Abstract. The phenomena of colloid coagulation and peptization have a significant role in the circulation of elements in the surface layer of lithosphere, and in particular in the soil environment. Thanks to their structural properties, the mineral, mineral-organic and organic colloids that occur in colloidal systems largely influence the entire processes leading to erosion. The majority of issues related to the intensification of migration soil colloids and ions in the lithosphere are related to their electrokinetic properties. An attempt has been made in this paper to determine the dispersion state of soil colloidal systems exposed to water erosion by measuring the difference of electrical potentials generated in the gravimetric sedimentation process of colloidal particles.

Preliminary results make it plausible to claim that, depending on the quantity and quality of ions in soil solutions and on the qualitative and quantitative composition of colloids, the potential difference determined using measurement electrodes is proportional to the electrokinetic potential of the particles. Such measurements can be carried out in the field. The suggested method is based on recording the difference in potentials with a conjugated measurement electrode, which enables determination of the state of soil colloidal dispersion in the biochemical processes, which occur in the surface layers of the lithosphere.

Due to their situation, mountain soils are often exposed to erosion phenomena, affected mainly by the surface flow of rainwater. Through the migration of mineral and organic particles, the erosion leads to degradation of the upper levels of soils, and, therefore, soil productivity decreases [4, 8]. Moreover, strongly absorbed
heavy metals as well as nitrogen, phosphorus, potassium and calcium ions occur on the surface of dispersed soil colloids, which make their way from soils to the surface water in that form and cause eutrophication [3].

One of the major factors to determine the rate of susceptibility of soils to erosion is the content of colloidal fraction and the durability of colloidal systems in soils. ‘Colloidal fraction of soils’ refers to specific groups of minerals in the group of aluminosilicates that have hydroxyl ions embedded structurally in their crystalline lattices [1]. A colloidal fraction contains particles of the solid phase of soils, less than 2 micrometers in diameter, and it is chiefly composed of argillaceous minerals, organic matter (humus), as well as iron and aluminium oxides and hydroxides. The minimum diameter of colloids liberated from water dispersion is 10 nm [6]. Owing to the small size of colloids and depending on their physiochemical properties, they can occur in the form of dispersion systems where the dispersion centre is the soil solution. Additionally, colloids are relatively reactive to the sorption of a variety of chemical particles, as they have large specific surface, are provided with electrical load and a considerable number of surface functional groups.

In natural conditions, the occurrence and durability of colloidal systems in soil depends on the qualitative and quantitative composition of the colloidal fraction, on the interaction of colloidal fraction with the ions in soil solution, on organic matter, as well as on the physiochemical properties of the environment [7]. The major physiochemical properties influencing the stability of colloidal systems include temperature, oxygen contents, and the concentration of hydrogen and hydroxide ions [5, 7].

The dispersion properties of colloidal systems are measured mainly by determining the zeta potential based on the phenomena of electrophoresis and electroosmosis. In this paper, an attempt has been made to develop a system of measuring the dispersion of colloidal systems of mountain soils using a method based on the Dorn effect.

SOIL DISPERSION MEASUREMENT SYSTEM PROJECT GUIDELINES

The objective of the project was to develop thick-layered systems within LTCC (Low Temperature Co-fire Ceramics) technology, involving a system of conjugated electrodes with high internal impedance, provided with its own power source and internal EEPROM memory to enable measurement of the distribution in time of the potential differences in soil solutions. Preliminary tests revealed that, depending on the quantity and quality of ions in soil solutions and on the qualitative and quantitative composition of colloids, the potential difference determined by the measurement electrodes is proportional to the electrokinetic potential of the particles. Such measurements can be carried out in the field.
The basic element having impact on the quality of measurement is the arrangement of electrodes immersed in the soil solution during the measurement. It must be pointed out that the quality of the electrodes and their manufacturing method are of key importance to measurements of this type.

The following project guidelines were established:
– the electrode structures should be compatible with the existing measurement modules that enable measurements in arrangements of three and five electrodes;
– the electrodes should be made of Pt and PdAg in order to test the impact of the material in the electrodes on the measurement;
– the electrode structures should be made of a material neutral to the tested soil solutions, so that they do not disrupt the measurement;
– the system of electrodes should fit into the measurement container (not longer than 70 mm), and it should also be feasible to carry out the measurements in a centrifuge.

Based on the project guidelines, a system of electrodes was designed and produced using LTCC technology. Considering the range of advantages, this microelectronics technology seems most adequate for developing this type of electrode systems for measuring potential differences in soil solutions.

Four types of structures involving measurement electrodes were designed within the limitations construction requirements and to meet the specificity of the measurements:
– structure A – three electrodes (1 reference electrode and 2 measurement electrodes); the electrodes are made of PdAg pastes;
– structure B – three electrodes (1 reference electrode and 2 measurement electrodes); the electrodes are made of Pt pastes;
– structure C – five electrodes (1 reference electrode and 4 measurement electrodes); the electrodes are made of PdAg pastes;
– structure D – five electrodes (1 reference electrode and 4 measurement electrodes); the electrodes are made of Pt pastes.

Prior to burn-up, all test structures were made of four layers of LTCC ceramic foil, 165 \( \mu \text{m} \) in thickness. Each structure (after burn-up) underwent laser adjustment and had the dimensions \( 65.0 \times 10.0 \times 0.6 \text{ mm}^3 \).

To enable correct transmission of measurement signals to the electrodes, internal (embedded) paths were applied, connected to the electrodes via cable bushes.

METHODS

The mountain soils selected for the tests were formed from weathered diluvial light clay from near the village of Waliszów (Lower Silesia), and reference soils with similar grain composition from near Wrocław, each with different physiochemical properties (Table 1). An important criterion for choosing the samples was the need to maintain similar granulometric compositions with
diversified physiochemical properties. Extremely important was to have a diversified phosphorus content in the soil. It is supposed that this chemical component might have a crucial influence on the state of soil colloid dispersity [2]. The control was of soil from experimental fields of the Agricultural University of Wrocław, characterized by a similar granulometric composition and a high dose of phosphorus fertilizer applied annually. However, the mountain soil sample had a very low phosphorus content. The soil material sampled from the humus layers of the soils was put into 0.5 m² trays on stands to achieve a gradient of 6°. The lower part of the tray was provided with holes to enable free outflow of gravitational water. The soils in trays were sprinkled with 20 mm of artificial precipitation (distilled water) every 48 h, for 60 days.

The leachate from surface outflow was subject to the following analyses:
- granulometric composition – Malvern Size Meter;
- physiochemical and chemical properties: reaction (pH) – potentiometer test, the contents of organic C using the Tiurin method, plant-available forms of phosphorus, potassium using the Egner-Riehm method, and of magnesium using the AAS method;
- sedimentation rate test using a specially designed device in order to determine the dispersion state in colloidal systems.

The sedimentation rate was determined using a device designed to measure the difference of electrical potentials during gravitational sedimentation of particles in the solid phase of soil. Soil samples were prepared in the form of water suspension in accordance with the method of determining granulometric composition using the Cassagrande and Prószyński method. After a 10 min sedimentation period, 100 cm³ of suspension was pipetted from a 1 000 cm³ cylinder, and the difference of electrical potential was measured across the sample. Measurement time was 16 h. The results obtained gave curves of the values of electrical potential change against sedimentation time.

<table>
<thead>
<tr>
<th></th>
<th>pH (H₂O)</th>
<th>C org. (%)</th>
<th>Plant available forms mg 100 g soil</th>
<th>Conductivity (μs)</th>
<th>Colloidal fraction content &lt;2 μm (%)</th>
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<tr>
<td></td>
<td>before</td>
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<tr>
<td>Waliszów</td>
<td>7.4</td>
<td>7.6</td>
<td>3.16</td>
<td>2.37</td>
<td>11.0</td>
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<tr>
<td>Control</td>
<td>6.7</td>
<td>6.4</td>
<td>1.42</td>
<td>1.23</td>
<td>21.0</td>
</tr>
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TABLE 1. PHYSICOCHEMICAL PROPERTIES OF INVESTIGATED SOILS SAMPLES AT THE BEGINNING OF AND AFTER THE FINISHING TRAY EXPERIMENT
RESULTS

The leachate drained from the soil tested in trays was dried and weighed. A 4.9 g solid phase was obtained from the Waliszów sample, and 28.1 g from the control sample. In the Waliszów sample, the material eroded from the soil contained mostly fractions from 100 to 110 µm in diameter (12%), and the colloidal fraction of less than 2 µm in diameter was washed out in the minute amount of less than 1% of the eroded material (Fig. 1). The results obtained for the control sample revealed lower durability of the colloidal systems in the sample. A prevalence of solid phase particles was encountered in the eroded material from the soil, sized from 20 to 30 µm in diameter (7%), and from 8 to 9 µm in diameter (5%). The analysis of granulometric composition after the washing showed that more colloidal fractions had been washed out from the soil in the control sample (Fig. 1). This was probably because the soil contained much more assimilable phosphor and fewer fractions of organic carbon (Table 1), which resulted in a greater stabilization of the soil colloids and therefore an increase in their peptization and susceptibility to washing out. The results of the granulometric composition indicated changes in graining of the tested soils due to surface erosion and showed tendencies similar to the case of measuring the dispersion state of soil colloidal systems based on the sedimentation rate (Fig. 2). The diagrams feature the curves of the differences in electrical potentials during the 16-hour measurement. The results obtained for the showed a steeper angle for the curve slope to the time axis in the Waliszów samples compared to that for the control samples, evidence of
faster sedimentation of the washable fraction in the Waliszów sample. In the control samples, the potential difference curve runs was shallow, meaning that either no sedimentation occurred at all, or that it was very slow due to considerable dispersion of the colloidal fraction in the soil.

The problems related to dispersion determination using this method described here can occur in soil samples with small clay fractions (less than 10%), as well as in those with large clay fractions (more than 80%). The tested method does not provide satisfactorily repeatability of results. For the sandy soil samples (less than 10% clay fraction), this is probably due to too fast sedimentation and hence it is unfeasible to start the measurements at the same time. In the case of clay soils (more than 80% clay fraction), the measurement is disrupted by excessive contact of the measurement electrodes with argillaceous particles that may stick to the electrodes, and thus cause breaks in the contact of the electrodes with the suspension. For the above soils, the suspension must be either thickened (for less than 10% of clay particles), or diluted (for over 80% of clay particles), and the results must be processed mathematically.

Fig. 2. Electrical difference potential (mV) of eroded soil material.
The determined physiochemical properties of the tested soils, both before and after they were washed in trays, showed that soil reaction changed slightly as a result of washing. The results showed a minor increase in pH value for the Waliszów sample, and a fall of the value for the control sample (Table 1). When the tested soils were washed, a decrease in the contents of organic carbon was observed by some 0.8% in the Waliszów sample and by 0.2% in the control sample. The plant-absorbable forms of phosphor, potassium and magnesium also featured a decrease in the contents in tested soils after the soils were washed in trays. The losses of the components discussed above and observed in the soil from Waliszów greatly exceeded those in the control samples (Table 1).

CONCLUSIONS

1. The suggested measurement of the differences of potentials in soil solutions, using conjugated electrodes produced using LTCC technology, which form parts of an autonomous system with high input impedance and its own power source, enables assessment of the stability of colloidial systems of soils.

2. The measurement of electrical potentials with the designed measurement device, based on the sedimentation potential method, is an indicator of the dispersion state of the soil colloidal systems.

3. Determining dispersion of colloidal systems with the designed device, using a method of measuring differences of electrical potentials, should be carried out for soil samples with between 10 and 80% clay fractions.

REFERENCES

powodujących zjawiska erozji. Większość zagadnień związanych z nasileniem procesów przemieszczania się koloidów i jonów w litosferze związana jest z ich właściwościami elektrokinetycznymi. W pracy tej podjęto próbę określenia stanu dyspersjiności układów koloidalnych gleb narażonych na erozję wodną poprzez pomiar różnic potencjałów elektrycznych powstałych w trakcie grawimetrycznej sedymetacji cząstek koloidalnych.

Wstępne wyniki pozwalają stwierdzić, że w zależności od ilości i jakości jonów zawartych w roztworach glebowych oraz składu jakościowego i ilościowego koloidów, określana różnica potencjałów na elektrodach pomiarowych jest proporcjonalna do elektrokinetycznego potencjału cząstek. Pomiary takie można wykonywać w warunkach polowych. Proponowana metodyka polega na rejestracji różnicy potencjałów sprzężoną elektrodą pomiarową pozwalającą określić stan dyspersji układów koloidalnych gleb w biochemicznych procesach zachodzących w powierzchniowych warstwach litosfery.