Ions Flow Dynamics Research using Fast Magnetic Resonance Imaging Method

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Abstract. Ions flow is known physical phenomenon used for capacitive deionization concentration characterization, for electrical impedance tomography, for ion exchange and demineralization and cells electrolysis. In general, the cited methods are oriented to static presentation of the ions flow. The goal of this paper is to demonstrate ions flow in water solution using magnetic resonance imaging method. Fast magnetic resonance imaging resonance method of the ions flow between 2 silver electrodes connected to the DC battery allows to see particular pictures or video dynamics of movement of ions in the water solution.

Keywords: Ions flow, Migration process, Water solution, Magnetic Resonance Imaging

1. Introduction

Ions exchange and ions flow are used extensively in water and wastewater treatment. Ion exchange is primarily used for the removal of hardness ions, such as magnesium and calcium, and for water demineralization, [1]. In an electrochemical cell, a spontaneous chemical reaction produces an electric current. In an electrolytic cell, the reverse process takes place. The passage of an electric current through an electrolytic solution causes a chemical reaction. This process is known as electrolysis, [2]. Experiments were carried out for characterization of capacitive deionization concentration profiles for small volume sample-preparation. A voltage is applied over two porous carbon electrodes resulting in ions moving from and to the electrodes, [3]. Acceleration of salt ions transport caused by external electric field using a plastic container was experimentally tested. During a migration test, the flux of ions is given by the simplified Nernst-Planck equation where concentration is assumed to be equal to the activity of the ionic species [4]. Preparation and application of electrodes in capacitive deionization is a novel ion removal technology that uses static electrical force to drive ions to the charged electrode and stores the ions into porous structure of the electrode, [5]. Measurement of ion diffusion, by magnetic resonance electrical impedance tomography, is using magnetic flux density measured by MRI, [6] and [7].

The above mention methods are describing the ions distribution only in a static way, without dynamics and actual physical reality.

2. Subject and Methods

For investigation of the ions flow dynamics, using magnetic resonance imaging, an experimental measurement arrangement was used, Fig. 1. A glass container, dimensions 90x90x90 mm, filled with watery solution of the copper sulfate as a salt of copper was used. Two silver electrodes (length 60 mm, thickness 5 mm) were vertically inserted to the water solution.

Watery solution of the copper sulfate as a salt of copper is described as:

 $CuO + H_2SO_4 \longrightarrow CuSO_4 + H_2O_7$

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molecular weight: 159.602 g/mol, 1% concentration of solution was used. This solution is generally utilized for MRI phantoms. Temperature of the solution during the measurement was 24^{0} C, pH = 6.35. The concentration of the solution was chosen in respect with the speed ions movement and capability of the imaging sequence. Increasing the concentration, the process of ions flow speed is increasing and vice versa.

b)





Fig. 1. a) A glass container, filled with watery solution of the copper sulfate. b) Measuring vessel with silver electrodes placed into the radiofrequency coil of the magnetic resonance imager.

Magnetic resonance imaging was realized on the ESAOTE 0.2 Tesla imager. Because the ions flow speed is relatively high, the fast scan – Scout (TE = 16 ms; TR = 23 ms; slice thickness = 10 mm; matrix 128x128; FOV = 120 mm) in 2 imaging planes was used: vertical and horizontal. Resultant images were saved as a movie, 32 pictures in 60 second. After imaging, the pictures were evaluated separately. For the next measurement, about 20 second relaxation time was needed, return to the initial position of ions.

The following tables show selected images of ions flow measured every 10 seconds. The electrical parameters for the electrodes were: 4 V/11.7 mA, 5 V/17.1 mA, 6 V/22.2 mA.



Table 1.Vertical imaging of ions flow in [z, y] plane. Fast scan – Scout.



Table 2Horizontal imaging of ions flow in [x, y] plane. Fast scan – Scout.

From obtained video using MRI, images were extracted in each 10 seconds from the 32 scanned images. In each image, orthogonal slice to the electrodes in same position was made and values of pixels intensity in grayscale were obtained, Fig 2.



Fig. 2. a) For illustration of the horizontal imaging plane data, vertical image of electrodes supplied by 6 V voltage was selected. b) Graphical interpretation of the horizontal imaging plane data.

3. Results and Conclusions

The goal of this study was an investigation of the ions flow dynamics using magnetic resonance imaging method. A glass container, filled with watery solution of the copper sulfate and two silver electrodes were used as subjects of experimental research. The concentration of the solution was chosen in respect with the speed ions movement and capability of the imaging sequence.

Ions flow change is relatively rapid physical phenomenon, that is why the fast scan was used in 2 imaging planes: vertical and horizontal. Resultant images were saved as a movie, 32 pictures in 60 second. After imaging the pictures were evaluated separately. The paper presents selected images, every 10 seconds detected by different voltages connected to the silver electrodes.

Dynamic sequences of resultant images are surprisingly interesting and altogether different with published static pictures generated by MRI methods.

Naturally, this is a first step of research experiments in the field of real-time dynamics of flow of ions. The next research will be oriented to the investigation of another kinds of electrodes (flat, circular, point), different materials of electrodes (carbon, copper, gold), using different water solutions, using an extended scale of voltages. The dynamic pictures could be different using higher magnetic field of the MRI magnet and using sophisticated fast imaging sequences with quantitative interpretation of magnetization dephasing, different relaxation times and data evaluation.

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