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The use of electrodialysis for recovery of sodium hydroxide from the high alkaline solution as a model of mercerization wastewater

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A B S T R A C T

The possibility of alkali recovery from a high alkaline solution as a model for mercerization wastewater by electrodialysis (ED) was examined. ED with feed and bleed configuration was used in which the diluate chamber conductivity was kept at a given value by dosing an alkaline solution. The effect of the diluate chamber's concentration on the efficiency of the ED was investigated. It was found out that the efficiency of the ED was just slightly affected by changing the concentration of the solution in diluate chamber. The calculated values of current efficiency in ED process were about 60%. Since the ion exchange membranes, particularly the anion exchange ones are suspected to be damaged in high alkaline media, their properties including electrochemical resistivity, apparent permselectivity, FT-IR spectrum, and the current-voltage characteristics were investigated. The results confirmed that the membranes possess a promising chemical stability since their properties were not affected by the alkaline media. Hence, the obtained results show that the electrodialysis is an appropriate method for alkaline recovery.

1. Introduction

Electrodialysis (ED) is a conventional technology which has been utilized in different applications and industries including water desalination [1–3], salt pre-concentration [4], acid and base recovery from industrial wastewaters [5], and food industries [6–8]. ED consists of a series of anions and cations exchange membranes placed alternatively between two electrodes. The membranes are separated by spacer gaskets and form individual cells. When an electrical potential is applied to the electrodes the migration of ions to the electrodes with opposite charge starts. The process at the end results in increasing the concentration of brine, and dilution of the feed in the corresponding cells.

However, to be assured of high efficiency of ED process a special attention must be paid to its key components such as ion exchange membranes. Based on the preparation method the ion exchange membranes can be classified into homogeneous or heterogeneous membranes. The homogeneous membrane is a polymer whose structure is directly implemented with ion exchange moiety. Hence, a relatively even distribution of the charged groups over the entire membrane matrix is obtained which is considered as the prominent feature of homogeneous membrane [9–12]. On the other hand, the heterogeneous membranes are produced by premixing a finely powdered ion-exchange resins with a binder polymer. The membrane was then formed from the mixture resulting in a structure where the ion exchange groups are clustered and unevenly distributed in membrane matrix [13,14]. The membranes used in ED are expected to possess: high permselectivity, low electrical resistance and high chemical stability. Even though the homogenous membranes show better characteristics in terms of resistance and permselectivity the heterogeneous membrane are used in electrodialysis frequently due to the low production costs [15].

Although ED is an excellent technology, it has some limitations including scaling and fouling on the membrane surface [16], and the concentration polarization. Concentration polarization which lowers the energy efficiency, develops when the deionization in the feed solution proceeds. Thus a high cumulative resistance appears within the cell, which decreases the cell efficiency [17].

Mercerization is the name given to the conversion of native cellulose (cellulose I) into the more stable cellulose II polymorph. The conversion is accomplished by swelling cellulose I fibres in concentrated sodium hydroxide solution, Fig. 1. Although no dissolution occurs, the reorganization of the chains is caused by swelling. Cellulose II is generated when the swelling agent is removed. Mercerization causes an improvement in the properties of cotton yarns and fabrics. It results in improved fibre tension, increased fibre surface gloss, decreased fibre contractility and finally it enhances the dye uptake. Hence, the wastewater of textile mercerization is high alkali waste

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Nomenclature

List of Symbols

Q_{real} (C)	Real charge
Q_{theo} (C)	Theoretical charge
η%	Current efficiency
Z_i	Valance number of i
υ_i	Stoichiometric number of i
Δn (mole)	Moles number of i which is transported during ED
N	Number of membrane pairs
F(C/mole)	Faraday constant
Δm (kg)	Mass of i which is transported during ED
Δt (s)	Time of electrodialysis
A (m^2)	Surface area of the membrane
E_m(W h/kg)	Consumed energy for transferring 1 kg of salt in ED (specific energy consumption)
U (V)	Potential
J (kg/h m^2)	Mass flux
i_{lim} (mA)	Limiting current
T_1	Counter ion transport number in membrane
t_1	Counter ion transport number in solution
D (cm^2/s)	Diffusion coefficient of the salt in solution
C_f (mole/l)	Final concentration of NaOH
C_i (mole/l)	Initial concentration of NaOH
C_{dosing} (mole/l)	The concentration of NaOH in dosing solution
V_f (l)	Final volume of NaOH solution
Vi (l)	Initial volume of NaOH solution
V_{dosing} (l)	Volume of NaOH solution which was injected into diluate as dosing solution during ED
P%	Apparent permselectivity
d (cm)	Membrane thickness
ρ (Ω.cm)	Specific resistivity
δ (cm)	Diffusion layer thickness
k (mS/cm)	Specific conductivity
R_A(Ω cm^2)	Surface resistivity
ρ(Ω cm)	Specific resistivity
I (A)	Current
j(A cm^{-2})	Current density

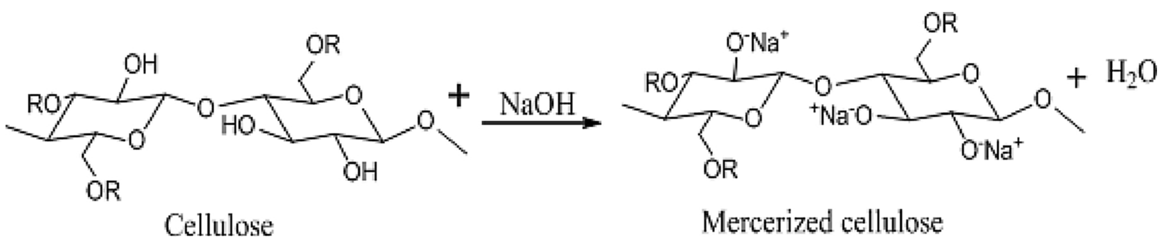

Fig. 1. Schematic presentation of mercerization process.

liquor [18–20]. Because of its high alkalinity, large amount of acid must be consumed to neutralize the alkali when the wastewater is treated. Otherwise, it will cause the difficulty in the subsequent bio-treatment process and have a negative effect on the equipment. Therefore, it is desired to purify and recover the alkali from the waste alkali liquor of the mercerization.

There are few researches carried out about the treatment of the mercerization wastewater using membrane processes. Mainly pressure driven membranes processes were utilized [21–23]. Because the pressure driven processes are based on size exclusion, multi-stage process must be designed. First microfiltration and ultrafiltration membranes were used to remove the turbidity. Then NaOH retention was achieved in another stage using nanofiltration membranes. Further concentration of the alkaline solution was performed with evaporation. This results in complicated technological sequence with high energy consumption.

Since the driving force in electro-membrane processes is the electrical voltage differences, they can offer more efficient method for concentrating of small ionic compounds such as NaOH from a feed solution.

Hence, this work aimed to investigate the possible application of electrodialysis for recovery of the alkali from mercerization wastewater.

2. Experimental

2.1. Reagents

All the chemicals ($NaNO_3$, NaOH, HNO_3, HCl, Na_2SO_4, and NaCl) were of analytical grade and purchased from Merck (Germany). The demineralized water that was used in all the experiments is being produced in MemBrain Ltd., (Stráž pod Ralskem) by reverse osmosis ($k < 10$ μS cm^{-1}). The anion and cation exchange resins used for producing of membranes were purchased from Purolite (USA). The strong basic quaternary ammonium groups and sulfonic acid groups are ion exchangers in anion and cation exchange membranes respectively.

2.2. Membranes

The anion (AM-PP) and cation (CM-PP) exchange membranes were the commercial membranes which were produced in MemBrain Ltd., (Stráž pod Ralskem). The heterogeneous membranes were produced by extruding the mixture of the ion exchange resin with polyethylene granulate in a given ratio. The membranes were reinforced by pressing a polypropylene fabric at 150 °C and 50 atm to improve their chemical and mechanical stability. The anion exchange membranes contain sulfonamide group connected to the quaternary ammonium as functional group and the cation exchange membranes possess R-SO_3^- group as cation exchanger.

2.3. Apparatus

The electrodialysis was carried out with pilot unit EDR-Z/10-0.8 MemBrain Ltd., (Stráž pod Ralskem). The pH and the conductivity of the solutions were measured by SenTix® 940 glass electrode and TetraCon 925 conductivity cell respectively. The probes were connected to the WTW multi 3420. It must be mentioned that the conductivity cell also possesses the temperature sensor. The solution was circulated through the system with a peristaltic pump Heidolph (PD 5001, Germany). The titration was performed with Titroline Alpha Plus (Schott instrument, Germany). The current voltage characteristics (CVC) was recorded with a *SP*-300 potentiostate/galvanostate (BioLogic, France) connected to EC-lab software. The IR spectrum was recorded by Nicolet™ iS™ 50, FT-IR Spectrometer (Thermo fisher scientific, USA).