Reuse of dredged sediments for hydraulic barriers: adsorption and hydraulic conductivity improvement through polymers

La réutilisation des sédiments dragués pour barrières hydrauliques: l'adsorption et l'amélioration de la conductivité hydraulique avec des polymères

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ABSTRACT: Environmental management and handling of dredged sediments is important worldwide, as enormous amounts of dredged material emerge from maintenance, construction and remedial works within water systems. Usually these materials, after temporary upland disposal in lagoons, are disposed in landfills. The aim of this study is to analyse the possible reuse of these sediments as a low-cost alternative material for landfill covers. The mechanisms through which polymers can improve the efficiency of dredged sediments for waste containment impermeable barriers were investigated. An anionic polymer was adsorbed to the surface of a dredged sediment. Hydraulic conductivity and batch sorption tests were executed to study the barrier performance and the transport parameters of this treated soil. Polymer treatment maintained low hydraulic conductivity of the soil to electrolyte solutions in the long term. The polymer treatment helped the soil to retain the spread of pollution.

RÉSUMÉ: La gestion de l'environnement et des sédiments dragués est important partout, parce que énormes quantités de matériaux de dragage sortent de l'entretien, la construction et les travaux de réparation dans les systèmes d'eau. Habituellement, ces matériaux, après le stockage dans les lagunes temporaires, sont déplacé dans les décharges. Le but de cette étude est d'analyser la possibilité de réutiliser ces sédiments en tant que matériau alternative à faible coût pour les couvertures d'enfouissement. Les mécanismes par lesquels les polymères peuvent améliorer l'efficacité des sédiments dragués pour les barrières de confinement des déchets imperméables ont été examiné. Un polymère anionique a été adsorbé à la surface des sédiments de dragage. Des essais de conductivité hydraulique et de sorption ont été exécutés pour étudier la performance de barrière et les propriétés de transport de cette terre traitée. Le traitement de polymère maintient une faible conductivité hydraulique du sol à le solutions électrolyte à long terme. Le traitement polymère contribué à résister la propagation de la pollution dans le sol.

KEYWORDS: reuse of dredged sediments, polymer treatment, low permeable hydraulic barriers.

1 INTRODUCTION

Soil contamination by heavy metals has been a long-term and worldwide environmental problem generated by anthropogenic activities of the past several decades. Heavy metals present in soils could find their way into human and animal populations through direct exposure or food chain/web, posing a serious risk to human health (Garcia-Sanchez et al. 1999; Gao et al. 2003; Ling et al. 2007). Heavy metals may be retained in clay soils by several soil phases or mechanisms, such as exchangeable, carbonate, hydroxide and organic phases (Griffin et al. 1976; Plassard et al. 2000; Sharma and Reddy 2004). The factors affecting the sorption of contaminants in soils are: (1) contaminant characteristics, such as water solubility, polar-ionic character, octanol-water partition coefficient; (2) soil characteristics such as mineralogy, permeability, porosity, texture, homogeneity, organic carbon content, surface charge, and surface area; and (3) fluid media characteristics, such as pH, salt content, dissolved carbon content.

Landfill sites for both chemical and industrial waste might be a serious threat for the environment, when not properly designed. To avoid pollution of the ground and groundwater, landfill sites are sealed with compacted clay liners (CCLs), geomembranes and Geosynthetic Clay Liners (GCLs). Suitable barriers must have a low permeability. To meet this property, the soil contained in CCLs and GCLs must fulfill some well-known physical and hydraulic criteria (Daniel 1993, Mitchell 1993).

Next to standard CCL and GCLs, there are emerging innovative barrier materials and systems, more efficient and/or less costly. Alternative evapotranspirative barriers (Malusis and Benson, 2006, Zornberg and McCartney 2010, Kison et al. 2012) or alternative barrier materials (such as, among others, paper sludge (Rajasekaran et al. 2000) dredged sediments (Di Emidio et al. 2006) can be necessary when: (1) high costs are associated with prescriptive materials and methods, (2) prescribed materials are not readily available, (Shackelford, 2005) and (3) when alternative materials are available in large quantities. In this regard, Di Emidio et al. (2006) studied the suitability of dredged materials to be used as alternative cover liner material for landfills. Different dredged materials were analyzed by means of laboratory tests, focusing on physical properties and hydraulic conductivity performance. As a result, acceptable zones (Daniel, 1993) based on hydraulic conductivity were established. Test results showed suitability of dredged sediments as hydraulic barrier alternative materials. Therefore, the use of dredged materials for cover liners represents an interesting opportunity for the future reuse of non-contaminated dredged materials.

On the other hand, dredged sediments are often polluted with contaminants, such as heavy metals (Singh et al. 2000, Mulligan et al. 2001, Peng et al. 2009). Methods to remove said metals from dredged sediment (Mulligan et al. 2001, Meegoda and Ruvini 2001, Bradl 2005, Peng et al. 2009) might be cumbersome and expensive. Therefore, alternative methods resulting in dredged sediments that retain heavy metals are highly needed.

Mazzieri et al. (2010) compared a polymer amended GCL with a conventional GCL permeated with a synthetic metal-rich acidic solution in order to compare the hydraulic, buffering and contaminant retention properties of the GCL materials. The breakthrough of metals occurred much earlier in the untreated GCL than in the polymer treated GCL, which was able to retain metals more effectively. Further insights are required to better understand the mobility of heavy metals in polymer treated clays and the ability of such clays to retain the heavy metals in the long-term.

This study involves the treatment of kaolin clay (as reference material) and dredged sediments with different percentages of an anionic polymer, Na-CMC (Sodium CarboxyMethyl Cellulose). This treatment is meant to improve their hydraulic performance as a lining material. This paper shows preliminary results (using $MgCl_2$ and sea water as reference solutions) to study the effects on both the hydraulic conductivity and the adsorption characteristics of polymer treated clays, such as kaolin and dredged sediments. The adsorption on polymer treated clays of heavy metals such as Zn, Cu and Pb is currently under investigation.

2 MATERIALS

A commercial processed kaolin Rotoclay® HB (Goonvean, St. Austell, UK) and a dredged sediment (DS) were used in this investigation. The kaolin was chosen as reference material because it has been largely used in previous laboratory research. The dredged sediment was obtained from Kluizendok in Ghent, Belgium. Table 1 shows some properties of the base materials used in this research. Both materials were treated with an anionic polymer, Sodium CarboxyMethylCellulose (Na-CMC) using different polymer dosages (2% and 8%) by dry weight of soil. The treatment consists of pouring a soil in a polymeric solution using a mechanical stirrer. The slurries obtained are then oven dried. After drying, the soils are ground using a mortar grinder (Di Emidio, 2010, 2012).

Deionised water, produced using a water purification system, was used as reference solution. A reference electrolyte compound, $MgCl_2$, was used for preliminary batch sorption tests on the treated and untreated soils. The electrolyte solutions were prepared by dissolving salts in deionised water. Moreover, natural seawater from the North Sea (near Oostende in Belgium) was used as permeant solution for the hydraulic conductivity tests on the treated and untreated soils. Table 2 and 3 show the chemical characteristics of deionized water and seawater.

3 METHODS

3.1 *Batch sorption test*

To study the adsorption of $MgCl_2$ on the treated and untreated soils, batch sorption tests were performed following the ASTM D4646. Different concentrations of $MgCl_2$ were used to prepare the equilibrium solutions for the batch sorption test. The untreated and treated soils were mixed for 24 hours in a rotatory table with $MgCl_2$ solutions of different concentrations (100 mg/l, 600 mg/l, 2000 mg/l, 6000 mg/l), using a soil-to-solution ratio 1:4. Then the slurries were separated by centrifugation. A centrifugation speed of 3000 rpm was sufficient to separate untreated soils from the solution, whereas a centrifugation speed of 10000 rpm was necessary to separate the treated soils from the solution. The sorption isotherms were obtained by plotting the sorbed mass of Mg^{2+} and Cl^- (meq/100g of soil, measured with a Spectroquant Photometer) vs. the equilibrium $MgCl_2$ concentration.

Table 1. Properties of the materials analyzed

Parameter	*kaolin*	*DS*
Type / source	Rotoclay®/Austell	Kluizendok
Specific gravity (-)	2.64	2.75
Liquid Limit (-)	59.0	44.1
Plastic Limit (-)	38.0	27.1
Swell index (ml/2g)	3.71	2.29
Silt content (%)	62.4	49.3
Clay content (%)	35.3	5.0
Sand content (%)	0.0	45.7

Table 2. Chemical analysis of the solutions used

Parameter	*Deionized water*	*Seawater*
EC (mS/cm)	0.0039	49.9
Salinity (-)	0.0	32.4
pH (-)	7.57	7.78
Na^+ (M)	-	0.455
K^+ (M)	-	0.012
Mg^{2+} (M)	-	0.053
Ca^{2+} (M)	-	0.012
Cl^- (M)	-	0.561
SO_4^{2-} (M)	-	0.024
HCO_3^- (M)	-	0.003
CO_3^{2-} (M)	-	0.0003
NO_3^- (M)	-	0.0007

Table 3. Chemical properties of the $MgCl_2$ solutions used for the Batch Sorption test

$MgCl_2$ (mg/L)	*EC (mS/cm)*	*Salinity (-)*	*pH*
100	0.301	0.0	6.87
200	1.382	0.5	7.04
2000	4.16	2.1	7.3
6000	12.13	6.46	7.7

3.2 *Hydraulic conductivity test*

Flexible wall hydraulic conductivity tests were conducted in order to investigate the impact of 8% of polymer addition on the hydraulic performance of the soils to a high concentrated electrolyte solution (natural seawater). The hydraulic conductivity tests were performed with an average effective stress of 30 kPa on 10 cm diameter samples with an initial porosity of about n = 0.718 (kaolin) and n = 0.542 (dredged sediment). To prepare the kaolin samples, the untreated and treated soil were poured dry in a stainless steel ring (0,45g/cm², as a standard GCL, 10 cm diameter) with a fixed height between two porous stones and submerged with seawater, with a sitting weight on top, for about one week. The dredged sediment sample was prepared by standard proctor compaction (ASTM D0698) with a water content two points higher than the optimum, to simulate a Compacted Clay Liner.

4 RESULTS AND DISCUSSION

4.1 *Batch sorption test results*

Figure 1 shows the sorption isotherms of the treated and untreated kaolin (a) and of the treated and untreated dredged sediment (b). The adsorbed mass of ions is plotted here vs. the equilibrium concentration of the $MgCl_2$ solutions. As shown in the graphs, batch sorption test results demonstrate that the sorbed mass of magnesium cations is higher onto the polymer treated soil compared to the untreated soil.

4.2 *Hydraulic conductivity test results*

Figure 2 shows the hydraulic conductivity test results of the treated and untreated soils. As shown in Figure 2.a, the hydraulic conductivity to seawater of the kaolin treated with 8% of the polymer was lower compared to that of the kaolin treated with 2% of the polymer. This result demonstrates that the hydraulic performance of a kaolin clay as barrier increases with increasing polymer dosage.

Figure 2.b shows that the hydraulic conductivity to seawater of the dredged sediment treated with 8% of the polymer is nearly two orders of magnitude lower compared to that of the untreated dredged sediment.

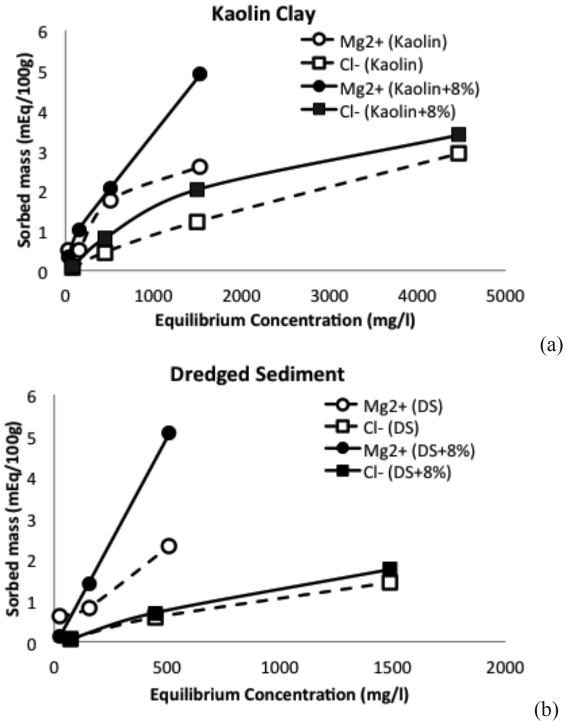

Figure 1. Sorption isotherms of kaolin (a) and dredged sediment, DS (b)

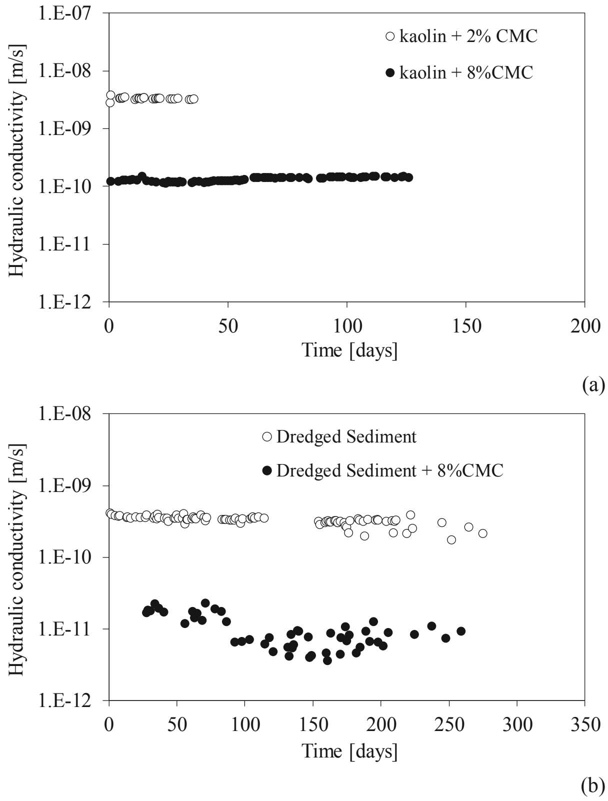

Figure 2. Hydraulic conductivity test results of (a) kaolin clay 2% CMC and 8% CMC, and (b) dredged sediment and dredged sediment treated with 8% CMC, permeated with natural seawater

5 CONCLUSION

The sorption isotherms of Mg^{2+} and Cl^{-} on the treated and untreated kaolin and on the treated and untreated dredged sediment were analyzed. The adsorbed mass of ions was plotted vs. the equilibrium concentrations. Batch sorption test results demonstrated that the sorbed mass of magnesium cations was higher onto the polymer treated soils compared to the untreated soils. These results are promising in view of metals retention in polymer treated dredged sediments. To further demonstrate the higher retention ability of polymer treated clays, the adsorption of heavy metals on kaolin, bentonite and dredged sediments is currently under investigation.

Hydraulic conductivity test results of treated and untreated soils were shown. The hydraulic conductivity to seawater of the kaolin treated with 8% of the polymer was lower compared to that of the kaolin treated with 2% of the polymer. This result demonstrates that the hydraulic performance of a kaolin clay increases (the hydraulic conductivity decreases) with increasing polymer dosage. The hydraulic conductivity to seawater of the dredged sediment treated with 8% of the polymer was significantly lower compared to that of the untreated dredged sediment. These results suggest the possible reuse of dredged sediments as alternative low cost impermeable barrier materials to isolate polluted sites and landfills.

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