Hybrid zero liquid discharge (ZLD) membrane/chemical process for the treatment of oil sands produced water

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Abstract

In this study, the applicability of a hybrid chemical/membrane process for the treatment of the boiler blow-down (BBD) water from steam assisted gravity drainage (SAGD) operation was explored. For the chemical pre-treatment prior to the membrane filtration, another waste stream of SAGD, i.e., ion exchanger regeneration wastewater (IERW), was used as a coagulant to reduce the concentration of organic matter and silica. The proposed method involved the direct use of the NF process for the purification of BBD water, followed by an integrated IERW conditioning and nanofiltration (NF) to purify the concentrated retentate. This process could operate with a zero-liquid discharge (ZLD) configuration and it was found to be an efficient method in terms of water recovery and water product quality.

Keywords: Wastewater treatment; Membrane; Nanofiltration; Process integration

1. Introduction

Water is an essential material for the oil sands industry, and many studies are focused on the improvement of the water treatment process in the SAGD operation. Different chemical methods, such as coagulation and ion exchange resins, are currently used in the SAGD plants to remove contaminants, particularly silica, calcium, and magnesium as these ions are mainly responsible for causing fouling and scaling of boiler tubes (Hayatbakhsh et al., 2016; Maiti et al., 2012; Pillai et al., 2017; Sadrzadeh et al., 2015; Shamaei et al., 2018). Several studies have indicated the high efficiency of hybrid treatment processes regarding fouling mitigation and water recovery (Li et al., 2011; Yang and Kim, 2009). Therefore, in this work, a hybrid membrane-based separation process was proposed for the treatment of BBD water. This method involved direct filtration of the BBD water with an NF process with 50% water recovery ratio (NF1) followed by the treatment of concentrated retentate by the IERW as a coagulant. IERW conditioning was conducted as a novel chemical pre-treatment for another post-treatment by an NF as the final polishing stage (NF2 in Figure 1). The IERW conditioning indicated a high removal of organic matter and silica. The effectiveness of the process was investigated regarding permeate flux, contaminant removal and fouling characteristics of the NF process.

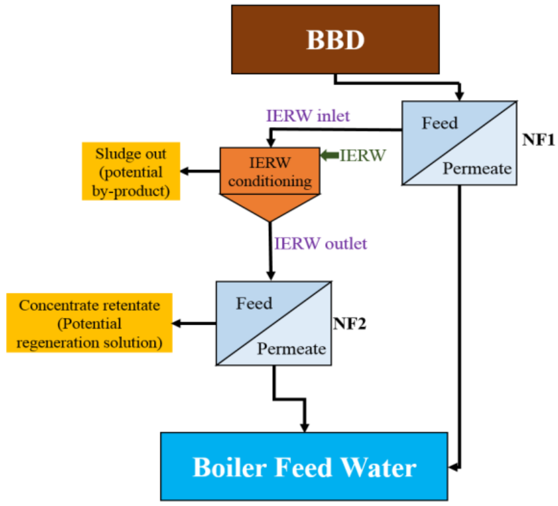

Figure 1. The proposed hybrid treatment process illustrating the ZLD configuration

2. Materials and Methods

Table 1 shows the properties of the main streams in the proposed hybrid process. Membrane filtration tests were conducted using the DOW FILMTEC NF90 membrane and a cross-flow filtration setup.

Table 1: Properties of IERW and BBD water.

Parameter	Unit	BBD water	IERW water	IERW inlet	IERW outlet
TDS	ppm	6525	66625	8500	16750
pH	---	11.6	6.2	10.9	11.6
Turbidity	NTU	0.86	0.25	0.9	1.2
TOC	ppm	230	6.7	443	108
Silica	ppm	78	5.2	111	3.2
Mg^{2+}	ppm	0.24	2200	0.16	0.07
Ca^{2+}	ppm	2.97	9450	2.78	3.82
Na^{+}	ppm	1806	22165	3975	8069

3. Results and Discussion

The permeate flux of the NF process for the purification of the BBD water and the concentrated retentate is depicted in Figure 2 (a). This flux trend was obtained by using pure water at first 30 min and then filtering the wastewater for 180 min followed by hydraulic washing of the membrane and pure water filtration again at 210 min. As can be observed, the initial flux of NF90 for the concentrated retentate was lower than that of BBD water. This can be attributed to the higher TDS concentration of concentrated retentate as compared to the BBD water. The flux decline for the NF1 of BBD water was, however, more severe than the concentrated retentate, which could be due to the higher initial permeation flux and organic fouling of the BBD water. Figure 2(b) shows the fouling characteristics and the contaminant removal for the filtration of the BBD and the concentrated retentate based on different parameters such as total flux decline (DR_t), reversible flux decline ratio (DR_r), irreversible flux decline (DR_{ir}), and flux recovery (FRR) ratio. DR_t, DR_r, and FRR of NF treatment for BBD water were 6.89%, 80%, and 97%, respectively. The low irreversible fouling ratio (3.3%) of this filtration indicates that the flux decline was mainly due to concentration polarization and formation of loose fouling layer which could easily removed by washing.

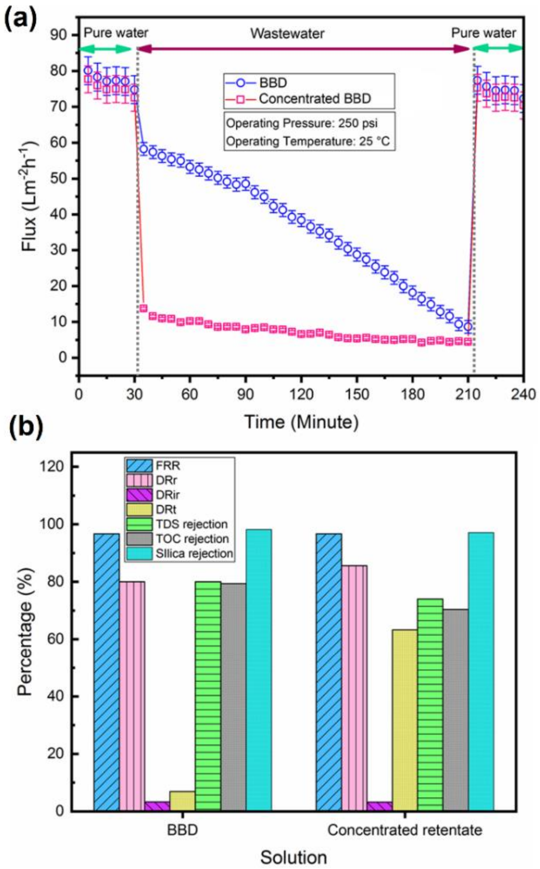

Figure 2. The permeate flux and fouling characterization of the NF while treating the BBD along with the concentrated retentate stream.

Furthermore, the TOC, TDS and silica rejection of NF90 for the BBD water were 79%, 80%, and 98%, respectively. The NF2 process for the IERW outlet also showed irreversible fouling as low as 3.2%. The filtration of concentrated retentate resulted in TOC, TDS, and silica rejection of 70%, 74%, 97 %, respectively. Overall, the filtration of BBD water and concentrated retentate demonstrated a low irreversible fouling ratio, and a high FRR and contaminant rejection percentage proving the high efficiency of the proposed integrated process for the treatment of the BBD water. In this system, the slurry waste stream of the IERW conditioning can be used as an industrial byproduct and the concentrated retentate of NF2 can be reused as the regeneration solution of the ion exchanger. Therefore, the proposed hybrid process can achieve a zero liquid discharge (ZLD) plan.

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