Application of Thermo-Time Domain Reflectometry Techniques to Estimate Oil Concentration of Unsaturated Soil.

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Introduction

After a contaminant reached the groundwater, we often notice the pollution of soil and/or the groundwater for the first time. When a pollutant reaches the groundwater, the pollutant spreads along with groundwater flow. It is important to detect a trace of the pollutant in unsaturated soil before it reaches the groundwater. For the early detection of pollution, simple monitoring techniques have been desired. Therefore, the purpose of our research was to estimate the mineral-oil concentration in soil with a thermo-time domain reflectometry (thermo-TDR) technique.

Materials & Methods

- Volcanic ash soil known as Kanto-loam passed through a 2-mm sieve.
- A contaminant was made by the mixture of mineral oil, i.e. Diesel fuel, and water (0~100 % volume basis).
- Oil and water contents ranged between 0 and 0.4 (m^3 m^{-3}).
- After soil mixed with the contaminant was packed in a 100 cm^3 sampler, volumetric heat capacity and dielectric constant were measured using a thermo-TDR probe in an incubator (20℃).
- We carried out experiments to investigate the relationship among oil concentration, volumetric heat capacity, and dielectric constant.
- Used a theoretical equations (3) and (4).
- The formula (5) and (6) derived from eqs. (3) and (4).
- We estimated the oil concentration from eqs.(2), (5) and (6).

$$\theta = \theta_w + \theta_o \quad (1)$$

$$C = \frac{\theta_o}{\theta_w + \theta_o} \times 100 \quad (2)$$

$$C_b = C_s V_s + C_w \theta_w + C_o V_o \quad (3)$$

$$\varepsilon_b = \frac{3 + (2+a)\theta_w(\varepsilon_w - \varepsilon_s) + 2\theta_o(\varepsilon_o - \varepsilon_s) + 2\theta_a(\varepsilon_a - \varepsilon_s)}{3 + \theta_w\left(\frac{\varepsilon_s}{\varepsilon_w} - 1\right) + \theta_o\left(\frac{\varepsilon_s}{\varepsilon_o} - 1\right) + \theta_a\left(\frac{\varepsilon_s}{\varepsilon_a} - 1\right)} + b \quad (4)$$

$$\theta_w = -\frac{(C_s - C_b)\left\{(\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_o} - 1\right) - 2(\varepsilon_o - \varepsilon_s)\right\} + C_o\left[-3(\varepsilon_b - b - \varepsilon_s) + \theta_a\left\{2(\varepsilon_a - \varepsilon_s) - (\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_a} - 1\right)\right\}\right]}{C_w\left\{(\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_o} - 1\right) - 2(\varepsilon_o - \varepsilon_s)\right\} + C_o\left\{(2+a)(\varepsilon_w - \varepsilon_s) - (\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_w} - 1\right)\right\}} \quad (5)$$

$$\theta_o = -\frac{(C_s - C_b)\left\{(\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_w} - 1\right) - (2+a)(\varepsilon_w - \varepsilon_s)\right\} + C_w\left[-3(\varepsilon_b - b - \varepsilon_s) + \theta_a\left\{2(\varepsilon_a - \varepsilon_s) - (\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_a} - 1\right)\right\}\right]}{C_o\left\{(\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_w} - 1\right) - (2+a)(\varepsilon_w - \varepsilon_s)\right\} + C_w\left\{2(\varepsilon_o - \varepsilon_s) - (\varepsilon_b - b)\left(\frac{\varepsilon_s}{\varepsilon_o} - 1\right)\right\}} \quad (6)$$

(3) de Vries, D.A., 1963 revised. (4) G.P. de Loor, 1968 revised. (5) (6) Noborio et al., 2009 revised.

Reference

de Vries, D.A., 1963 : Thermal properties of soils. In: W. R. van Wijk (Ed), Amsterdam, Physics of the plant environment.
G.P. de Loor, DIELECTRIC PROPERTIES OF HETEROGENEOUS MIXTURES CONTAINING WATER., 1968 : Microwave Power, 3(2), 67-73.
Noborio et al., 2009 : Measurement of Oil and Water Contents In Oil-Contaminated Unsaturated Soil with a Thermo-time domain reflectometry probe, ASA-CSSA-SSSA Annual International Meetings Abstract.

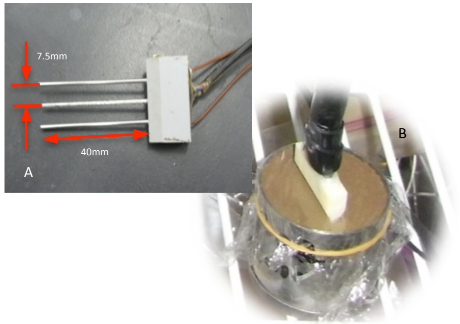

Fig. 1A. Thermo-TDR Probe
1B. Experiment image

Table. 1 Experimental Conditions

Soil	Volcanic Ash Soil
Contaminant oil	Light Mineral Oil (i.e. Diesel fuel)
Bulk density (Mg m^{-3})	0.7
C (%)	0, 25, 50, 75, 100
θ (m^3 m^{-3})	0, 0.1, 0.2, 0.3, 0.4

Table. 2 Physical Properties of Soil Constituents

	Dielectric Constant	Volumetric Heat Capacity (MJ/m^3/K)
Soil particles	5*	1
Water	80**	4.18**
Diesel fuel	1.8***	1.48****
Air	1**	—

*Noborio (2003), **Chemical Society of Japan (2004),
***Matsushima machinery institute Corporation,
****Sundarapandian, Devaradjane (2007)

θ : volumetric Liquid content (m^3 m^{-3})
θ_w: volumetric water content (m^3 m^{-3})
θ_o: volumetric oil content (m^3 m^{-3})
θ_a: volumetric air content (m^3 m^{-3})
ε_s: dielectric constant of soil particles
ε_w: dielectric constant of water
ε_o: dielectric constant of oil
ε_a: dielectric constant of air
C_s: volumetric heat capacity of soil particles (MJ m^{-3} K^{-1})
C_w: volumetric heat capacity of water (MJ m^{-3} K^{-1})
C_o: volumetric heat capacity of oil (MJ m^{-3} K^{-1})

Results & Discussions

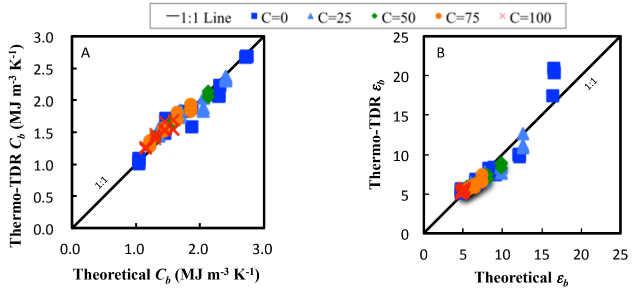

Fig. 2 theoretical versus measured value
(2A:Volumetric Heat Capacity, 2B:Dielectric Constant)

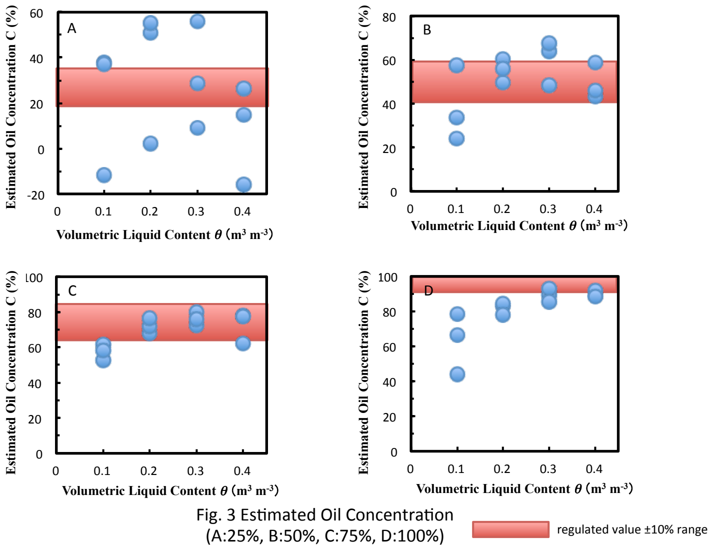

Fig. 3 Estimated Oil Concentration
(A:25%, B:50%, C:75%, D:100%)

- ✓ In volumetric heat capacity, measured and theoretical values were agreed well (Fig. 2A) whereas the values did not agree well particularly at higher dielectric constants (Fig. 2B).
- ✓ Estimation accuracy was not good for high and low oil concentrations (Fig. 3A and 3B).
- ✓ In particular, we accurately estimated at 50% and 75% of oil contents (Fig. 3B and 3C).

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