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Evaluation of pretreatments for a blowdown stream to feed a filtration system with discarded reverse osmosis membranes

Julia M. Frick [a,*], Liliana A. Féris [b], Isabel C. Tessaro [a]

[a] Laboratory of Membrane Separation Processes, Department of Chemical Engineering, Universidade Federal do Rio Grande do Sul, Rua Engenheiro Luiz Englert, s/n. ZC 90040-040 Porto Alegre, Brazil

[b] Laboratory of Separation and Unit Operations, Department of Chemical Engineering, Universidade Federal do Rio Grande do Sul, Rua Engenheiro Luiz Englert, s/n. ZC 90040-040 Porto Alegre, Brazil

HIGHLIGHTS

- This work studied the reuse of discarded reverse osmosis membranes.
- Blowdown wastewater was treated to reuse the permeate as make-up water.
- Coagulation, flocculation, sand filtration and GAC were proposed as pretreatments.
- Coagulation/flocculation/sand filtration showed the best result to feed RO systems.
- The permeate quality was good; the membranes presented high retention.

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ABSTRACT

In reverse osmosis demineralization processes, spiral wound modules are used and after approximately 5 years are discarded, since they lose their performance. These modules could be reused for other treatments that do not require a final permeate with so high quality, but still have limitations for feed water quality. The aim of this study is to propose a pretreatment configuration to a membrane filtration system that uses discarded membranes to treat the stream of a cooling tower for reuse as make-up water. Steps of coagulation/flocculation, sand filtration, sorption with GAC and combinations of these were proposed. Parameters as pH, electrical conductivity, turbidity, total hardness, COD, silica content and SDI were analyzed. The pretreated effluent was tested in a bench scale membrane filtration system. Permeate flux, salt retention and hydraulic permeability were evaluated to identify fouling. The best results were obtained coupling coagulation/flocculation with sand filtration. The RO discarded membranes presented high salt retention, about 97% and analysis of permeates indicates the possibility of reuse. MEV and EDS of SDI membranes showed a decrease of silica and total hardness scale, which are the main causes of fouling and the pretreated stream seems to present suitable characteristics to feed the RO filtration system.

1. Introduction

Reverse osmosis (RO) is a membrane separation process used for the separation of low molar mass solutes such as inorganic salts and small organic molecules. This technology is widely used for water treatment in desalination and demineralization processes and in several other industrial processes for stream concentration, separation and recovery. Currently it is also being used for wastewater treatment and water reuse.

The reverse osmosis systems are susceptible to several problems that affect the efficiency of the process. The main problem is fouling that is related to the interactions between the components in the feed stream and with the membrane. For correct RO operation, an effective pretreatment system is necessary, which aims to ensure compatibility between the membrane and the feed water in order to reduce fouling and minimize the chemical cleaning frequency [1]. The pretreatment system is possibly the most critical part, considering that, if it is not adequate, it will result in membrane degradation and irreversible fouling.

The feed water quality is the key for the process, so undesirable materials like suspended solids, dissolved organic matter, immiscible liquids, such as oils and greases, and sparingly soluble salts must be removed or reduced to the required levels to ensure a successful operation of a RO system [2].

Mainly four types of fouling may occur in the RO systems: inorganic (scaling), colloidal, organic and biofouling, which is caused

* Corresponding author. Tel.: +55 51 3308 4101.
E-mail address: juliamfrick@gmail.com (J.M. Frick).

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by microorganisms [3]. Scaling is the formation of a mineral layer on the membrane surface when the feed water is supersaturated in salts and inorganic compounds. The concentration of these sparingly soluble compounds may exceed its solubility limit, resulting in a precipitate [4]. Among these components, silica, iron, calcium, and magnesium (hardness) are major problems [5].

It is known that silica causes irreversible fouling, which is very hard to be removed even after chemical cleaning [6]. Besides, the presence of ions such as calcium and magnesium can cause scaling precipitation, and silica polymerization becomes even more pronounced [7]; evidencing the importance of pretreatment to reduce the content of silica and hardness in the feed stream.

Thin-film polyamide RO membranes are commonly used based on their high levels of both salt rejection and water fluxes; the membrane lifetime is very dependent on the quality of the feed stream and on the operating conditions, which is estimated to be a period between 3 and 5 years of continuous operation, and after that the membrane should be discarded. This fact generates a lot of discarded membrane modules, which represent an environmental problem, since these modules must be correctly disposed as a solid residue. An alternative that has been scarcely studied would be the reuse of these modules to treat other wastewater streams resulting in permeate with lower quality, but good enough to be reused in industrial processes [8].

Mohamedou et al. [9] studied the characteristics of RO disposed membranes in relation to permeability and salt rejection. It was observed that the permeability and salt retention of these membranes were lower compared to those of the new ones. However, they were similar to nanofiltration membranes, which justifies the possibility of reuse in other processes. Instead of the direct reuse, another alternative would be membrane modification. Lawler et al. [10] studied the use of different oxidants for the degradation of membrane selective layers; the support layer could be used in ultrafiltration processes. Ambrosi and Tessaro [11] presented a methodology to treat RO discarded membranes in order to make them reusable and to increase their life cycle. The membrane performance was evaluated in terms of two properties: water permeate flux and salt rejection. The results have demonstrated that potassium permanganate is an efficient agent to make the membrane reusable.

Another problem arises when module limitations are taken into consideration. The spiral wound configuration is the widely used module for RO systems because it provides a large membrane area in a small volume, it is easy to be replaced and different materials may be used for their manufacture [12]. However, the feed channels have a very small thickness, which make them susceptible to the phenomenon of fouling, requiring a feed stream with good quality. In most of the cases, pretreatments such as coagulation, sedimentation, filtration, microfiltration (MF) or ultrafiltration (UF), or some combination of these processes, are required in order to achieve a minimum feed quality to feed the RO spiral wound modules [13].

The type and amount of contaminants depend on the source of water or wastewater. The choice of the correct pretreatment system depends on the effluent to be treated, and on the composition and nature of the contaminants [1]. A correct pretreatment system needs to control the amount of each pollutant and must be designed to receive the worst condition that the effluent can present, in order to withstand variations and still maintain the efficiency of the process [14].

Even for reuse discarded spiral wound membrane modules, the feed pretreatment is required in order that operational problems and fouling may still occur. The change is the low quality of the final permeate.

The pretreatment for RO systems can be relatively simple or complex, which is highly dependent upon the physical, chemical and microbiological qualities of the feed water [15]. Basically there are two types of pretreatments used in the RO systems: conventional treatment, which includes steps of disinfection, coagulation, flocculation, sedimentation and filtration processes; and specific treatment, which includes membrane filtration techniques such as microfiltration (MF) and ultrafiltration (UF) [16]. Still other advanced treatments as adsorption and ion exchange can also be used, exclusively or coupling with other systems, for more specific treatments or higher efficiency of contaminant removal.

Table 1
Correlations between SDI_5 and SDI_{15}.

Time	Range of values	Limit for spiral wound RO membranes
SDI_{15} (15 min)	0–6.67	<3.0
SDI_5 (5 min)	0–20	<9.0

The pretreatment commonly used comprises steps of coagulation/flocculation, sand filtration and sorption with activated carbon. Abdessemed & Nezzal [17] studied the treatment of an effluent for reuse containing organic matter using techniques of coagulation, adsorption with activated carbon and UF. Gabelich et al. [18] compared three types of pretreatment for RO: MF; conventional treatment, comprising coagulation, flocculation, sedimentation, filtration, and treatment with conventional ozonation and biofiltration. In the same line of research, Shon, Vigneswaran & Chon [19] studied the MF, UF, coagulation with ferric chloride and adsorption with activated carbon as pretreatments for a desalination system of seawater with RO.

Specifically with the blowdown stream, some works studied its reuse using membrane techniques. Altman et al. [20] studied the reuse of the wastewater from a cooling tower with nanofiltration, using as pretreatments a sand filter, granular activated carbon and cartridge filters. Zhang et al. [21] used ultrafiltration as pretreatment to a RO system in order to reuse the water purge. Conventional treatments such as coagulation are also studied. Wang et al. [22] evaluated coagulation as pretreatment of a membrane distillation system, which improves the permeate flux.

The Silt Density Index (SDI) is a parameter widely accepted to evaluate the tendency of fouling that a feed stream presents. It is considered as one of the most important parameters for the design and operation of RO membrane process. SDI analytical protocol is standardized in the ASTM D4189-07 [23]; this method evaluates the quantity of matter in water, based on fouling variation of a 0.45-μm membrane during a dead-end filtration time.

To guarantee the correct operation of RO systems, SDI values less than 4.0 for hollow fiber modules and less than 5.0 for the spiral wound modules are recommended [24]. However, as a precaution to assure correct operation, a threshold value of 3.0 for spiral wound modules has been used [25]. In addition to SDI values, a turbidity less than 1.0 NTU is also indicated.

Considering these limitations, the aim of this study is to compare different pretreatments, like coagulation/flocculation, gravity sand filtration, sorption using granular activated carbon (GAC) and combinations of these, for a filtration membrane process which will use pieces of discarded RO membranes taken from spiral wound modules to treat the blowdown stream from a cooling tower in order to reuse part of it as make-up water, thus, increasing the lifetime of a solid waste and minimizing the disposal of an effluent.

Table 2
New membrane characteristics according to the manufacturer.

Membrane characteristics	
Model	8040-ACMI-TSA — Trisep
Material	Aromatic polyamide composite membrane
Configuration	Spiral wound
Area (m^2)	33.4
pH range	4–11
Maximum SDI (5 min)	5.0
Maximum turbidity	1.0
Salt rejection (% NaCl)	>99.5