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Reverse-pressure back-flush in pilot scale, dead-end ultrafiltration of surface water

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Abstract

A simple protocol that makes use of the inertia of water to generate a rapid negative pressure differential across capillary ultrafiltration membranes is reported. This short-interval back-flush technique, preceded by cross-flow forward flush, was evaluated as an alternative to conventional back-flush to maintain membrane flux productivity in a pilot dead-end filtration application.

Intermittent back-flush conditions are created when a reverse-pressure pulse, during which product is drawn in the reverse direction through the membrane wall, is introduced. The duration of the negative pressure-pulse peak is very short (1–2 s), after which it subsides and levels out in accordance with the net positive suction head of the centrifugal pump used to recirculate the feed. Reverse-pressure spikes of up to −90 kPa, which subside after only a few second to −40 kPa, were generated.

The combined effect of reverse-pressure pulsation sequence of events is that of (i) a short back-flush (direct result of negative trans-membrane pressure conditions that are introduced) and (ii) flow destabilisation (sudden retardation and start-up of lumen-flow) during a forward flush that precedes the reverse-pressure pulse event.

The reverse-pressure pulse technique was evaluated in a dead-end filtration pilot study producing potable water from a surface resource without the addition of chemicals. The membranes suffered no adverse effects and their flux performance was maintained reasonably well, even though the feed water turbidity reached values as high as 90 NTU during the exercise.

Keywords: Back-flush; Flow destabilisation; Fouling; Capillary membranes

1. Introduction

The drawback of pressure-driven membrane operations is the decline in flux that occurs as a result of concentration polarization and fouling. The effectiveness of the membrane operation decreases as result of this, while the specific operating cost in terms of electrical power consumption per unit volume product (kWh/m^3) increases.

Various hydraulic and mechanical methods have been investigated to reduce the resistance caused by concentration polarization in order to improve the efficacy of the separation process and decrease operating cost. Back-flushing with permeate [1–5] has been studied with varying degrees of success in both cross-flow and dead-end filtration applications and has become the most commonly used operating protocol in full-scale capillary-type membrane plants.

Numerous researchers have investigated the effect of pulsatile flow (flow destabilization) on flux performance improvement and various approaches to pulsation [6–11] and rapid backpulsing [12] have been reported. Amongst these devices are perforated rotating distributors upstream of ceramic tubular membranes [13,14] and collapsible-tube pulse generators [15,16]. Volumetric pumps and pistons [17–19], and pump-induced pulsatile flow in baffled tubular membranes were also investigated [20]. Valve arrangements at the feed,

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concentrate and permeate sides of membrane modules were studied by Stairmand and Bellhouse [21] as well as Milisic and Bersillon [22].

Intermittent cross-flow microfiltration received attention by Farley and White [23] in their study of cyclical stop–start operation as a technique to improve flux performance. They also suggested that the removal of applied pressure for a certain period allows reversible fouling, such as concentration polarisation, to dissipate. In another laboratory study, Chang et al. [24] combined dead-end filtration with cross-flow filtration and back-flushing, thereby combining the advantages of lower energy consumption and sweeping and lifting of accumulated deposits from the membranes studied. A piston drove their tubular ceramic membranes and the forward–reverse filtration cycles were operated without cross-flow. It is evident from the above findings that flux of a membrane system is improved if the concentration polarization layer can be reduced or dislodged by either increasing shear at the membrane/feed interface or by the incorporation of a protocol to dissipate the concentration polarization layer.

This work builds on the work of others and reports on a simple protocol to incorporate both flow destabilisation (cross-flow) and concentration polarisation dissipation (back-flush through reverse-pressure pulsing) as a flux enhancement strategy in a dead-end filtration application. The technique was investigated during a pilot study on the production of potable water using capillary ultrafiltration membranes. The protocol was tested on a 30 m^2 capillary membrane pilot plant operated on surface water without the addition of chemicals to coagulate the intake water.

2. Flux and fouling

Fouling may be defined as any process that results in loss of performance of a membrane caused by the deposition of suspended or dissolved (colloidal) substances on its surface, at its pore openings or within its pores [25]. This loss of flux performance may occur over a period of a few seconds or minutes through to several days [26]. Fouling-associated loss of membrane permeability is possibly the most important reason for the slow acceptance of ultrafiltration in various areas of the chemical and biological processing industry [27,28] as well as drinking water production.

Concentration polarization is by definition a reversible process and it is not considered as membrane fouling per se, but rather as a flux reduction phenomenon inherent to all pressure-driven membrane filtration processes. It may either precede fouling or occur simultaneously with fouling. Flow destabilisation is quite often sufficient to reduce resistance to transport caused by concentration polarization. Fouling is another matter. The different mechanisms of fouling include adsorption (physico-chemical interactions between solutes and the membrane), complex formation and aggregation (interactions between retained solutes, especially at the mass transport boundary layer), and pore blocking. It is more difficult to remove fouling by in-process protocols and chemical cleaning is often the only solution. However, back-flushing of capillary membranes has proved to be effective in reducing cake or gel layer resistances, which in many cases is a precursor to semi-permanent fouling.

3. Potential foulants in surface water

Low-pressure membrane operations such as ultrafiltration and microfiltration are becoming accepted practices to treat surface water for drinking purposes. Surface water varies greatly in quality and geographical location and seasonal fluctuations affect the nature and concentration of organic and inorganic materials in raw water sources.

About 80% of the dissolved organic carbon in surface waters consists of a variety of molecules loosely termed natural organic material (NOM) that can be subdivided into two groups, namely humic and fulvic acids [29,30]. The remaining 20% are made up of identifiable compounds that include carbohydrates, carboxylic acids, amino acids and hydrocarbons.

Being found in soils, NOM is often present in surface waters, concentrations of which may vary seasonally. NOM has no precisely defined structure but is known to contain polyphenolic molecules with a molar mass of 5,000–500,000 Da that cause water to have a yellow-black colour (this is typical of water along the south-facing mountain regions of the West Cape and western part of the East Cape Provinces of South Africa). Apart from the aesthetic undesirability of NOM in potable water, the polyphenolic molecules are known to form complexes with heavy metals (Al^{3+}, Fe^{3+}, Ca^{2+} and other cations) and pesticides [29,31,32]. These researchers also observed that these metal–NOM complexes form more stable and denser structures than NOM would have in the absence of these cations. When these complexes form a congealed film on the surface of a membrane filter, they are more difficult to remove by non-chemical methods.

The water along the south-coast mountain regions of South Africa is typically soft, with very little alkalinity. Calcium, as Ca, concentration levels are rarely above 10 mg/L. Iron and aluminium concentration levels, however, are seldom below 0.2 mg/L (Table 1).

Table 1
Typical raw water data from the Theewaterskloof impoundment used as feed

Chemical analysis (mg/L)	Raw water
Colour (PtCo)	32
Total hardness as $CaCO_3$	10.0
Total alkalinity as $CaCO_3$	5.1
Calcium as Ca	2.2
Aluminium as Al	0.27
Iron as Fe	0.320