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Application of column tests and electrical resistivity methods for leachate transport monitoring

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Abstract: *Application of column tests and electrical resistivity methods for leachate transport monitoring.* Development of the human civilization leads to the pollution of environment. One of the contaminations which are a real threat to soil and groundwater are leachates from landfills. In this paper the solute transport through soil was considered. For this purpose, the laboratory column tests of chlorides tracer and leachates transport on two soil samples have been carried out. Furthermore, the electrical resistivity method was applied as auxiliary tool to follow the movements of solute through the soil column what allowed to compare between the results obtained with column test method and electrical resistivity measurements. Breakthrough curves obtained by conductivity and resistivity methods represents similar trends which leads to the conclusion about the suitability of electrical resistivity methods for contamination transport monitoring in soil-water systems.

Key words: electrical resistivity method, column tests, leachate, chloride transport

INTRODUCTION

Contamination of soil and groundwater often referred to as soil-water systems is a significant problem which may be a result of irrigated agriculture, industrialization and urbanization but also poorly protected or reclaimed landfills, unauthorized waste disposal, incorrectly fertilized fields etc. (Koda 2011, Ogungbe et al. 2012). Contaminants dispersed

at the land surface migrate through the vadose zone to groundwater and move along in water streams causing contamination (Benson et al. 1997, Tsanis 2006, Belmonte-Jiménez et al. 2012, Urish 1983). The study of contaminant transport comprises variety of methods, such as: acquisition data from literature, laboratory batch and column tests, and also field tests, i.e. indirect methods based on electrical field distribution in soil (e.g. electrical resistivity methods).

Tracer testing is a very efficient and versatile multipurpose method to investigate the spreading of contamination in soil–water systems at the whole range of investigation scales, i.e. from the laboratory to the regional field. In the laboratory scale column tests are commonly performed (e.g. Fetter 2001, Ptak 2004). They are based on forcing the flow of water with tracer(s) through a soil column under conditions similar to natural, and subsequent measurements of solution concentration in the filtrate at the outflow(s) from the column (Jin et al. 1997, Kietlińska et al. 2004, Dontsova et al. 2006, Lewis and Sjöström 2010). Electrical resistivity methods are based on distribution of the electrical potential in soil. In this method an electrical direct current is applied into two current electrodes placed in the soil and the voltage

difference is measured between them (e.g. Dahlin 2001, Samouëlian et al. 2005). Electrical resistivity methods are widely used for detection and monitoring of groundwater contamination (e.g. Urish 1983, Benson et al. 1997, Wilkinson et al. 2010, Belmonte-Jiménez et al. 2012).

The combination of the electrical resistivity method and the tracer test is widely used for characterizing solute transport in soil (e.g. Binley et al. 1996, Olsen et al. 1999, Fronczyk et al. 2006, Müller et al. 2010), and also for defining the processes and parameters characterizing the soil, i.e.: effective porosity (Stephens et al. 1998, Lech et al. 2008), water content (Zhou et al. 2001), hydraulic properties (Abu-Hassanein et al. 1996, Camporese et al. 2011), chemical diffusion (Damasceno and Fratta 2006) and others. In the case of contaminated groundwater, the results of these models are useful in obtaining parameters required for hydrodynamic and mass transport models. These models could be used to: estimate (and predict) the spatial

contaminants' distribution in groundwater in time, assess associated risks, design effective monitoring networks and remediation methods etc. (Engegaard and Traberg 1996, Sandberg et al. 2002, Bowling et al. 2005, Day-Lewis and Singha 2008, Koda et al. 2012, 2013).

This paper presents results of laboratory column tests equipped with electrical resistivity measurer performed on two soil samples (MSa, grSa). The chloride tracer and leachates from Łubna landfill have been used for study. The column experiment supported by electrical resistivity method allows double monitoring of the contaminant movement (along the soil sample and at the outflow from the column) and comparison between results obtained by these methods, what was the main goal of the test.

MATERIAL AND METHODS

Tests were carried out on two soil samples (Fig. 1). Properties of tested soils are presented in Table 1. For each soil

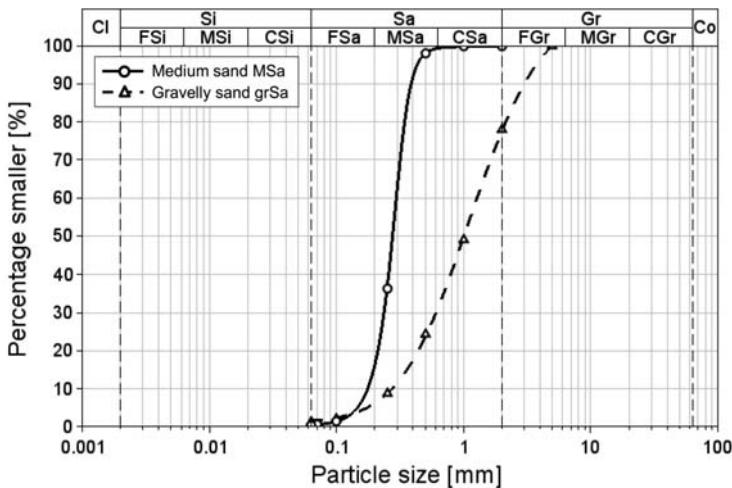


FIGURE 1. Particle size distribution curves of tested soils

TABLE 1. Properties of tested soils

Soil type	MSa	grSa
Relative density, I_D [%]	85	55
Coefficient of permeability, k_{10} [m/s]	$1.2 \cdot 10^{-4}$	$6.0 \cdot 10^{-5}$
Electrical conductivity, EC [$\mu\text{S}/\text{cm}$]	35	50
pH [-]	8.34	8.44

sample the laboratory tests of tracer (chlorides) and leachates transport (total ion content) have been performed.

Test setup for contamination transport measurement have been shown in Figure 2. The column test was conducted using 64 cm long and 9.8 cm of inner diameter thick-walled Plexiglas (methyl methacrylate) – PMMA column equipped with ten electrodes arranged in the Wenner array (4 cm distance between electrodes) (Fig. 2, Lech 2006, Fronczyk et al. 2009). The upward solute flow was forced by pressure difference and constant gradient was kept during the test duration. The electrical resistivity measurements along the column were taken at several levels: two levels (P1, P2) for medium

sand sample and four levels (P1, P2, P3, P4) for gravelly sand sample (levels notation as in Figure 2). Additionally, the physico-chemical parameters, such as: conductivity, pH and temperature of water, were controlled in the outflow from the column.

As the concentration of dissolved substances are a major factor controlling its electrical properties, the electrical resistivity methods can be used for determining contamination of groundwater. Based on the Archie’s law the formation factor was calculated using the following formula:

$$F = \frac{\rho_g}{\rho_f} \tag{1}$$

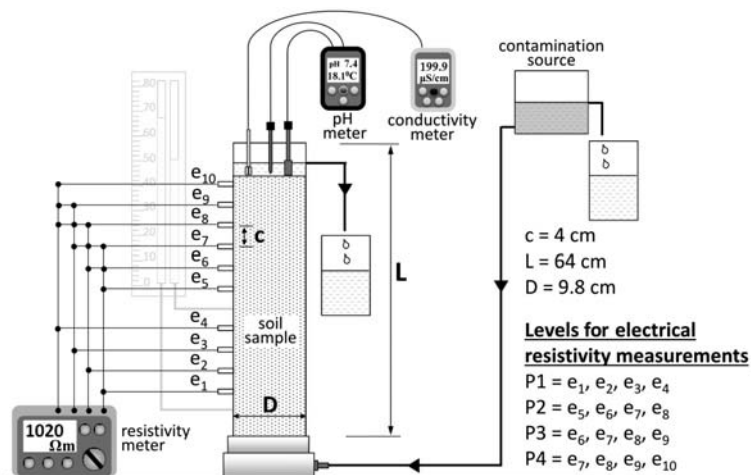


FIGURE 2. The experimental setup for contamination transport measurements

where:

F – formation factor [-];

ρ_g – resistivity of the fully saturated soil [Ωm];

ρ_f – resistivity of the liquid in soil pores [Ωm].

Most of soil minerals are good electrical insulators and the main component that allows flow of current in soil is liquid contained in the pores. Thus, the conductivity of soil is mostly electrolytic and depends mainly on water content and electrical resistivity of the fluid (Samouëlian et al. 2005). Formation factor (Eqn. 1) shows how much soil matrix increase the resistivity of liquid contained in soil pores. Thus the knowledge of formation factor can be used for determination of soil–water systems contamination.

Regarding the Archie’s (1942) law and the assumption that the formation factor is constant (independent of dissolved substances concentration), a relationship between measured soil resistivity ($\rho_{g(t)}$) and calculated conductivity of the liquid contamination in the soil pores can be expressed as:

$$\sigma_{\text{calc}} = k \frac{F}{\rho_{g(t)}} \quad (2)$$

where:

σ_{calc} – calculated conductivity of liquid contamination in soil pores [S/m];

$\rho_{g(t)}$ – measured electrical resistivity in time, (t) [Ωm];

k – geometric factor [-].

Test procedure

Both soil samples were formed in 0.05 m compacted layers of soil with moisture content of 10%. Before running the test, each column was fully saturated with distilled water and the solution was injected by the impulse method, compatible with practical realization of Dirac impulse method – superposition of the two Heaviside functions (Fig. 3), assuming the boundary conditions (Marciniak et al. 2009):

$$C(t) = \begin{cases} 0 & \text{for } t < t_1 \\ C_0 & \text{for } t_1 \leq t \leq t_2 \\ 0 & \text{for } t > t_2 \end{cases} \quad (3)$$

where:

$C(t)$ – electrical conductivity (EC) in time [$\mu\text{S/cm}$];

C_0 – electrical conductivity (EC) in input solution [$\mu\text{S/cm}$];

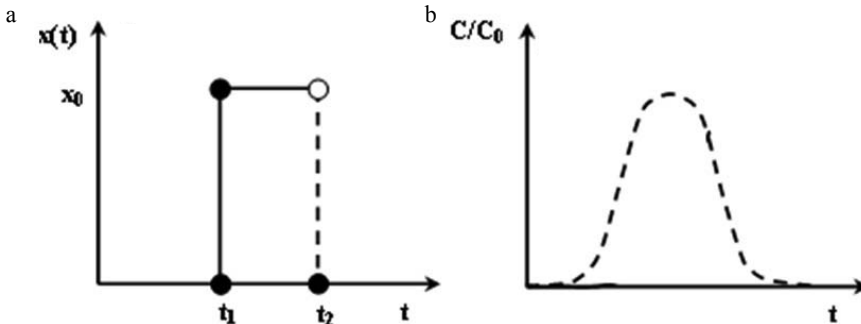


FIGURE 3. Injection of a tracer by a impulse method: a – a practical realization of an impulse function, b – an impulse breakthrough curve of a tracer (Okońska 2006)

t_1 – start time of tracer injection [min];
 t_2 – end time of tracer injection [min].

After sample preparation the tracer was started to inject. The chloride solution and leachates from closed municipal landfill Łubna have been examined (Table 2). The injection of tracer was stopped after reaching the maximum concentration of injected substance measured at the outflow from the column. In the next step the procedure was repeated with the injection of distilled water, the test was ended when the parameters of the injected distilled water were reached in the filtrate at the column outflow. During the test the electrical resistivity along soil columns and physico-chemical parameters, such as: electrical conductivity, pH and temperature, in filtrates at the outflow from the column were measured.

RESULTS AND DISCUSSION

The results of conductivity and electrical resistivity measurements for both solutes (chlorides and leachate) transport through the columns with MSa and grSa were shown in Figures 4 and 5. During the tests an increase of pH from 7.84 to 8.34 (chlorides solution) and from 6.9 to 9.84 (leachate) was observed in the column with MSa. In the case of the column with grSa pH varied from 7.62 to 8.13 for chlorides and from 6.67 to 9.45 for the leachate. Furthermore, in the case of leachate a phase of relatively low pH can be observed in both tests. These fluctuations may be caused by the variations in the ionic strength of contaminants in leachate used in these tests. The results of pH measurements have been shown on Figure 6.

TABLE 2. Leachate composition used to tests

Contamination indicator	Unit	Concentration
pH	–	7.7
BOD ₅	mgO ₂ /l	96
COD _{Cr}	mgO ₂ /l	1450
EC	μS/cm	12010
Ammonium	mgN _{NH+4} /l	443
Chlorides	mgCl ⁻ /l	1694
Sulphates	mgSO ₄ ²⁻ /l	108
Lead	mgPb/l	0.01
Cadmium	mgCd/l	0.0025
Copper	mgCu/l	0.008
Zinc	mgZn/l	0.049
Chromium (VI)	mgCr ⁺⁶ /l	0.031
Mercury	mgHg/l	0.0005
TOC	mgC/l	766
PAHs	mg/l	0.045

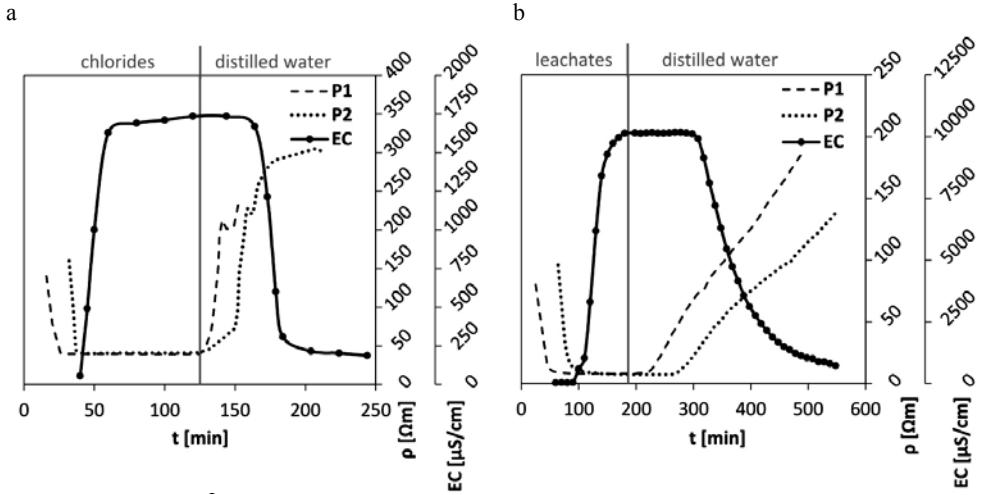


FIGURE 4. Breakthrough curves of conductivity and electrical resistivity in the MSa sample: a – chlorides, b – leachate

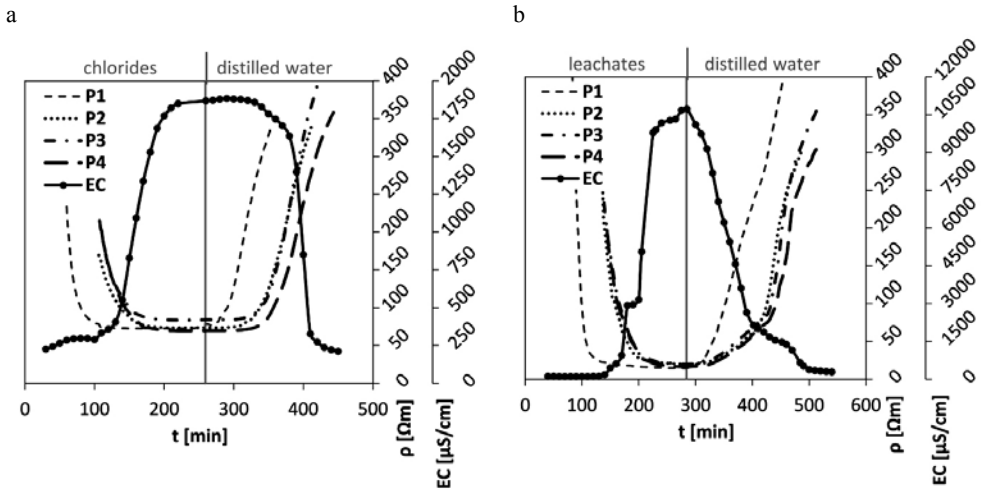


FIGURE 5. Breakthrough curves of conductivity and electrical resistivity in the grSa sample: a – chlorides, b – leachate

In Figures 4 and 5 it can be noticed that all breakthrough curves for each test both electrical conductivity and resistivity represents opposite trends (soil electrical resistivity decrease with increase of electrical conductivity of fluid contained in pores). As number of ions dissolved in pore water controls mainly its

electrical properties the electrical resistivity measurements can be successfully applied as a complementary studies for contamination transport. For test conditions the electrical conductivity of fluid contained in soil pores can be calculated from the measured soil electrical resistivity (Eqn. 2) using the values of param-

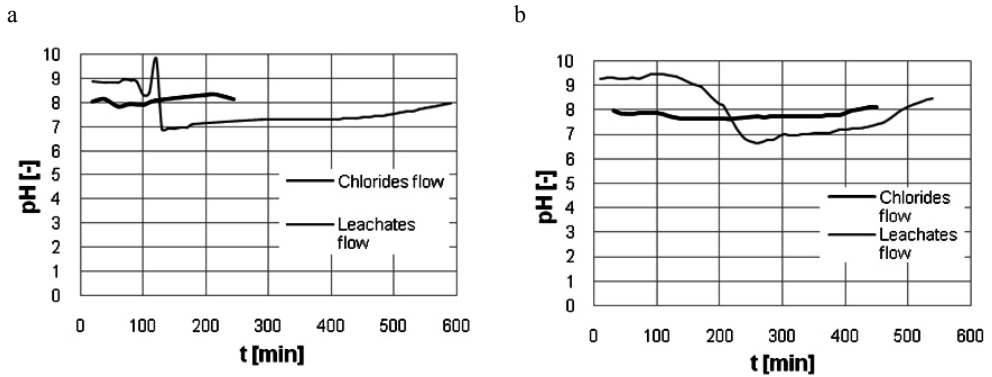


FIGURE 6. pH changes of solutes during column experiments: a – MSA sample, b – grSa sample

eters presented in Table 3. The measured and calculated electrical resistivity for each column are shown in Figures 7 and 8. For both MSA and grSa samples the electrical resistivity measurements reflect the trends of solute concentration changes. Moreover, it can be observed that conductivities calculated from resistivities for both samples are higher for chlorides compared to the leachate flow through the column. Although calibration between results obtained by these methods can be made for better data fit in specified measurement conditions.

CONCLUSIONS

The presented study allowed to draw the following conclusions:

1. Column test allows only to take measurements in filtrate at the out-flow without the possibility to control contamination transport through the soil sample along the column. However, applying the electrical resistivity method allows to obtain migration characteristics along the column.
2. As the conductivity of soil is mostly electrolytic and concentration of dis-

TABLE 3. Parameters for calculations of conductivity from soil resistivity measurements

Parameter	MSa				grSa							
	chlorides		leachates		chlorides				leachates			
	level											
	P1	P2	P1	P2	P1	P2	P3	P4	P1	P2	P3	P4
*F	5.86	5.72	5.86	5.72	11.37	13.78	14.56	12.0	11.37	13.78	14.56	12.0
k	1.26											
ρ_f	7.29		1.24		6.69				1.18			

*Variations of the formation factor for measured levels due to border conditions (level P1 nearest to bottom of the sample, level P4 nearest to the sample top) and some heterogeneities along the soil column length.

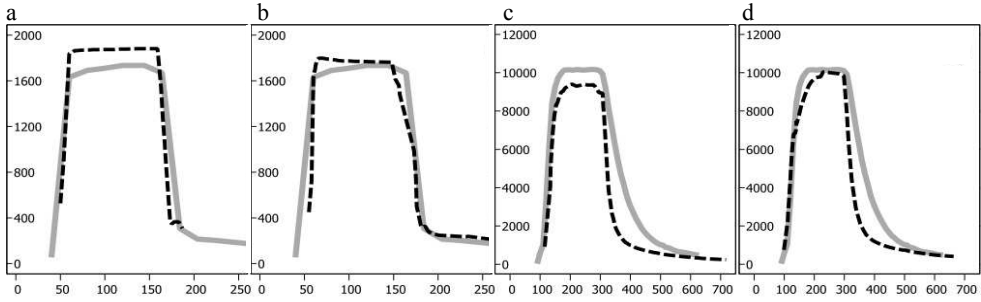


FIGURE 7. Calculated (dashed line) and measured (solid gray line) conductivity for the MSa sample: a, b – chlorides, c, d – leachateat levels (P1, P2, respectively)

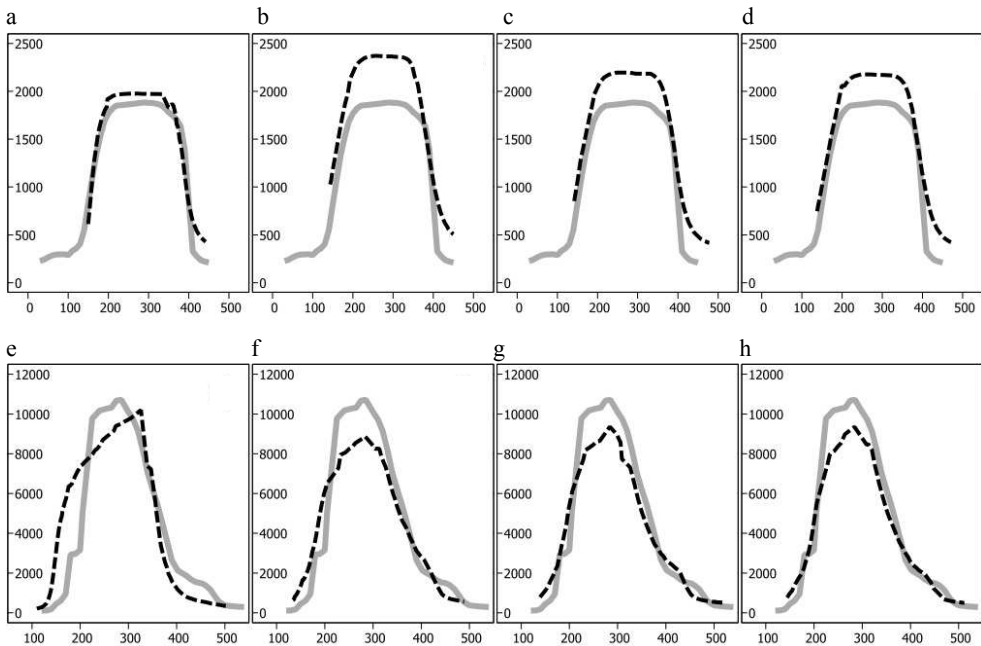


FIGURE 8. Calculated (dashed line) and measured (solid gray line) conductivities for the grSa sample: a–d – chloride sand, e–h – leachateat levels (P1, P2, P3, P4, respectively)

solved substances are a major factor controlling its electrical properties, the electrical resistivity are effective and non-invasive method for monitoring changes in water chemical composition, including contamination.

3. The electrical resistivity method can be successfully used as a part of a monitoring system of contaminant transport in soil–water systems. Such system may be an adequate and effective tool for interpretation of the migration paths of pollutants in field conditions.

4. Use of electrical resistivity methods for transport monitoring allows only to trace change in total ion content in groundwater without the possibility of determining the ions concentration.

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Streszczenie: *Monitoring przebiegu migracji odcieków składowiskowych z wykorzystaniem badań kolumnowych i elektrooporowych.* Produktem ubocznym rozwoju cywilizacyjnego są zanieczyszczenia, m.in. odcieki ze składowisk odpadów, które stanowią realne zagrożenie dla środowiska gruntowo-wodnego. Dobre rozpoznanie charakteru transportu tych zanieczyszczeń stanowi istotny aspekt w ochronie wód podziemnych. W artykule przedstawiono wyniki badań transportu oraz wymywania zanieczyszczeń w dwóch próbkach gruntów niespoistych przeprowadzone w warunkach laboratoryjnych z zastosowaniem kolumny filtracyjnej. Do badań użyto roztwór znacznikowy zawierający jony chlorkowe oraz odcieki pochodzące ze składowiska odpadów Łubna. Pomiar transportu zanieczyszczeń były realizowane z wykorzystaniem badań kolumnowych i metody elektrooporowej.

Na odpływie z kolumny wykonywano pomiary takich właściwości fizyczno-chemicznych, jak: przewodność elektryczna, pH oraz temperatura. Krzywe przejścia uzyskane na podstawie pomiarów przewodności i oporności charakteryzują się podobnym przebiegiem, co pozwala wnioskować o przydatności metody elektrooporowej w monitoringu transportu zanieczyszczeń w środowisku gruntowo-wodnym.

Słowa kluczowe: metoda elektrooporowa, badania kolumnowe, odcieki składowiskowe, migracja chlorków

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