Separation and Purification Technology 163 (2016) 181–188

Contents lists available at ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Application of integrated forward and reverse osmosis for coal mine wastewater desalination

Ramesh Thiruvenkatachari *, Mathew Francis, Michael Cunnington, Shi Su *

Commonwealth Scientific and Industrial Reserach Organisation (CSIRO), 1 Technology Court, Pullenvale, Queensland 4069, Australia

ARTICLE INFO

Article history:
Received 8 December 2015
Received in revised form 17 February 2016
Accepted 21 February 2016
Available online 23 February 2016

Keywords:
Coal mine wastewater
Forward osmosis
Reverse osmosis
Desalination
Integrated process

ABSTRACT

Water management is an integral part of coal mining operations. Due to the constraints on releasing saline water, coal mines require additional water storage facilities and therefore seek to minimise their inventory of saline water. Adopting efficient treatment technologies on-site would minimise the risk of wet season run-offs, freshwater contamination and allow segregation of different qualities of water to enable greater water recycling. This study aims to evaluate the application of an integrated forward osmosis (FO) and reverse osmosis (RO) system with three different actual coal mine waters, containing various concentrations of sulphates and silica that are generally associated with scaling and fouling of membrane systems. Three different FO draw solutions, di-sodium hydrogen phosphate (DHSP), sodium hexametaphosphate (SHMP) and sodium lignosulphonate (SLS) were evaluated. Two different modes of integrating the FO and RO systems were identified. The integrated system was able to concentrate the brackish mine waters, recovering more than 80% of the volume of mine water and obtaining dischargeable quality treated water. Simple physical cleaning with clean water circulation was found to be effective in restoring the FO water flux. The osmotic gradient between two mine waters was also utilised to adopt mine water as a draw solution. The effect of solution temperature on stand-alone and integrated FO and RO systems was also evaluated. The combination of FO with RO provided a better performance than individual FO or RO in treating coal mine wastewater. The FO unit served as an effective pre-treatment system prior to RO and the integrated FO–RO systems has a strong potential to successfully eliminate conventional pre-treatment processes for RO.

1. Introduction

Water resources in Australia face an enormous challenge in maintaining a sustainable balance between the amount of water extracted from water sources and ensuring appropriate environmentally safe flows. The problem is exacerbated due to the variability in climatic conditions [1,2]. Water is an integral part of various industrial operations, including coal mining, and is obtained from a variety of sources like ground water, surface water (rainfall and runoff) and fresh water from mains supply. Adopting efficient treatment technologies to reuse and recycle the water that is generally stored on-site after mining operations, is one of the effective water management strategies to minimise the risk of wet season run-offs and reduce the pressure on our water resources and the environment. A recent study on the water quality of mine water from different coal mines in Australia [3], has shown significant variation in the characteristics of mine water. The pH of the water sources ranged from acidic to basic in nature. Some streams showed higher dissolved solids concentration than the other and had the characteristics of fouling and scale formation.

Reverse osmosis (RO) is a mature process and one of the most commonly used desalination technologies in Australia [4] and more than 50% of the world's desalination water is produced by the RO process [5,6]. However, RO membranes can be very sensitive to fouling by various dissolved and undissolved constituents, particulate matter, salt precipitates, microorganisms, and would require extensive and expensive pre-treatment to ensure acceptable performance [7–11]. Currently, coal mine affected water is extensively pre-treated prior to RO treatment. The pre-treatment processes include lime neutralisation to adjust the pH, coagulation and precipitation where suspended solids, excess lime, some precipitated metal elements and gypsum are removed, multimedia filters to further reduce the concentration of suspended solids, membrane filtration units to reduce colloidal material and water softeners to reduce hardness and the addition of antiscalents prior

* Corresponding authors.
E-mail addresses: ramesh.thiruvenkatachari@csiro.au (R. Thiruvenkatachari), shi.su@csiro.au (S. Su).

http://dx.doi.org/10.1016/j.seppur.2016.02.034
1383-5866/

to RO treatment. This pre-treatment process comprises 10–36% of the total operating cost [10,12].

The forward osmosis (FO) process is an emerging low energy desalination technology [13–15], where water naturally traverses the semi permeable membrane (osmotic pressure is the driving force, instead of hydraulic pressure) from a lower solute concentration feed solution to a higher solute concentration solution, known as the draw solution. Clean water is then recovered from the diluted draw solution using a post treatment step [16], although direct application of fertiliser based draw solutions have been attempted [17,18]. The bulk of the research has focused on FO membrane development [19–24] and new draw solutions [18,25–28]. Reviewing the literature over the last decade, Lutchmiah et al. [29] reported that only 7% relate to applications for treating various wastewaters. Its application as a separation process for the treatment of complex wastewaters includes drilling mud and fracturing fluids from oil and gas operations [30,31], nutrient rich streams (centrate) [32], municipal wastewater [33,34], power plant wastewater [35], coke-oven wastewater [36], textile dye effluents [37], dewatering RO concentrate [38]. However, studies on the application of forward osmosis for coal mining impacted water are scarce [39,40]. Hybrid systems whereby FO is combined with thermal processes [31,41,42] or other membrane treatment methods like ultrafiltration, nanofiltration and reverse osmosis [27,43–45], have been adopted, generally replacing either chemical pre-treatment, or used to reduce the volume of the waste stream as a post treatment step. Particularly, studies on FO–RO combined systems have focused in treating NaCl solutions, secondary/tertiary treated effluent [44,46] or seawater [47–50]. This study aims to apply an integrated forward and reverse osmosis process in treating three different types of coal mine impacted waters.

2. Materials and methods

2.1. FO and RO experimental set-up

The fabricated bench scale forward and reverse osmosis systems used in this study are shown in Fig. 1. The forward osmosis unit consists of a membrane cell with an effective membrane area of 150 cm^2. Inlet and outlet ports were provided on both sides of the FO membrane cell to allow the circulation of feed water on one side and draw solution on the other side of the membrane using two variable speed peristaltic pumps (Longer Pumps, YT600-1J). A co-current cross-flow mode of operation was adopted throughout the study. The change in weights of the feed and draw solutions was monitored using weighing balances (Wedderburn Scales, Vibra AJ) and were data logged (Wedderburn, DI- Connect, version 1.5) with a time interval of 10 s. The temperature of the solutions were maintained at a set value (with variation of ±0.5 °C) using a water circulation bath (Thermoline Scientific BL-30). The pH and conductivities of the solutions were measured using a WP-81 analyser with $K = 1$ and K10 probes (TPS Australia Pty. Ltd.) and data logged every 10 s (WinTPS, version 1.35). The energy consumption of the FO unit was monitored using a power meter (CABAC Power Mate 10 A).

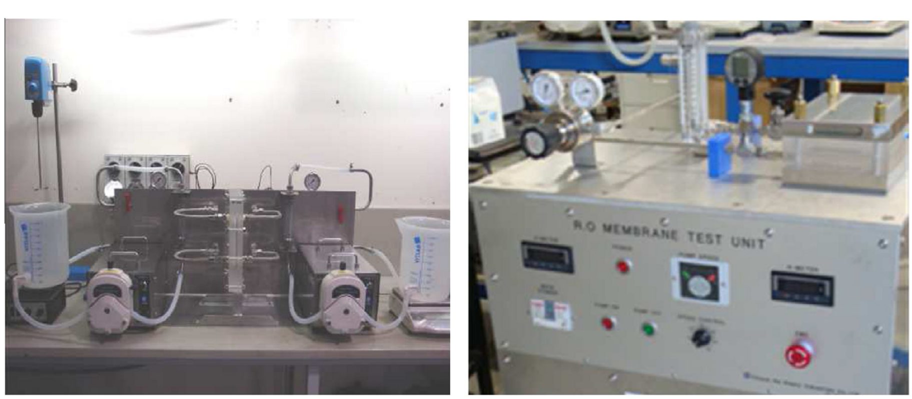
For the FO operation, water flux Jw (in $Lm^{-2}\,h^{-1}$) across the membrane was calculated from the change in volume (calculated from the weight change) of the draw/feed solution per unit time and for a given unit membrane area. An important aspect of the draw solution in the FO process, apart from its ability to produce higher water flux, is the amount of draw solute transport in the reverse direction to the water flux. Reverse solute flux (RSF), Js, which is the flux of salts through the membrane from the draw solution to feed solution, and the specific reverse solute flux (SRSF), which is the ratio of RSF to the flux of water through the membrane in the forward direction (Jw) [51,52] were determined. SRSF yields a salt transport (crossing the membrane from the draw solution to the feed solution) in grams per litre of water being produced (from feed solution to draw solution).

The RO unit consists of a membrane cell with an effective membrane area of 140 cm^2. A diaphragm pump (Hydracell DO3X) with a variable speed drive (VSD) was used to circulate the water through the cell. The required operating pressures were set using a pressure regulating valve and a needle valve. Pressure sensor (Keller ECO1), flowmeter (Blue-White Industries F-550) and pressure relief valve (DK-Lok D-Pro V66 Series) were installed inline. The energy use of the RO system was monitored from the VSD through the LabVIEW software computer programme.

Initially, experiments were carried out with FO as standalone process and then integrated with the RO system for the regeneration of draw solution and recovery of clean water from mine impacted water.

2.2. FO and RO membrane characteristics

Commercially available flat sheet FO membrane (Hydration Technology Innovations (HTI), Albany, USA) and polyamide FILMTEC brackish water RO membrane (BW-30) were used in this study. The FO membrane is a cellulose triacetate membrane embedded about a polyester screen mesh with a rejection layer and a support layer. The thickness of the membrane was measured using a micrometer Mitutoyo thickness gauge (Japan) and was found to be 90 ± 3 μm for FO membrane and 150 ± 2 μm for RO membrane. The pure water permeation coefficient for FO membrane was found to be 0.976 $L\,m^{-2}\,h^{-1}\,bar^{-1}$ and the RO membrane was 2.4 $L\,m^{-2}\,h^{-1}\,bar^{-1}$.



(a) (b)

Fig. 1. Photo of the lab scale flat sheet (a) FO and (b) RO test units.