A METHOD FOR MEASUREING THE PERMITTIVITYOF ARTIFICIAL FROZEN SOIL USING NETWORK ANALYZER

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ABSTRACT:

Frozen soil is best observed by microwave remote sensing due to the big difference of the permittivity comparing with unfrozen soil. The dielectric property of frozen soil has much relation with its microwave radiation. So permittivity is a bridge parameter in monitoring the status of frozen soil and its water content using microwave remote sensing. However, little data of the permittivity of frozen soil has been published. This has restricted the development of permittivity model of frozen soil profoundly. We got soil of different texture from wild field in northern china where seasonal freeze/thaw occurs every year, prepared these soil to frozen soil samples of different temperature. Many problems occurred during the measurement using a network analyzer and a high temperature probe. Among these difficulties the preparing of frozen soil samples, the control of temperature and water content of frozen soil samples and the contact between sample and probe are most significant. These difficulties are finally solved by designing a sample holder. The sample holder ensures the accuracy and repeatability of the measurement of the permittivity of frozen soil. A set of measured data show that the results are credible.

1. INTRODUCTION

Frozen soil either permanent or seasonal covers nearly 80% of the total land area in the northern hemisphere. The freezing and thawing process of frozen soil is of great significance for climate and hydrology modeling and further understanding of global change. Microwave remote sensing is a effective technology in monitoring the temporal and spatial distribution of this process. The permittivity of the soil surface is a key parameter in modeling the scattering and emission of microwave signature. And the state of frozen soil is inferred based on the knowledge of the relations between the properties and the permittivity of frozen soil.

Many experiments have been conducted in order to determine the dielectric behavior of soil with different water or saline content in the microwave region (Martti et al., 1985; John 2001; S; Olhoeft, 1977). Data from these experiments are used to support the dielectric model of soil. However, few have measured the permittivity of frozen soil in a wide range of frequency.

Many methods were used to measure the dielectric properties of soil under the room temperature. However, when the soil is frozen, the soil water change into ice and the soil sample becomes hard. These methods can’t be applied to measuring frozen soil directly.

The purpose of this paper is to design a feasible method for measuring the permittivity of frozen soil in the laboratory using a microwave network analyzer over a wide range of frequency which covers the mostly used wave bands in microwave remote sensing. In section 2, the measurement system and a sample holder designed for frozen soil are presented. In section 3, frozen soils of different water content was measured using this method. Permittivity data of these soils are compared with values computed by model.

2. MEASUREMENT SYSTEM

2.1. The Network Analyzer

A network analyzer is used to carry out the measurement. We use a Agilent vector network analyzer and a 85070E Dielectric Probe Kit which contains a high temperature probe. The high temperature probe withstands a wide –40 ºC to +200 ºC temperature range, which allows measurements of frozen soil. This method is called the coaxial probe technique. The material is measured simply by placing the probe on a flat face of a solid or immersing it into a liquid. (Fig.1)

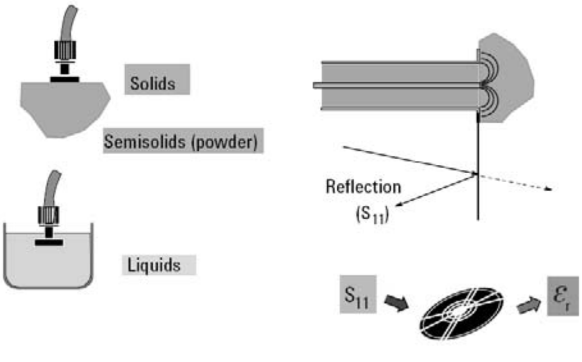

Figure 1. Illustration of coaxial probe

The probe transmits an electromagnetic wave in a range of pre-determined frequencies and captures the reflected part which is not transmitted. Software is then used to compute the permittivity from the coefficient of reflection.

The coaxial probe model which is used to compute permittivity assumes both an infinite ground plane and semi-infinite sample size. However, from a practical point of view, these assumptions are justified if reflections from finite boundaries are not sensed at the probe aperture. The sample requirements of this method is

$$Diameter > 20mm$$

$$Thickness > \left|\frac{20}{\sqrt{\varepsilon^*}}\right| mm$$

where ε^* is the complex permittivity of the sample (Agilent, 2003) . In fact, a thickness of 2cm is thick enough for most dielectric.

The error of the analyzer is calibrated before measuring the permittivity of the sample by measuring three standards: 25℃ deionized water, air, and a short circuit. In addition, a “refresh calibration” is required to be performed just before each measurement to eliminate the error caused by temperature change and the cable instability. To perform the “refresh calibration” the re-measurement of a single calibration standard is needed.

2.2. Soil Samples Preparation

Soil samples were obtained from the Wali region of north Beijing, China. The soil type was silt loam (sand: 32.56%, silt: 62.83%, clay: 4.21%). Soil gathered form the field needs to be grinded and filtrated by a 2-mm sieve to exclude large aggregates and assure the homogeneousness of the soil samples. Then they were mixed with calculated quantities of pure water, placed in sealed plastic boxes, and set aside for 48 hour to allow the water content to come to equilibrium. We prepared soil samples with different volumetric moisture content (5%, 10%, 15%, 20%, 25% and 30%). Soil samples that have low water content may need more time to be homogeneous, so it’s practical to set them aside for more time before measuring. Make sure that the soil in the box is enough for the whole measurement process.

2.3. Sample Holder and Measurement

After the soil samples are homogeneous, we pick some moist soil from these boxes, sealed the soil container, put them into the temperature controller to make frozen soil. Before freezing, a flat surface of the soil sample is needed in order for a perfect contact with the probe when measuring. But the former shaped flat surface becomes uneven because of the freezing and swell of the soil water. In addition, there are frost concentrates at the surface due to the evaporation-congelation effect during the freezing process. The frost may melt into water when contact the frozen soil sample to the probe which has a room temperature. These difficulties make it impossible to measure the permittivity of frozen soil in the way used in the measurement of unfrozen soil. There are three main difficulties in all:

(1) The soil sample must be homogeneous and isotropic;

(2) Make sure that the surface moisture doesn’t change during the freezing procedure；

(3) Ensure that the probe contact well with the surface of the frozen soil sample, so that there is no air between the probe and the frozen soil；

(4) Make sure that the frozen soil doesn’t melt or change temperature when contacted with the probe, it requires that the temperature of the probe and the frozen soil samples are of the same.

A sample holder was designed to solve these problems. The sample holder is made of stainless metal. It has two parts as shown in Figure 2. The left part is has a cylindrical space in the center which is to be filled with soil sample. The space is large enough (d=21mm which is 1 mm longer than that of the probe) to meet the requirement of being equivalently semi-infinite. It has no bottom, and the end of the wall is shaped like a circular wedge.

Figure 2. The sample holder

This kind of design aim to facilitate the procedure of taking the moist soil out from the boxes in which it becomes homogeneous. During this step one simply needs to press this part of the sample holder vertically into the moist soil and the soil sample filling the space is not disturbed. Then screw the right part of the sample holder to the bottom of the left part. The two parts are joined by the screw. There is cylindrical steel convex at the center bottom of the right part which can not be seen in Figure 2. The soil in the left part of the sample holder can be pushed up by screwing the right part. When the probe was connected to the left part (Figure 3), screwing the left part will squeeze the soil to the probe allowing no interspaces between them. At the same time this will change the density and the volumetric water content of the soil sample. The volume of the cylindrical soil sample in the sample holder can be calculated according to the position where the left part was screwed to. So the density and the volumetric water content become controllable to some extent.

After the probe and the sample holder are connected tightly, they were frozen together in the temperature controller to an expected temperature. A thermometer was set in the temperature controller to supervise the actual temperature of the frozen soil sample by measuring the soil that has the same properties with the soil measured by the probe. Because the soil in the sample holder was nearly sealed by the sample holder and the probe, there would be little loss of moisture during the whole measurement. When the expected soil temperature was achieved, a measure of permittivity was triggered. Then the real part and the imaginary part of the measured complex permittivity were shown on the screen of the network analyzer respectively.

Figure 3. The probe and the sample holder in temperature controller

The four main difficulties mentioned before are solved during this procedure. However, the refresh calibration can not be performed in the process of measuring frozen soil using the method shown above. To solve this problem, we used a cable the shape of which was always fixed and not easy to change in order to minimize the error. A comparative experiment showed that this disadvantage caused a error less than ±3% of the measured permittivity over the range of the pre-determined frequencies.

3. MEASUREMENT RESULTS

The measured results are shown in Figure 4.

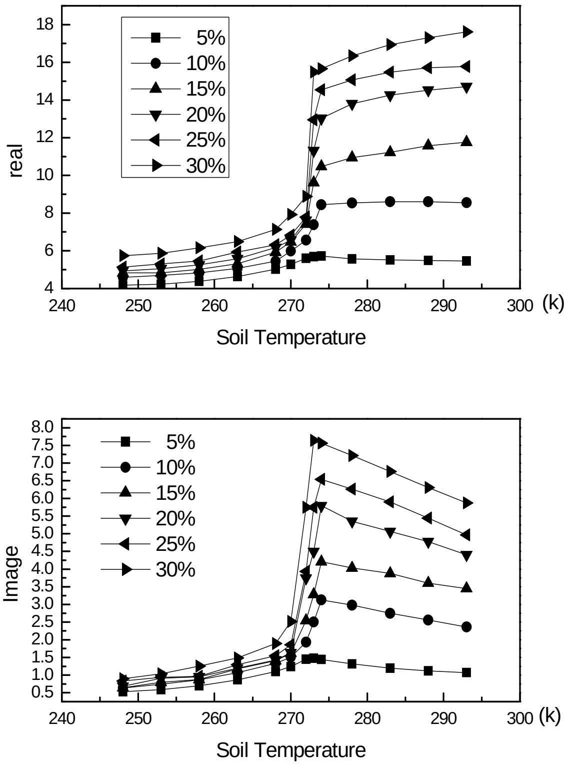

Figure 4. The measured soil permittivity in frequency of 6.89GHz with different water content and temperature

These results are reasonable comparing with the calculation results by Zhang (Zhang et al., 2003). Repeated measurements for the same soil sample were conducted. The relative measurement errors change with water content, temperature and frequency but are less than 5%. These errors are probably due to tiny differences of water content and density of the soil sample.

4. CONCLUSION

Measuring frozen soil is different comparing to measuring unfrozen soil using a network analyzer. The sample holder and the method presented in this paper can solve the problems encountered when measuring the frozen soil directly and ensure the accuracy and repeatability of the measure of the permittivity.

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