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Investigation of Current Routes in Electrodeionization System Resin Beds During Chromium Removal

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ABSTRACT

The elucidation and quantification of resin bed conductivity during electrodeionization processes facilitate improved cell design and performance. The aim of this project was to identify the current pathways in two types of resin beds and the various ionic forms that are present during chromium removal using a porous-plug model. The first bed consisted of an IRA-67 resin (a gelatinous weak base anion resin) prepared with hydroxyl groups, which resulted in a specific conductivity of $\overline{\kappa}=4.8\times10^{-4}\,\mathrm{S\,cm^{-1}}$. When this anionic resin was conditioned with chloride groups, the value of $\overline{\kappa}$ was $2.98\times10^{-3}\,\mathrm{S\,cm^{-1}}$. Finally, for the mixed bed, which was comprised of IRA-67 and Dowex Mac-3 (a macroporous weak acid cation exchange resin) in a 1:1 ratio, $\overline{\kappa}$ was increased to $0.017\,\mathrm{S\,cm^{-1}}$. Our results showed that mixed-bed resins provide conductivities that are 35-fold higher than those of resins with hydroxyl groups and six-fold higher than those of resins with chloride groups.

1. Introduction

Electrodeionization (EDI) may be considered as a hybrid of electrodialysis and ion-exchange technologies. These combined systems minimize a number of difficulties that are prevalent in present electrodialysis technologies, particularly when the concentrations in the dilute chamber are low, when a polarization concentration phenomenon emerges. In contrast to other membrane technologies, EDI has several advantages in achieving enhanced contaminant removal [1–4], which has facilitated the design of various systems for generating ultrapure water and efficiently removing metal ions.

In EDI processes, polarization concentrations do not appear in the cell due to the activity of the resin, which serves as a permanent ionic conductive medium in the dilute compartment [5]. This asset has enabled the development of a wide range of applications, which is primarily due to high process efficiencies and very low concentrations at the cell outlet [6]. However, despite these benefits, the development of EDI technologies over the last 50 years has been quite slow due to a fundamental lack of understanding of the kinetics involved. In 1959, Glueckauf proposed a mechanism that consists of two steps [7]: a) diffusion, whereby ions move to a solid exchanger, and b) ionic conductivity through the solid, from resins to membranes, where diffusion is the controlling factor, as the ion concentrations may be ~1,000 to 100,000 times lower than the concentrations within the resins [8]. Hence, in the control stage, velocity of diffusion is contingent on several factors: 1) the surface area of the solid, 2) the thickness of the double layer, and 3) the chemical potential gradient between the solid and liquid phases.

Several researchers have attempted to explain the mechanism, and their studies have focused primarily on two phenomena: the ionic conductivity of the resin bed and in situ resin regeneration. Typically, resin bed conductivity is studied using the porous-plug model [9–10], which was created by Wyllie (1955) [11]. This model investigates the packed bed as a conductance element, assuming that current may proceed via three pathways: the interstitial solution, solid, and interstitial solution-solid pathways (Fig. 1a). This model considers the use of empirical parameters that show the ratio of current that crosses each path. In this manner, the electrochemical properties of a resin bed, in terms of the specific conductance, are studied through three conductance elements:

$$\kappa_b = \kappa_1 + \kappa_2 + \kappa_3 \tag{1}$$

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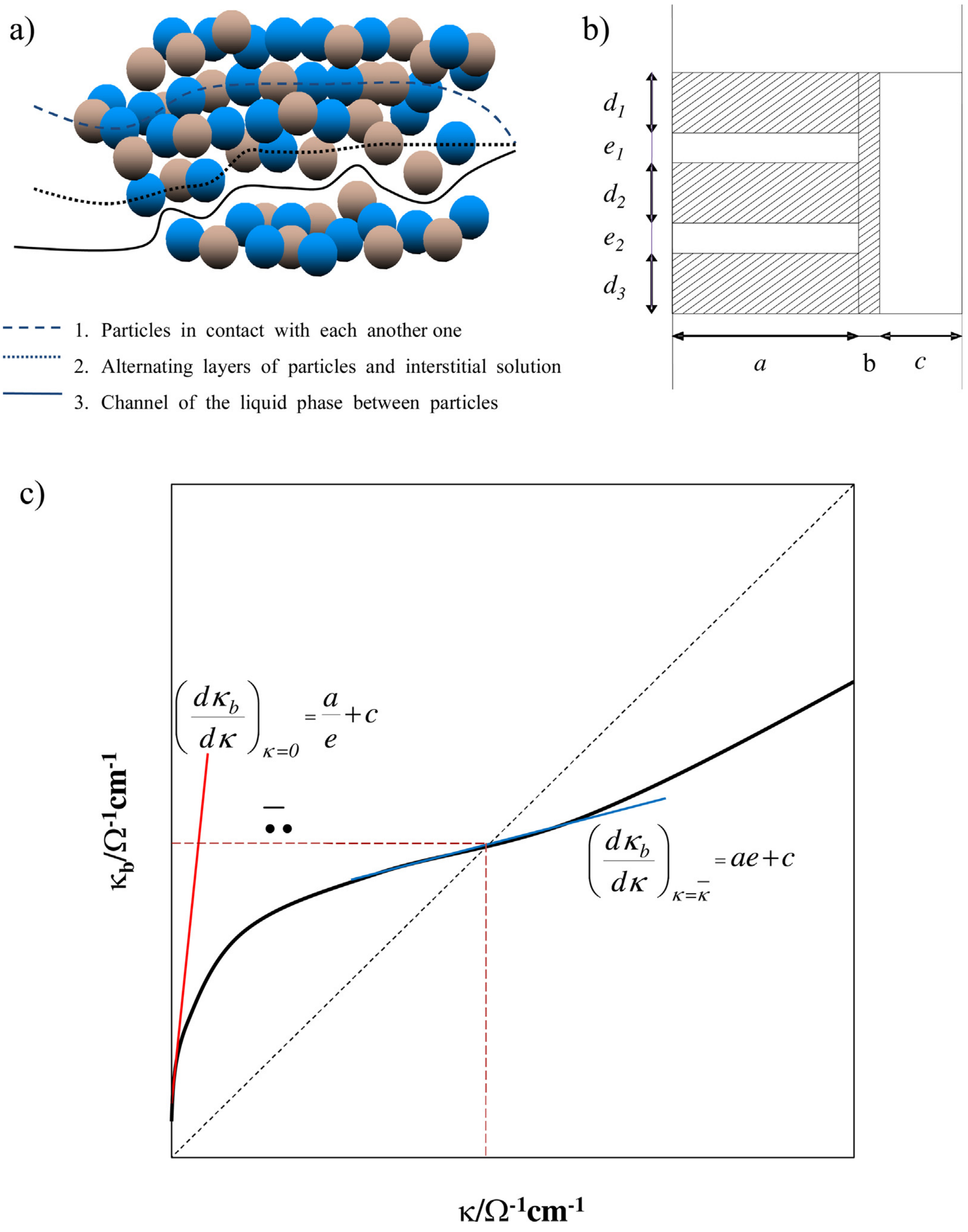

Fig. 1. Porous-plug model a) Current routes through the resin bed, b) Simplified conductive element model, c) Typical plot for obtaining porous plug parameters: specific conductance of the bed, κ_b, versus the specific conductance of the interstitial solution, κ.

where

$$\kappa_1 = \frac{a\kappa\bar{\kappa}}{d\kappa + e\bar{\kappa}} \tag{2}$$

$$\kappa_2 = \mathrm{b}\bar{\kappa} \tag{3}$$

$$\kappa_3 = c\kappa \tag{4}$$

κ_b = Specific conductance of the bed

κ_1 = Contribution of the specific conductance of the solid and interstitial solution path

κ_2 = Contribution of the specific conductance of the solid path

κ_3 = Contribution of the specific conductance of the solution path

κ = Specific conductance of the interstitial solution

$\bar{\kappa}$ = Specific conductance of the resin

a = Fraction of current circulating through the solid and solution path

b = Fraction of current circulating through the solid path

c = Fraction of current circulating through the solution path

d = Fraction of current in the solid-solution path circulating only through the solid phase

e = Fraction of current in the solid-solution path circulating through the liquid phase

The geometric parameters a, b, c,d, and e indicate the fraction of current that circulates through each zone, shown in Fig. 1b, which may be obtained from a plot of the specific conductance of the bed