Measurement of Bentonite-water Potential Using a Thermocouple Psychrometer

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1. Introduction

Bentonite, a kind of swelling clay is favorably used for the buffer of a high-level waste (HLW) repository, because it has the ability to prevent water intrusion into a repository, to retard the release of radionuclides from wastes, and to support containers encapsulating the wastes from external impacts. The bentonite buffer will remain unsaturated for a certain period of time after its emplacement, due to a combinational process of decay heat from the wastes and the inflow of groundwater, and, for that period, the movement of groundwater and radionuclides through it is dominated by bentonite-water potential. Therefore, the water potential measurement is inevitably needed to assess the barrier performance of the buffer of a HLW repository.

The water potential has been widely studied for plant soils since 1960's, using the direct and indirect techniques of measurement (piezometry, tensiometry, thermocouple psychrometry, and measurements with electrical resistance sensor, heat dissipation sensor, filter paper technique, vapor equilibration etc.) [1-3]. However, not much data has been reported on the water potential of bentonite as a buffer material of a HLW repository. The present study intends to establish an optimal procedure of measurement for the thermocouple psychrometry using a domestic bentonite, and also to investigate the dependency of water potential on water contents which can be expected under disposal environments.

2. Materials and Method

A domestic bentonite was used for the water potential measurements. The bentonite, which was taken from Kyeongju, Kyeongsangbuk-do, was dried below 110 ^{o}C, pulverized, and then passed through No. 200 of ASTM (American Society for Testing and Materials) standard sieves. It contains montmorillonite (70%), feldspar (29%), and small amounts of quartz (~1%). Its chemical composition and particle size distribution are as shown in Table 1 and Figure 1, respectively. The adjustment of the water content of samples was made by drying them at 110 ^{o}C for 24 hours and then adding demineralized water to the dried samples by pre-weighed amounts using a sprayer. The sample after their adjustment of water content was left in a desiccator for more than 3 days for its water content equilibrium. Part of the prepared sample was used for checking a final water content (ω), which was determined by the following equation:

$$\omega\ (\%) = \frac{\text{mass of wet sample} - \text{mass of dry sample}}{\text{mass of dry sample}} \times 100$$

The water potential of the samples was measured using a commercial sample chamber C52 (Wescor Inc.) and a water potential system PSYPRO (Wescor Inc.). The sample chamber is enclosed within a module built of insulating board that surrounds the chamber on the sides with about 5 cm to 10 cm insulation, to provide uniform temperature of the sample and chamber. The measurement was conducted in two manners: the single step procedure for the water contents beyond 10 % and the two-step procedure for the low water content ranging from 3 % to 10 %. The keys of the two-step procedure consist of (1) the first thing, one drop of distilled water is placed on a filter paper disc in the inner sample holder for water condensation on the thermocouple junction followed by the measurement and (2) after pushing the slide to move to the outer sample holder, the measurement is done for the bentonite sample.

3. Results and Discussion

4.1. Psychrometric curves and optimal psychrometer settings

It was observed that the characteristic curves obtained from the thermocouple psychrometer consisted of three regions as labeled in Figure 2(a): Region I for delay after cooling, Region II for plateau average in which the evaporative cooling of the water from the junction holds the temperature of the junction constant, and Region III for a time interval with the temperature of the thermocouple reaching the ambient temperature. Following the single procedure of measurement, a complete sequence diagram was obtained within about 120 seconds for the samples with higher water content (> 10%), whereas, below this water content, we failed to complete the scan sequence as the psychrometer could not condense the water on its junction due to dryness. For this problem the dry samples less than 10% employed the two-step procedure of measurement. However, since the total duration of scan sequence was a very short time not exceeding about 5 seconds as shown in Figure 2(b), great care is needed to set the time intervals for delay after cooling, plateau average during evaporative cooling of the condensed water, and increase of the thermocouple temperature toward the ambient temperature.

4.2. Dependency of water potential on the water content

Table 2 lists the measured water potentials of the bentonite samples. As seen in this table, the values ranged from -108.18 MPa to -1.36 MPa when the water contents were between 3.4 % and 35.7 %. Figure 3 shows that the water potential was negatively decreased with increasing the water content up to about 20 %, beyond which it reached a constant value. This states that the drier samples reveal the more negative water potentials, which is expected to be due to an increase in the capillary forces arising from curved air-water interfaces in the voids of the bentonite sample or in surface forces bonding water molecules as the sample become drier. It was found for the water content beyond about 20 % that the water potentials approached the saturation value and there was no discrimination among their values by means of the thermocouple psychrometry method.

4. Conclusions

Concerning the measurement of bentonite-water potential, the single procedure was applicable for the samples with higher water content (> 10%), whereas, below this water content, it was possible to measure the water potential by applying the two-step procedure of measurement. The water potential was negatively decreased with increasing the water content up to about 20 %, beyond which it approached a saturation value.

REFERENCES

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[2] H. H. Wiebe, "Measuring water potential from free water to oven dryness," Plant Physiol, Vol.68, p.1218 (1981).
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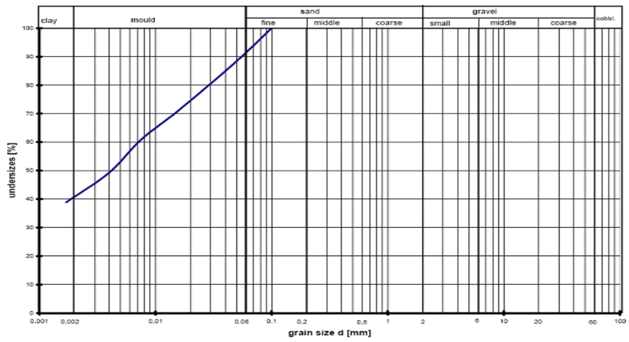
Table 1. Chemical composition of the bentonite.

Chemical constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	FeO	SO_3	TiO_2
Percentage (%)	56.8	20.0	6.00	2.6	0.8	0.9	1.3	0.2	1.3	0.8

Table 2. Water potentials of the samples with various water contents.

Sensor	Sample type	Water content (%)	Water potential (MPa)
PSYPRO*	Powder	3.4	-108.18
		5.4	-112
		6.04	-101.51
		7.4	-86.13
		10.5	-81.2
		14.4	-61.63
		21.5	-7.11
		26.2	-3.37
		31.3	-1.49
		35.7	-1.36

Figure 1. Particle size distribution of the bentonite.



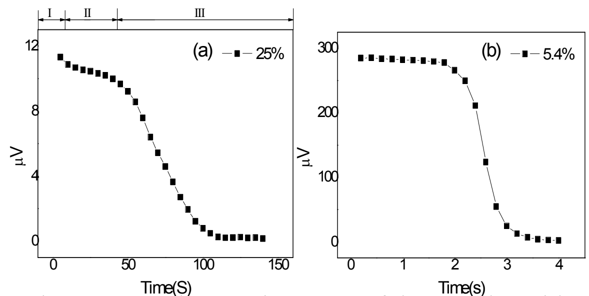


Figure 2. Psychrometric curves of the samples with 5.4 % and 25 %.

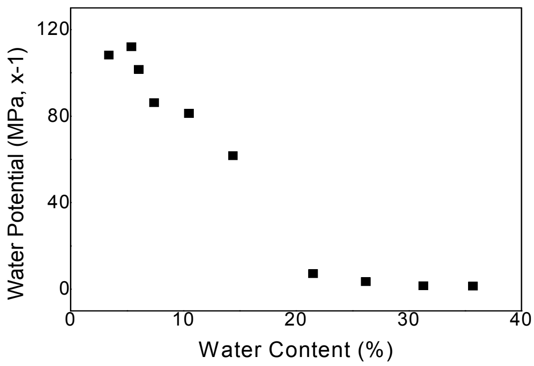


Fig.3. Effect of water content on the water potential.