the recirculation flow. The permeate flow is only about 5–10% of the total recirculation flow in the system.

After some time the resistance for filtration, as a result of fouling and osmotic pressure difference, has become so large that a system flush is necessary. With a system flush the concentrated water is flushed out of the module, and so periodically a concentrate flow is released (Fig. 1, right). To perform a system flush the concentrate valve is opened, while the permeate valve is closed and the displacement pump is switched off. A forward flush is thus performed and normally feed water is used for this. Sometimes air is injected into the feed water (Fig. 2) creating a so-called air flush [8]. Furthermore, is it even possible to back flush capillary nanofiltration membranes with permeate [9]. By the back flush scaling and fouling can be (partially) removed.

1.2. Two-phase flow in industrial processes

Two-phase flow is a well-known phenomenon in many industrial applications. In literature two-phase flow is reported to be effective to enhance heat and mass transfer in reactors, dialysers and heat exchangers [10,11]. Depending on the superficial velocities and the pipe geometry different two-phase flow patterns occur, like bubble flow, slug flow and annular flow. The segmented flow pattern slug flow is reported to be very effective in small diameter tubes to increase heat and mass transfer rates compared to single-phase flow. Slug flow was found to augment radial mass transfer in reactors with catalytically active walls [12]. These results suggest that slug flow could be a useful means to improve the efficiency of many devices, which employ small diameter tubes and laminar flow by enhancing radial mass transport or reducing axial dispersion. Such devices, in addition to reactors, include tubes with an absorbing wall for liquid chromatography or for selective removal of solutes, tubular dialysers and reverse osmosis, or ultrafiltration systems having a semi-permeable wall.

In heat transfer experiments conducted in a 0.25 in. copper tube under a variety of two-phase flow conditions it was reported that for bubble train flow the heat transfer rates were up to 2.5 times the rate of pure liquid regimes [12]. The radial heat transfer was investigated in a solid–liquid slug flow system and increased heat transfer rates were reported with increase in flow rates and decrease in slug length [13].

The two-phase flow pattern slug flow in small diameter channels is often called bubble train flow or Taylor flow. Bubble train flow or Taylor flow differs from slug flow in large diameter tubes. In capillaries the flow is essentially laminar and predominantly

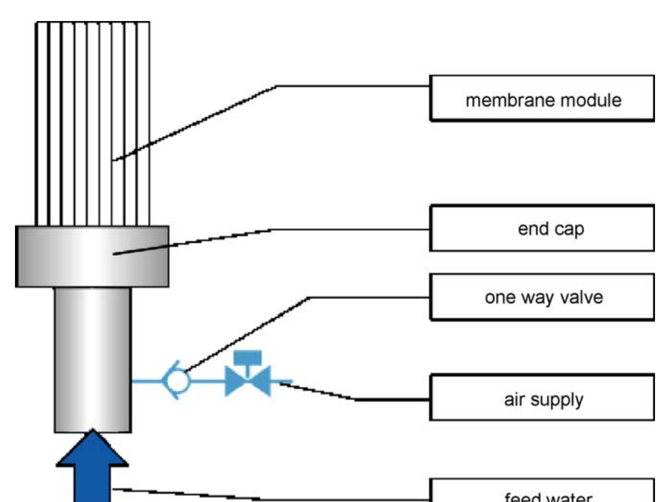

Fig. 2. Injection of air in the end cap during cleaning of direct capillary nanofiltration.