Effects of Moisture Content and Shrinkage on Soil-Thermal Properties for Peat Soils in Japan

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Abstract: Wetland is known as a source of atmospheric methane, typically produced by microbiological and chemical processes under anaerobic conditions. Soil temperature in the wetlands is a key factor to control the processes. Peat soils can be found in many types of wetlands. Peat soils contain high organic matter content and thus shows unique physical properties such as high total porosity and shrinkage. This study aims to study the heat transport of peat soils at variably saturated conditions and effects of volume shrinkage on thermal properties of peat soils. Study area of this research is Bibai marsh, Hokkaido in Japan. Undisturbed peat samples were obtained from two different peat profiles at different depths. In general, the thermal conductivity (TC) and the heat capacity (HC) of peat soils linearly increased with increasing volumetric water content, and simple two-phase (solid and water phases) models for TC and HC could generally express TC and HC behaviors, respectively, for most of peat soils. In addition, the observed volume-shrinkage of the peat soils under dry conditions did not affect the TC and HC behaviors for the studied samples.

Keywords: Peat soil, Thermal properties, Shrinkage

1 Introduction

Wetlands are recognized as a significant element in the natural environment. Various projects on the wetland conservation and restoration have been implemented since wetlands possess a great diversity of ecosystem and have functions to store and purify water. Furthermore, in developing countries, wetlands are also important as the sites for residential or industrial developments, and other infrastructure developments such as a landfill.

The wetland is also known as a source of atmospheric methane, typically produced by microbiological and chemical processes under anaerobic conditions. Soil temperature in the wetlands is a key factor to control the processes. Microbiological respiration rates and degree of anaerobic condition depend strongly on soil temperature [1]. A decrease in soil temperature reduces the rate of decomposition and increases the rate of peat accumulation [2]. Chapman and Thurlow [3] reported for a bog in Scotland that an increase in surface temperature of 4.5 °C might double CO_2 emissions and increase methane emissions by 60% based on observations at two different wetland sites. Thus, the knowledge of heat transport process in the wetlands is essential for assessing the environmental risk in the wetlands under natural conditions and developments, hereunder understanding and simulating the emissions of the greenhouse gases from the wetlands.

Peat can be found in many types of wetlands. Peat contains high organic matter content and has unique physical properties such as a high total porosity and shrinkage characteristics. Water content of peat soils can vary from about 200% to more than 2000% of dry weight. Hobbs [4] reported that 5 m of fibrous peat may contain 4.7 m of water and as little as 300 mm of solid [4]. These unique physical properties may influence heat transport characteristics for peat soils.

Heat transport in soils is governed by thermal properties such as thermal conductivity and specific heat capacity. In this study, the thermal properties for differently-decomposed and variably saturated Peat soils were measured to investigate the effects of moisture content and shrinkage on heat transport.

2 Material and Methods

The study site was Bibai marsh, Hokkaido in Japan. Undisturbed Peat samples were taken from two different sites in Hokkaido Bibai marsh at different depths using 100cm^3 cylindrical cores (i.d.:5.01cm, length: 5.11cm). Peat 1 was sampled inside the marsh area, while Peat 2 was sampled from the area nearby a drainage ditch surrounding the marsh. Physical and chemical properties of the Peat samples are shown in Table 1. Fiber content show that Peat 2 is more decomposed than Peat 1.

Table 2*: Soil physical and chemical properties for Peat soil samples [5]*

Site	Depth (cm)	Particle density ρ_s (g/cm^3)	Dry bulk density ρ_d (g/cm^3)	Gravimetric water content w (%)	Porosity Φ (cm^3/cm^3)	Saturated hydraulic conductivity Ks (cm/s)	Loss-on-ignition Li (%)	SOC	SON	Fiber Content
Peat 1	10	1.42	0.092	1211	0.93	3.68E-03	82.5	60.6	1.2	84.4
	20	1.49	0.158	573	0.86	3.96E-03	48.7	33.3	1.5	91
	30	1.37	0.108	592	0.92	3.69E-03	56.5	36.5	1	86.9
Peat 2	10	2.63	0.315	283	0.88	5.75E-03	78.8	89.7	2.1	42.0
	20	1.86	0.112	700	0.94	-	94.6	73	1.3	75.2
	40	1.44	0.130	922	0.91	-	96.7	86.6	1.1	62.5
	50	1.8	0.110	955	0.94	1.72E-03	96.8	73	0.9	73.4

The peat samples were initially saturated and subsequently drained using two different methods corresponding to the matric suction ranges. A hanging water suction method was used for low matric suctions up to pF 2 (- 100 cm H_2O) and a pressure plate apparatus for medium suctions (pF 2 to pF 4, i.e., - 100 cm H_2O to -10000 cm H_2O). Finally, the samples were air-dried (defined as pF 6 condition).The thermal properties (thermal conductivity and specific heat capacity) of the samples at different soil moisture suction levels were measured by using Decagon KD2-Pro probe.

3 Results and Discussion

Figure 1 shows water retention characteristics and volume shrinkage of Peat 1 and Peat 2 at different depth levels as a function of pF value. Except for surface layers (i.e., 10 cm depth) for both Peat 1 and Peat 2, all soils exhibited showed higher water retention characteristics up to pF 2, where around 60-70% of water saturation is still maintained, indicating a formation of well-developed organic matrix with micro-pore structure with increasing a degree of decomposition. As shown in Figure 2, both Peat 1 and Peat 2 samples gradually shrank with increasing pF (i.e,. drying), showing 50% to 85% of shrinkage under dry conditions. Peat 1 at 20 cm depth and Peat 2 at 50 cm depth showed high volume shrinkage at pF 4 condition, while the volume shrinkage for Peat 1 at 10 cm was not significant as compared to that for other soils likely because a surface layer in Peat 1 is mainly composed of fresh *Sphagnum* mosses.

Figure 2a and 2b show thermal conductivity (TC) and heat capacity (HC) as a function of volumetric water content. The solid lines in Figure 2 represent calculated TC and HC lines by assuming soil volume containing 10% of organic matter whose TC and HC are assumed as 0.25 W/m/K from de Vries [6] and 2.5 MJ/m^3/K from Campbell and Norman [7], respectively, and 90% of soil pore. Linear increases of TC and HC with increasing volumetric water content were considered. The TC of 0.60 W/m/K and HC of 4.18 MJ/m^3/K for water were used in the calculation.

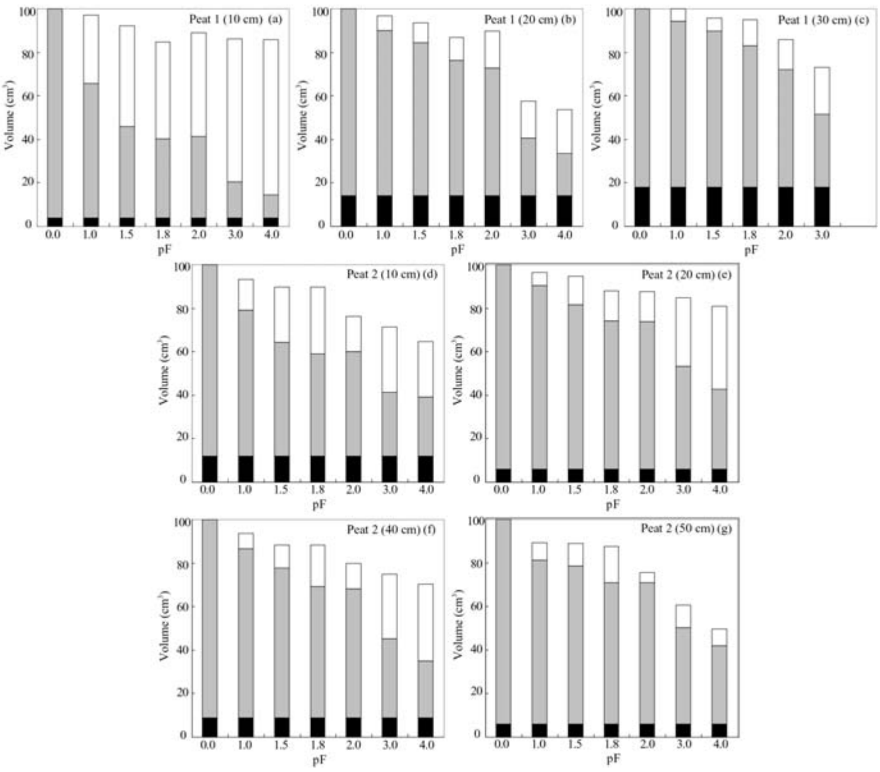

Figure 1: *Water retention and shrinkage characteristic of Peat 1 and Peat 2 soils with different depths. (Solid:* ■ *Water:* ▨ *Air:* ☐*)*

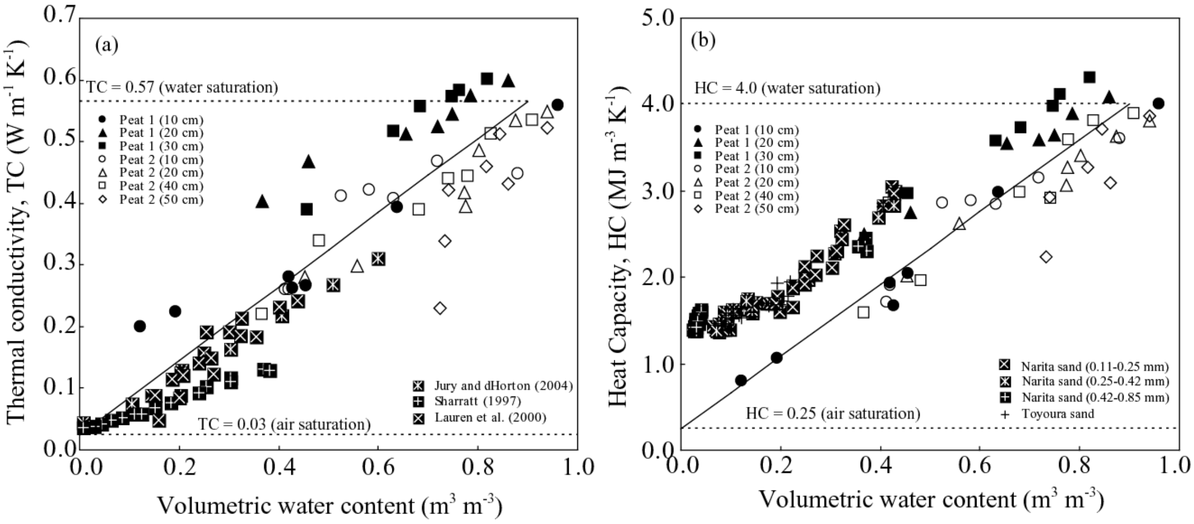

Figure 2: *(a) Thermal conductivity and (b) heat capacity as a function of volumetric water content.*

For sandy and loamy-clayey soils, Hamamoto et al. [8] and many previous works have reported a rapid increase of TC under dry condition due to an improvement of thermal contact between adjacent solids but lower incremental increase of TC under dry condition where the water film becomes thicker and the increase in TC with increasing soil water content depends largely on the displacement of air by water. In contrast to the above TC behaviors for normal soils, as shown in Figure 2a, the TC for all soils including three different peat soils from literature linearly increased with increasing volumetric water content, suggesting that heat transport through water phase highly governs heat transport characteristics for the peat soils. The linear TC behavior for the peat soils as a function of water content even under dry conditions may also indicate small shrinkage effects on the TC. The linear increase of TC for the peat soils has been also reported by Hamamoto et al. [8].

Except for Peat 1 at 20 cm and 30 cm depths, the predictive line captured the general trend of the TC behavior for all soils including literature data but slightly overestimated them. Since the line is calculated based on only volumetric fraction of water and organic matter, the finding indicates that water-phase tortuosity reduced the TC values for the peat soils. The TC for Peat 1 at 20 cm and 30 cm depths showed higher values than those for Peat 2. The difference in solid constituent (i.e., organic matter and small amount of mineral component) might affect the TC behaviors for Peat 1 and Peat 2 samples, as partially expected by lower loss in ignition (Li) values for Peat 1. Detailed physical properties for Peat 1 at 20 and 30 cm samples will be further investigated.

Similar to the TC data, the HC data for all soils (including reference HC data for four different sand size fractions) linearly increased with increasing volumetric water content (Figure 2b). The HC for Peat 1 at 20 cm and 30 cm depths showed higher values as compared to other peat soils and predictive line. In addition, the HC behavior for the Peat 1 at 20 cm and 30 cm depths under dry condition was similar to those for the sandy soils, likely supporting the unique solid constituents for the peat soils, which significantly governs the HC behaviors.

4 Conclusions

The thermal conductivity (TC) and heat capacity (HC) of the peat soils are mainly affected by the volumetric water content, showing the linear increase of TC and HC with increasing water content. The trend was generally described by simple two-phase (i.e., volumetric fractions of organic matter and water) models, respectively, except for the data for Peat 1 at 20 and 30 cm depths. It was suggested that the difference in solid constituent for the peat 1 at 20 and 30 cm depths might affect the TC and HC behaviors. In addition, clear shrinkage effects on the TC and HC were not observed for studied samples.

In perspective, with accumulations of TC and HC data for soils including more decomposed peat soils and micro-scale observations of pore structure e.g., using X-ray CT scanner, the effects of complex soil-pore structure induced by rich organic matter on thermal properties should be further investigated and accurate predictive TC and HC models available for peat soils will be developed.

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