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APPLICATION OF THE TDR METHOD FOR THE MEASUREMENT OF MOISTURE IN DEGRADED SOIL ENRICHED WITH BIONA-312 SUBSTRATE

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Abstract: The present study aimed at a determination of the formula allowing water content to be calculated for model degraded soil enriched with Biona-312 ion exchange substrate. To this end a mixture of sand and Biona-312 was prepared which was monitored for water content changes. Moisture was determined both gravimetrically and reflectometrically (TDR method). To improve the reliability of the TDR method individual calibration was made. The specific calibration formula as polynomial of the third degree was found for water content determination in sand supplemented with Biona-312. The results confirmed the high potential of the TDR method in moisture monitoring, especially when individual calibration is done.

Key words: Biona-312 ion exchange substrate, moisture, soil, TDR

INTRODUCTION

Time domain reflectometry (TDR) is a method for moisture measurements of porous media including soils. It is an indirect method that determines the water content based on the dependence of the dielectric constant (ε) on electromagnetic signal propagation velocity in the examined medium. The advantage of the TDR method is the possibility of continuous water content measurement and monitoring of the obtained results (Noborio, 2001).

To obtain measurement results as water content in the described method, the registered signal propagation velocity (time) is recalculated into ε and then into moisture (θ) according to certain empirical formulas. Currently to calculate the water content in porous materials Topp's formula or Malicki's formula can be used (Topp *et al.*, 1980; Malicki *et al.*, 1996). The latter is more accurate and determines the water content with the error contained in the range: 0.15 – 0.05 $m^3 m^{-3}$, however it is not an ideal solution. The purpose of the present work was to determine the formula which would allow water content to be calculated with higher accuracy in a model degraded soil enriched with ion exchange substrate Biona-312. The Biona-312 represents a group of ion exchange substrates prepared at the Institute of Physical Organic Chemistry of Belarusian National Academy of Science in Minsk (Soldatov *at al.*, 1978; Soldatov, 1988). Ion exchange substrates are mixtures of ion exchangers saturated with macro- and microelements. They serve as nutrient carriers and can be used as fertilizers intensifying plant cover in the biological restoration of degraded soil (Soldatov *et al.*, 1998;

Chomczyńska and Pawłowski, 2003). The effect of ion exchange substrates on the moisture properties of degraded soil has not been studied so far. To evaluate the influence of ion exchange substrate on water retention in the degraded soil a convenient and adequate method for water content measurement is required. Such a method could be time domain reflectometry with a more reliable formula for recalculating results. To support our proposal of a new formula specific for the studied media gravimetric measurements of water content in the model soil were also carried out. This latter method, being a direct one, is conceived to be more credible than the TDR method and served for the calibration.

MATERIALS AND METHODS

In the studies sand and ion exchange substrate Biona-312 were used. Sand served as a model of degraded soil. It was taken from the sand mine situated in Niemce, near Lublin (Poland). The granulometric sand composition was as follows: fraction with diameter below 0.10 mm – 52%, fraction 0.10 – 0.25mm – 37% and fraction 0.25 – 5.0mm – 11%. Ion exchange substrate Biona-312 was prepared at Institute of Physical Organic Chemistry of BNAS in Minsk (Belarus) and served as a fertilizer additive. It was a mixture of 56% (mass) of ion exchange substrate Biona-111 and 44% of clinoptylolite. The Biona-111 consisted of strong acid cation exchanger KU-2 and polyfunctional anion exchanger EDE-10P mixed in mass ratio: 1:1.5. The mentioned ion exchangers were characterized by total ion exchange capacities of 5 and 11mmolg^{-1}, respectively.

For the needs of the experiment a homogenous mixture of sand with 2% (v/v) addition of Biona-312 was prepared. The bulk density of the mixture was 1,55 g cm^{-3}. The dose of the added Biona-312 was selected from practical and economic considerations (Soldatov *et al.*, 1998). The prepared mixture was placed in six containers of 785cm^3 volume (each). Then, the six volumes of the mixture were saturated to full water capacity and allowed to dry. For 84 days the water content in mixture volumes was measured gravimetrically and using TDR method with Malicki's formula (Malicki *et al.*, 1996):

$$\theta = \frac{\left(\varepsilon^{0,5} - 0.819 - 0.168\times\rho - 0.159\times\rho^2\right)}{7.17 + 1.18\times\rho} \qquad (1)$$

where ε is apparent permittivity (dielectric constant), ρ is bulk density of the examined medium and θ is volumetric water content.

The used TDR setup consisted of electromagnetic pulse generator, concentric cables and six probes. The probes were installed vertically and penetrated the mixture in the each container from the top to the bottom.

The obtained results served to calculate mean values – representing both series of measurements corresponding to both of the used methods. To compare the reliability of both methods significance of difference between mean values was determined using Student-t test at the significance level α=0.05. For the same purpose, linear correlation analysis was carried out for the results obtained with the use of both methods (Zgirski and Gondko, 1998; Zieliński and Zieliński, 1991). To develop a new formula for recalculating ε into water content values, the curvilinear dependence was established between the values of dielectric constant and moisture determined using the gravimetric method (Zając, 1988). To compare the reliability of the gravimetric method and the TDR method with the newly developed formula, linear correlation analysis was carried out and the significance of difference between mean values was determined again.

RESULTS AND DISCUSSION

The results obtained using the gravimetric and the TDR methods (Malicki's formula) are presented in Fig. 1 (line and circles). Clear differences in the moisture are apparent, especially in low levels. The mean values for both considered series of measurements ($0.0717 m^3 m^{-3}$ and $0.0817 m^3 m^{-3}$) differed significantly at $\alpha=0.05$ (Table 1). The correlation analysis indicated that the "a" regression coefficient was out of a range from 0.98 to 1.02 as well as the "b" coefficient (intercept) was different from 0 (Fig. 2). Thus, statistical analyses proved that both applied methods differed in reliability (Zigirski and Gondko, 1998). That is why the application of a new formula was required. The formula was estimated by searching for the equation describing the relation between water content (determined gravimetrically) and dielectric constant (determined with the TDR device) – Fig. 3. The obtained polynomial formula was as follows:

$$\theta = 5 \times 10^{-5} \times \varepsilon^3 - 2.75 \times 10^{-3} \times \varepsilon^2 + 5.82 \times 10^{-2} \times \varepsilon - 0.14034 \quad (2)$$

where: ε is the dielectric constant determined using the TDR device and θ is volumetric water content.

The TDR measurements (marked by the triangles) showed good agreement with the gravimetric measurements (marked by the line) – Fig. 1. Correlation analyses proved that application of the new formula allowed moisture measurements to be more reliable than those obtained with Malicki's formula. Figure 4 presents the relation between the gravimetric and reflectometric (TDR) measurements and indicates that the regression coefficient had a value in the range between 0.98 and 1.02 and a coefficient "b" of close to zero. The mean values calculated on the basis of measurements obtained with the gravimetric method and TDR method with the new formula ($0.0717 m^3 m^{-3}$ and $0.0719 m^3 m^{-3}$) did not differ significantly (Table 1). It also proved that both methods had the same reliability.

Table 1. The significance of differences between mean values for measurement series obtained with studied methods

methods	mean values	t_d	t_t	differences
gravimetric TDR (Malicki's formula)	0.0717 0.0817	2.4520	2.0211	significant
gravimetric TDR (our new formula)	0.0717 0.0719	0.6074	2.0211	insignificant

Explanations: t_d – experimental value of Student-t test, t_t - theoretical value of Student-t test

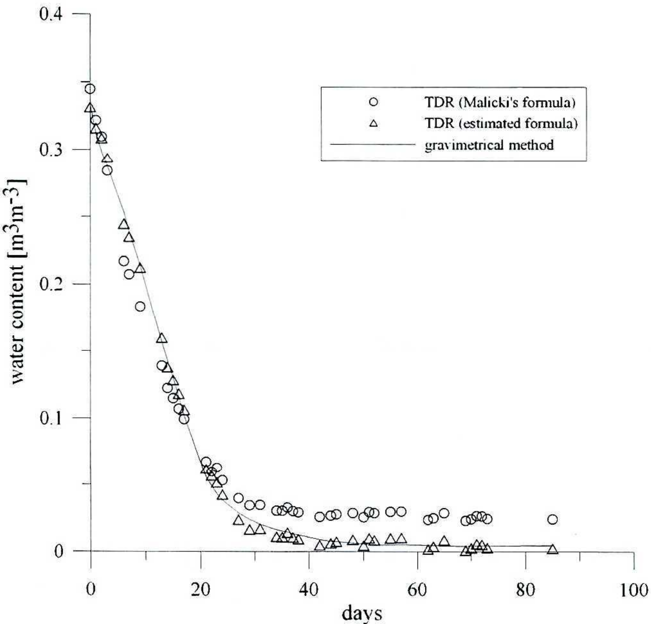

Fig. 1 Water loss rate in studied medium

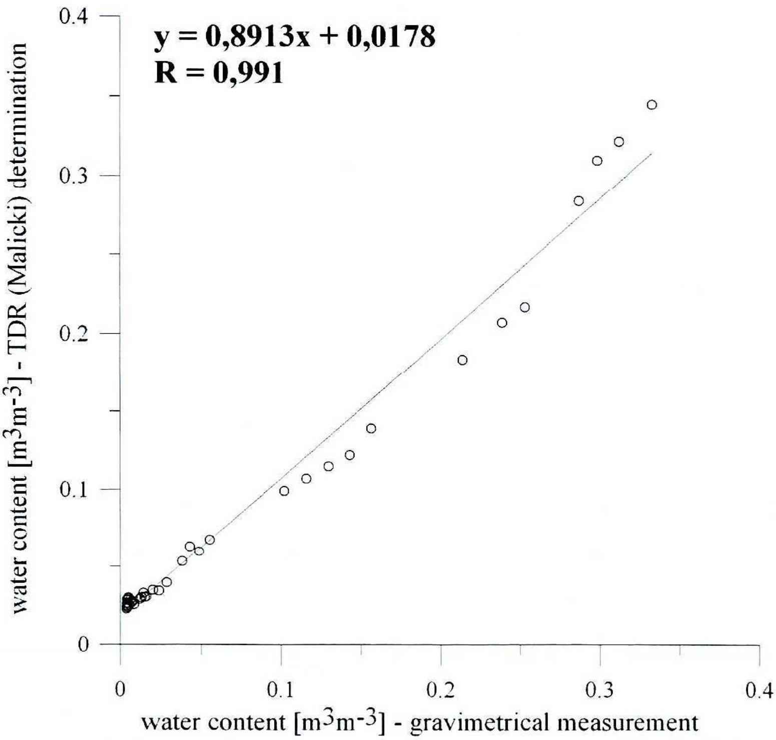

Fig. 2 Comparison of results between the TDR method (Malicki's formula) and the gravimetric method

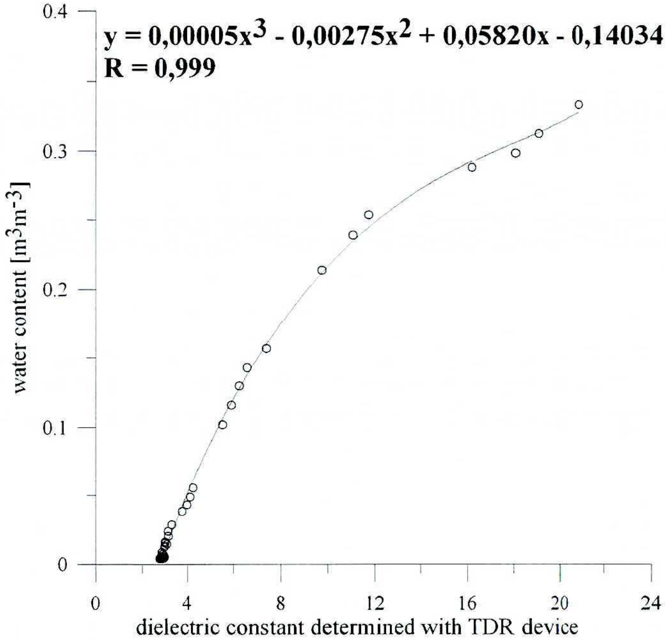

Fig. 3 Dependence of the moisture and dielectric constant for the studied medium

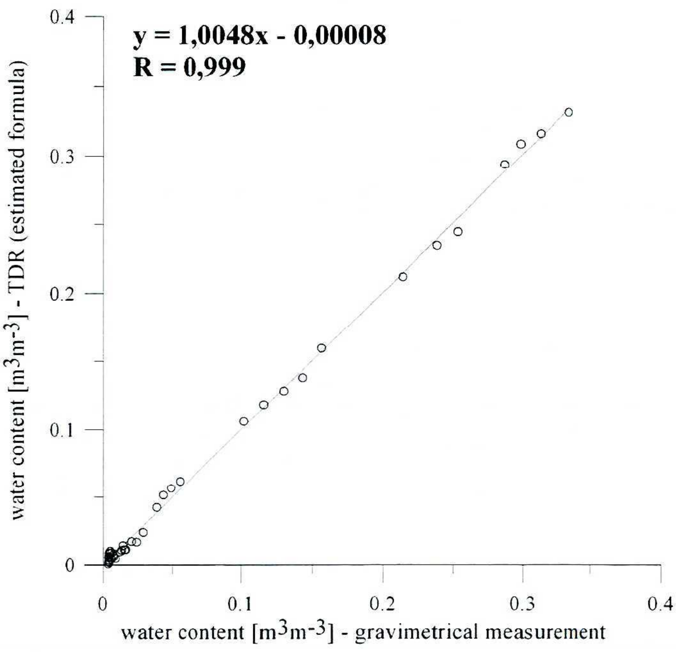

Fig. 4 Comparison of results of the TDR method (the new formula) and the gravimetric method

The new formula found in our studies is similar to the equation proposed by Ren *et al.* (1999), where a relation between the dielectric constant and water content in sand and clay loam was as follows:

$$\theta = 8.76 \times 10^{5} \times \varepsilon^{3} - 4.03 \times 10^{-3} \times \varepsilon^{2} + 7.01 \times 10^{-2} \times \varepsilon - 0.161 \qquad (3)$$

A different formula, describing the relationship between water content and ε was found by Noborio *et al.* (1999) for clay loam. The authors related the volumetric water content with dielectric constant using a general formula:

$$\theta = a + b \times \varepsilon^{c} \qquad (4)$$

where a, b and c were the calibration constants.

For the examined material these constants were a = -0.0340, b = 0.0458 and c = 0.718 with r = 0.993 which was lower than that determined for our new formula.

The formulas describing the relationship between volumetric water content and dielectric constant obtained by fitting the TDR results to gravimetric measurements were presented by Sobczuk et al. (2005) in the case of moisture measurements for building materials. The calculated formulas for autoclaved aerated concrete with different bulk densities (400, 500, 600 and 700 kg m^{-3}) were also polynomials but of the second degree:

$$\theta_{400} = -1.0 \times 10^{-3} \times \varepsilon^{2} + 4.26 \times 10^{-2} \times \varepsilon - 3.37 \times 10^{-2} \qquad (5)$$

$$\theta_{500} = -7.0 \times 10^{-4} \times \varepsilon^{2} + 3.336 \times 10^{-2} \times \varepsilon + 2.02 \times 10^{-2} \qquad (6)$$

$$\theta_{600} = -5.0 \times 10^{-4} \times \varepsilon^{2} + 2.87 \times 10^{-2} \times \varepsilon + 6.8 \times 10^{-3} \qquad (7)$$

$$\theta_{700} = -7.0 \times 10^{-4} \times \varepsilon^{2} + 3.29 \times 10^{-2} \times \varepsilon - 1.05 \times 10^{-2} \qquad (8)$$

Application of these formulas allowed TDR measurements to be more compatible with gravimetric measurements than those obtained with Malicki's formula. Assuming that the gravimetric method is highly reliable and the results obtained with it are nearly the same as the results for TDR method with individual formulas, it can be said that the application of new formulas for determination of water content in individual materials (in our case sand plus Biona-312) improves the reliability of the TDR method.

CONCLUSIONS

Based on the results presented herein the following conclusions are offered:

- in spite of the wide application of Malicki's formula in TDR moisture measurements, calibration for individual materials will be frequently required,
- the newly developed formula for converting dielectric constant (ε) values into moisture values for a given medium allows more reliable results to be obtained,
- material-specific calibration increases the reliability of the measurements.

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