INFLUENCE OF THE ELECTRIC FIELD ON MIGRATION OF THE IRON NANOPARTICLES

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Abstract
The application of the electric field for supporting the migration of the iron nanoparticles through the ground is relatively new idea, which was studied for the first time by A. Adamse in his dissertation thesis (2006) with quite inconsistent results. If the electric field is applied to the underground, several mechanisms can be involved in it. These mechanisms (electroosmosis, electrophoresis, electromigration and electrolysis) can affect the migration of the iron nanoparticles and except that it can afford other positives. For example increasing in efficiency of the contamination dissociation and releasing of contaminant allocated in the ground pores to groundwater. There will be presented results of the laboratory columns tests on the poster focused on testing the influence of the electric field on migration of the iron nanoparticles in the sandy ground.

Keywords: nanoiron, migration, electric field

1. INTRODUCTION
The positive influence of the electric field on migration of the iron nanoparticles through the ground was studied for the first time by A. Adams [1]. If the electric field is applied to the underground, several mechanisms can be involved in it.

1.1 Electroosmosis
The electroosmotic flow (EOF) is caused by ionization of silanoll groups species on the inner side of capillary (if pH>7). As the consequence of these ionization has the inner side of capillary negative charge, which attracts cations from the solution and they can migrate towards cathode. Because the capillary has small size, anions are taken with cations towards cathode too (if the mobility of EOF is bigger than anions mobility) [2]. This process can help to remove the contamination from the ground pores to groundwater, where it can be decomposed more effectively by reactions with nanoiron.

The resultant flow $Q$ as the consequence of electroosmosis is described by equation:

$$Q = k_e \Delta E A$$

where $k_e$ is coefficient of electro-osmotic conduction, $\Delta E$ is applied gradient of voltage, and $A$ is surface of cross section.

1.2 Electrophoresis
The migration of colloids and macromolecules induced by the electric field is called electrophoresis. These principles are used with separation methods to divide agents with different mobility in direct electric field, where charged molecules (ions) with different electrophoretic mobility are separated. If the separation proceeds in capillary, the electroosmosis has impact too [4]. Generally is very complicated to define the influence of electrophoresis to the nanoiron migration, thanks to nanoiron´s varied particle size distribution and surface charge.

The force $F_e$ affected the charged particle is described by equation:

$$F_e = q \times E$$

where $q$ is particle charge and $E$ is intensity of electric field [1].
1.3 Electromigration

The electromigration means the motion of agents with nonzero charge (e.g., $\text{Fe}^{2+}$ or OH⁻) towards electrode with opposite charge. The resultant flow $J_m$ is described by equation:

$$J_m = u_i^* \times c_i \times \nabla(-E)$$

where $u_i^*$ is effective ions mobility, $c_i$ is molar ions concentration and $E$ is electric potential [1].

1.4 Electrolysis

Electrolysis means the physical-chemically process induced by the flow of the electric current through liquid with chemical changes on electrodes. The electro conductive liquid contains mix of positive and negative ions created by the electrochemical dissociation. The positive and negative ions migrate towards negative (resp. positive) electrode and chemical reactions between ions-electrode, ions-ions and ions-liquid there happen.

2. LABORATORY TESTS AND RESULTS

In the first stage of tests, focused on study of electrokinetic’s influence on migration of the nanoiron, were carried out the static experiments, which can prove the functionality of this method. The horizontal oriented glass cylinder was used with electrodes on both ends connected to the electric DC source.

The water suspension with dispersed nanorion with concentration 54 mg/l was applied to the cylinder (retrospectively confirm by measuring on ICP-OES). To increase the electric conductivity of water was dissolved the NaCl (final concentration 0.5 g/l). Results of these tests were used to design the optimal column test.

**Fig. 1** Static laboratory experiment.

Static tests prove partial migration of nanorion towards positive electrode. However the influence of electrokinetics on migration of nanorion was not so dominant to prevent from noticeably reduce the sedimentation at vertical oriented cylinder with positive electrode at upward.

The column experiments with ground were realized at next stage of laboratory tests. Vertically oriented glass cylinder filled by ground with flow of the water against gravity there was used [4]. Electrodes were placed at the ends of column. Ground environment was simulated by silicic sand (effective porosity 39%, filtration coefficient $1 \times 10^{-3}$ m/s), gravel filter was used at the bottom of the column (high 3 cm). The nanorion suspension was applied continually by peristaltic pump. Samples of output water for measuring of nanorion concentration were taken during the test. Block scheme of the experimental setup is described on **Fig. 2**.

**Fig. 2** Block scheme of column test.

Two tests with short columns (length 10 cm) were performed at the first step to prove the influence of the electrokinetics mechanism on migration of the nanoiron at a flow column set up: column K1 – without electric current; column K2 – with direct electric current (positive electrode was placed on the top of the column to accelerating the migration of the nanoiron). Parameters of these tests are in **Tab. 1**. The main criterion was the visual observation of the nanoiron migration through columns. Approximately two times more rapid
migration of the nanoiron was observed when the electric current was applied and the measuring of total iron concentration in output water confirmed this observation.

**Table 1** Parameters of column tests 1 and 2.

<table>
<thead>
<tr>
<th>Column identification</th>
<th>DC source (V/mA)</th>
<th>Column length (cm)</th>
<th>Pore volume (ml)</th>
<th>Nanoiron batching time (min)</th>
<th>Flow (ml/min)</th>
<th>Fe&lt;sub&gt;in&lt;/sub&gt; (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>0</td>
<td>10</td>
<td>316</td>
<td>126</td>
<td>75,7</td>
<td>28</td>
</tr>
<tr>
<td>K2</td>
<td>10V/2,6mA</td>
<td>10</td>
<td>285</td>
<td>63</td>
<td>75,7</td>
<td>65</td>
</tr>
</tbody>
</table>

Similar configuration for next column tests was done with longer glass cylinder (34 cm) and the change of electrodes polarity to migration of the nanoiron was tested. In column K5 the positive electrode was used in the bottom of column to reduce the migration of the nanoiron (positive electrode could attract the nanorion with negative surface). In column K6 the electrodes was connected reversely with the positive electrode at the top of the column. Parameters of these tests are in **Tab. 2**. Graphs of total iron concentration in output columns water and distribution of iron in ground are in **Fig. 3**. Total balance of injected nanoiron is in **Tab. 3**.

**Table 2** Parameters of column tests 5 and 6.

<table>
<thead>
<tr>
<th>Column identification</th>
<th>DC source (V/mA)</th>
<th>Column length (cm)</th>
<th>Electrodes polarity upper/bottom</th>
<th>Pore volume (ml)</th>
<th>Nanoiron batching time (min)</th>
<th>Flow (ml/min)</th>
<th>Fe&lt;sub&gt;in&lt;/sub&gt; (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K5</td>
<td>30V/7,6mA</td>
<td>28,8</td>
<td>- / +</td>
<td>720</td>
<td>251</td>
<td>73,3</td>
<td>578</td>
</tr>
<tr>
<td>K6</td>
<td>30V/7mA</td>
<td>29,3</td>
<td>+ / -</td>
<td>665</td>
<td>243</td>
<td>74,4</td>
<td>344</td>
</tr>
</tbody>
</table>

**Fig. 3** Comparison of column tests 5 and 6: normalize concentration of total iron in output water.

**Table 3** Comparison of column tests 5 and 6: balance of nanoiron.

<table>
<thead>
<tr>
<th>Column identification</th>
<th>Amount of injected nanoiron (g)</th>
<th>Nanoiron in column ground (g)</th>
<th>Nanoiron in output water (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K5</td>
<td>10,4</td>
<td>10,38 (99,8%)</td>
<td>0,02 (0,2%)</td>
</tr>
<tr>
<td>K6</td>
<td>6,2</td>
<td>4,9 (79%)</td>
<td>1,3 (21%)</td>
</tr>
</tbody>
</table>
3. SUMMARY

At the first stage of laboratory tests were performed experiments in static configuration which proved partial migration of the nanofluid towards positive electrode. However, the influence of electrokinetics was not so dominant to prevent from noticeably reduction of the sedimentation at vertical orientated cylinder with positive electrode at upward. The absence of ground in static tests could be responsible for negative results, because without ground there are no capillaries where the electroosmosis processes could happen.

Two experiments with short columns (length 10 cm) were performed at the beginning of column tests with the ground (one column with electric current and one column without). The aim of these experiments was to prove the influence of electrokinetics mechanisms to migration of the nanofluid. Approximately two times...
more rapid migration of the nanoiron was observed when the electric current was applied and the measuring of total iron concentration in output water confirmed this observation.

The influence of changed electrodes polarity on migration of the nanoiron was investigated at the next stage of column tests with longer columns (34 cm) and with higher input concentration of the nanoiron. For column with a positive electrode at the bottom was not observed the migration of nanoiron outside, neither after 25th pore volume. For the next column with reversed polarity (negative electrode at the bottom) the first iron nanoparticles could be observed at 5th pore volume. And at the end of the experiment (for 28th pore volume) the output concentration of nanoiron was on 55% of input concentration.

Applied iron nanoparticles had negative charge of surface, so the negative electrode at the input of column caused repulsion from the electrode’s surface which decreased the tendency of the nanoiron to the sediment. At the reversed polarity nanoparticles were attracted and their migration was decelerated.

Results of laboratory tests prove positive effect of the electric field to improve the aggregation stability of the nanoiron to increase their migration in ground.

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LITERATURE