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Economical treatment of reverse osmosis reject of textile industry effluent by electrodialysis–evaporation integrated process

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HIGHLIGHTS

- Electrodialysis for concentration of RO reject to reduce volume load on evaporator.
- Optimization of experimental parameters to design a pilot system.
- Economic estimation of hybrid process for concentration of RO reject.

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ABSTRACT

Membrane separation methods such as electrodialysis (ED) can reduce the volume load on evaporators by facilitating further concentration of rejects from reverse osmosis (RO) plants. ED studies were carried out on a bench-scale system using five membrane cell pairs to obtain a textile effluent concentrate containing approximately 6 times the quantity of salts present in the RO reject. The limiting current densities were determined to be in the range 2.15–3.35 amp/m^2 for feed flow rates varying from 18 to 108 L/h. Apart from feed rate, the influence of volume of concentrate and current on membrane performance was evaluated to optimize current utilization. An estimation of energy requirement of an integrated process constituting ED and evaporation for concentration of inorganics present in textile effluent from 4.35% to 24% was made and found to be approximately one eighth of the operating cost incurred by evaporation alone. Detailed design of a commercial ED system revealed that a membrane area of 13.1 m^2 was required to treat a feed rate of 1500 L/h. The payback period to recover capital investment was found to be 110 days.

1. Introduction

Membrane separation processes have shown great potential for replacing or complementing conventional methods like distillation and evaporation since they are economical, safe and eco-friendly.

Electrodialysis (ED) is a membrane based separation process in which ionizable species such as salts and acids are transferred through a membrane from one solution into another solution by imposition of a direct electric potential. ED provides a tool for changing the concentration of dissolved salts in solutions without significantly changing the concentration and composition of the non-ionic constituents of the solutions [1]. ED has already found widespread commercial acceptance for the demineralization of brackish water and considerable information is available in the literature regarding the fundamentals of the process [2]. ED is also finding increasing application in demineralization of surface water [3]. For example, a recent publication disclosed commercial scale demineralization of whey by ED technique [4].

Reverse osmosis (RO) usually concentrates dissolved solids present in ground water or aqueous industrial effluents that have concentrations above 500–1500 ppm to about 3–5% resulting in recovery of at least 50–80% of water of drinkable or dischargeable quality in the form of permeate [5]. The balance concentrate containing ≅3–5% dissolved solids is also known as reject and cannot be further concentrated by RO due to high osmotic pressure and is therefore sent to an evaporator to remove the remaining water and concentrate the solids to dryness for incineration or safe disposal through land filling. Evaporation proves to be highly expensive owing to large steam requirements and high latent heat of vaporization of water required to bring about a phase change [6]. To reduce the load on evaporator and save energy a low cost intermediate process must be introduced to concentrate the RO reject to near saturation level of about 15–25% inorganic components. ED is currently being studied as a method to concentrate brackish water RO rejects and obtain solid salts that can be further reused [7–10]. In some part of the world,

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Nomenclature

A_{eff}	effective membrane area
A_{prac}	practical membrane area
A_{cp}	cell pair area
a	constant 'a' for the LCD calculation ($As^{b}m^{1-b}/keq$)
b	constant 'b' for the LCD calculation
C_s^c	concentration of concentrate out (keq/m^3)
C_s^d	concentration of diluate out (keq/m^3)
C_s^{fd}	concentration of diluate in (keq/m^3)
C_s^{fc}	concentration of concentrate in (keq/m^3)
C_s^{Δ}	concentration difference between concentrate and diluate (keq/m^3)
E_{spec}	specific power consumption (kWh/m^3)
F	Faraday constant (A s/keq)
I	current (A)
i	current density (A/m^2)
i_{lim}	LCD (A/m^2)
L	length of process path (m)
N_{st}	number of cell pairs
Q	flow rate, production rate (m^3/day)
u	linear flow velocity (m/s)
U	voltage drop (V)
w	width of cell (m)
z	electrochemical valence

Greek symbols

β	effective area of cell factor (spacer-shadow)
Δ	thickness of unit cell
Λ	equivalent conductance of solution (Sm^2/keq)
$\rho_A + \rho_C$	total area resistance of membranes (Ω m^2)
ζ	current utilization

salt can be manufactured by means of ED process to which concentrated brine discharged from a RO seawater desalination plant is supplied [11]. ED has the potential to economically concentrate RO rejects to near saturation level by transfer of most of the inorganic ions present in the reject to a receiving solution having a volume which is about 1/5 the original volume of the reject. The integrated process of ED and evaporator for treating the RO reject is shown in Fig. 1.

The focus of the present study is to determine the performance characteristics of ED for concentration of RO reject of textile effluent to reduce the volume load on evaporation. Optimization of experimental parameters such as feed flow rate, voltage and current was carried out to design a pilot system capable of processing textile RO reject at the rate of 1500 L/h. An economic estimation which compares the cost of process incorporating ED unit operation against a process carried out in the absence of ED for treatment of the RO reject of textile industrial effluent is included in this work.

2. Experimental

2.1. Materials

Cation exchange (CMI-7000) and anion exchange (AMI-7001) Ultrex™ ion exchange membranes were purchased from M/s. Membranes International Inc., New Jersey, USA and their properties as specified by the supplier are provided in Table 1. The membrane material for ED is usually polystyrene crosslinked with divinyl benzene. For preparation of cation transfer membrane, the polymer is modified by sulfonation whereas amination is done to synthesize anion transfer membrane. RO reject of textile effluent was collected from Permionics RO system working at KNIT Textiles, Tiruppur, Tamil Nadu, India. Demineralized water for concentrate and electrode wash solutions was generated in the laboratory RO system. Gaskets and spacers were fabricated from polypropylene sheets purchased locally. Flanges for housing cathode and anode electrodes, feed inlet and outlet arrangements were fabricated from Nylon blocks. Anode and cathode SS electrode plates were fabricated from stainless steel 316 and coated with titanium. The outer dimension of each distributor and gasket in the ED cell was 15.2 cm × 15.2 cm. The effective area of each membrane available for ion transfer was 10.5 cm × 10.5 cm.

2.2. Characterization of textile RO reject

The textile effluent was treated through RO using thin film composite (TFC) polyamide spiral wound membrane at a pressure of 18 bar. The RO reject was thoroughly analyzed by standard APHA

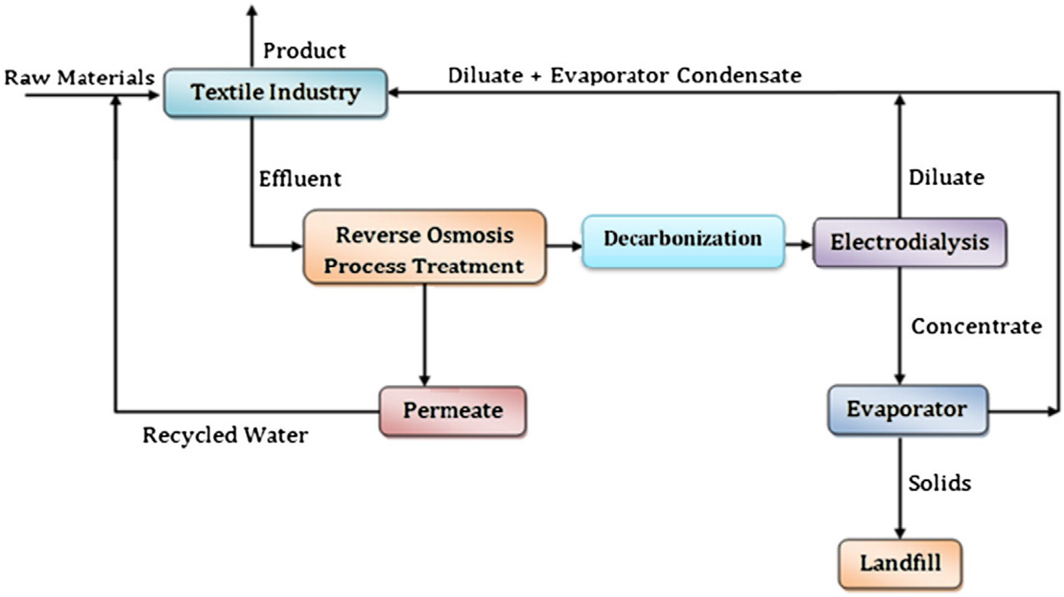

Fig. 1. Flow sheet showing the integrated process for the concentration of RO reject.