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AN ASSESSMENT OF ULTRAFILTRATION MEMBRANE MATERIALS IN SODIUM DODECYL SULFATE REMOVAL FROM WATER SOLUTIONS

The objective of the research was to investigate the transport and separation properties of ultrafiltration membranes for sodium dodecyl sulfate (SDS) salt solutions. In the tests, the membranes made from different materials were applied. Experiments were carried out in a laboratory ultrafiltration cell at a pressure of 0.10 MPa and pH equal to 7. The concentration of SDS in model solutions amounted to 5, 100 and 300 mg/dm^3.

The efficiency of SDS separation was found to be influenced by the type of membrane material. A decrease in separation and transport properties of these membranes with increasing SDS concentrations was observed. Polyethersufone (PES) was considered as the membrane material of the best separation characteristics.

1. INTRODUCTION

The use of surfactants for industrial purposes and in many consumer products such as soaps and detergents has resulted in their worldwide consumption of approximately 10.4 million tonnes per annum [1]. Environmental concerns and economic reasons have brought about an increased application of ultrafiltration treatment to wastewater containing surfactants.

A surfactant is essentially a molecular structure that consists of a hydrophilic and a hydrophobic component. In anionic surfactants, the hydrophilic component is commonly an anion, either carboxyl, sulpho, sulphate groups, or occasionally phosphatic

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group. The hydrophobic component usually contains from 8 to 18 carbon atoms in the hydrocarbon chain and can be aliphatic, aromatic or a mixture of both. When surfactant molecules aggregate in aqueous solutions, micelles are formed withdrawing the hydrophobic groups from the water. The hydrophilic groups in the micelle orient towards the water, whilst the hydrophobic groups are repelled towards the interior of the micellar structure. Formation of these micelles only occurs at certain concentrations dependent on the type of surfactant. Critical micellar concentration (cmc) is the point where the solution is dominated by the formation of micelles. At the concentrations higher than cmc, monomers and micelles coexist in equilibrium. The question of how the surfactant molecules are arranged in the solute–membrane interaction is of fundamental importance and can influence the experimental procedure of ultrafiltration [2].

Membrane processes, such as ultrafiltration, have been suggested as a means of recovery of surfactants with critical micellar concentrations. If the surfactant concentration is low, i.e. at monomer concentration (c < cmc), then nanofiltration has been suggested as an effective removal process.

2. MATERIAL AND METHODS

Experiments were performed in a laboratory set-up (figure 1) which was used to determine the separation and transport properties of the membranes. The main part of the system was an Amicon 8400 ultrafiltration cell with the total volume of 350 cm^3 and the diameter of 76 mm. All experiments were carried out at a pressure of 0.10 MPa and pH equal to 7. Three concentrations of SDS in model solutions amounting to 5, 100 and 300 mg/dm^3 were used during the experiments.

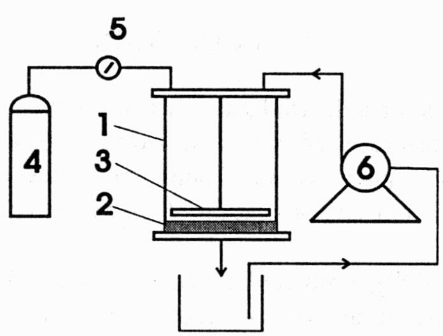

Fig. 1. Experimental set-up: *1* – ultrafiltration cell (Amicon 8400), *2* – membrane, *3* – stirrer, *4* – gas cylinder, *5* – reducer, *6* – recirculation pump

In the study, five types of Intersep Nadir ultrafiltration membranes were used: regenerated cellulose (C), cellulose acetate (CA), polyamide (PA), polysulfone (PS) and polyethersulfone (PES). The molecular weight cut-off (MWCO) of the membranes tested amounted to 4, 10 and 30 kDa. The mean pore radius of the membranes is given in the table.

Table

Mean pore radius (R) for Nadir-Intersep membranes

Membrane type	MWCO		
	4 kDa	10 kDa	30 kDa
PS	0.8	3.2	9.54
PA	2.13	1.93	11.12
PES	0.62	2.04	8.38
CA	0.75	1.24	3.59
C	0.82	5.01	4.89

The concentrations of SDS in the feed and permeate were determined by means of colour reaction with Rhodamine G6 indicator and spectrophotometric measurements of the absorbance at a wavelength (λ) of 565 nanometers.

3. RESULTS AND DISCUSSION

The objective of the experiments was to evaluate the removal of anionic surfactants from water solutions by ultrafiltration. The anionic surfactant chosen was sodium dodecyl sulfate (SDS). The concentration of the solution was lower than the critical micelle concentration, therefore the solution was monomer in character.

The retention properties of the five membrane materials tested at the MWCO of 30 kDa are illustrated in figure 2. The worst separation effect, i.e. 8–11% and 10–14%, was achieved for the membranes made from regenerated cellulose (C) and polyamide (PA), respectively. Such a low separation for the polyamide membrane was probably due to its large pore diameter, whereas poor separation for the regenerated cellulose membrane resulted from the positive charge of the membrane material [3] (due to dissociation of carboxylic groups SDS was negatively charged).

The retention for the PA membrane was several per cent higher than that for the C membrane. This can be explained by the experimental conditions, i.e., pH approaching 7. This pH enables disassociation of carboxylic groups which negatively charge the membrane material [4].

The separation achieved for the cellulose acetate (CA) membrane was slightly improved and amounted to 17–21%. According to TAKAGI et al. [5], the charge of this polymer is the same as that of the molecules in the solution. Because SDS is negatively charged, the membrane also becomes negatively charged, therefore in the solution an electrostatic repulsion between the membrane and SDS particles occurs.

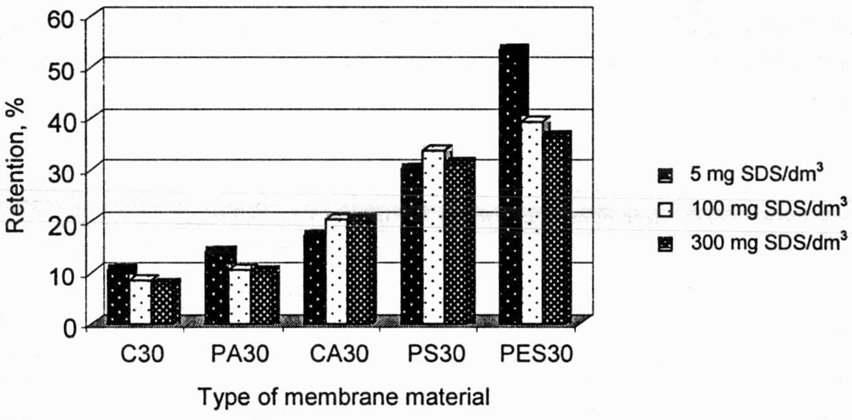

Fig. 2. Retention characteristics of SDS vs membrane type and surfactant concentration

The highest retention coefficient was characteristic of the polysulfone (PS) and polyethersulfone (PES) membranes despite their large pore diameter (table 1). The separation coefficients were 30–34% and 36–53%, respectively. Once again, this was probably due to electrostatic repulsion between the SDS particles and the membrane material. NYSTROM et al. [6] confirmed that modified PES and PS membranes operating in the pH value exceeding 3.5 were negatively charged. The retention for the PES30 membrane was greater than that recorded for the PS30 membrane, which could be attributed to the fact that the pore size of the PES30 membrane was smaller.

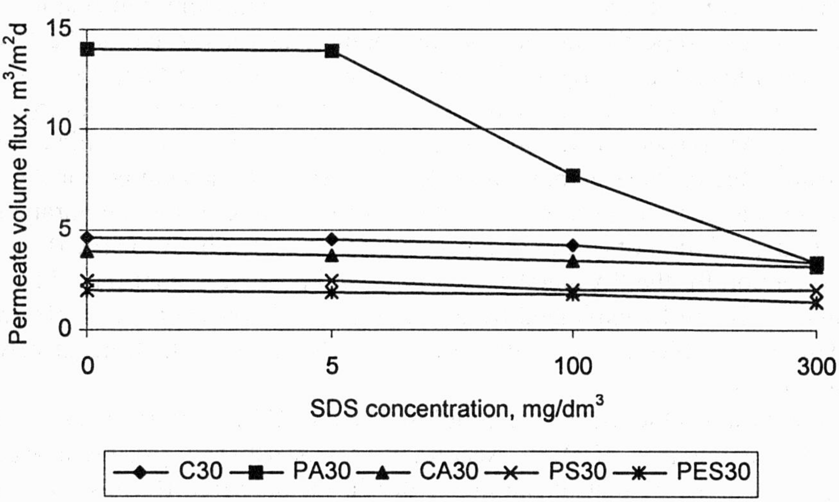

Fig. 3. Effect of SDS concentration on the transport properties of various membranes

The data recorded implied that the PA30 membrane had the best transport properties, provided that only distilled water was used (figure 3). This can be explained by the largest diameter of membrane pores and a spongy material structure [7]. This membrane showed the highest reduction of volume flux recorded, i.e., 45% for 100 mg SDS/dm^3 and 76% for 300 mg SDS/dm^3.

The volume fluxes recorded for the CA and C membranes at the pressure of 0.10 MPa were 3.87 and 4.59 m^3/m^{2}d, respectively. Performance efficiency of the regenerated cellulose (C) membrane was slightly better due to its larger pore diameter. The decrease in volume flux for both these membranes was almost the same, i.e. 8–12% for 100 mg SDS/dm^3 and 21–27% for 300 mg SDS/dm^3.

The lowest volume flux was observed for the PS and PES membranes despite their larger pore size. This should be explained by low hydrophilic properties of these membranes [8]. The reduction in volume flux recorded for PS and PES membranes amounted to 23% and 30%, respectively (at the concentration of 300 mg SDS/dm^3 in the feed solution). A higher concentration of SDS resulted in an increase of the intensity of concentration polarisation at the membrane surface. This brought about the decrease in volume flux.

Because it was found that the PES membrane offered the best separation effect, further research was carried out using this material. The comparison of the PES membrane with the C membrane proved that their properties were radically different.

Using the SDS in the concentrations mentioned previously (i.e. 5, 100 and 300 mg SDS/dm^3), the best separation effect, i.e. 57–71% and 59–68%, was achieved for PES4 and PES10, respectively (figure 4). The increase in the MWCO of the membrane from 4 kDa to 10 kDa had practically no influence on the retention of SDS. For the PES30 membrane the retention coefficient was approximately 15 to 20% lower.

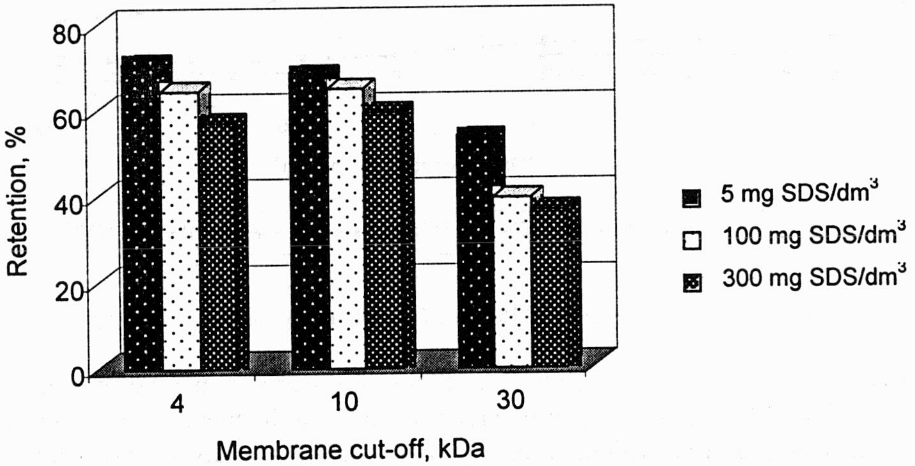

Fig. 4. Effect of SDS concentration on the retention coefficient for PES membranes

The membranes made from regenerated cellulose (C) had lower separation efficiencies (figure 5), which amounted to 11–63%, 8–40% and 18–26% for 5, 100 and 300 mg SDS/dm^3, respectively. The separation effect of these membranes decreased when the MWCO and the SDS concentrations were increased.

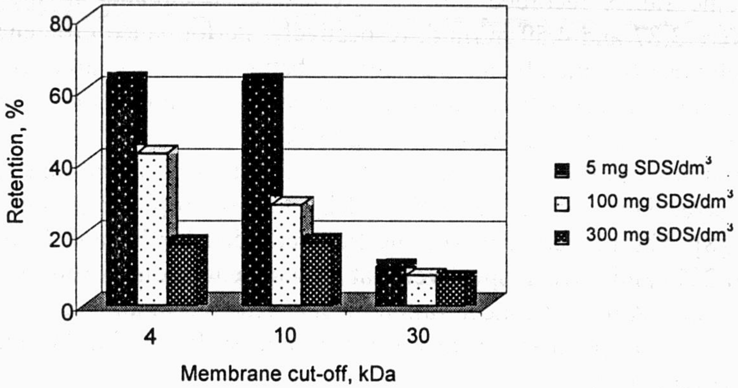

Fig. 5. Effect of SDS concentration on the retention coefficient for C membranes

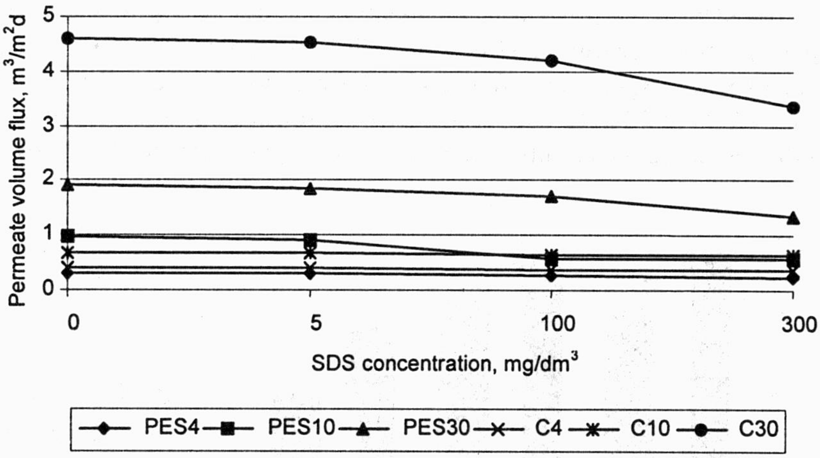

Fig. 6. Transport properties of PES and C membranes vs SDS concentration

It is worth noting that during ultrafiltrafion test, separation may be connected with the formation of both micelles and polarisation layer on the membrane surface. It can effect the decrease of the volume flux (figure 6). The biggest decrease of volume flux (27%) was observed for the C30 membrane with a SDS concentration of 300 mg SDS/dm^3.

4. CONCLUSIONS

The following conclusions can be deduced from the experimental investigation:

• The ultrafiltration efficiency of sodium dodecyl sulfate (SDS) separation was found to be influenced by the type of membrane material. The membrane, which showed the best separation characteristics, was made from polyethersufone (PES). The retention coefficient amounted up to 71%.

• A decrease in the separation and transport properties of the membranes tested with the increasing SDS concentrations was observed.

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OCENA SKUTECZNOŚCI MEMBRAN ULTRAFILTRACYJNYCH W USUWANIU SOLI SODOWEJ SIARCZANU DODECYLU Z ROZTWORÓW WODNYCH

Przedstawiono właściwości transportowe i separacyjne ultrafiltracyjnych membran wykonanych z różnych materiałów. Właściwości te badano podczas separacji soli sodowej siarczanu dodecylu (SDS) z roztworów wodnych w komorze ultrafiltracyjnej pod ciśnieniem 0,10 MPa i w roztworze o obojętnym odczynie. Stężenie SDS wynosiło 5, 100 i 300 mg/dm^3. Stwierdzono, że skuteczność separacji zależy od materiału, z jakiego wykonano membrany. Obserwowano, że ze wzrostem stężenia SDS pogarszały się właściwości separacyjne i transportowe membran. Przeprowadzone badania wykazały, że najlepszym efektem separacji charakteryzowały się membrany wykonane z polieterosulfonu.