Treatment of RO brine—towards sustainable water reclamation practice


ABSTRACT

Treatment and disposal of RO brine is an important part in sustaining the water reclamation practice. RO brine generated from water reclamation contains high concentration of organic and inorganic compounds. Cost-effective technologies for treatment of RO brine are still relatively unexplored. Thus, this study aim to determine a feasible treatment process for removal of both organic and inorganic compounds in RO brine generated from NEWater production. The proposed treatment consists of biological activated carbon (BAC) column followed by capacitive deionization (CDI) process for organic and inorganic removals, respectively. Preliminary bench-scale study demonstrated about 20% TOC removal efficiency was achieved using BAC at 40 mins empty bed contact time (EBCT) while the CDI process was able to remove more than 90% conductivity reducing it from 2.19 mS/cm to only about 164 μS/cm. More than 90% cations and anions in the BAC effluent were removed using CDI process. In addition, TOC and TN removals of 78% and 91%, respectively were also attained through this process. About 90% water recovery was achieved. This process shows the potential of increased water recovery in the reclamation process while volume for disposal can be further minimized. Further studies on the sustainable operation and process optimization are ongoing.

Key words | biological activated carbon, capacitive deionization, inorganic removal, organic removal, RO brine, water recovery

INTRODUCTION

The reverse osmosis (RO) process has been a widely applied technology for water reclamation of treated used water (secondary effluent) due to its affordable cost and reliability. High quality permeate suitable for indirect potable or direct non-potable use after disinfection is produced from RO process while another stream, RO brine, is also generated simultaneously. Management issues related to proper treatment and disposal of RO brine is an important part in sustaining the water reclamation practice. The brine generated from water reclamation contains both moderate to high concentration of organic and inorganic compounds. The organics present in the RO brine mainly consists of slow- and hard-to-degrade organic constituents (Lew et al. 2005). For brine disposal in inland water bodies, these organics have to be removed prior to discharge. Currently, there is little knowledge on the organic characteristics in the RO brine, and effective technology for removal of the moderate to high concentration of organics present in the brine. Besides organics, inorganic compounds with total dissolved solids (TDS) concentration typically higher than 2,000 ppm have to be removed too prior to brine disposal. Cost-effective technologies for treatment of RO brine are still unexplored. A novel treatment process consisting of a biological activated carbon (BAC) and
capacitive deionization (CDI) process is proposed for RO brine treatment in this study. The biological activated carbon (BAC) process consists of both activated carbon adsorption and biodegradation of organics by microorganisms. The advantages of combining adsorption and biodegradation in BAC are: activated carbon can be partially regenerated by biochemical activities while the carbon bed is in operation (Rodman et al. 1978; Rice & Robson 1982); less biodegradable organics can be adsorbed on the carbon first, and are then slowly degraded by microorganisms (Weber & Ying 1978; Rice & Robson 1982); and biological reaction rates become higher on activated carbon due to an enrichment of the organics by carbon adsorption (Weber & Ying 1978). With these characteristics, BAC may be potentially useful for removal of organics in RO brine, which consists of less biodegradable organics.

CDI process has been applied for removal of inorganic compounds from different types of water, namely, seawater, groundwater, industrial process water and wastewater (Weldemoed & Schutte 2005; Garrido et al. 2006; ENPAR Technologies Inc. 2007). The CDI process cycle consists of purification phase, regeneration phase and purge phase (Figure 1). During purification phase, an electrical field with a potential difference of about 1.2–1.5 volts (direct current) between the two electrodes will remove the dissolved ions from the water as it passes through the electric field. The anions and cations will be attracted to the opposite charge and directed to the respective electrode until saturation occurs. During purification phase, permeate with lower conductivity will be generated as product water. Regeneration then takes place by reversing the potential. Hence, the ions are expelled into the rinse water and eventually purge out from the cell into a concentrate stream. In practice, more than 80% of water can be recovered with CDI process (Dietz 2004). CDI process generally has lower energy consumption as compared with membrane process as high pressure pumps are not required to achieve the treatment process in CDI (Weldemoed & Schutte 2005).

Therefore, the aim of this study at the preliminary stage is to determine the feasibility of the combined BAC and CDI process for removal of both organic and inorganic compounds in RO brine generated from NEWater production. The proposed treatment process flow chart is illustrated in Figure 2.

**METHODS**

**RO brine**

RO brine was used as feed to the BAC column. RO brine was collected weekly from the 2nd stage RO process from the Bedok NEWater Plant, Singapore and stored at 4°C in the laboratory’s cold room until use. The RO brine quality is summarized in Table 1.

**Bench-scale systems**

Bench-scales BAC column and CDI process unit were set-up for the preliminary testing. The experimental set-up of the BAC column and CDI unit are shown in Figure 3 (a) and (b), respectively.
BAC column

The BAC column had a diameter of 50 mm and an effective packing height of 500 mm. Packing material used was granular activated carbon (Filtrasorb® F400D, Calgon Carbon Co.) with an effective size and density of 0.65 mm and 0.47 g/cm³. An empty bed contact time (EBCT) of 40 mins and a daily flow rate of 35.4 L were maintained in the column.

CDI process

The bench-scale CDI process (Model: DesEL 400, ENPAR Technologies Inc., Canada) with a flow rate of up to 250 mL/min and an electrode surface area of 0.7 m² was operated in batch mode.

Water quality analysis

The water quality though each stage of treatment was characterized using pH, conductivity, color, total organic carbon (TOC), total nitrogen (TN), anions and cations. The pH was measured using the Horiba pH meter F-54 BW (Horiba Ltd, Japan) while conductivity was quantified using WTW Conductivity meter LF 538 (WTW, Germany). Color was measured using the UV-Vis Spectrophotometer DR 4000 U (Program 1660, Hach Company, USA), and TOC and TN were analyzed using the Total Organic Carbon analyzer TOC-VCSH (Shidmadzu, Japan). The anions and cations were determined using the Dionex LC 20 Chromatography (Dionex Corporation, USA). The anions analyzed were Cl⁻, NO₂⁻, NO₃⁻, PO₄³⁻ and SO₄²⁻ and cations were Na⁺, NH₄⁺, K⁺, Mg²⁺ and Ca²⁺. Chemical oxygen demand (COD) was quantified only for RO brine and BAC effluent. All water quality analyses were carried out in accordance with Standard Methods for Water and Wastewater Analysis (APHA 1998).

RESULTS AND DISCUSSION

Performance of BAC column

The BAC effluent quality is summarized in Table 2. The pH and conductivity in the BAC effluent did not differ significantly from the RO brine. However, the BAC effluent color was less intense (74 Pt-Co) compared to the RO brine (109 Pt-Co). The anions and cations concentrations in the BAC effluent were also similar to the RO brine. This is expected as BAC column is targeting at biodegradation activity for organic matter removal. Slight reduction in the TN was noted in the BAC effluent (approximately 10% TN
removal efficiency was achieved in the BAC column). This could be due to mineralization of organic N to ammonium-nitrogen under anaerobic conditions, reduction of inorganic N in the RO brine and utilized to support biomass growth and activity.

Organic matter removal

The changes in the normalized TOC (TOC of BAC effluent with respect to TOC of RO brine) is summarized in Figure 4. It is noted from this figure that the normalized TOC increased sharply from 0.10 to 0.54 when treating an initial RO brine volume of 770 L. This indicated exhaustion of the GAC adsorption capacity at the initial stage of treatment, while the biological activity of the microorganisms still had not dominated the TOC removal process. Subsequently, a gradual increase was noted when treating a volume of up to 2,200 L. At this stage, more significant biodegradation activity could have contributed to the TOC removal while exhaustion of the adsorption capacity still took place. The normalized TOC reached stable performance after the BAC column had treated more than 2,200 L of RO brine, which the biodegradation activity of TOC could be at a rate similar to exhaustion rate of the activated carbon at an EBCT of 40 min. Biodegradation could provide regeneration capability of the active sites on activated carbon and also degradation of the organic compounds even though they have not been adsorbed onto the activated carbon (Chudyk & Snoeyink 1984). This will prolong the life span of the BAC for removing organics from the RO brine.

TOC and COD removals in the BAC column are summarized in Figure 5. The COD removal efficiency followed similar trend as the TOC removal efficiency which showed that the compounds responsible for oxygen demand in the RO brine consisted mainly of organic matters. The stabilized performance and the respective periods are summarized in Table 3. The TOC and COD removal efficiencies during stabilized stage were at an average of 25.0 and 39.6%, respectively. This gave an average TOC and COD effluent concentrations of 25.4 and 38.9 mg/L, respectively.

Performance of CDI process

This preliminary study demonstrated that the bench-scale CDI process was able to achieve a process rate and permeate production rate of up to 264 and 236 L/d, respectively. Water recovery up to 90% was attained. The preliminary results indicated that CDI process was able to achieve conductivity removal efficiency of about 92%, while TOC and TN removal efficiencies were at 78.0 and 91%, respectively. The cations and anions removal efficiencies

Table 2 | Effluent quality from BAC column

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.67 ± 0.31</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>2158 ± 185</td>
</tr>
<tr>
<td>Color (Pt-Co)</td>
<td>74 ± 2</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>19.08 ± 3.93</td>
</tr>
</tbody>
</table>

Figure 4 | Change in normalized TOC in the BAC column treating RO brine.

Figure 5 | Change in TOC and COD removal efficiencies in the BAC column treating RO brine.
were more than 90%. The feed (BAC effluent) and CDI permeate from a selected run is summarized in Table 4.

This preliminary testing demonstrated that the CDI process is capable of producing high grade permeate quality from a single cell bench-scale unit. However, conditions for CDI process operation would need to be optimized to formulate a feasible condition for long term operation. Quality of the feed and permeate, water recovery rate, fouling potential of the CDI unit and frequency of membrane cleaning are the few important factors that would need to be carefully considered in the process conditions. The capital and O&M costs would also need to be considered in the next stage as this will determine the overall clean water production costs.

It has been reported that the cost of CDI modules (CDTT module manufacturing costs) had reduced significantly in the recent years from US$75,000 per module in 1997 to US$1,000 per module in 2004 (Welgemoed 2005). In addition, the energy consumption for CDI plants typically decreases with the increase in plant capacity (Garrido et al. 2006). The energy consumption of a CDI plant has been demonstrated to reduce from 30 to 50% when increasing treatment capacity from 10 m³/day to larger plants treating brackish water. In addition, the CDI plant has the advantage of low operational costs and minimal maintenance while being highly reliable (Nieto & Seed 2005).

### CONCLUSIONS

Feasibility of a novel treatment process, consisting of a BAC column and a CDI process unit, to remove the organic and inorganic compounds in the RO brine from a water reclamation plant had demonstrated promising results. Preliminary bench-scale study demonstrated about 20% TOC removal efficiency was achieved using BAC at 40 min EBCT while the CDI process was able to remove more than 90% conductivity reducing it from 2.19 mS/cm to only about 164 μS/cm. More than 90% anions and cations in the BAC effluent were removed using the CDI process. In addition, TOC and TN removals of 78 and 91%, respectively, were also attained through the CDI process with water recovery of about 90%. The novel treatment process demonstrated the potential of increasing water recovery in the reclamation process while further reducing the brine for disposal. Further studies on the sustainable operation and process optimisation are ongoing.

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REFERENCES


