Soil Thermal Conductivity Affected by Salt Solutions

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ABSTRACT

Thermal properties, i.e. thermal diffusivity, volumetric heat capacity, and thermal conductivity, of clay-containing soils affected by salt solutions were investigated using the dual-probe heat-pulse (DPHP) method. As the concentrations of NaCl and $CaCl_2$ increased from 0 to 1.0 mol/L in unsaturated loamy sand, loam with montmorillonite or kaolinite, and volcanic ash soil with various solution contents ranged between 0.1 and 0.3 m^3/m^3, thermal properties of those soils decreased as did previous studies. There were big dips in decreasing thermal properties of the soils toward 0.05 mol/L NaCl (Fig. 1a) and $CaCl_2$ (Fig. 1b). Alternated micro-structures of clay, silt, and sand particles by salt solutions may contribute to those large decreases (Fig. 2). Our simulation results revealed that thermal conductivity of the dispersed clay particle arrangement showed in Fig. 2b was smaller than that of the flocculated arrangement (Table 2).

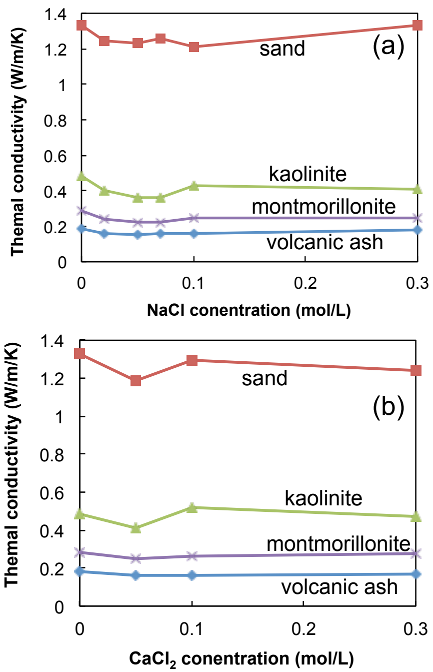

Fig. 1. Measured thermal conductivity varied with concentrations of salt solutions for θ=0.1 m^3/m^3.

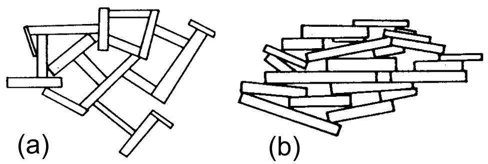

Fig. 2. Clay particle arrangement: (a) flocculated, (b) dispersed (Push, 1970).

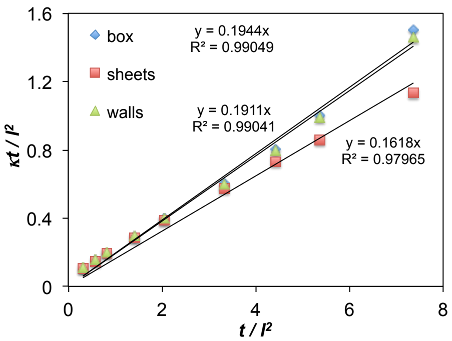

Fig. 4. COMSOL simulation results of thermal diffusivity analyzed with Eq. 1.

SIMULATION

To investigate the effect of altered micro-structures of soil particles on heat transfer, numerical simulation was conducted using the COMSOL Multiphysics simulator (Table 1; Fig. 3).

Table 1. Thermal properties of soil constituents used for simulation.

	λ (W/m/K)	C_v (MJ/m³/K)	κ (x10⁻⁶ m²/s)
clay particle	2.92	2.39	1.222
solution	0.57	4.18	0.136

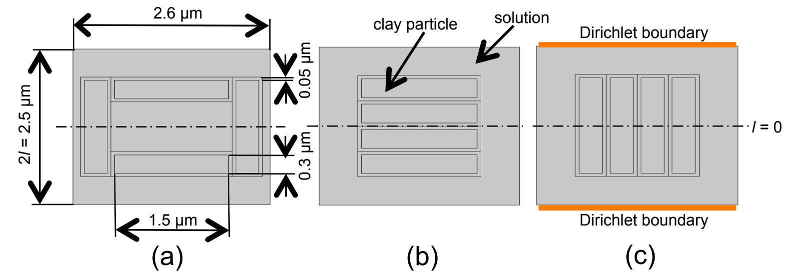

Fig. 3. Clay particle structure in solution: (a) box, (b) sheets, and (c) walls like arrangements used for COMSOL simulation.

Relative temperature in parallel plane (Carslaw and Jaeger, 1959)

$$T_r = 1 - \frac{4}{\pi}\sum_{n=0}^{\infty}\frac{(-1)^n}{2n+1}\exp\left[-(2n+1)^2\pi^2\frac{\kappa t}{4\ell^2}\right] \qquad t \le 0\ T = 283\ \mathrm{K};\quad t > 0\ T_{\pm l} = 303\ \mathrm{K} \qquad (1)$$

Table 2. Thermal properties estimated of 3 arrangements (Figs. 3, and 4).

	box	sheets	walls
κ (x10⁻⁶ m²/s)	0.194	0.162	0.191
C_v (MJ/m³/K)	3.684	3.684	3.684
λ (W/m/K)	0.715	0.597	0.704

CONCLUSIONS

The simulation results revealed that dispersed structure (Figs. 2b, and 3b) decreased thermal conductivity compared with flocculated structure (Figs. 2a, and 3a) as listed in Table 2.

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