Korean J. Soil Sci. Fert. **40**(1), 71-76(2007)

Article

Swelling Patterns and relevant Hydraulic Conductivities of Na-Bentonite under Various Acidic and Alkali conditions

Doug-Young Chung[1,*], Jae E. Yang[2], Taek-G. Oh[1], and Kyo-S. Lee[1]

[1]*Department of Bioenvironmental Chemistry, College of Agricultural and Life Science, Chungnam National University, Daejeon 305-764, Korea*
[2]*Division of Biological Environment, Kangwon National University, Chuncheon 200-701, Korea*

We investigated the effects of solution pH on swelling characteristics and relevant hydraulic conductivity of different particle sizes of Na-bentonite which have significantly high swelling capacity. The results showed that the time taken to reach the maximum swelling indexes for all pH levels ranged from 84 hours and 156 hours for pH 6.5 or above by NaOH and pH 3.5 by HCl, respectively. The maximum swelling index slightly increased with increasing particle size, while the maximum swelling indexes were less or approximately half of that of the indigenous Na-bentonite. The changes in swelling indexes before and after solution treatment were distinctive in acidic condition, especially in pH 3.5 by HCl while there were not much differences in alkali condition. For hydraulic conductivities of fully swelled Na-bentonite in a given solution pH, elution did not occur under pressure below 1 bar. But elution started as the pressure was raised to 1.5 bars or above after 500 seconds. The stabilized hydraulic conductivities observed from 1.5, 3.0, and 5.0 bars ranged from 7 x 10^{-3} cm day^{-1} to 6 x 10^{-3} cm day^{-1}, indicating that the hydraulic conductivities were slightly higher in acidic condition than that of normal condition.

Key words : Swelling, Hydraulic Conductivities, Na-Bentonite, Acid and Alkali

Introduction

The swelling of smectite aggregate plays an important role in the microstructural evolution of bentonite. Bentonite is widely used as barrier material for waste disposal since bentonite possesses a remarkable swelling due to water absorption and therefore restricts the migration of water and contaminants through it. The origin of the swelling effect of bentonite to reach a fundamental approach to relate swelling potential to basic particle-water-cation interactions has been widely studied by many researchers (Low, 1987; Quirk, 1997). These processes are highly complex and include fluid flow, heat transport, interaction between water/solution and bentonite, as well as mechanical reaction of the bentonite itself (Gens et al., 1998). The swelling process of bentonite results from the change of the microscopic structure of the expandable minerals. Xie et al., (2003) suggested that the swelling potential of bentonite depends not only on the density, moisture change, but also on the mineral characteristics (e.g. specific surface, expandable mineral fraction etc.) and fluid chemical composition.

Bentonite swells and shrinks due to a change in water content, which can lead to cracking of the liner. Subsequently, the liner becomes more permeable. Landfill leachate typically contains water, heavy metals, organic material in various stages of decomposition, and inorganics such as ammonia, sulfate, and metal cations. Organic materials found in landfill leachate are typically volatile fatty acids, and humic and fulvic compounds (Christensen et al., 1994). The volatile fatty acids are mostly found in the acid and methane production phases while the humic and fulvic compounds comprise most of the organics in older, methanogenic leachate (Christensen et al.,1994). Typically, pH values of leachates in landfill where the ammonium ion is most prevalent range from 5 to 8. The ammonium ion is continuously released in leachate until all wastes are degraded (Robinson, 1995).

Hydraulic conductivity of a soil generally depends on electrolyte concentration and the hydraulic conductivity decreases due to swelling and dispersion of soil. Hydraulic conductivity testing, however, may take several months to perform, especially at higher bentonite contents. An alternative approach is to use mathematical

Received : 22 January 2007 Accepted : 15 February 2007
*Corresponding author: Phone : 82428216739,
E-mail : dychung@cnu.ac.kr

models to predict the hydraulic conductivity based on the properties of the sand and the bentonite (Abichou, 1999; Chapuis, 1990). Lee (2002) investigated the effect of humic acid produced from landfill leachate. The results showed that humic acid and electrical conductivity decreased swelling capacity, resulting in increase in hydraulic conductivity. Thus, change in the swelling capacity by pH depending on the waste composition may affect hydraulic conductivity. However, the effect of solution pH on swelling and relative hydraulic conductivity of bentonite has scarcely been investigated. The objective of the present study was to investigate the effect of pH on swelling characteristics and relative hydraulic conductivity of four levels of particle sizes of Na-bentonite.

Materials and Methods

Wyoming Na-bentonite (Table 1) which contains greater than 95 % of smectite was used to measure swelling characteristics and relevant saturated hydraulic conductivity depending on solution pH ranging from 3.5 to 8.5 adjusted with acids (HCl, Phosphoric acid, Citric acid, and Oxalic acid) or alkaline (KOH and NaOH). To measure the swelling indexes(SI) of the bentonite, bentonite samples were sieved and separated into four different sizes of particles (60-80 mesh, 80-100 mesh, 100-120 mesh, and 120 mesh or greater). To measure the SI two grams of each separated bentonite were slowly added into 100 mls of different pH solution in a graduate cylinder and there was a 4-7 min interval between addition of the sample. These samples were left over up to 156 hours until there were no more changes in swelling. Then SI of each graduated cylinder was averaged by taking a measure of the stabilized height along the cylinder because of irregular swelling line around the graduated cylinder.

Table 1. General properties of Na-bentonite used in this experiment.

Property	Value	Property	Value
Liquid limit (%)	487	SiO_2 (%)	63.97
Plasticity index (%)	450	MgO (%)	15.66
Percent Passing #200 Sieve	65	Na_2O (%)	4.51
Specific Gravity	2.55	CaO (%)	3.46

The hydraulic conductivity tests were performed on the swelled Na-bentonite under different pH conditions in a modified rigid wall permeameter equipped with an air-pump to apply pressure over the top of the specimens (Fig. 1). After saturating the specimens with deionized water and different pH solution, hydraulic conductivity was measured while maintaining 5 cm hydraulic head with different pH solution for each column. Also additional pressure in addition to hydraulic head was applied over the water surface of the column if eluent from the bottom of the column was not collected for 3 days after starting experiment. The air pressures applied by air pump were 150, 300, and 500 Kpa. Each pressure exerted continuously until steady hydraulic conductivities of the specimens were obtained.

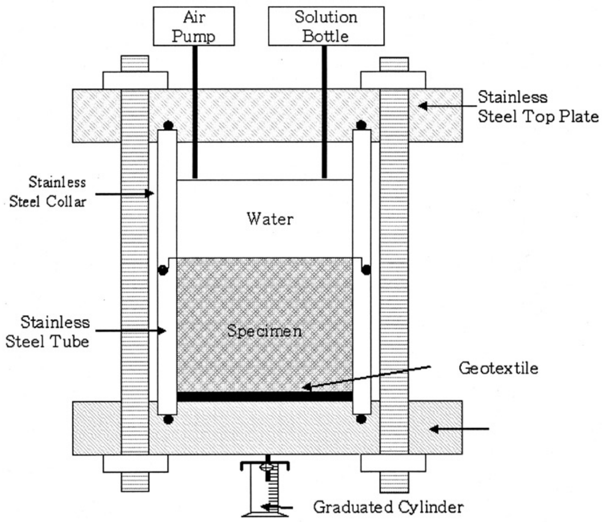

Fig. 1. Diagram of rigid wall permeamete.

Results and Discussion

Fig. 2 through Fig. 6 showed the swelling characteristics of four different sizes of bentonite particles influenced by acidic or alkaline conditions ranging from pH 3.5 to pH 8.5 with 1.0 unit increment. The swelling index of Na-bentonite treated with distilled water was approximately 110. As shown in Fig. 2, the swelling of 60-80 mesh size of bentonite particle was gradually increased with increasing retention time and the maximum swelling indexes (SI) ranged from 35 to 43 for pH 3.5 and 4.5, respectively. However, the increase in SI was retarded after 72 hours in pH 4.5 while SI still gradually increased in pH 3.5. This indicated that the pH was significantly reduced the swelling compared to that of original Na-bentonite. For changes in SI depending on the particle size, SI decreased with increasing particle size although the maximum SI was increased with increasing particle size. Comparing the effect of acid type on the swelling of bentonite, HCl was most effective in reduction of swelling and lower pH was slightly effective in reduction of swelling. The order of reduction for the acids was as follows: HCl > Phosphoric acid > Citric acid ≈ Oxalic acid.

For the effects of pH above neutral on swelling, the results showed that the maximum SI was slightly higher by 5 for the Na-bentonite treated with pH 8.5 solution of NaOH than those of Na-bentonite observed from acid treatments. The changes in SI were not distinctive throughout the experiment except pH 8.5 solution of NaOH.

For pH 8.5 solution of NaOH, SI rapidly approached to the maximum SI till 72 hours and then stabilized. Although the maximum SI treated with alkaline solution was less than half of the original Na-bentonite, the maximum SI observed from alkaline solution was similar to the results observer from pH 4.5 of citric acid. From

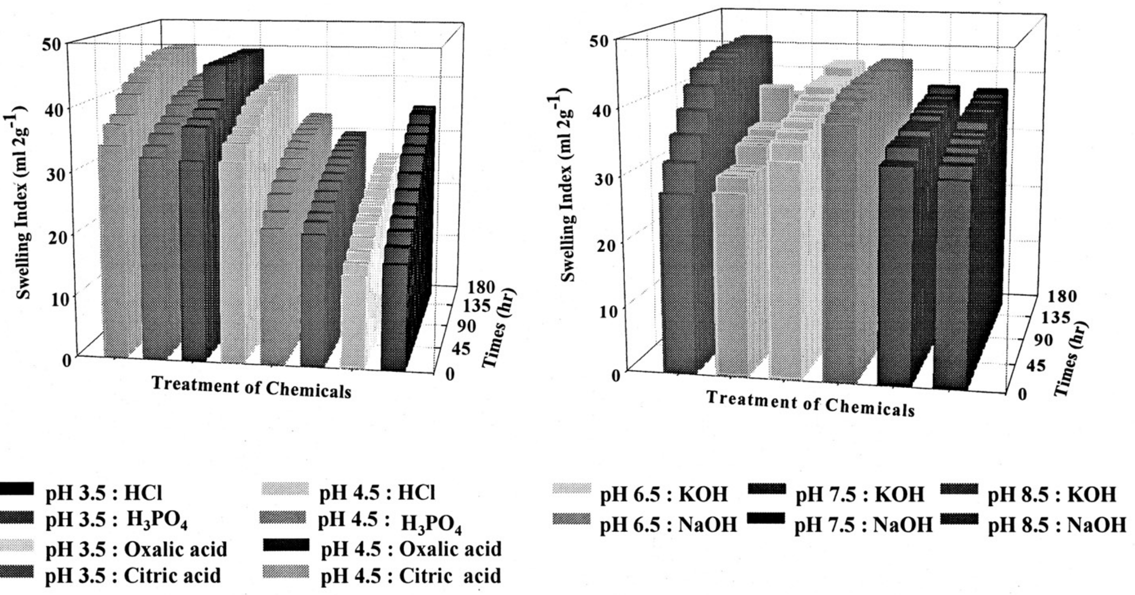

Fig. 2. Comparisons of swelling for 60-80 mesh particles in pH 3.5 and 4.5 (left) and 7.5 and 8.5 (alkali) adjusted with different chemical sources.

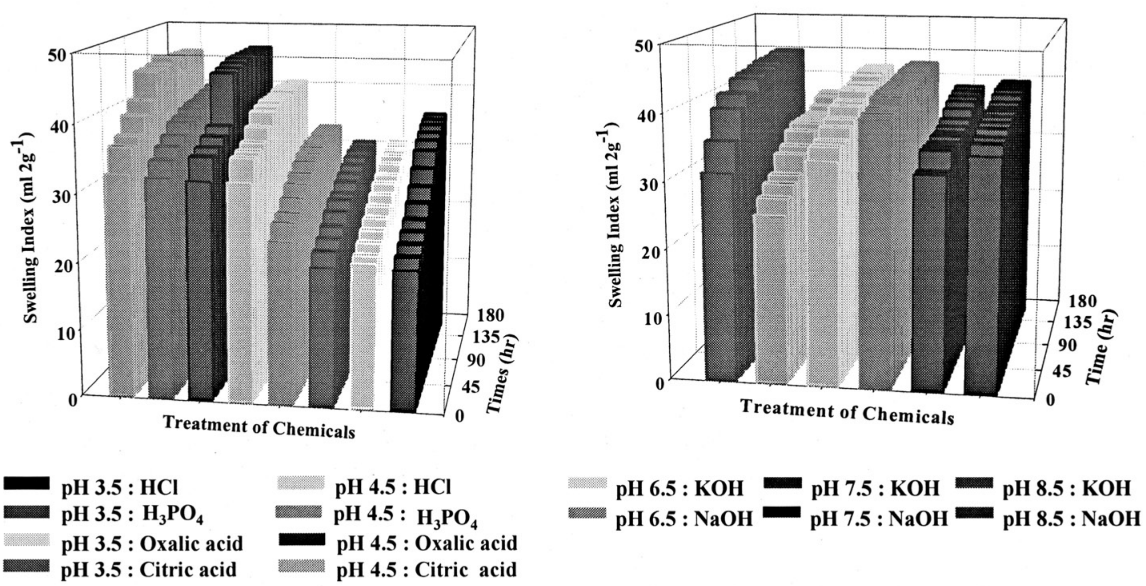

Fig. 3. Comparisons of swelling for 80-100 mesh particles in pH 3.5 and 4.5 (left) and 7.5 and 8.5 (alkali) adjusted with different chemical sources.

these results we could assume that the types of chemical are important in changes of SI.

As shown in Fig. 2, similar results were also obtained from the 80-100 particle size of Na-bentonite (Fig 3). But maximum SI was greater than those from pH 3.5. The maximum SI was approximately 46 from pH 4.5 of oxalic and citric acids while those from pH 4.5 of HCl and phosphoric acid were about 35. Compared to SIs from pH 3.5 results, increase in particle size of Na-bentonite was distinctively effective in increase of SI from oxalic and citric acids regardless of pH except HCl and phosphoric acids. The changes in SI between initial and final swelling ranged from approximately 9 to 15. Most distinctive increase in SI was observed from pH 4.5 of HCl although the maximum SI was approximately 36. From alkaline solution, similar results were observed as shown in 60-80 mesh particle of Na-bentonite. From these results, we could assume that swelling can be influenced by both of pH and particle size.

For 100-120 mesh particle size, the results showed that

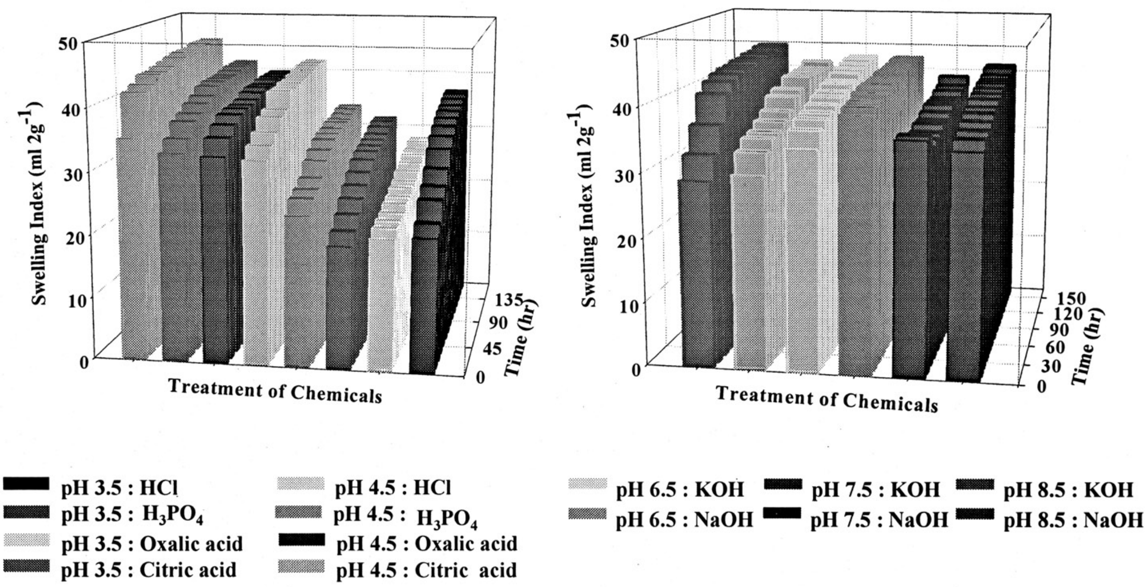

Fig. 4. Comparisons of swelling for 100-120 mesh particles in pH 3.5 and 4.5 (left) and 7.5 and 8.5 (alkali) adjusted with different chemical sources.

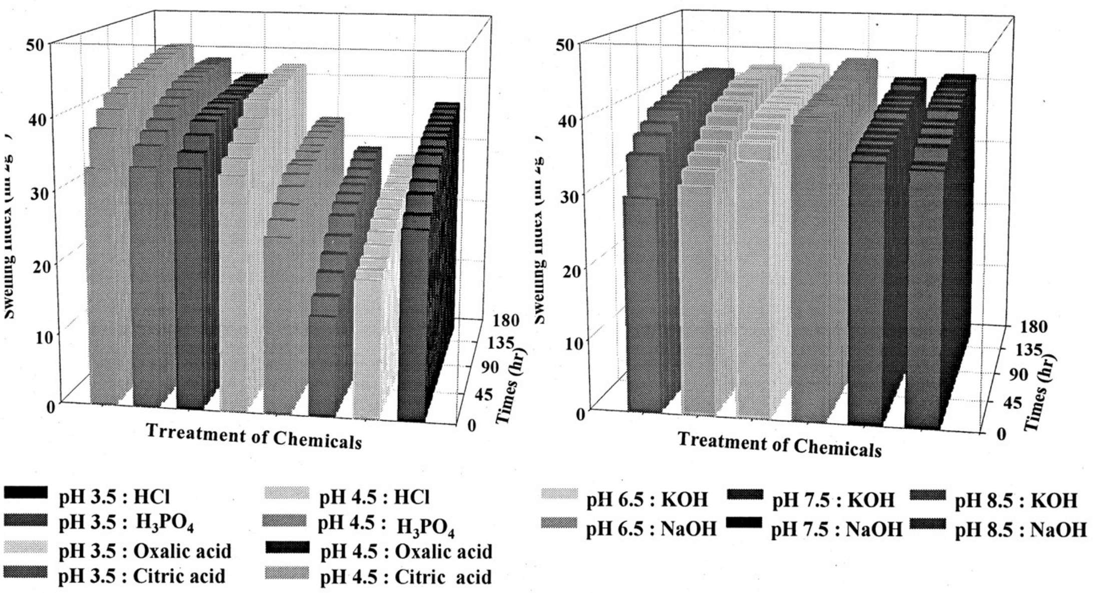

Fig. 5. Comparisons of swelling for greater than 120 mesh particles in pH 3.5 and 4.5 (left) and 7.5 and 8.5 (alkali) adjusted with different chemical sources.

SI's were similar or less than those observed with 80-100 mesh particle size (Fig. 4). But HCl and phosphoric acid strongly influenced the swelling of Na-B regardless of particle size. Also there were not significant changes in swelling. This can represent that alkalinity is not detrimental factor in governing swelling of bentonite

The results of 120 mesh or greater were similar to the results of 100-120 mesh particle size. But the time required to reach the maximum SI was shortened, indicating that the swelling can be easily done with increasing particle size (Fig. 5). For swelling of Na-bentonite by alkaline solution, the the time of maximum swelling was similar except ph 8.5 of NaOH solution. As seen in previous results, it took almost 105 hours to reach the maximum SI.

Hydraulic conductivities (HS) were measured with a modified rigid wall permeameter by treating distilled water and three different pH solution adjusted with oxalic acid and KOH (Fig. 6). The results showed that there was flux detected from the bottom of the permeameter under atmospheric pressure although the swelling was poor. However, the effluent was collected as air pressure was added through the air nozzle over the water surface. The highest initial HS obtained from distilled water head was approximately 8 $\times$ 10^{-3} cm day^{-1} while HS's from treatments of pH 3.5, 6.5, and 8.5 were 4.2 $\times$ 10^{-3}, 5.01 $\times$ 10^{-3}, and 3.45 $\times$ 10^{-3} cm day^{-1}, respectively. However, the HS's were rapidly stabilized to around 10^{-3} cm day^{-1}. We could not find any air-pressure effect on the stabilized HS. But there were distinctive differences in HS before HS reached to the stabilized HD observed in this experiment.

Conclusion

Swelling Indexes can be significantly influenced by soil solution pH, resulting in that substances protonating H+ can influence the swelling index. And the particle size can be detrimental factor in swelling and its relevant hydraulic conductivity. Hydraulic conductivity may not be influenced by solution pH of soil although the swelling capacity drastically decreased. However, it needs further investigation about possibility of failure to develop synthetic porous media which can be used as

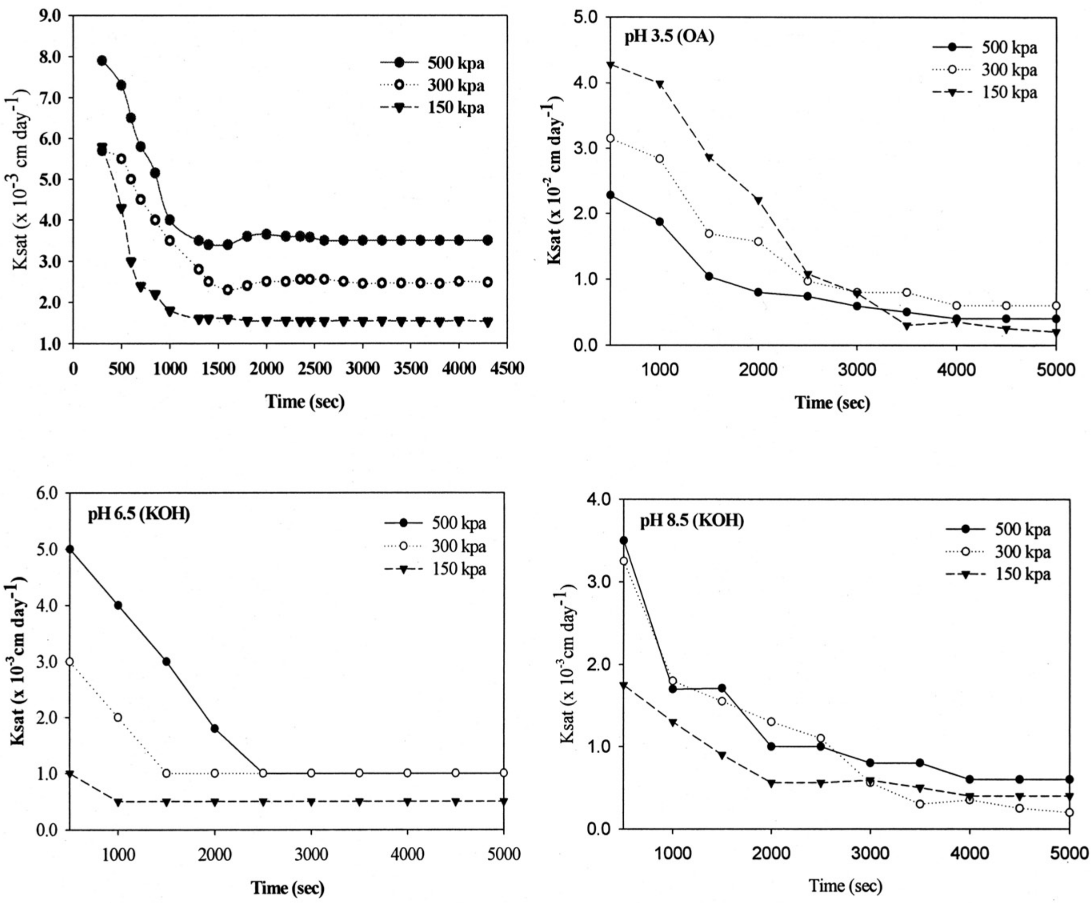

Fig. 6. Hydraulic conductivities of Na-bentonite by different pH solution through the permeameter.

slow release substance as well as a protective barriers of Na-betonite in the agricultural materials.

Acknowledge

This Study was supported by Technology Development Program (2004155-3) for Agriculture and Forestry, Ministry of Agriculture and Forestry, Republic of Korea

References

Abichou, T. 1999. Hydraulic properties of foundry sands and their use as hydraulic barriers. Ph.D. thesis, University of Wisconsin-Madison, Wisconsin, USA.

Chapuis, R. 1990. Simulated sand-bentonite liners: predicting permeability from laboratory tests. Canadian Geotechnical Journal, 27: 47-57.

Quirk, J.P. 1997. Application of double-layer theories to the extensive crystalline swelling of Limontmorillonite. Langmuir, 13:pp.6241-6248.

Low, P.F. 1987. Structural component of the swelling pressure of clays. Langmuir, 3:pp.18-25.

Gens, A., Garcia-Molina, A. J., Oliviella, S., Alonso, E. E. and Huertas, F. 1998. Analysis of a full scale in situ test simulating repository conditions. Int. J. Numer. Anal. Meth. Geomech., 22:pp.515-548.

Christensen, Thomas H., Kjeldsen, Peter, Albrechtsen, Hans-Jorgen, Heron, Gorm, Neilsen, Per H., Bjerg, Poul L., Holm, Peter E. 1994. Attenuation of Landfill Leachate Pollutants in Aquifers. Critical Reviews in Environmental Science and Technology, 24(2): 119-202.

Han Young Soo and Jai Young Lee. 2002. A study on the hydraulic characteristics of the geosynthetic clay liners (GCL) with humic substances of leachate on the landfill. J.of KoSSGE. Vol. 7.1 33-40

Robinson, Howard D. 1995. "A Review of the Composition of Leachates from Domestic Wastes in Landfill Sites" A Report for the UK Department of the Environment, Reference: DE0918A/FR1.

Xie, M., Kolditz, O., Tripathy, S. and Schanz, T. 2003. Numerical modelling of swelling processes in compacted bentonite. ROCKFLOW-Preprint 2003-4, Center of Applied Geosciences, University of Tübingen, Germany.

산과 알칼리 조건하에서 Na-벤토나이트의 팽창경향과 상대적 수리전도도

정덕영[1,*] · 양재의[2] · 오택근[1] · 이교석[1]

[1]충남대학교 생물환경화학, [2]강원대학교 자원생물환경학과

높은 팽창능을 가진 서로 다른 입경의 Na-bentonite의 팽창특성과 상대적 수리전도도를 서로 다른 pH 조건하에서 조사하였다. 조사 결과 최대 팽창에 도달하는 시간은 각각 pH 6.5 이상의 조건에서는 84 시간 그리고 염산으로 처리한 pH 3.5 조건에서는 156 시간 정도가 소요되었다. 그리고 이와 같은 pH 조건하에서 팽창은 증류수로 처리시의 50 % 정도이나 입경이 증가할수록 최대 팽창지수는 다소 증가하는 경향을 보여주었다. 한편 처리 전후의 변화는 HCl으로 처리된 pH 3.5에서는 변화가 매우 크나 알카리 조건에서는 변화가 거의 없었다. 완전히 팽창된 조건하에서 수리전도도는 대기압이나 1 bar 정도의 수두압하에서는 용출이 발생하지 않았다. 그러나 인위적으로 가한 수두압이 1.5bar 이상으로 약 500초 정도 가해졌을 때 용출이 발생하기 시작하였다. 1.5, 3.0, 그리고 5.0 bars 조건하에서 안정화된 수리전도도는 7×10^{-3}cm day^{-1} 내지 6×10^{-3} cm day^{-1}, 정도로 조사되었다. 그리고 수리전도도는 증류수로 처리하였을 때보다 산성조건하에서 다소 높은 것으로 조사되었다.