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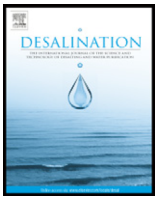

Oilfield produced water treatment by ceramic membranes: Preliminary process cost estimation

S.E. Weschenfelder [a,b,*], A.C.C. Mello [a,b], C.P. Borges [c], J.C. Campos [b]

[a] Technology for Water Treatment and Reuse Department, Petrobras Research Center, Rio de Janeiro, Brazil
[b] School of Chemistry, Inorganic Processes Department, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[c] COPPE/Chemical Engineer Program, Federal University of Rio de Janeiro Rio de Janeiro, Brazil

HIGHLIGHTS

- The microfiltration process enables the treatment and reuse of produced water.
- The process costs have been related to cross flow velocity and water recovery.
- OPEX and CAPEX have been estimated for a real-scale plant under optimal conditions.
- The OPEX was found to be equal to US$0.23/m^3.
- The CAPEX for a full scale plant was estimated at MUS$7.33.

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ABSTRACT

The application of ceramic membranes for oilfield produced water treatment has been considered a very promising technology, mainly due to the oil and grease separation efficiency and process robustness. The purpose of this study was to obtain a preliminary estimate of operating expenses (OPEX) and capital expenditures (CAPEX) for a full scale ceramic membrane plant, based on data obtained in lab scale tests and from literature information. Different crossflow velocities (CFVs) and water recovery rates were simulated and the results were correlated to the OPEX, CAPEX and total cost (TC) per cubic meter of treated effluent. An increase of US $0.10/m^3 in the OPEX and a 55% boost in the value referring to the CAPEX, by increasing the water recovery rate from 80% to 95% were observed. It was found that, under an optimal CFV (2.0 $m \cdot s^{-1}$) and considering the water recovery rate equal to 95%, the cost related to OPEX and TC were, respectively, US$0.23/m^3 and US$3.21/m^3. The CAPEX for a full scale plant, capable of treating 1000 $m^3 \cdot h^{-1}$ of produced water, was estimated at MUS$7.33. In all of the experimental conditions assessed, it was possible to generate a permeate stream with oil and grease content (C_O) lower than 5 $mg \cdot L^{-1}$.

1. Introduction

Oilfield produced water is a byproduct of the oil extraction process from subsurface geological formations. Its composition typically includes the presence of oil, dissolved organic compounds and inorganic particles [1]. Depending on the oil producing field, the produced water may present oil and grease content higher than 500 $mg \cdot L^{-1}$ and salt concentrations (C_S) between 80 and 200,000 $mg \cdot L^{-1}$. In many cases this effluent is reused for the purposes of irrigation, reinjection into reservoir aiming to enhance oil recovery, or also for steam generation through the application of subsequent desalination processes. However, C_O higher than 5 $mg \cdot L^{-1}$ may compromise the injection of water in the reservoir, as well as the efficiency of the salt removal processes [2–6].

Conventional produced water treatment processes may include flotation systems, hydrocyclones, and nutshell or mixed media filters. These types of equipment, however, have a reduced efficiency in removing solids and oil and grease particles whose dimensions are smaller than 5.0 μm, making it difficult to generate an effluent that is appropriate for reuse [2,7–9].

The membrane separation processes can be presented as an alternative technology to the conventional processes used in treating oilfield produced water. Ceramic membranes have been taken into consideration for presenting advantages connected to its greater mechanical, chemical and thermal resistance, in addition to its efficiency in removing oil and grease from streams with a high load of solids and oily contaminants, without the addition of chemical products [2]. The membranes used for that purpose may be produced from different materials,

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* Corresponding author at: Technology for Water Treatment and Reuse Department, Petrobras Research Center, Rio de Janeiro, Brazil.
E-mail address: silvioweschenfelder@petrobras.com.br (S.E. Weschenfelder).

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among which zirconium oxide, aluminum oxide and titanium oxide are highlighted. Many studies have been made comparing the performance of different inorganic materials for treating oily effluents. The reported results show that zirconium oxide membranes provide slightly higher fluxes than aluminum oxide and titanium oxide membranes [10–12]. Also different pore sizes have also been compared to oily water treatment. Hua et al. [13] reported that the use of membranes with pore sizes of 0.2 μm was not appropriate for high quality effluent. Similar results were also obtained by Srijaroonrat et al. [14] and Ebrahimi et al. [6]. They also concluded that the use of membranes with pore sizes of 0.1 μm gives the best results in terms of flux compared to the pore sizes of 0.05 μm and 0.5 μm.

The purpose of this work was to assess the operating expenses and capital expenditures involved in a full scale ceramic membrane plant for the treatment of oilfield produced water. The performance of the microfiltration process was assessed in laboratory scale experiments using a synthetically-prepared effluent and simulating real operating situations.

2. Materials and methods

2.1. Membrane characteristics

To perform the experiments, commercial zirconium oxide (ZrO_2) membranes were evaluated. The membranes have 19 channels of 3 mm, microfiltration area equivalent to 0.0381 m^2 and mean pore sizes of 0.1 μm. According to the manufacturer, Likuid Nanotek, these membranes can withstand pressures up to 8 bar, pH values between 0 and 14 and temperatures up to 100 °C.

2.1.1. Experiment system

The experimental system consisted of a membrane module, a recirculation pump, pressure gauges and flow meters, flow control valves in the feed, permeate and concentrate streams, one tank to collect the permeate and a heated and mechanically agitated feed tank. The permeate mass was continuously monitored by data acquisition. A schematic representation of the experiment set-up is shown in Fig. 1.

During testing, the valves V-1 and V-2 remained opened and the feed flow rate was controlled by the frequency inverter connected to the pump B-1. The ΔP_{TM} was adjusted through valve V-3 and calculated as the difference between the mean pressure given by PI-1 and PI-2 and the pressure given by PI-3.

2.1.2. Synthetic effluents

The effluent used in the tests was synthetically prepared with distilled water, salt (sodium chloride) and oil. The oil was added to the saline mixture and immediately emulsified with a Turrax mixer (Ultra-Turrax T-50). The emulsion was deemed stable when the oil droplet mean size, as measured by a particle size analyzer (Malvern Mastersizer Micro) ranged from 10 to 30 μm.

The oil had a density equal to 28°API and was obtained directly from an offshore oil production unit. Its concentration was determined by an infrared spectrophotometer (Horiba OCMA-350).

2.1.3. Experiments

Before starting each experiment and after the chemical cleaning procedure, the membrane hydraulic permeability was determined. For such measurement, distilled water was applied and the permeate flux was recorded, under a turbulent flow ($CFV = 3.0\ m \cdot s^{-1}$) at 25 °C in different ΔP_{TM}: 1.0, 2.0, and 3.0 bar. The hydraulic permeability was considered as the slope of a linear correlation between the permeate flux and ΔP_{TM}.

To assess the influence of salinity on the permeate flux, experiments were carried out using a synthetic solution containing $C_O = 180\ mg \cdot L^{-1}$ and various C_S ($0\ mg \cdot L^{-1}$, $25{,}000\ mg \cdot L^{-1}$, $50{,}000\ mg \cdot L^{-1}$, $75{,}000\ mg \cdot L^{-1}$ and $100{,}000\ mg \cdot L^{-1}$) under a CFV equal to $3.0\ m \cdot s^{-1}$ and ΔP_{TM} equal to 0.5 bar.

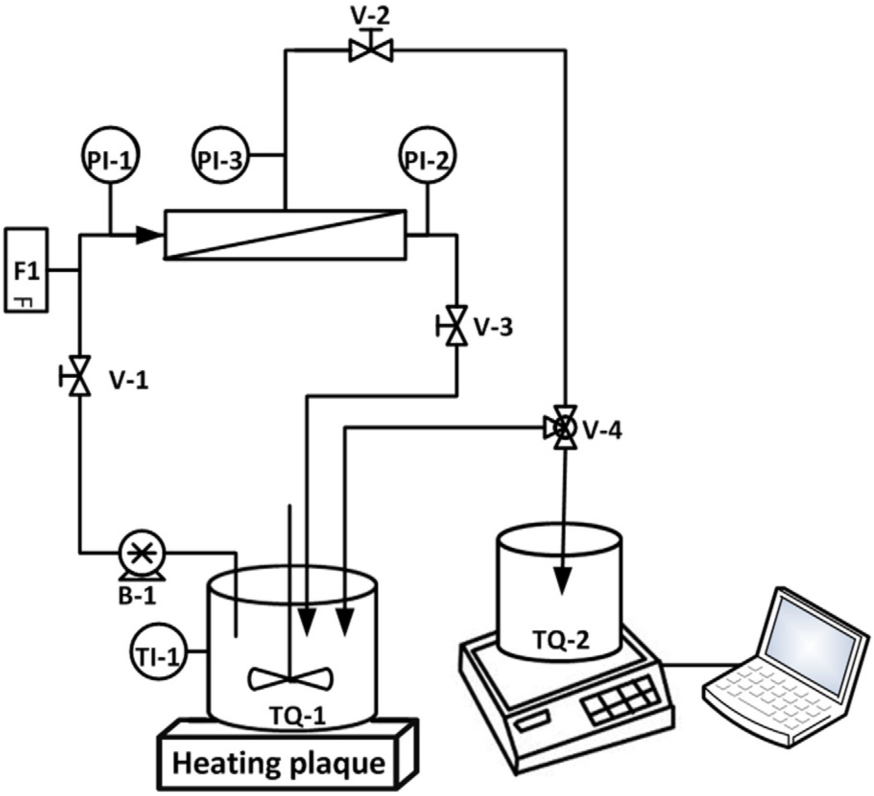

Fig. 1. Schematic drawing of the experiment set-up.