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The effect of restriction membranes on mass transfer in an electrodialysis with filtration membrane process

Huining Deng[a], George Q. Chen[b], Sally L. Gras[b,c], Sandra E. Kentish[b,*]

[a] School of Marine Science and Engineering, Hebei University of Technology, Tianjin 300130, PR China
[b] Department of Chemical and Biomolecular Engineering, The University of Melbourne, Victoria 3010, Australia
[c] Bio21 Molecular Science and Biotechnology Institute, The University of Melbourne, Victoria 3010, Australia

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ABSTRACT

In an electrodialysis with filtration membrane (EDFM) separation process, a pair of restriction membranes is used to prevent leakage of molecules into the electrode solution. Driven by the electrical potential gradient, ions transport across these membranes in different directions, resulting in concentration changes in the feed and permeate compartments respectively. However, the effects of these restriction membranes have not been systemically studied to date. In the present work, the performance of a non-charged polyacrylamide (PAm) membrane and two ion-exchange membranes were compared. PAm restriction membranes were found to give the most stable operation, with only slight concentration and pH changes in the feed and permeate compartments. The configurations with either cation or anion exchange membranes showed more significant changes in electrolyte concentration in opposing directions but the same pH trend, as the current density increased. The configuration with cation exchange membranes as restriction membranes resulted in the highest protein recovery, while the use of anion exchange membranes would appear as the best choice for separation of a protein with net positive charge. The results of this work provide important insights for the design and operation of EDFM processes and a better understanding of the transport phenomena that occur during the separation of bioactive compounds.

1. Introduction

Electrodialysis with filtration membrane (EDFM) is an emerging membrane technology for fractionation of electrically charged bioactive compounds such as proteins or their peptides [1,2]. Driven by an electric potential difference across the filtration membrane, the EDFM process shows improved selectivity and reduced fouling compared to pressure-driven membrane processes [3,4]. Selective transport of the bioactive molecules across the separation membrane is achieved by both differences in charge and molecular size. As the approach is similar to electrophoresis, it is sometimes referred to as an electrophoretic membrane contactor, particularly if a larger porous membrane is used as the separation medium for protein separation [5–8]. One or a series of separation membranes with different pore sizes has been used to extract proteins from egg white [9] and whey [7], to extract peptides from protein hydrolysate [10–12], and to purify charged molecules with low molecular weight [13]. Bazinet and co-workers have studied the effect of the electric field [14–16], pH [17], ionic strength [4] and membrane physicochemical properties [18] on both the separation ability and membrane fouling within the EDFM process; but an understanding and optimization of the EDFM process is far from complete.

A basic EDFM configuration is composed of one separation membrane, two restriction membranes and a pair of electrodes, as shown in Fig. 1. Normally, buffers are used as the cathode and anode solutions and are circulated in a closed loop to neutralize the base generated from cathode reactions, with acid from the anode. The two inner compartments can be designated to be feed and permeate, these are allocated according to the direction of the electric field and the charge of the protein to be extracted. The separation membrane is selected based on the charge and molecular weight of the mixture to be fractionated. Since the characteristics of this membrane determine the selectivity and flux of EDFM, the membrane charge, apparent pore radius and electro-osmotic flux have been intensively studied [6,13,19]. However, few works have focused on the effect of the restriction membranes on the EDMF process. The restriction membranes act to conduct electric current and restrict molecules from leaking into the electrode compartments. Their charge and pore size will also influence the transport of ions in the EDFM and are therefore an important consideration.

* Corresponding author.
E-mail address: sandraek@unimelb.edu.au (S.E. Kentish).

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Nomenclature

C	concentration
D	Fickian diffusion coefficient (cm^2/s)
F	Faraday constant (96,485 s A/mol)
I	Current density (A/cm^2)
J	Flux (mol/cm^2 s)
m	Mass of the solution
T	Ion transport number
x	Distance across the membrane (m)
z	Valence
φ	Electrical potential (V)

Subscripts

A	Anion
A′	All anions except the proteins
BSA	Bovine serum albumin
C	Cation
f	Feed
i	Each ionic species
M	Restriction membrane
p	Permeate
SM	Separation membrane

Gel membranes are commonly used as restriction membranes [9,20], where the current is carried by the ions in the electrolyte solution which swells the membrane structure. Neutral materials such as polyacrylamide (PAm) are typically selected for this purpose. The restriction membranes have a tighter structure than separation membranes, which is adjusted by the degree of crosslinking (see Fig. 1(a)). Suitable restriction membranes normally have a molecular weight cut-off just smaller than the molecular weight of the smallest proteins in the mixture to be separated.

Ion-exchange membranes (IEMs) offer an alternative for restriction membranes. They exhibit low resistance to counter-ion migration because of their high charge density. Moreover, the migration of

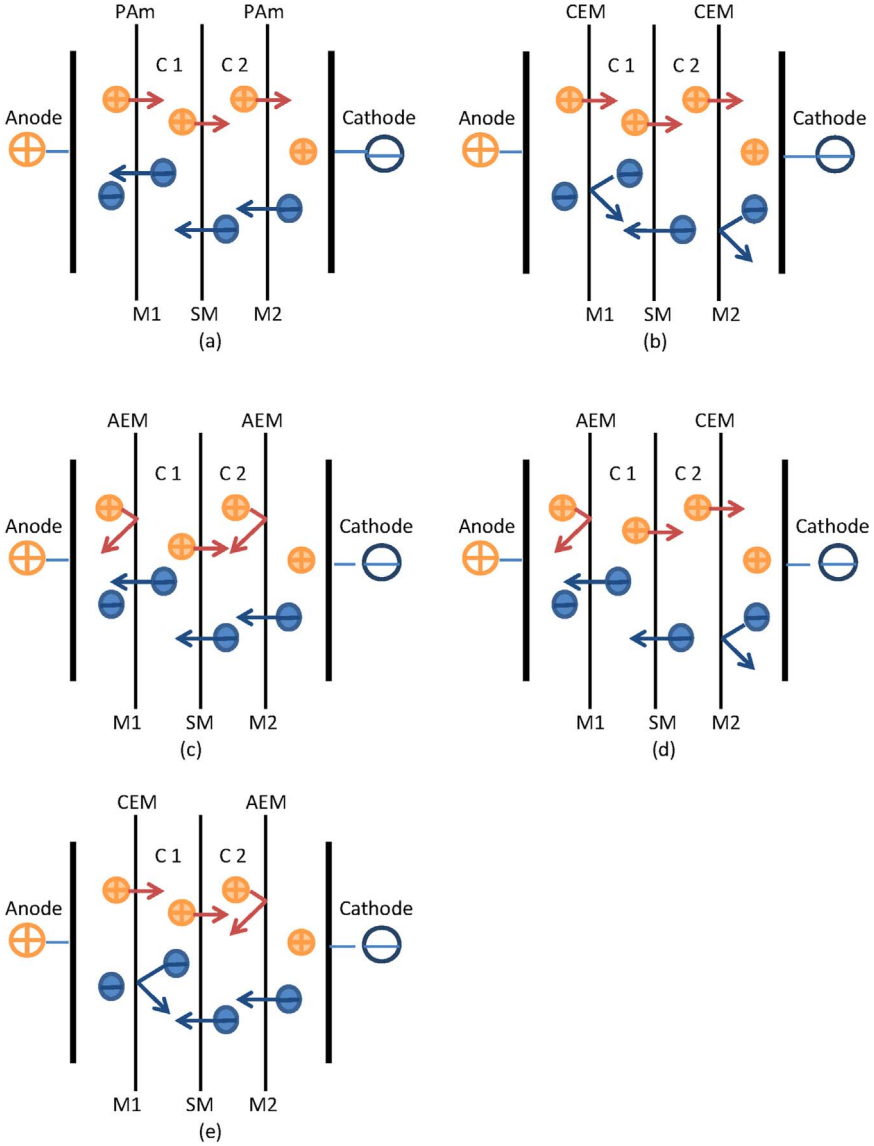

Fig. 1. EDFM configurations with ion-exchange membranes (cation-exchange membranes, CEM or anion-exchange membranes, AEM) or non-charged polyacrylamide (PAm) membranes acting as restriction membranes. SM is the separation membrane, M1 and M2 are the two restriction membranes and C1 and C2 are the two inner compartments used for the feed and permeate solutions. The movement of positively and negatively charged species is indicated by the arrows.