J. Indian Inst. Sci., July–Aug. 2005, **85**, 215–221

Recovery and reuse of water from effluents of cooling tower

S. KALIAPPAN*, C. SATHISH AND T. NIRMALKUMAR
Centre for Environmental Studies, Anna University, Chennai 600 025, India.
email: drkalsun@yahoo.com; Phone: 91-044-22203193; Fax. 091-44-22354717.

Received on July 7, 2004; Revised on February 21, 05, and July 25, 2005.

Abstract

Membrane technology is emerging as a viable and economical option in the reclamation of wastewater. The present study involves the feasibility of recycling and reusing the wastewater let out from a fertilizer unit. Cooling water blowdown from the waste stream has high salt concentration. An economically and technically viable reverse osmosis process has been employed to treat the wastewater. Feed water needs to be pretreated to apply reverse osmosis process.

Effluents from the cooling tower of the fertilizer unit studied contained about 50 mg/l of suspended solids and need to be removed prior to treatment with reverse osmosis unit to remove total dissolved solids (2500 mg/l). Pretreatment with a microfilter of sizes 5 and 1 μm and carbon filter completely removed the suspended solids achieving a silt density index of 5. Pretreated water was sent to the reverse osmosis system, maintained at operating pressures of 275×10^3, 310×10^3, 344×10^3, 379×10^3 and 413×10^3 Pa, to reduce the level of the total dissolved solids. The best level of TDS (270 mg/l) was achieved at a maximum pressure of 413×10^3 Pa. The maximum amount of salt rejected by the membrane was 89.2% and the maximum recovery of 56.0% was obtained at a pressure of 413×10^3 Pa.

Keywords: Reverse osmosis, permeate flux, salt rejection, recovery.

1. Introduction

Industrial wastewater treatment techniques are changing rapidly so as to meet the stringent regulations of the pollution control boards. Treatment of wastewater from fertilizer industries is complex and challenging, as their blowdown water generally consists of high total dissolved solids (TDS) and requires huge quantity of water for cooling tower make-up. In this present study, a leading fertilizer industry at Chennai has been considered. The blowdown water from the cooling tower of the unit consists of TDS in the range of 2000–2500 mg/l. Blowdown is a term for water that is removed from the recirculating cooling water to reduce contaminant build-up in the tower water. As evaporation occurs, dissolved solids build up in the water stream. By removing blowdown and adding fresh make-up water, the level of dissolved solids in the water can be maintained to reduce mineral scale build-up and other contaminants in the tower, cooling condensers and process heat-exchangers. Silica concentrations frequently limit the cycles of concentration in the cooling tower circulating water. The result is high blowdown rates and more wastewater for disposal. The blowdown was required to be hauled off-site at a very high cost, to recover water for re-use. If the blowdown water can be treated to meet the permissible limits [1, 2], (para-

*Author for correspondence.

meters such as pH = 6.5–8.5, turbidity < 50 mg/l, iron and manganese < 0.5 mg/l, dissolved oxygen = 3 mg/l, chloride as NaCl < 750 ppm, sulphate as SO_4 < 1200 ppm and TDS about 2000 mg/l), it would be possible to reuse it as make-up water.

Until recently, alternative treatment methods used to achieve zero liquid discharge (ZLD) consisted of combinations of thermal and membrane processes, sometimes coupled with evaporation ponds [3]. Membrane technology is emerging as a viable and economical option in the reclamation of wastewater. These processes include reverse osmosis, electrodialysis, brine concentrators, crystallizers, and spray dryers.

An attempt has been made to treat the blowdown water using reverse osmosis (RO) technique because of its simplicity in design, installation and operation. RO is the most versatile method for water purification system to produce high purity water. However, the quality of the water being fed into the reverse osmosis membrane is critical to its performance and lifetime [4]. Silt density index (SDI) expresses the suitability of water for reverse osmosis, and quantifies the amount of particulate contamination in a water source. It is used to measure the degree of fouling. Most RO membranes recommend a value for silt density index, usually 5, for the influent water [5]. Water exceeding this value is unfit for RO, and will usually void performance of the membrane. On the other hand, using low SDI is observed to extend, sometimes double the lifetime of the reverse osmosis membrane.

Further, RO has proved to be the most reliable and cost-effective method of desalinating water [6], and hence its use has become widespread. Energy consumption is usually 70% lesser than for comparable evaporation technologies. Advancements have been made in membrane technology, resulting in stable, long-lived membrane elements. Component parts have been improved as well, reducing maintenance and downtime [7]. Additional advancements in pretreatment have been made in recent years, further extending the membrane life and improving performance. RO delivers product water or permeate having essentially the same temperature as the raw water source (an increase of 1°C (1.8°F) may occur due to pumping and friction in the piping).

In general, the per cent recovery achieved by the RO, after pretreatment, is limited only by osmotic pressure of the reject. The wastewater should undergo some pretreatment before treatment with RO. Ultrafiltration has evolved as an one-step solution for most of the pretreatment and prior to reverse osmosis ensures consistency and cost-effectiveness by providing water with an SDI ≤ 1.0 [8, 9].

Hardness should then be removed from the filtered water. The preferred method for high TDS cooling tower blowdown consists of conventional lime-soda softening followed by filtration and weak acid cation (WAC) ion exchange. Other hardness removal methods can be considered depending upon site-specific conditions. Lime-soda softening in conventional solids contact clarifier is an economical method of removing the bulk of the hardness (calcium and magnesium) and other scale-forming cations such as barium and strontium. The effluent from the clarifier is filtered with dual media gravity or pressure filters for reduction of suspended solids. RO permeate is then directed back to the cooling tower or may be used as cycle make-up after additional treatment. The highly concentrated RO reject may be disposed of in an evaporation pond if the plant is located in an arid region, and where not feasible, direct the stream to a crystallizer or spray dryer [10] with landfill.

Table I
Characteristics of effluents from cooling tower

Sl. no	Parameter	Value
1.	pH	7
2.	Conductivity (*m*s/cm)	3350
3.	Total hardness	351
4.	Calcium hardness	256
5.	Total dissolved solids	2500
6.	Total suspended solids (TSS)	50
7.	Chloride	713
8.	Sodium	678
9.	Potassium	54
10.	Sulphate	233

Note: Except for pH and conductivity, all other parameters are in mg/l.

2. Materials and methods

2.1. *Wastewater characterization*

Cooling tower effluent from a fertilizer unit was used for the study. Samples were collected at the blowdown sampling point 1 called corrosion coupon. The collected samples were analyzed for parameters such as pH, conductivity, total hardness, calcium hardness, TDS, TSS, chloride, sodium, potassium and sulphate [11] (Table I).

2.2. *Experimental procedure*

The experimental set-up of a laboratory-scale RO system is shown in Fig. 1. The feed water was taken from the collection tank, which stores effluents from the cooling tower. The TDS in the cooling tower effluent was found to be 2000–2500 mg/l, the pH 7–7.5, and the SDI 8.5. The water from the collection tank was first pumped to the sediment filter main-

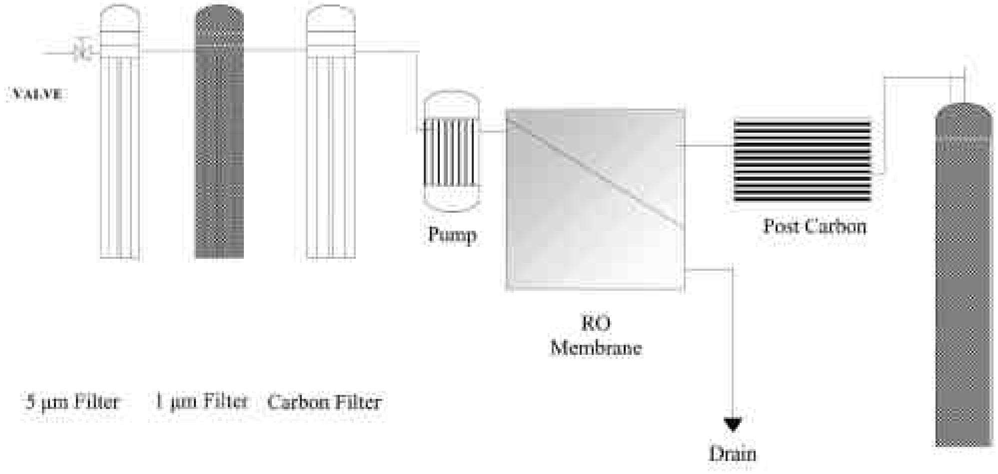

FIG. 1. Experimental set-up of reverse osmosis.

taining the flow rate at about 0.2 lpm. A 5 *m*m-polypropylene filter which removes dirt, algae and all suspended contaminants present in the water was used. Dissolved solids > 5 *m*m were retained on the filter.

The outlet water from the sediment filter contains dissolved particles of size up to 5 *m*m. The water from 5 *m*m filter was then pumped to 1 *m*m filter. The dissolved particles of size greater than 1 *m*m were retained on the filter. The outlet water from 1 *m*m filter was then sent to a carbon filter, which traps particles of metal such as lead and copper and removes chlorine and volatile organic chemicals. The carbon filter was mainly used to improve the quality of water and to protect the membranes. The water was then passed through an RO module consisting of a thin film composite membrane of pore size 0.0001 *m*m using a high-pressure pump. The maximum inlet pressure was about 413×10^3 Pa.

The membrane holds up the dissolved solids. The TDS in the permeate water was found to be 270 mg/l. The water was then passed through a post-carbon filter for further treatment. High recovery is thus achieved given that the RO pretreatment includes removal of hardness, alkalinity and carbon dioxide to levels indicated to be safe, and free of scaling potential. Therefore, the RO module can effectively remove TDS from wastewater.

High cycles of concentration (eqn 2) are important because the volume of the RO reject decreases as the cycles of concentration increase [12]. Equations (1) and (2) express the recovery and the cycles of concentration.

$$\text{Recovery} = \frac{}{\text{Feed volume}} \times 100 \tag{1}$$

$$\text{Cycles of concentration} = \frac{100}{(100 - \text{Recovery})}\,. \tag{2}$$

2.3 *Determination of SDI*

SDI testing is commonly used as an 'early alert' to ensure that particulates in feed water do not plug the micropores in reverse osmosis membranes. The SDI was determined by placing a 0.45 *m*m membrane filter in the equipment. The feed water pressure was adjusted to 206×10^3 Pa and the initial time t_0 necessary to filter 500 ml of the sample was noted. The filter was then kept in operation for 15 min under 206×10^3 Pa feed pressure. After 15 min, time t_1 necessary to filter 500 ml was noted. The SDI was calculated using eqn (3).

$$\text{SDI} = \frac{(1 - t_0)}{t_1} \times \frac{100}{t}$$

where t_0 is the initial time required to filter 500 ml, t_1, the time required to filter 500 ml after 15 min and t, the time between the measurements in 15 min. The SDI was determined to be 5. This shows a reduction of suspended contaminants in the effluent.

3. Results and discussion

The quality of the cooling tower effluents for ready disposal into water bodies exceeds the permissible limits with reference to parameters such as TDS, hardness, chloride, sulphate, sodium and potassium (Table I). The effluent has TDS of 2500 mg/l, which is mainly due to evaporation in cooling towers. RO system, operating at neutral or acidic pH, may be employed, by keeping the concentration cycles within limits (due to high hardness).

To operate the RO, all hardness and other cationic species that would scale the membranes need to be removed, as also suspended solids, to minimize membrane plugging. Pretreatment employing microfiltration of 5 and 1 *m*m and carbon filtration were effective in complete removal of suspended solids.

Suspended solids and colloidal materials in feed water are the major impediments to the RO systems. Despite pretreatment (including 5 *m*m prefilters), fine particles continue to foul membranes.

To determine SDI, a 0.45-*m*m filter was exposed to the feed water under pressure. An SDI of less than 5 is considered acceptable for the reverse osmosis systems [5], implying that the membranes foul lesser at or below this value [13].

In this study, the SDI was determined using eqn (3). The SDI of 5 as determined in this study matches with the results of other studies [14]. Permeate flux and salt retention are the main parameters that determine the performance of an RO system. These parameters are mainly influenced by factors such as pressure and recovery. These variables influence the performance of the system in their own way. In practice, performances are usually influenced by multiple parameters.

3.1. *Effect of pressure*

The pretreated water was fed to reverse osmosis at different operating pressures such as 275×10^3, 310×10^3, 344×10^3, 379×10^3 and 413×10^3 Pa. The permeate was analyzed for pH, conductivity, total hardness, calcium hardness, TDS, chloride, sodium, potassium and sulphate (Table II). Feed water pressure affects both the permeate flux and salt rejection of RO membranes (Fig. 2). The permeate flux across the membrane increases in direct relationship to increase in feed water pressure. Increased feed water pressure also results in

Table II
Performance of RO at different operating pressures

Sl no.	Parameter	Feed	Characteristics at different pressures (× 103 Pa)									
			275		310		344		379		413	
			P	% R	P	% R	P	% R	P	% R	P	% R
1.	pH	7	6.7	–	6.7	–	6.7	–	6.8	–	6.8	–
2.	Conductivity (*m*s/cm)	3350	387.5	–	370.0	–	345	–	342.0	–	338	–
3.	Total hardness	351	57.5	82.2	56.0	84.1	54.5	84.5	52.5	85.5	50.0	85.7
4.	Calcium hardness	256	54.5	78.7	52.5	79.5	52.5	79.5	49.5	80.6	48.0	81.2
5.	Total dissolved solids	2500	305.5	87.8	295.0	88.2	275	89.0	272.5	89.1	270	89.2
6.	Chloride	713	123.5	82.7	120.0	83.2	116	83.7	115.0	83.8	113	84.2
7.	Sodium	678	85.5	87.4	84.5	87.5	83	87.8	80.0	88.2	79.0	88.4
8.	Potassium	54	14.5	73.1	13.0	76.0	11	79.6	10.5	80.5	10.0	81.5
9.	Sulphate	233	24.5	89.5	22.0	90.5	18	92.3	16.5	93.0	16.0	93.1

P = Permeation; % R = Percentage rejection.

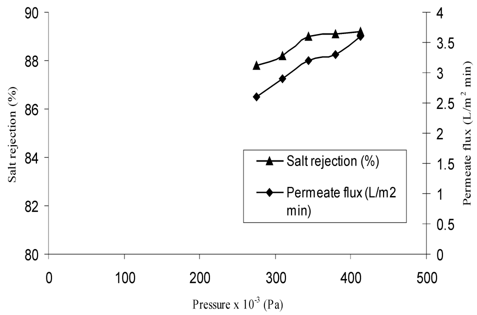

FIG. 2. Effect of pressure on membrane salt rejection and permeate flux.

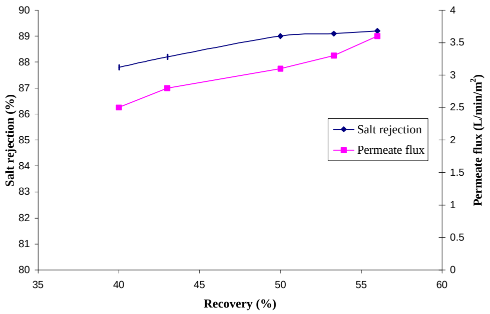

FIG. 3. Effect of increasing recovery on salt rejection and permeate flux.

increased salt rejection but, as demonstrated in Fig. 2, the relationship is less direct than for permeate flux. Because RO membranes are imperfect barriers to dissolved salts in feed water, there is always some salt passage through the membrane [15]. As the feed water pressure is increased, the salt passage becomes high since water is pushed through the membrane at a faster rate. However, there is an upper limit to the amount of salt that can be removed by increasing feed water pressure. This is confirmed by the salt rejection curve (Fig. 2) which shows that beyond a certain pressure level salt rejection can no longer be increased [16].

3.2. *Effect of recovery*

The recovery of water relates the permeate and feed water flows. It is observed that when recovery increases, the permeate flux decreases and does not show any further change, while osmotic pressure is equal to feed pressure. The amount of water recovered with respect to salt rejection and permeate flux is shown in Fig. 3. It is observed that at a pressure of 413×10^3 Pa, recovery of 56.0% is achieved. As the percentage recovery increases (feed water pressure remaining constant), the salts in the residual feed get concentrated and the natural osmotic pressure tends to increase. This can negate the driving effect of feed pressure, slowing or halting the RO process and causing permeate flux and salt rejection to decrease. The maximum per cent recovery usually depends not on a limiting osmotic pressure, but on the concentration of salts present in the feed water and their tendency to precipitate on the membrane surface as mineral scale.

The most common sparingly soluble salts are calcium carbonate (limestone), calcium sulfate (gypsum), and silica. Chemical treatment of the feed water can be used to inhibit mineral scaling. The salt in the permeate is not affected by the applied pressure, but rather is proportional to the concentration difference. In fact, higher operating pressures do tend to increase the global rejection.

4. Conclusions

The cooling tower effluent from the fertilizer unit under study contains 50 mg/l of suspended solids and 2500 mg/l of TDS. Prefiltration by 5 and 1 *m*m filter was found to be effective in the complete removal of suspended solids. This treatment achieves an SDI of 5 indicating less membrane clogging. The pretreated water sent to the reverse osmosis system, operating at a maximum pressure of 413×10^3 Pa, achieved salt rejection of 89.2% and recovery of 56.0%. The salt rejections at 275×10^3, 310×10^3, 344×10^3 and 379×10^3 Pa were found to be 87.8, 88.2, 89.0 and 89.1%, respectively. The recoveries of water at the above operating pressures were found to be 40.0, 43.0, 50 and 53.3%, respectively. From these results, it is concluded that RO is a viable technique that can help in the recovery of about 56% of water at an operating pressure of 413×10^3 Pa from the blowdown water.

References

1. *Marley's Cooling tower fundamentals. Section I. On maintaining water quality*, Olympic Engineered Sales, Bellevue, WA, USA (2004).
2. Robert A. Corbitt, *Standard handbook of environmental engineering*, McGraw-Hill (1989).
3. R. Boyce, Michael Ferrigno and Davesh Sharma, A new zero liquid discharge strategy. Boiler make-up from cooling tower blowdown, *Proc. Int. Water Conf.*, Pittsburgh (1999).
4. Shuichi Chino, Isamu Sugiyama, Jeffrey Hollooway and Deb Mukhopadhyay, A new high efficiency reverse osmosis, *Proc. Int. Water Conf.*, Pittsburgh (1999).
5. Silt Density Index, www.watertreatmentguide.com/determining_ sdi.htm (2000).
6. W. Byrne, *Reverse osmosis–A practical guide for industrial users*, Tall Oak Publishing (1995).
7. A. G. Fane, P. Beatson, and H. Li, Membrane fouling and its control in environmental application. *Wat. Sci. Technol.*, **41**, 303–308 (2000).
8. D. Mukhopadyay and S. Whipple, RO system that reduces membrane scaling and fouling tendencies. *Ultrapure Wat.* **14**, 21–30 (1997).
9. H. Ozaki, H. Sharma, K. W. Saktaywin and D. Wang, Application of ultra low pressure RO membrane to water and wastewater. *Wat. Sci. Technol.*, **42**, 123–135 (2000).
10. C. A. Buckley, C. J. Brouckaert and G. E. Raneken, Wastewater reuse–the South African experience, *Wat. Sci. Technol.*, **41**, 303–308 (2000).
11. *Standard methods for the examination of water and wastewater*, American Public Health Association, 17th edn (1989).
12. Khaled Moftah, High pH RO for wastewater treatment, *Proc. Int. Water Conf.*, Pittsburgh (2002).
13. R. Goozner and B. Gotlinsky, Field results for the reduction of SDI by pre-RO filters. *Ultrapure Wat.*, **7**, 20 (1990).
14. www.osmolabstore.com/documents/1201696-Lit.
15. C. Ratanatamskul, K. Yamamoto, T. Urase, and S. Ohgaki, Effect of operating conditions on rejection of anionic pollutants in the water environment by nanofiltration especially in very low pressure range, *Wat. Sci. Technol.*, **34**, 149–156 (1996).
16. M. R. Wiesner and P. Aptel, Mass transport and permeate flux and fouling in pressure-driven processes. In *Water treatment membrane handbook* (Malleviella, J., ed.), Ch. 4, pp. 4.1–4.30, McGraw-Hill (1996).