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Removal of inorganic trace contaminants by electrodialysis in a remote Australian community

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Abstract

Water provision for developing countries is a critical issue as a vast number of lives are lost annually due to lack of access to safe drinking water. The presence and fate of inorganic trace contaminants is of particular concern. Trace inorganic contaminants have been found in elevated concentrations in drinking waters supplied directly from brackish groundwaters in developing countries. Desalination and the removal of trace inorganic contaminants from bore water sources from a remote community in Australia using electrodialysis (ED) were investigated. The influence of applied voltage on the removal of the trace contaminants was evaluated. While the results from this study demonstrated that ED is an effectual method for the removal of total dissolved solids and a number of trace inorganic contaminants from brackish groundwaters to below drinking water guideline levels, the deposition of trace contaminants on the membranes (fouling) influenced the ED process in relation to ionic flux and the effectiveness of trace contaminant removal.

Keywords: Electrodialysis; Brackish groundwater; Inorganic trace contaminant removal; Desalination

1. Introduction

Water provision in remote communities is a serious problem globally, as a vast number of lives are lost annually due to lack of access to potable drinking water [1]. In Australia, approximately 67% of indigenous communities with a population less than 100 people use bore water for their supply [2]. In these remote communities, drinking water is generally sourced from groundwater bores of varying quality, with salinity and hardness being widespread issues. Health issues related to salinity range from dehydration (as a result of reduced water consumption) to kidney dysfunction and hypertension [3,4]. While there are no drinking water guideline values for calcium (Ca^{2+}) and magnesium (Mg^{2+}), high levels of hardness can reduce the palatability of water and also cause water distribution pipes to block. High salt concentrations and hardness are however not the only issues facing remote communities.

The occurrence and fate of inorganic (mineral origin) trace contaminants in surface, brackish and groundwaters are also of considerable concern with

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regards to public health and the environment. While a number of compounds occur naturally within groundwaters, the concentration of these compounds at elevated levels and the consumption of drinking water supplied from contaminated groundwater can lead to significant health issues. The bore water investigated in this study contains a number of trace contaminants such as bromide (Br^-), Ca^{2+}, fluoride (F^-), Mg^{2+}, sodium (Na^+), strontium (Sr^{2+}) and zinc (Zn^{2+}). A number of these contaminants were above drinking water guidelines.

Br^- is naturally present in raw water, especially in groundwater and surface water in coastal regions, as Br^- salts or as organic bromine substances [5]. Br^- is generally considered non-toxic at concentrations found in most drinking water sources; however, when water containing high levels of Br^- are treated by ozonation, bromate species are formed, which are highly toxic for human health [6].

In developing countries such as Morocco, F^- concentrations up to 20 mg/L have been found in groundwaters [7,8], while the maximum acceptable concentration level is 1.5 mg/L [1]. The detrimental effects of excess concentrations of F^- on teeth and the skeletal system (dental and skeletal fluorosis) is prevalent [9]. Sr^{2+} minerals are widely distributed throughout the earth and are released to the groundwater by the weathering of rocks and soils. High concentrations of Sr^{2+} in groundwater of up to 53 mg/L have been reported in certain parts of Denmark [10].

Sr^{2+} has relatively low toxicity but continued exposure may have adverse health effects. Studies have however have shown that the ingestion of higher levels of Sr^{2+} in drinking water prenatally may have a protective effect against caries [11]. There is also no guideline value established for Sr^{2+}.

Zn^{2+} concentrations are usually low in drinking water, compared to the WHO guideline value of 3 mg/L [1]. Significant anthropogenic influences have led to increases in the bioavailability of Zn^{2+} in the environment. Ingestion of enhanced Zn^{2+} can cause memory impairments and copper deficiencies [12]. Elevated concentrations of Zn^{2+} have also been linked to Alzheimer's disease [13].

The importance of membrane processes, such as electrodialysis (ED), for treatment of drinking water is a continuously growing field. ED has been used for a wide range of applications including desalination, the production of potable water from brackish water [14,15], seawater [16,17] and industrial wastewater [18,19] and numerous other applications. The fouling of ion-exchange membranes is the main problem of electromembrane technologies. Fouling manifests itself as an increase in the electrical resistance, a decrease in the selectivity of the ion-exchange membrane and a decline in the flux of ions [20]. Scaling is the precipitation of crystalline divalent and trivalent ion hydroxides such as $CaCO_3$, $MgCO_3$, $Mg(OH)_2$ and $CaSO_4$ on the concentrate of the cation-exchange, and to a lesser extent on the anion-exchange membranes [21,22]. The build-up of a scalant layer on the ion-exchange membranes leads to an increase in stack resistance, which in turn reduces the effectiveness of the ED process and leads to a decrease in membrane integrity [20].

The aim of this study is the evaluation of ED for desalination and the removal of selected inorganic trace contaminants from a brackish groundwater sourced from a remote Australian community. The focus of this study was the influence of applied voltage.

2. Materials and methods

2.1. Electrodialysis system characteristics

The ED stack used was a BEL-500 unit (Berghof, Germany) with seven Neosepta CMX-SB cation-exchange membranes (CEMs) and six Neosepta AMX-SB anion-exchange membranes (AEMs) (supplied by Eurodia, Germany; manufactured by Tokuyama Soda Ltd., Tokyo, Japan) providing for each an available membrane area of 58 cm^2. The ED stack was connected to a DC electric potential (GW Instek DC Power supply Model GPR-1810HD, Taiwan) through TiO_2-coated titanium electrodes. The layout of the ED system used in the experiments is shown in Fig. 1. The setup consisted of three separate solution containers for the diluate (4 L), for the concentrate (4 L) and for the electrode rinse (2 L), which were recirculated by three peristaltic pumps.

2.2. Bore water location and characteristics

The ED experiments were performed with bore water (bore number RN13693) sourced from Pine Hill