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Research paper

Swelling and hydraulic conductivity of bentonites permeated with landfill leachates

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ABSTRACT

This study investigates and discusses the free swell and hydraulic conductivities of bentonites which were gathered from the local companies in Turkey. Total of 26 hydraulic conductivity tests were carried out along the study 12 of which were permeated with deionized (DIW) and tap water (TW) and the rest of them were permeated with landfill leachates (LLs). The free swell volumes of bentonites decreased when the pore fluid type was changed from water to LL. The recorded final swell volumes were within the range of 14.5–27.0 mL/2g in water, whereas 5.0–19.5 mL/2g in LLs. The hydraulic conductivity tests were performed on artificially prepared geosynthetic clay liners (AP-GCLs) which were prepared in the laboratory. The hydraulic conductivities of AP-GCLs were within the range of 5.2×10^{-12} to 3.0×10^{-11} m/s when TW and DIW were used as the permeant. The results also showed that the hydraulic conductivities permeated with LLs were almost the same as with those permeated with DIW or TW. The hydraulic conductivities of AP-GCLs to LLs were within the range of 2.3×10^{-12} to 2.0×10^{-11} m/s. Electrical conductivity and pH measurements were also conducted on influents and effluents along the test duration. The effluent to influent ratio of electrical conductivity was generally less than 1.0 which indicates the continuation of cation exchange process between bentonites and LLs. This conclusion was further approved with the ICP analysis conducted on influent and effluent samples. The exchangeable Ca^{2+} concentrations in the effluents were still less than those in the influents when the tests were terminated. In contrast, Na^+ concentrations in effluent were greater than those of influent, suggesting the fully replacement of cations were not completed at the time of termination. The uncompleted cation exchange process was physically observed by performing free swell tests on post-test samples. The free swell values of bentonites were in between characteristics of the values obtained in water and LLs. It was expected that the hydraulic conductivity of AP-GCLs would increase when LLs are used as the permeant. However, comparable results were measured as with those of water. This is possibly due to the greater effective stress applied during the study which masked the negative influence of cation exchange on the hydraulic conductivity of the AP-GCLs.

1. Introductıon

Geosynthetic clay liners (GCLs) are carpet-like thin materials which are composed of bentonites and geotextiles. In most geoenvironmental applications, GCLs are used for having successful barrier performance.

Bentonites are natural materials that satisfy low hydraulic conductivity to water. The hydraulic conductivity behaviors of bentonites are governed by montmorillonite which are major mineral component of bentonites. Bentonite can swell around ten times of their dry volumes when they are faced with water (Jo et al., 2001; Kolstad et al., 2004; Komine, 2004). Hence, there are little pore spaces available between clay particles for mobile water, resulting low hydraulic conductivity for bentonite (Mitchell and Soga, 2005). However, swelling of bentonite is affected from the pore fluid chemistry. In this case, the thickness of diffuse double layer surrounding the particles decreases and the volume of pore spaces between particles increase, resulting increase in the hydraulic conductivity (Sridharan, 1991; Sivapullaiah et al., 2000).

Researchers put effort into understanding how pore fluid chemistry change the hydraulic conductivity of bentonites, hence GCLs. The studies reported in the literature are categorized into two sections in terms of permeants used during the hydraulic conductivity tests: i) inorganic salt solutions and ii) real waste leachates. In the first category studies, GCLs were permeated with salt solutions that had monovalent cations, divalent cations or both. The influences of solution concentration, cation valence and pH on the hydraulic conductivity of GCLs were investigated. It was found that increase in the cation valence and solution concentration or decrease in the pH resulted in an increase in the hydraulic conductivity of GCLs. In these studies, researchers addressed the relationship between the free swell of bentonites and hydraulic conductivity of GCL as well. That is, the greater the free swell, the lower is the hydraulic conductivity (Petrov et al., 1997; Shackelford et al., 2000; Jo

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et al., 2001; Kolstad et al., 2004; Lee and Shackelford, 2005; Katsumi et al., 2007, 2008; Benson et al., 2010; Di Emidio et al., 2015).

In contrast, complex environment of waste leachates (or landfill leachates) made it difficult to express the hydraulic conductivity results. That is why the second category studies are scarce in the literature when compared to those of the studies conducted on GCLs with inorganic salt solutions (Ruhl and Daniel, 1997; Ashmawy et al., 2002; Shan and Lai, 2002). In these studies, it was concluded that leachate compositions had great influences on the hydraulic conductivities. Thus, it is hard to say a unique tendency for hydraulic conductivity of GCLs when landfill leachates are used as the permeants. On account of technological development and extended knowledge from the previous studies conducted with ionorganic salt solutions, recent studies have reconsidered the hydraulic conductivities of GCLs with real landfill leachates (Katsumi et al., 2007; Guyonnet et al., 2009; Bradshaw and Benson, 2013). However, these studies are still limited and deserved to pay more attention.

The aim of this study is to investigate and discuss the free swell and hydraulic conductivities of six bentonites which are potential candidate for GCL manufacturing. For this purpose, artificial GCLs were prepared in the laboratory by placing the bentonites between geotextiles without needle punching (i.e. fiber free). Then, GCLs were directly permeated with three landfill leachates using flexible-wall permeameters. The hydraulic conductivity results of GCLs are interpreted with the free swell of bentonites as well.

2. Materials and methods

2.1. Materials

2.1.1. Bentonites

This study was conducted with six bentonites. Two bentonites were already available in the laboratory at the time of study. The other four bentonites were supplied from local companies in Turkey (Table 1). Bentonites are commercial products which were either natural or treated. In addition, Bentonite-1 was in clod sized form, whereas others were in the powdered form. To get small particles for Bentonite-1, clods were crushed and sieved from No. 40 sieve (0.425 mm). The particles passing through No. 40 sieve were used for Bentonite-1 in this study. The other bentonites (Bentonite 2–6) were used as obtained. The names of manufacturers and brief information about the bentonites are summarized in Table 1.

2.1.2. Permeants

Free swell and hydraulic conductivity tests were conducted using deionized water (DIW), tap water (TW) and landfill leachates (LLs). Deionized water was collected from Milli-Q Gradient water purification system. Tap water was the natural drinking water of İzmir. LLs were taken from the landfills which are located at the west part of Turkey. All leachates were stored into plastic bags and were kept in refrigerator along the test duration. The cation concentrations (i.e. Na^+, K^+, Mg^{2+}, Ca^{2+}), pH and electrical conductivities of LLs are presented in Table 2.

Table 1
Manufacturers and brief information about bentonites supplied from companies.

Bentonite	Manufacturer	Location	Brief information	Particle form
1	Süd-Chemie	Balıkesir	Na-treated	Granular
2	Karakaya	Ankara	Na-treated	Powdered
3	Eczacıbaşı	İstanbul	Activated	Powdered
4	Eczacıbaşı	İstanbul	Unactivated	Powdered
5	Çanbensan	Çankırı	Na-Ca treated	Powdered
6	Çanbensan	Çankırı	Polymer treated	Powdered

2.2. Methods

2.2.1. Index properties of bentonites

The natural water contents and specific gravities of bentonites were determined in accordance with ASTM:D2216-10, 2010 and ASTM:D854-14, 2014, respectively. To determine the particle size distribution curves of bentonites, wet-sieving method was carried out as specified in ASTM:D422-63, 2007. Consistency limits of bentonites were determined according to ASTM:D4318-05, 2005.

The soil index properties of bentonites are summarized in Table 3. The natural water contents (i.e. air-dried) were within the range of 9–12%, whereas specific gravities were within the range of 2.67–2.76. Based on the particle size distribution curves shown in Fig. 1, bentonites contain negligible amount of sand grains. The fines content of the bentonites were greater than 96%, whereas the clay contents were as low as 31%. The liquid limits of bentonites were in broad range (149–552%). In contrast, plastic limits were between 34% and 48% (Table 3).

2.2.2. Mineralogical analysis of bentonites

The mineralogical compositions of bentonites were determined using an X-ray diffractometer (XRD). The samples were sieved from No. 200 (75 μm) and then oven dried at 60 °C. The XRD patterns were recorded with a GE Seifert 3003-PTS diffractometer using Cu-Kα radiation. The Rietveld method was used to estimate the quantitative amounts of mineral phases in the bentonites. Based on the XRD patterns, the montmorillonite contents of the bentonites were between 61% and 77% (Table 3).

2.2.3. Free swell test

Free swell tests were conducted in DIW and LLs (ASTM:D5890-11, 2011). For this purpose, graduated cylinders were filled with test liquids to 90 mL levels. Then, 2 g bentonites were poured with 0.1 g increments into the graduated cylinders. About 10 min were allowed between the increments for hydrating and swelling the bentonite particles. After all particles were poured, graduated cylinders were filled to the 100 mL level with the same liquids and open ends of all cylinders were covered with parafilm to obstruct evaporation. Then, they were left for swelling. After 24 h of hydration, the final volumes of swollen bentonites were recorded.

2.2.4. Sample preparation for hydraulic conductivity tests

Hydraulic conductivity tests were conducted on artificially prepared GCLs (AP-GCLs). For this purpose, sample diameters were kept rather high (i.e. 15 cm) to accomplish laying homogeneous bentonite layers between geotextiles. The target initial heights and mass per unit areas for the AP-GCLs were 0.6 cm and 0.5 kg/m^2, respectively.

To prepare the sample precisely, the plexiglass base pedestal was dismantled from the permeameter and placed over the balance. Instead of a porous stone, a heavy non-woven geotextile (Drefon S-1000) was placed on the pedestal and a woven carrier geotextile was laid on it. Adequate amount of air-dried bentonite was weighed and poured on the woven geotextile. Then, a non-woven geotextile was placed over the bentonite. After sitting the upper heavy non-woven geotextile, the base pedestal with AP-GCL was slightly removed from the balance. The circumference of the sample was moistened using a squirt bottle. Hence, AP-GCL retained itself without bentonite loss until attaching the base pedestal to the permeameter. Then, the top pedestal was placed over the heavy geotextile. Finally, latex membrane was placed on the AP-GCL and three O-rings were mounted on each pedestals.

2.2.5. Hydraulic conductivity tests

The average effective stress applied during the hydraulic conductivity tests was 90 kPa and the hydraulic gradient was around 200. DIW, TW and three LLs were used as the permeant in the hydraulic conductivity tests. Before commencing the permeation, GCLs were soaked in the permeameter for 48 h with the test liquids (i.e. non-prehydrated).

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