Time Domain Reflectometry Usage to Moisture Content Estimation in Electrically Conductive Mineral Wastes

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Abstract. The article presents the possibilities of using domain-time reflectometry (TDR) to determine the moisture content of waste. The TDR method consists in measuring the time of electromagnetic pulse transmission and reflection from the obstacle back to the source point. The impulse is a step signal of voltage. The reflected signal contains information about the dielectric properties of the material being tested. Therefore, qualitative and quantitative properties of the material can be detected. The tests were carried out using a stationary reflectometric device and an electronic temperature and humidity meter. The obtained results were validated using the traditional weight method, obtaining 94% convergence of results in the measurement cycle. On the basis of the obtained results, the usefulness of reflectometric methods in the study of the moisture content of wastes was determined.

Keywords: Reflectometry · TDR · Moisture · Waste

1 Introduction

Studies on municipal solid waste (MSW) require constant control of many physical parameters that determine the degree of their processing. Currently, many scientific centers are working on changing traditional measurement technologies to modern systems that allow to control biodegradation processes in an automated manner. The commonly used trend in humidity monitoring is its simultaneous measurement with temperature and pH conditions [7, 8].

The most popular technique for determining moisture content in waste is thermogravimetry (oven drying). This method requires appropriate measurement conditions and belongs to a group of destructive and local measurements. In order to avoid measurement errors, they are increasingly replaced with methods known from agriculture, which belong to fast and non-destructive measurement groups [7, 11].

The classic technique for determining moisture content is the gravimetric method. The principle of this measurement method is to determine the water content, which

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evaporates from the sample during drying at 105 °C. The disadvantage of this method is the use of material samples of relatively low weight (up to 1 kg), which are collected in a selected batch of waste. According to this research method, it often leads to erroneous inference resulting from the evaporation of water during the transport of waste from the place of their collection to the laboratory [4, 10].

Due to the problem of changes in moisture content of waste samples during transport, for many years work has been underway on the use of electrical and electromagnetic properties of waste for the study of humidity. These methods have been known for many years in soil research techniques [5, 8].

Time-domain reflectometry is an electro-magnetic measurement technique used to determine the electrical conductivity of materials - dielectric and spectroscopic properties of materials; qualitative and quantitative control of liquids; examinations of vegetable oils; cable fault detection; and measurement of soil moisture [1, 2].

The method uses special measuring probes that measure the electric pulse flow time in the aqueous solution around the waste between the probe electrodes. The probe consists of two electrically connected waveguides: concentric and parallel (formed by two parallel metal rods). An initial voltage spike with a fixed rise and fall time runs from the generator towards the sensor. The recorder register its course as it passes the splitter. The measurement results are recorded in the form of a waveform, showing the relationship between the time of electrical impulse flow and the length and distance of the electrodes in the probe (Fig. 1). On this basis, the dielectric constant (bulk electrical permittivity) is determined [8, 9].

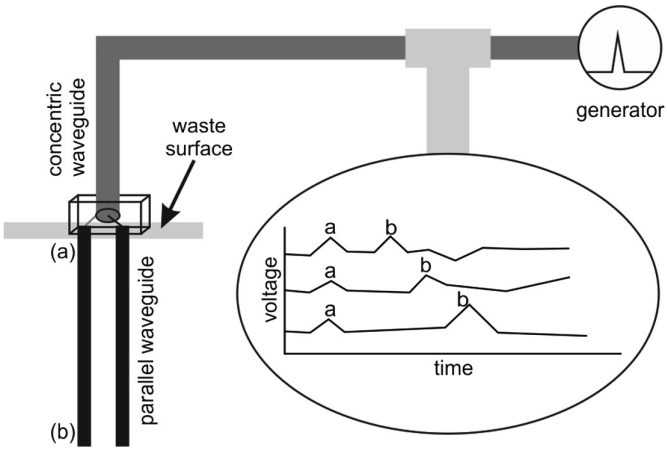

Fig. 1. TDR measurement method scheme

A comparison of the presented methods for determining moisture in waste is presented in Table 1.

Table 1. Advantages and disadvantages of gravimetric, thermogravimetric, and TDR measurements [5, 10]

Method	Advantages	Disadvantages
Gravimetric	Accurate absolute measure Medium sampling volume Very simple calculation	Questionable sampling locations (heterogeneous material) Destructive Time-consuming preparations
Thermogravimetric	Accurate absolute measure Very simple calculation	Questionable sampling locations (heterogeneous material) Small sampling volume Destructive Time-consuming preparations
Time-domain reflectometry	Inexpensive method Automation possible Non-destructive Possibility of constant measurement	Measurements may be material-sensitive Small measurement volume Needs correction of disturbance material Hard to average measurements

The aim of this article is to use two parallel indirect methods, gravimetric and time-domain reflectometry (TDR). The purpose of the presented paper is to validate and to clarify the limits of gravimetric and TDR for long-term moisture measurements in semi-technological laboratory containers.

2 Materials and Methods

The test installation consisted of a system of 6 rectangular containers with the dimensions of the 2 × 3 m base and a height of 1.5 m. Each container was filled with MSW. The main components of the MSW were ashes (58%), construction waste (17%), paper (15%), plastics (10%). In 2 containers, 3 TDR measurement probes were placed at a depth of 1 m. Samples for comparative tests were taken from the same depth at 6 h intervals in the form of cores with a diameter of 25 mm, from which moisture content was analyzed in the lowest batch of material (Fig. 2). Prior to the measurements, the probes were conditioned in a thermostat, in 0.1 KCl solution and 30°C.

The TDR measurement set consisted of three-rod type probes connected to a coaxial cable with an automatic data acquisition system and a coaxial multiplexer. All set components were manufactured by Campbell Scientific (Logan, UT, USA).

Humidity determined by the gravimetric method was carried out according to PN-Z-15008/02: 1993, using the Memmert UN55 dryer and the Radwag AS.310 analytical balance [3, 7].

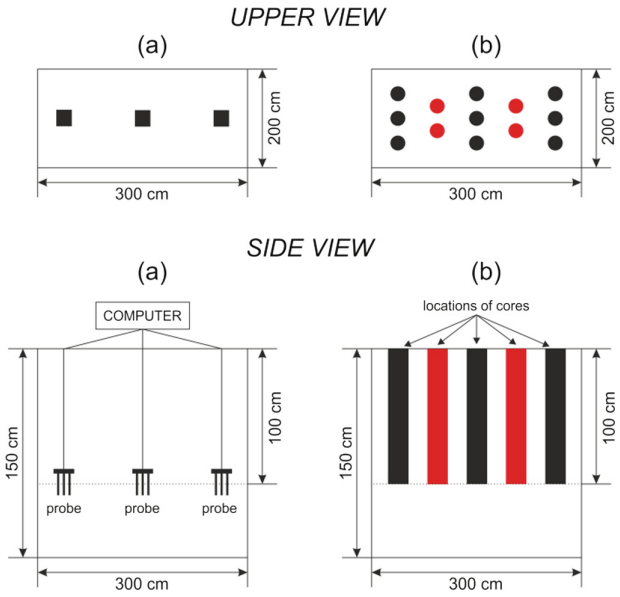

Fig. 2. Scheme of the experimental station - (a) container for TDR measurement, (b) container for humidity measurement by gravimetric method

3 Results

The results of conducted measurements are presented in Figs. 3 and 4. The measurements carried out using TDR probes and the gravimetric method show similar reaction. Analyzing the variability of humidity over time, both methods registered its decrease, but in the case of the TDR method it is clearly non-linear. The resulting differences between the methods can be partly explained by the inhomogeneity of the material or the periodic occurrence of air around the measurement probes. The gravimetric method allows for very accurate determination of humidity, while TDR measures local moisture in the so-called effective volume around the sensor.

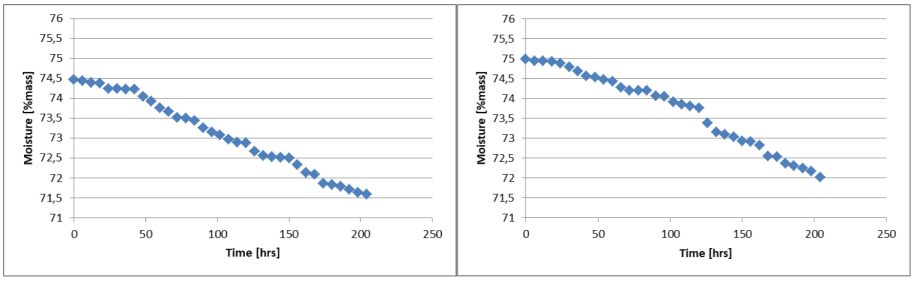

Fig. 3. The results of TDR moisture measurements - container 1 (left), container 2 (right)

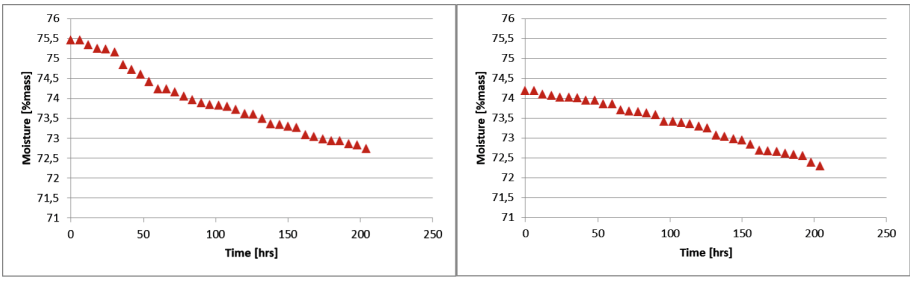

Fig. 4. The results of moisture measurements by weight method - containers 3–4 (left), containers 5–6 (right)

This phenomenon is the cause of undervaluation of the measurement results obtained in the TDR method. This effect has an impact on the slope of the moisture profile seen in Figs. 3 and 4. The standard error of the TDR measurements made was 1.6% with a standard deviation of 0.094%. Gravimetric measurements are characterized by significantly higher accuracy (standard error 0.4% and standard deviation 0.008%).

Comparison of the average values of the obtained results allows to state that the determination of moisture in waste by TDR method can partially replace the gravimetric method. The experiments carried out showed that during the first 100 h of measurement, the obtained values are within the 5% limit of quantification of the gravimetric method. Monitoring of humidity in the next 100 h showed discrepancies between the analyzed methods. It can be seen from Figs. 3 and 4 that the probes, along with the progressing drying of the waste mass, indicated a lower moisture content of the material than the gravimetric method. The cause of this phenomenon is the mentioned inhomogeneity of the material. The TDR method, when measuring the surface moisture of the material, does not show the moisture accumulated in the molecular structure of the waste, which is a source of error in the presented measurements.

4 Summary

The article presents long-lasting moisture measurements of the MSW using the TDR method and gravimetric analysis. The proposed measuring techniques during the tests demonstrated no signs of unreliability or technical problems. Measurements conducted with the use of TDR probes showed a higher measurement difficulty due to the need to place them inside the waste container. In the proposed semi-technical scale, both methods of humidity testing show significant similarity of the obtained results. The use of TDR also allowed to avoid the destruction of the tested position, in contrast to the gravimetric method, which used a total of 10 kg of waste.

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