**Separation Science and Technology**
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

# Mechanism of Charged Membrane Ultrafiltration of Salt Solutions

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**To cite this Article** Van Oss, Carel J.(1980) 'Mechanism of Charged Membrane Ultrafiltration of Salt Solutions', Separation Science and Technology, 15: 2, 159 — 161
**To link to this Article: DOI:** 10.1080/01496398008056090
**URL:** http://dx.doi.org/10.1080/01496398008056090

SEPARATION SCIENCE AND TECHNOLOGY, 15(2), pp. 159–161, 1980

## NOTE

# Mechanism of Charged Membrane Ultrafiltration of Salt Solutions

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## Abstract

The mechanism of removal of electrolytes from acid mine water by charged membrane ultrafiltration, as employed by Bhattacharyya et al., is analyzed. In view of the influence of co-ions on the performance of the charged membranes, of the streaming potential engendered by the applied pressure differential, and of the preponderance of multivalent cations in mine water, the theoretically ideal conditions for this ultrafiltration would encompass the use of *cationic* membranes at a low pH (obtained with HCl) and relatively high pressures. It would not seem that Reynolds numbers $>2500$ are required, nor that temperature differences would significantly influence the separation efficiency.

As Bhattacharyya et al. recently noted (*1*): "The separation of ionic solutes by charged ultrafiltration membranes is due to repulsion of co-ions by the fixed charge groups in the membrane skin." They demonstrated that bi- and trivalent cations, in synthetic acid mine water with $SO_4^{2-}$ as counterions, could be retained to a significant extent by ultrafiltration through anionic membranes at a transmembrane pressure of 5.6 Pa and under conditions of upstream turbulence with a Reynolds number (Re) of 6000. A study of these authors' results (*1*) may, in the light of an analysis of the mechanism of ion retention by charged ultrafilter membranes, lead to a few interesting conclusions and perhaps to some fruitful suggestions.

The repulsion of co-ions by the charged membranes (*1*) is most effective when the co-ions are multivalent and the counterions are monovalent (*2*, *3*). The repulsion of co-ions by charged membranes is significantly enhanced by the streaming potential engendered by the forced flux through the charged pores of ultrafiltration membranes (*4*). Thus the electrolyte retention is, up to a certain point, proportional to the applied pressure:

$$E = \frac{P\zeta\varepsilon}{4\pi\eta\lambda} \tag{1}$$

(where $E$ is the streaming potential, $P$ is the pressure differential, $\zeta$ is the electrokinetic potential of the pore wall, $\varepsilon$ is the dielectric constant of the liquid medium, $\eta$ is its viscosity, and $\lambda$ is its conductivity) and inversely proportional to the upstream ionic strength (*2*, *4*). The pore size of the charged membranes should not exceed a certain (fairly small) diameter to obviate the escape of co-ions through pore-lumina at too large a distance from the charged pore-perimeters to become repelled by them (*2*, *4*). This critical pore size limit is also apparent from the results of Bhattacharyya et al. as exemplified by the improved electrolyte retention they observed at lower "initial water fluxes" (*1*). Turbulence close to the membrane surface is required to prevent local increases in salt concentration that would significantly decrease the membranes' ion retention, but a minimal turbulence (*5*) sufficient to attain that goal need not be exceeded (*2*, *3*); in practice (in tubular membrane systems), this is attained at Re $\approx$ 2300 (*2*).

In the light of these considerations, optimal electrolyte removal by charged membrane ultrafiltration from the actual mine water of which Bhattacharyya et al. give the composition (*1*) may (ideally) be obtained under the following conditions:

1. Given the preponderance of bi- and trivalent cations, a *positively* charged membrane would be most effective, in which case the anions would best be monovalent, and as a low pH would be desirable to enhance the membranes' $\zeta$-potential, acidification with HCl (instead of with $H_2SO_4$) would be preferable.
2. There probably is no advantage in generating greater upstream turbulence than that corresponding to Re $\approx$ 2500.
3. As high a pressure differential as is compatible with membrane longevity and energy cost should be aimed at, in order to maximize the streaming potential across the pores of the membrane skin and thus the electrolyte retention.
4. Higher temperatures of operation are unlikely to increase the salt retention appreciably because the influences of temperature on the viscosity, conductivity, and dielectric constant of the solution (see Eq. 1) virtually cancel each other out (*4*, *6*).

If anionic membranes are preferred, e.g., for reasons of longevity,

$SO_4^{2-}$ will lead to better salt retention than $Cl^-$ ions [see also Bhattacharyya et al. (*7*)], but then a high pH will be more advantageous to attain maximum membrane and streaming potentials.

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*Received by editor June 22, 1979*