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Analysis on Permittivity of Soil to Evaluate Pore Water Contamination

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요 약 문

저주파수에서 유전상수 측정시 100kHz 이하의 주파수 영역에서는 전극분극효과가 발생하므로 100kHz 이상의 주파수에서 유전상수가 평가되어야 한다. 유전상수는 쌍극자모멘트의 수에 비례하기 때문에 흙의 유전상수는 체적함수비에 따른 선형적인 증가경향을 나타내었다. 용액에 이온성분이 존재하는 경우에는 수화작용에 의한 물분자의 배향분극 발현의 감소로 인하여 유전상수가 감소한다. 흙과 중금속 혼합시료의 경우 함수비가 큰 시료에서는 용액의 유전특성이 발현되지만, 함수비가 작은 경우에는 공간전하분극의 영향으로 유전상수가 10-20%정도 증가하는 경향을 나타내었다. 현장에서의 정확한 오염도 평가를 위해서는 토양의 함수비에 대한 평가가 반드시 수행되어야 한다.

key words: permittivity, volumetric water content, electrode polarization, heavy metal

1. Introduction

In-situ monitoring using an electrical method has been proposed as a simple and cost-effective contaminant detecting method (Kaya and Fang 1997; Rowe et al. 2001). Some researchers have proposed the potential availability of the permittivity in estimating subsurface contamination through laboratory experiments (Santamarina and Fam 1997; Darayan et al. 1998; Francisca and Rinaldi 2003). Permittivity is a measure of the extent to which the electrical charge distribution in a material can be polarized by the application of an electric field. However, factors affecting the permittivity of soil are still unclear. As identifying the factors affecting permittivity of soil is very important prior to application in the field, parametric studies based on laboratory tests have been performed in this study. The main purposes of this study are to identify the presence of measurement distortions such as electrode polarization and to investigate the factors affecting the permittivity of soil at low frequency.

2. Experimental Section

Two kinds of soil including silica sand(Jumunjin sand) and local soil(SNU soil) which was collected from Seoul National University, were used. The soils were sieved through sieve No.10, and then oven dried at 105°C for 24 hours. The soils were thoroughly mixed with water at different water contents and then the soil-water mixture was placed into the acrylic mold and directly compacted to the designed dry density.

The capacitor-type acrylic mold was specially designed for measuring the permittivity of specimen. Cell consists of acrylic mold and two circular disk electrodes made of brass. The two brass electrodes of capacitor-type cell are 70mm in diameter and are 20mm apart. The sample was placed between the two electrodes of the acrylic mold.

The measurements were achieved using HP4285A Precision LCR meter (Hewlett-Packard, USA) in the range of 75 kHz to 12 MHz and Agilent 4263B LCR meter (Agilent Technologies Japan, Ltd.) in the range of 100 Hz to 1 MHz. A sinusoidal excitation is imposed and measurements are repeated at different frequencies. To remove the residual impedance effects, calibrations were performed in open and short circuit condition. Edge capacitance or fringe capacitance is formed on the edges of the electrodes and consequently the measured capacitance is larger than the capacitance of the material. The corrected capacitance value can be calculated by subtracting the edge capacitance from the measured capacitance.

3. Results and Analysis

3.1. Electrode polarization effects

The current in the electrodes, cables, and in the measurement system involves electron flow, while the current in wet soil is ionic in nature. Given the incompatibility among charges, charge accumulation occurs at the electrode-specimen interface. This effect is called electrode polarization, and it is frequently observed in the low frequency measurement using two-terminal electrode systems. Electrode polarization causes measured permittivity values to increase as frequency decreases. Fig. 1 shows two-terminal electrode measurement data for deionized water, tap water and aqueous aluminum solutions with varying conductivities. The electrode polarization effect, which causes measured permittivity values to increase as frequency decreases, was observed at lower frequencies. The minimum frequency at which electrode polarization does not significantly affect the permittivity measurements is known as the limiting lower frequency. The limiting lower frequency is proportional to the conductivity of material, therefore highly conductive specimens are affected by electrode polarization to higher frequencies than less conductive materials. The range where electrode polarization effects are suspected is denoted on the permittivity data as shown in Fig. 1. It is apparent that values of permittivity at frequencies less than approximately 10 ~ 100 kHz are affected by electrode polarization.

3.2. Influence of volumetric water content

Permittivity is governed by volumetric water content, defined as the ratio of the volume of pore water to the total volume of soil, since the permittivity is proportional to the number of dipole moments per unit volume. The permittivity of the test soils against volumetric water content at three different frequencies, 100 kHz, 1 MHz and 10 MHz, are shown in Fig. 2. The permittivity of soil increased with increasing volumetric water content and decreasing frequency. The increase of volumetric water content means that the number of the permanent electric dipoles such as water molecules which can cause orientational polarization increases and the amount of air in the pore space decreases.

The increase in permittivity of soils with measuring frequencies were caused by the spatial polarization. Especially, the permittivity of the SNU soil at 100 kHz shows that the permittivity of the soil-water mixture exceeded the permittivity of water and reached a peak, and then decreased with volumetric water content at higher volumetric water contents, but not at high frequencies. Since the spatial polarization developed at low frequencies, it is apparent that trends of permittivity versus volumetric water content vary in the different frequency bands.

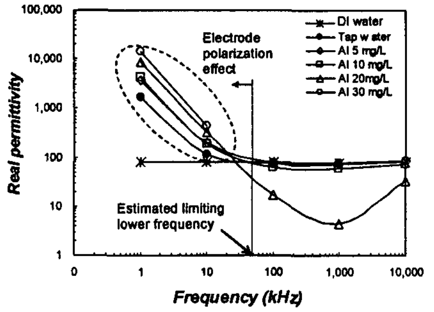


Fig. 1. Electrode polarization effect in permittivity of solution

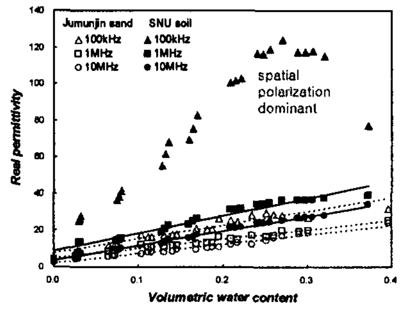


Fig. 2. Permittivity of the test soil with volumetric water content

3.3 Influence of pore fluid contamination

The effect of cationic concentration on permittivity was explored. The spectral responses of permittivity of lead at frequency ranges from 10kHz to 10MHz are shown in Figure 4. The decrease in permittivity with concentration reflects the reduced mobility of water molecules involved in ion hydration. Water involved with hydrating ions in electrolytes makes a lower contribution to global polarization than free water, resulting in lower permittivity of electrolyte solutions at higher concentrations.

In order to evaluate whether permittivity was sensitive enough to detect contamination due to heavy metals, relative variations defined as the ratio of electrical properties of the contaminated soil to that of uncontaminated soil against their concentration, are shown in Fig. 4. The important findings obtained from Fig. 4 are as follows. Firstly, the data show that it was difficult to identify the ion type using complex permittivity data. Secondly, at low volumetric water content, the measurement of permittivity alone may lead to some degree of ambiguity in the results mainly due to spatial polarization. The permittivity of soil is primarily dependent on soil types and volumetric water content. Therefore, in order to utilize the electrical measurement method for investigating subsurface contamination, pre-evaluation of soil types and volumetric water content of subsurface is required.

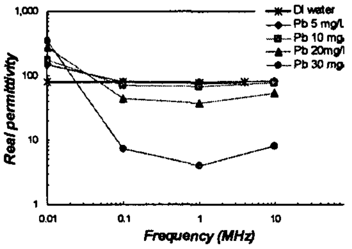
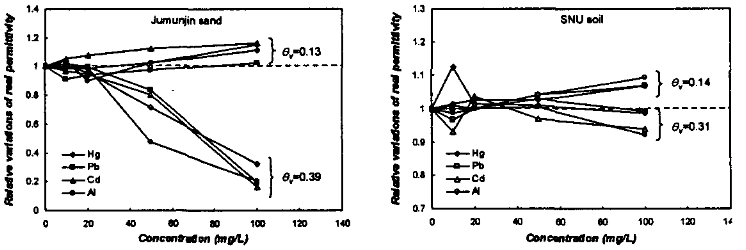


Fig. 3. Spectral responses for permittivity of lead(Pb) solution



(a) Junmunjin sand

(b) SNU soil

Fig. 4. Relative variations of permittivity at 10MHz for mixtures of soil with cationic species

4. Conclusions

(1) Electrode polarization effect was observed at frequencies less than approximately 10～100 kHz. However, accurate and effective experimental method for eliminating electrode polarization has not yet been proposed. Future works for quantitative evaluation of electrode polarization are recommended.

(2) The permittivity of soil increased continuously with volumetric water content. This is evidenced by the facts that the permittivity is proportional to the number of dipole moments per unit volume. A linear relationship between the permittivity of soil and the volumetric water content was valid at high frequencies(MHz ranges), since the spatial polarization developed at lower frequencies.

(3) Ionic constituents in water result in significant reduction in the permittivity due to the decreased orientational polarization of water molecules caused by hydration of ions. Since the permittivity is primarily dependent on the volumetric water content of soil, pre-evaluation of the volumetric water content is required.

5. Acknowledgement

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6. References

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