Electrochemical ion exchange (EIX) is a novel separation process, which has been developed at Harwell over a number of years. Absorption of ions into an EIX electrode is controlled by an externally applied potential. Elution is achieved by simple polarity reversal - no eluant chemicals are required. This enables multiple use of ion exchange capacity. EIX has been demonstrated to absorb cations of Ia, IIA, transition and post-transition metals as well as anions. To date, EIX has mainly been applied to nuclear waste streams. For example, using an inorganic ion exchanger, caesium and cobalt have been selectively removed from sodium- and lithium-bearing feeds respectively. With appropriate ion exchangers, anions such as nitrate, borate, chloride, and sulphate can also be removed by EIX. Other potential applications include removal of heavy metals (e.g. Hg and Cd) from industrial effluents and conventional water softening. This paper gives a summary of the scientific principles involved, as well as details of operating experience.

Introduction

Electrochemical ion exchange (EIX) was first investigated as a process for brackish water desalination. This novel separation process has since been developed at Harwell over a number of years. Absorption of ions into an EIX electrode is controlled by an externally applied potential. Elution is achieved by simple polarity reversal - no eluant chemicals are required. This enables multiple use of ion exchange capacity by repeated absorption/elution cycles (> 2000 cycles over 2 years in one case). As the process is controlled electrically, EIX has many new and desirable features compared to conventional ion exchange.
OBJECTIVES

The primary objective has been to remove (radioactive) cations and anions from nuclear waste. Potential non-nuclear applications including water-softening (Ca, Mg removal), industrial effluent processing (Pb, Cd, Hg removal), and precious metal recovery (e.g. Ag, Au).

APPROACH

Principles of EIX

In EIX, a weak acidic or basic ion exchanger is bonded to a mesh electrode by means of an elastomeric binder, for the removal of cations or anions respectively. During the absorption cycle for a cation, the EIX electrode is made cathodic. Electrolysis of water generates a local alkaline environment within the electrode structure:

\[ 2\text{H}_2\text{O} + 2e^- \rightarrow \text{H}_2 + 2\text{OH}^- \]

The hydroxyl ions deprotonate the exchanger, generating active sites:

\[ \text{RCOOH} + \text{OH}^- \rightarrow \text{RCOO}^- + \text{H}_2\text{O} \]

which then undergo exchange:

\[ \text{RCOO}^- + \text{M}^+ \rightarrow \text{RCOOM} \]

The applied potential also induces migration into the ion exchanger, enhancing the kinetics, and enabling high utilization of capacity.

Elution of cations from the EIX electrode is achieved by reversing the polarity. This produces a local acidic environment within the electrode:

\[ 2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4e^- \]

Electrogenerated protons displace metal ions from the weak cation exchanger:

\[ \text{RCOOM} + \text{H}^+ \rightarrow \text{RCOOH} + \text{M}^+ \]

The presence of the electric field gradient enables virtually complete elution.

An equivalent set of reactions is invoked when an anion is absorbed and desorbed within a weak base anion exchanger.

Electrode Manufacture

A simple, reproducible method has been developed for the fabrication of EIX electrodes. A slurry of ion exchanger/binder/solvent is poured onto a metal mesh, contained in a Perspex mould. Solvent evaporation gives a very strong, non-friable electrode (see Figure 1).