Determination of water content in clay and organic soil using microwave oven

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Abstract. The article deals with the techniques of soil water content determination using microwave radiation. Its practical application would allow solving the problems of resource efficiency in geotechnical survey due to reduction of energy and resource intensity of laboratory analysis as well as its acceleration by means of decreasing labour intensity and, as a result, cost reduction. The article presents a detail analysis of approaches to soil water content determination and soil drying, considers its features and application. The study in soil of different composition, typical for Western Siberia including organic and organic-mineral ones, is a peculiarity of the given article, which makes it rather topical. The article compares and analyzes the results of the investigation into soil water content, which are obtained via conventional techniques and the original one developed by the authors, consisting in microwave drying. The authors also give recommendation on microwave technique application to dry soil.

1. Introduction

When developing modern economy the most urgent task is to increase the resource efficiency in all branches of industry. Particularly, in building industry one of the most significant stages is engineering-geological survey. One of the main trends in solving this problem is time reduction of soil tests and increase in field and laboratory work efficiency due to rapid dry of disperse soils when determining water content, preparing samples for grading test, water permeability test, natural slope angle determination, solid particles density and other tests. In international practice, household microwave ovens are widely used to dry soil, which reduces the time of soil water content determination, test and facility cost. Therefore, a comparative analysis of water content determination of clay and organic soils in microwave and drying ovens is of particular interest.

The purpose of the article is to study the process of drying clay, organic, and organic-mineral soils in microwave oven to determine their water content. The tasks include: review of domestic and foreign literature dealing with methods of soil water content tests; identification and description of specific features of clay and organic soil drying, laboratory test to determine the identification indicators of soil composition and physical properties, determination and comparison of their water content when drying in microwave and convection ovens, developing brief recommendations on using microwave oven to dry finely dispersed soils rapidly.

As it was evident from the literature and standard review, there are many ways of soil water content test [1-18]. In our case, according to the existing specifications, the drying technique in convection oven up to constant moisture is required. According to GOST 5180 [2] soil samples of 15-50 g (10-20 g for hydroscopic content, 10-15 g for water content at plastic limit) are dried at temperature 105±2 °C during 5 hours, after that soil samples are weighed in 2 hours before mass difference at two series weighing of not less than 0.02 g. According to GOST 11305 [3] peat samples of 5–10 g are placed in the oven heated up to 105–110°C and dried during 2.5–4.0 hours, after weighing the portions are dried during 30 min, if losses are not more than 0.01 g, test ends. Using rapid technique [3] the peat portions of 5–6 g are placed in the oven heated up to 165–170 °C, after which they are dried at 145–150 °C during 30 min, but at water content (water content is a relationship of water weight to the initial weight of wet peat) more 55 % – 45 min. According to ASTM D2216 [17] drying of dispersed and rocky soil is performed at 110±5°C. To decrease gypsum dehydration of saline soil or organic loss in peats, they are dried at 60° C or in a desiccator.

According to ASTM D 4643 [18], to determine water content a portion of 100-200 g (for soil containing up to 10 % of fraction more than 2 mm) are placed in the oven for 3 min at defrost mode, then after a minute it is weighed up to the moment when the weight loss is less than 0,1 % at reweighting. The initial time of clay soil drying can be increased up to 12 min. Water content is calculated as a relationship of water weight to the dry soil weight with accuracy up to 0.1 %.

Clay and organic soils have a number of features developed while drying. Organic soils can lose organic matter and increase in mass after removal of free water. As for clay soils [19], the processes taking place at their firing are divided into several stages depending on the temperature. The 1-st stage of water removal includes three phases: water movement inside the clay soil, vapor development, and vapor transfer from the surface. Oversanded clay is less sensitive to drying than clays with more content of clay particles. The process of water removal is reversible and, after water saturation, clay has the same plasticity as before drying. Some researchers have indicated some loss of swelling property.

Drying depends on mineral composition of clays: montmorillonite gives off and preserves water slowly and heavily. The value of relative drying shrinkage is within the range 2-8 %, dispersed clays show more shrinkage, oversanded clays – less one. At temperatures from 100 to 400 °C the 2-nd stage is observed: in the course of water removal montmorillonite losses 5-6 % of chemically bound water (2/3 of the whole water content), kaolin - 13 %. Within this period the crystal lattice of clay minerals weakens and there occurs a preparation for the third stage – dehydration process taking place at temperatures from 400 to 700 °C [19]. As T.G. Makeeva and Yu.M. Yegorov stated [20], *"microwave field have an effect on soil at the atomic-molecular level generating dielectric heating. In this case there is a migration of moisture and phase transfer of bound water in soil depending on the structure and texture of soil and molecular-structure features of water as well as microwave field parameters and polarization at the interface of bound water and transition water. Energy absorption of electromagnetic waves from absorbed water of dispersed system is a limiting stage and corresponds to the water-binding energy equal to the value of layered charge by radiation frequency"* [20].

According to Prokhina A.V. [21], X-ray diffraction analysis shows that no significant changes are observed at clay microwave treatment. Grouping in terms of the particle sizes indicates that in samples of green clay the prevailing fraction is particles of 5-10 mkm radius, but after microwave treatment the particles of radius less than 0.01 mkm prevail. Uniform sample heating in microwave oven is an advantage of the technique [22]. In drying ovens at temperature 100–160°C the loss of physical and weakly bound water is observed. Sample drying occurs from the edge to the center, which is the main disadvantage, as due to low heat conductivity insufficient energy penetrates to the inner part of sample to evaporate water.

As a result of brief review, it should be noted that despite complexity and ambiguity of clay and organic soil drying in microwave oven, free water is largely removed from them and, as it has been mentioned, ovens are rather helpful for soil laboratory tests [26, 27].

2.Materials and methods

In this article the authors study typical for Western Siberia peats, clays, and peaty soils (table1, figure 1) from different sites: Bely Yar settlement (№1-7), Dvurechensk oil field (№ 8, 17, 18), Kalinovoye field (№ 13-15), Danenbergovsk field (№ 9,16,17), and from sites of Tomsk city (№ 10-12). According to the methods [1-4, 18, 23-25], the following values were determined: water content (*w*), organic content (I_r), and water content at plastic and liquid limits (w_L and w_p) of clay and peaty soils.

In laboratory tests the following equipment was used: drying oven DO–0.25–100, air-dry chamber ADC–80–Kasimov, microwave ovens LG of 900 Watt power and Wellton WMO–1700GW of variable power, balance of the accuracy 0.01. To compare the results of drying in convection and microwave ovens every soil sample was divided in two parts and, according to the methods [2, 18] 4-8 portions of different weight and/or different water content were selected from every part. Drying was performed up to the moment of soil mass difference with container at two series weighings not more than 0.02 g [2]. The time of sample drying in convection oven met the specifications [2, 18], the test time in microwave drying was defined by water content and sample weight.

Table 1. Results of water content determination in clay and peaty soils

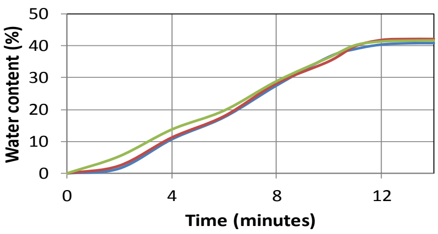
№ sample	Soil type	Mass of charge, g	Water content, % when drying in oven: microwave			convection		
			average	minimum	maximum	average	minimum	maximum
1.	Clay loam (Bely Yar settlement)	50	26.3	25.5	27.3	25	24.5	25.7
2.	Clay loam (Bely Yar settlement)	15	25.7	24.5	26.8	25.3	24.3	26.3
3.	Clay loam (Bely Yar settlement)	100	42	41	42	41	40	41
4.	Clay loam (Bely Yar settlement)	9-10	15.5	14.8	15.9	16.7	16.5	16.9
5.	Clay loam (Bely Yar settlement)	18-22	32	32	33	33	33	33
6.	Clay loam (Bely Yar settlement)	18-22	21.8	21.2	22.3	23.8	22.4	25.8
7.	Clay loam (Bely Yar settlement)	18-22	19.8	19.7	19.9	19.5	19.2	19.8
8.	Clay loam (Dvurechinsk field)	18-22	35	35	36	35	33	37
9.	Low peat clay loam (Danenbergovsk field)	18-22	30	29	31	29	27	30
10.	Clay sand (Tomsk, Solyanaya st.)	18-22	24.4	23.6	25.2	24.3	23.5	24.6
11.	Clay sand (Tomsk, Solyanaya st.)	30-40	20	19.6	20,3	20	19.7	20.4
12.	Clay sand (Tomsk, Ivanovskogo st.)	40-50	14.3	14.1	14.7	14.1	13.8	14.6
13.	Clay (Kalinovoye field)	18-22	32	32	33	33	33	33
14.	Clay (Kalinovoye field)	18-22	24.7	24.1	25.1	25.6	25.2	26
15.	Clay (Kalinovoye field)	18-22	17.3	16.9	17.8	16.2	15.8	17
16.	Low peat clay (Danenbergovsk field)	18-22	58	56	60	60	58	61
17.	Least decomposed moss peat (Dvurechinsk field)	15–20	2527	2253	2794	2816	2390	3003
18.	Least decomposed moss peat (Dvurechinsk field)	5–10	2513	2200	2754	2587	2250	3063
19.	Least decomposed moss peat (Dvurechinsk field)	100-200	3188	3125	3255	2994	2412	3327

Tests were performed using several schemes: the same soil of different water content and in portions of different weight (table 1, samples № 3-7, 13-15); at different water content in the same portions (№ 5-10 and № 13-16); at the same water content (№ 1, 2 and № 17, 18) at water content of plastic limit by compression (№ 4).

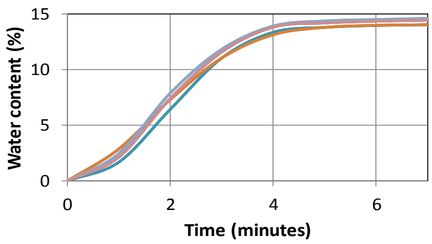
3. Results and discussion

In the course of drying tests it was observed that from the very beginning of test intensive evaporation is typical for almost all studied samples (figure 1). The given stage took from 30 (most samples) to 80% of test time, which was defined by both sample water content and its initial weight (figure 1).

Clay soils gave positive results: in most cases the spread of water content values met the specification requirements for the results of simultaneous determinations of the parameter at microwave and convection drying (table1). The permissible ranges were exceeded for the portions of 15 g (№ 2), which was not evidently enough to obtain reliable results for clay of natural moisture. At the same time sample № 4 of 9-10 g (after compression) had an acceptable spread of values.



a)



b)

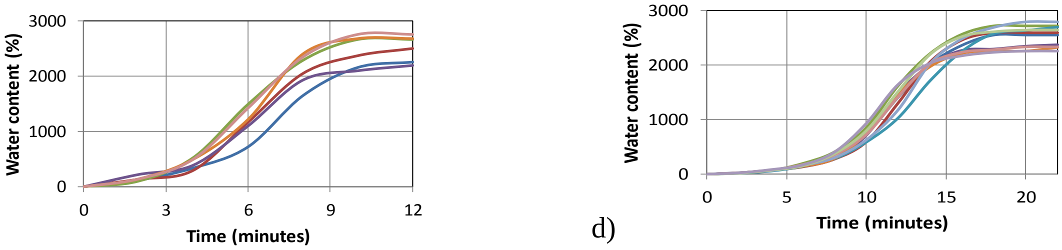


Fig. 1. Dependence of soil water content on drying time: a) clay loam and b) clay c) least decomposed moss peat (5-10 g); d) least decomposed moss peat (15-20 g)

Right after beginning of drying, a dense dry crust formed on the clay soil samples. Further evaporation through it took place with strong heating of the sample. Hence, it was necessary to mix soil after the first weighing to give it a shape providing more evaporation area.

The study of peat has shown that spread of water content values while drying in microwave oven is higher in most cases than at drying in convection oven (table1, figure 1). In both cases it does not meet the specification requirements for the results of simultaneous parameter determination (at moisture more than 100% the permissible difference is 5% [2], water content – 1 % [3]). Maximal water content (1500–3000 % and more) is registered for the samples of low decomposed moss peat. The spread of its values and drying time increase as the water content grows. With the increase in the weight of portions from 5-10 to 15-20 g, the spread of values decreases (figure 1, c, d; table 1). The increase in sample number up to 8–10 portions did not improve the results as well (figure 1, c). For the sample weight of 100–200 g of moss peat from the other site (№ 19) significant variations of simultaneous determination were also observed.

Consequently, it is necessary to distinguish good reproducibility of the results obtained by both methods as well as the fact that spread of values obtained by microwave technique is comparable with that of conventional technique of convection heating. While mineral soil has a narrow spread of water content values [26], as it has been demonstrated by working at undrained peats [27], it is not simple to obtain the same results for peats. Therefore, it is appropriate to determine the parameters of physical properties using one portion [4], increasing the number of selected samples up to 15–20, taking into account their different types. In all test there was no increase in soil weight at control weighing.

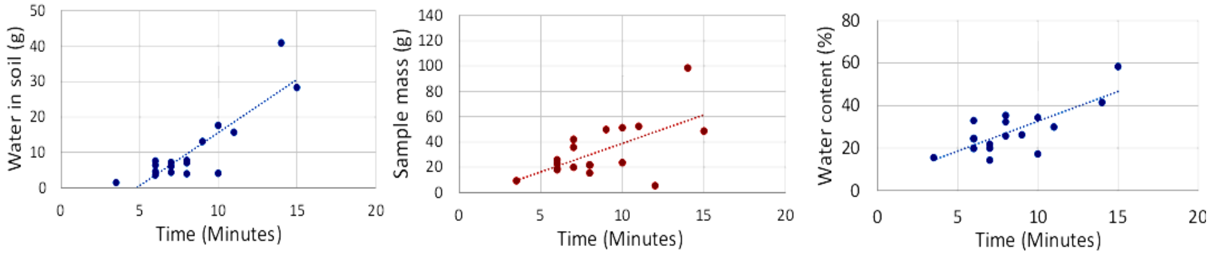


Fig. 2. Dependence of water in soil (a), sample mass (b) and moisture (c) on soil drying time

To analyze the effect of such experimental factors as water content and sample weight on the time of drying, they were compared side-by-side by means of dependency graphs showing the determination coefficient (figure 2). It was revealed that the maximum determination coefficient R^2 =0.75 was obtained for dependency of water weight in a sample on the drying time (figure 2, a). The determination coefficients R^2 were considerably less (0.58 and 0.38, respectively) and characterized the dependencies of drying time on water content and portion weight of the initial soil samples (figure 2, b, c). Hence, it is obvious that in case of clay soil samples the drying time depends mostly on mass of containing water. It is defined by the fact that drying is regulated by, first of all, absorbed microwave energy used for heating liquid volume in a sample and, to a lesser extent, depends on sample structural features and its initials parameters that are characterized by its initial weight and natural moisture. From the practical point of view it means that optimal weight of sample portion may be considered the one at which the obtained results would have good repeatability with each other and the results obtained by conventional methods.

The tests allowed developing some recommendations to improve the technique of water content determination using microwave oven for cohesive soils.

1. Application of microwave oven eliminates the use of metal containers, therefore, it is recommended to use porcelain ones. Samples should also contain low amount of conducting minerals.

2. The optimal weight of portions is recommended to be in the range from 20 to 50 g, which corresponds to the existing specifications. To determine water content at plastic limit, the portion weight of 5-10 g would be enough. The optimal portion weight is defined by the initial soil water saturation and ranges from 15 to 50 g for medium-, highly decomposed peats and organic mineral soils. For low decomposed water-saturated peats the portions of more than 100 g are recommended to be used, the number of samples being not more than 2–3. At multiple water content determination it is reasonable to use rapid method according to [4].

3. The time recommended for drying to determine water content is 10–15 min and more – for clay with high water content (40-50%); 10 min – for peaty soil; 5 min – to determine hygroscopic water content, clay sand water content, and water content at plastic limit of all clay soil types. The intervals between control weighing are 1–2 min. The drying time of peat portions of more than 100 g is 30–40 min, weight 30–50 g – 10–15 min, weight 5–10 g – 3–5 min. The intervals between control weighing of portions of more than 50 g is about 3–5 min and 1–2 min of portions more than 5–10 g and low peaty soil.

4. Increase in evaporation area of test samples would allow intensifying the soil drying process by means of their thin layer rolling and covering the channel surface, using pallet knife as well as their mixing at control weighing.

4.Conclusions

Hence, the research results have proved that household microwave ovens are an effective means to rapidly determine water content in clay, sandy, and organic soils [26, 27], since tests are carried out in shorter time and the results obtained are more accurate than they are when using drying ovens. An attractive feature of this technique is that sample weight does not increase in control weighing at microwave drying (figure 1), which increases the accuracy of soil water content determination. The authors anticipate that the suggested recommendations would allow wide application of low-cost technique in both field and laboratory conditions, as well as its possible inclusion in the updated version of GOST 5180 as an additional method.

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