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The hydraulic conductivity of bentonites treated with sodium carboxymethyl cellulose

Halyna Zadvernyuk
(The Institute of Environmental Geochemistry of National Academy of Sciences of Ukraine, Kyiv, Ukraine)

Abstract:
Background: *Bentonite is often used as the main component of engineering barriers to isolate toxic substances and prevent pollutant migration. However, long-term exposure to bentonite to contaminants can significantly deteriorate its isolating properties. Therefore, the clays are modified to overcome the problem. One of the most promising materials is bentonite modified with polymer.*

Materials and Methods: *One of the main characteristics of barrier materials is hydraulic conductivity. Sets of hydraulic conductivity tests were conducted to evaluate the influence of polymer treatment and prehydration on the hydraulic conductivity of bentonites. The tests were conducted in flexible wall permeameter on samples confined by an effective stress* σ *=16 kPa and with initial porosity n=0.70. The permeant solutions were deionized water and a 20 mM* $CaCl_2$ *solution.*

Results: *The hydraulic conductivity of bentonites to* $CaCl_2$ *solutions (20 mM) increased due to compress the double layer thickness. The bentonites treated with sodium carboxymethyl cellulose (2% and 5%) had lower hydraulic conductivity than untreated bentonite.*

The hydraulic conductivity of the untreated clay after prehydration increased from k = 7.9E−12 to k = 6.8E−11 m/s (after 100 days). The hydraulic conductivity of the bentonites treated with polymer to $CaCl_2$ *after prehydration decreased slightly, from k = 7.8E−12 m/s to k = 5.3E−12 (after 100 days).*

Conclusion: *Modification of bentonite with sodium carboxymethyl cellulose and prehydration of samples result in decrease in hydraulic conductivity.*

Keys Word: *Bentonite; Sodium carboxymethyl cellulose; Hydraulic conductivity; Prehydration.*

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I. Introduction

Bentonite is widely used in different industries but also for environmental protection. Due to its high sorption capacity, it can be applied as an adsorbent of hazards and oil spills to remove from the water surface [1]. One of principal applications of clay is engineering barriers for landfills, underground landfills for toxic waste [2], and high-level waste repositories [3] to isolate the contaminants from the surrounding environment and prevent pollutant migration. The requirements for mineral barriers as the main component of traditional sealing systems are their low hydraulic conductivity, long-term compatibility with the chemicals to be contained, high sorption capacity, and low diffusion coefficient [4]. The experiment has shown that bentonite has a high sorption capacity [5]. One of main characteristics of mineral barriers is hydraulic conductivity. Because of its low hydraulic conductivity, bentonite is used to isolate pollutants. However, long-term exposure to contaminants in the clay can essentially increase its hydraulic conductivity [6], which causes damage to the environment and human health. Clays are modified to overcome this problem. A wide range of modified clays is proposed: organoclays, multiswellable bentonites, trisoplast, HYPER clay, dense prehydrated geosynthetic clay liners, bentonite polymer nanocomposite, etc. Their advantages and drawbacks are discussed in the paper [7]. Bentonites treated with anionic polymer are one of the most promising materials for barrier applications.

The aim of this study was to investigate the influence of polymer treatment and prehydration on the hydraulic performance of bentonite to electrolyte solutions.

II. Materials and Methods

The Ca-bentonite of the Cherkasy deposit of bentonite and palygorskite clays (Ukraine) was used for the research. Result of X-ray diffraction show that bentonite consists primarily of montmorillonite (85%) but also contains quartz, feldspars, and calcite.

Sodium carboxymethyl cellulose was applied for the modification.

Deionised water and 20 mM $CaCl_2$ solutions were used to evaluate the hydraulic conductivity of the samples.

The bentonite was modified in the following way: the clay was first activated with sodium carbonate and then mixed with a polymer solution of the appropriate concentration. Bentonite was treated with an amount of polymer equal to 2% and 5% of the dry weight of the clay. After that, the sample was dehydrated in an oven at 105℃ and crushed. The fraction ≤ 100 µm was used in the experiment.

Different tests for the evaluation of hydraulic conductivity are considered in the paper [8]. Usually, the constant head test and the falling head test are applied to measure hydraulic conductivity in a laboratory. The falling head method, described in detail [9], was used for the experiment. The test is commonly used to determine hydraulic conductivity (permeability) of fine-grained soils with intermediate and low permeability, such as clays and silts.

A flexible wall permeameter was used to test the hydraulic conductivity described in ASTM D 5084 [10]. Hydraulic conductivity tests were conducted on thin layers of bentonites prepared with a mass per unit area of 4.5 kg/m2, a dry thickness of 7 mm, and an initial porosity of 0.70 following the procedure described by Jo et al. [11]. The effective stress was 16.0 kPa. The hydraulic gradient was 125. First, the specimens were hydrated with salt solutions (non-prehydrated tests) or deionized water (prehydrated tests) for 48 h. After 48 h, the hydraulic gradient was applied by opening the effluent valve.

III. Results and Discussion

According with [13], the low hydraulic conductivity of bentonites is due to adsorbed water molecules and hydrated ions in the interlayer of bentonites that restrict the pore space available for the flow. The thickness of the adsorbed layer is inversely related to the ions concentration and valence. The clays are sensitive to changes in the composition of the pore fluid. In particular, electrolyte solutions with high ion concentration and valence cause the collapse of the thickness of the diffuse double layer and, therefore, an increase in hydraulic conductivity.

As expected, the hydraulic conductivity of untreated bentonite to the 20 mM $CaCl_2$ solution was higher than of deionized water. The hydraulic conductivity to deionized water was k = 6.24E−12 m/s after 100 days of permeation), whereas the hydraulic conductivity to $CaCl_2$ was k = 4.56E−11 m/s (after 100 days of permeation).

The obtained results demonstrate that polymer addition decreases the hydraulic conductivity of the clay (Fig. 1). The hydraulic conductivity of the untreated clay to the 20 mM $CaCl_2$ solution was k=4.56E−11 m/s (after 100 days of permeation), whereas the hydraulic conductivity of the (clay + 2% Na-CMC) was k = 2.45E−11 m/s (after 100 days). Hydraulic conductivity to the $CaCl_2$ solutions (20 mM) decreased with increasing polymer dosage up to 5% Na-CMC. The hydraulic conductivity of the clay treated with 5% Na-CMC was k=9.48E−12 m/s after 100 days. These results were in good agreement with the research [13].

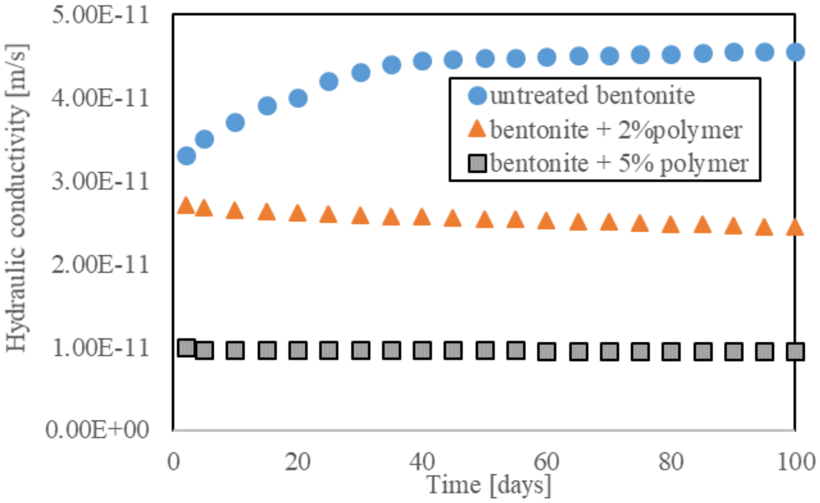

Figure 1. Hydraulic conductivity of untreated bentonite, bentonite + 2% polymer and bentonite +5% polymer to the $CaCl_2$ solution.

Effect of prehydration on hydraulic conductivity of untreated bentonite and polymer treated clays is illustrated in the Fig. 2. The hydraulic conductivity to deionized water of the natural clay and the polymer treated clay were k = 7.9E−12 m/s and k = 7.8E−12 m/s, respectively. The hydraulic conductivity to water was not influenced by the presence of the polymer.

The hydraulic conductivity of the untreated clay after prehydration increased from k = 7.9E−12 to k = 6.8E−11 m/s. The hydraulic conductivity of the polymer treated clay to $CaCl_2$ after prehydration decreased slightly, from k = 7.8E−12 m/s to k = 5.3E−12.

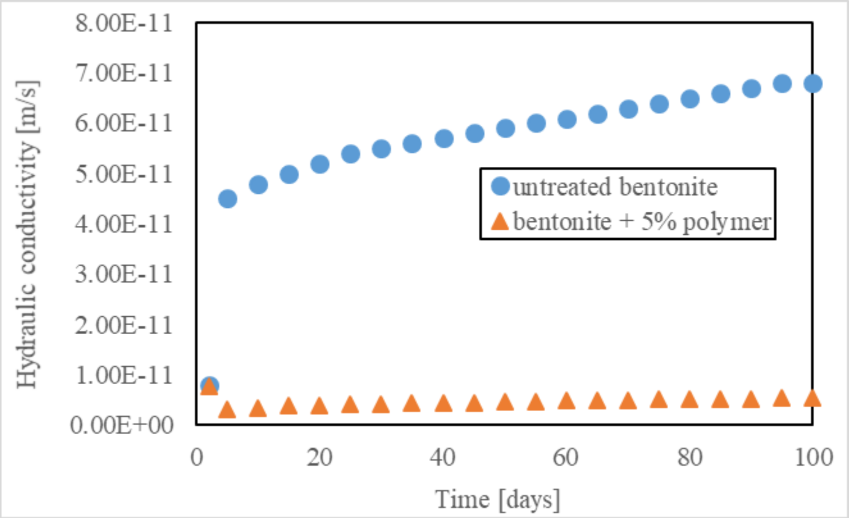

Figure 2. Hydraulic conductivity of untreated bentonite and polymer treated bentonite after prehydration (48 hours).

IV. Conclusions

The hydraulic conductivity of untreated bentonite to $CaCl_2$ solutions was higher than to deionized water. It can be explained by the fact that the Ca^{2+}ions, entering the interlayer between bentonite platelets, compress the double layer thickness.

Treatment of the clay with polymer causes decreases in hydraulic conductivity to the $CaCl_2$ compared to untreated clay. A lower value hydraulic conductivity has clays treated with higher polymer concentrations.

Sample prehydration causes an increase in the hydraulic conductivity of untreated clay to $CaCl_2$ solutions and a decrease in the hydraulic conductivity of polymer treated clay.

Obtained results illustrate advances in characteristics of bentonites treated with sodium carboxymethyl cellulose comparing with untreated clays for improving their insulating properties, particularly hydraulic conductivity. It would be interesting to investigate the long-term barrier performance of the polymer treated bentonites.

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