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Evaluation of ceramic membranes for oilfield produced water treatment aiming reinjection in offshore units

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ABSTRACT

Oilfield produced water (OPW) contains not only a complex mixture of organic and inorganic compounds, but also a significant amount of suspend solids and oil and grease (O&G), that need to be almost completely removed prior to reinjection (reuse) in oilfield reservoirs. For the separation of both contaminants from OPW, membrane technology has been described as a potential solution. Therefore, for this study, a multichannel ultrafiltration ceramic membrane (ZrO_2) was used in experiments. The effect of operational conditions on membrane filtration efficiency and the membrane cleaning strategy were investigated using real OPW. The permeate obtained with the membranes was free of suspended solids and presented an O&G content under 5 mg L^{-1}. Based on the results obtained, it is possible to highlight the ceramic membrane separation process as a promising technology for treating OPW in offshore units, being capable to generate a permeate stream suitable for reinjection in restrictive oilfield reservoirs.

1. Introduction

Oil reservoirs have a natural water layer known as formation water. Along with the water injected to maintain the reservoir pressure, the formation water is brought from underground formations to the surface during oil and gas production and constitutes the major effluent in oil production, the OPW. The cost of managing this large volume of water is a key consideration to oil and gas producers (Clark and Veil, 2009).

OPW contains a complex mixture of organic and inorganic compounds. Both the characteristics and the volume of water produced vary greatly from well to well and they rely on the lifetime of the reservoir and the kind of hydrocarbons produced (Igunnu and Chen, 2012). Its disposal depends on the type of installation, injection water availability, facilities for treatment and feasibility for reusing.

A conventional oil production plant configuration, applied worldwide in offshore units, is described in Fig. 1. The inlet stream, a mixture of oil, gas and water, is brought from the reservoir, heated and fed to a three-phase separator, followed by an electrostatic treater. The water stream originated has a typical oil content varying from 0.02 to 0.2% w/w. This stream is usually treated by hydrocyclones and dissolved gas flotators, which are unable to remove suspended particles with particle size below 5.0 µm, as well as rarely reach the water quality for reinjection in terms of the suspended solids and O&G content (Li and Lee, 2009). The majority of Brazilian reservoirs require less than 5 mg L^{-1} for both parameters. Therefore, in order to achieve the water quality, membrane filtration has been described as a high potential technology, combining the advantage of being robust and compact.

For aqueous feed streams with 0.1–10% of oil content, either microfiltration (MF) or ultrafiltration (UF) has the capability of generating a permeate with less than 5 mg L^{-1} of suspended solids and O&G content. Both polymeric and inorganic membranes have been studied. Nevertheless, in recent years, there is a growing interest in using ceramic membranes for this application because organic membranes are sensitivity to polar solvents, chlorinated solvents and high oil fraction. Other advantages of ceramic membranes are related to the ability to treat oily waters without additional chemicals and its resistance against mechanical, thermal and chemical stress, allowing a better regeneration of the membrane with harsh chemical cleanings. However, the membrane's high cost is pointed out as a typical disadvantage that is generally compensated by longer lifetimes,

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robustness and better performance (Silalahia and Leiknes, 2011; Abadi et al., 2011).

Several membrane materials have been tested and compared based on their ability to separate oil and water. The results show mostly the same oil rejection efficiency for zirconia, alumina and polymeric membranes, but higher fluxes when zirconia membranes are applied (Wang et al., 2000; Yang et al., 1998; Kwan and Yeung, 2008; Ashaghi et al., 2007). Moreover, different pore sizes have also been compared for oily water treatment. Srijaroonrat et al. (1999) reported that pore size of 0.1 μm gives the best results in terms of flux and O&G removal compared to pore sizes of 0.05 μm and 0.5 μm for treating oil in water emulsions. Similar results were also obtained with synthetic OPW (Ebrahimi et al., 2010).

The operational conditions reported in the literature for the filtration of oily wastewater with ceramic membranes vary significantly, as summarized in Table 1. Qaisrani and Samhaber (2011) showed that process parameters like cross flow velocity (CFV), backwashing and transmembrane pressure (TMP) had significantly influenced the fouling and that these parameters played a significant role in enhancing process efficiency. The shear stress generated by cross flow velocity is known to be effective for fouling control by reduction of boundary layer thickness, as follows, the particle deposition on membrane surface.

The permeate quality is strongly affected by TMP and it has been observed that the O&G content in the permeate increases when TMP is intensified. The permeate flux also increases with TMP, carrying more oil droplets to the membrane surface and maximizing the deposition. Under this condition, the droplets may deforme and pass through the membrane pores. The study carried out by Abadi et al. (2011) with a 0.2 μm ceramic membrane revealed that TMP above 1.25 bar was not appropriate for a high quality effluent. Hua et al. (2007) concluded that the TMP above 2.0 bar resulted in a reduction of the effluent quality. Finally, Zhong et al. (2003) observed that discharge requirements were exceeded at TMP of 1.55 bar with a 0.2 μm membrane for refinery oily water treatment. These authors also concluded that the oil content in the permeate decreased when higher CFV was applied.

Membrane cleaning is still a very important issue in membrane filtration processes. After a certain period of operation, it is necessary to regenerate the membrane in order to maintain the process efficiency. Nevertheless, almost all of the researches carried in membrane filtration field are related to fouling and their control, but the cleaning step has not been properly addressed according to Blanpain-Avet et al. (2009).

In order to select the most appropriate cleaning protocol, the study of membrane autopsies can be very helpful, detecting and identifying the specific membrane fouling compounds, as well as analyzing the membrane integrity. Different deposits affect the filtration performance in many ways, so that the cleaning strategies will depend on the type of deposit. In the literature, there are no studies related to membrane autopsies and their application to OPW.

Until now, most of the studies about the application of ceramics for treating OPW with ceramic membranes were carried out using synthetic OPW in experiments, excepting Abadi et al. (2011), who used refinery wastewater and Li and Lee (2009), who applied CBM produced water to their studies. However, OPW is considerably different from the effluents used by those authors. Most of them ran their experiments during a short period of time, making the prediction of the long-term filtration behavior more difficult.

The overall objective of this work was to provide more information and increase the understanding on the application of ceramic membranes for OPW treatment aiming the reinjection in offshore oil production platforms. In this sense, experiments were conducted with an ultrafiltration ceramic membrane using a real OPW sample in order to better evaluate the fouling

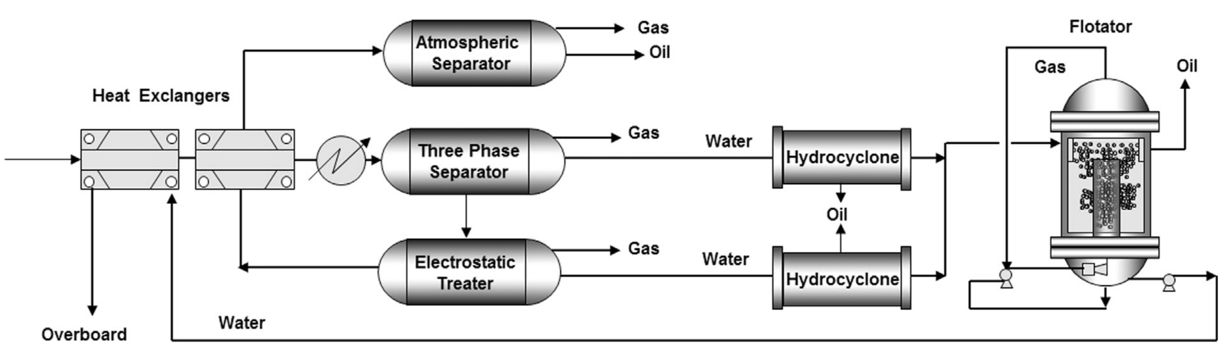

Fig. 1. Typical Brazilian offshore production plant.

Table 1
Summary of operational conditions reported in literature for oily wastewater ceramic membrane filtration.

Reference	Treated water	Membrane	Operational conditions
Silalahia and Leiknes (2011)	Oil/water emulsion	α-Al_2O_3 0.1, 0.2, 0.5 μm	TMP = 0.5–2.0 bar CFV = 4.5 m s^{-1}
Abadi et al. (2011)	Refinery wastewater	α-Al_2O_3 0.2 μm	TMP = 0.75–1.75 bar CFV = 0.75–2.25 m s^{-1}
Srijaroonrat et al. (1999)	Oil/water emulsion	ZrO_2, Al_2O_3 0.05, 0.1, 0.5 μm	TMP = 1.0–4.0 bar CFV = 0.47–2.16 m s^{-1}
Hua et al. (2007)	Synthetic oily wastewater	α-Al_2O_3 0.05 μm	TMP = 0.5–3.0 bar CFV = 0.2–1.7 m s^{-1}
Zhong et al. (2003)	Refinery oily water	ZrO_2 0.2 μm	TMP = 0.45–1.55 bar CFV = 0.58–2.56 m s^{-1}
Ebrahimi et al. (2009)	Synthetic OPW	Al_2O_3/TiO_2 0.1, 0.2, 0.05 μm	TMP = 0.5–2.0 bar CFV = 0.6–1.3 m s^{-1}
Mueller et al. (1997)	Synthetic OPW	α-Al_2O_3 0.2, 0.8 μm	TMP = 0.7–1.4 bar CFV = 0.24–0.91 m s^{-1}