Determination of electrical parameters for the electrochemical treatment of soils contaminated with oil

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Abstract. The electrochemical method of soil cleaning by passing small amperage has rather high efficiency for oil products, phenols, salts, heavy metals, and other chemicals pollution. Cleaning can be realized through a whole complex of physical, chemical and biological processes. The most important are the electrokinetic movement of the pollutant, the oxidation and evaporation of the components. The arrangement of anodes and cathodes that reduces the resistance between the electrodes by creating in the interelectrode space an electric field close to homogeneous is considered. This calculation allows to determine the number of electrodes, the amperage between them, the voltage depending on the properties of the soil, the area, the depth of contamination of the treated area, the geometric parameters of the electrodes and the required degree of cleaning.

1. Introduction
The electrochemical method of soil cleaning is the passing a small amount of electric current. It has rather high efficiency in soils polluted with oil products, phenols, salts, heavy metals and other chemicals [1]. Its main advantage is cleaning at a depth of up to several meters in situ, without changing the structure of the soil, its extraction and transportation. Such technologies can be applied even in cases of groundwater pollution [2].

Electrochemical cleaning can be implemented through a complex of physical, chemical and biological processes. Physical processes include the electrokinetic movement of a pollutant in the electric field towards the electrodes, where they can be pumped out. Soil electro-heating causes partial evaporation of pollutants, such as light petroleum hydrocarbons. Also there is direct and indirect oxidation of components with the formation of gaseous substances.

Variations of electrochemical treatment are used to clean polluted groundwater too. The first technology includes drilling of electrode wells, which are located in a special way. So directional polluted water move to the cathode well and is removed from it [3]. Another technology variant uses a complex of electrodes and active geochemical barriers. The latter are located between the cathode and the anode so that the electrokinetic flow of polluted waters passes through the block with a sorbent or chemical reagents [4].
Exactly analysis of different cleaning processes is quite difficult because the soil is not an inert electrochemical cell and requires consideration of all chemical, physical and biological phenomena complex. However it is possible to single out some general characteristics of electrochemical soil cleaning.

The research purpose was to analyze the characteristics of the electrochemical cleaning of various types of soils contaminated by petroleum hydrocarbons and highly mineralized salt solution (modeling soil contamination during oil production) and to determine the electrical parameters of the cleaning. In particular the amperage, voltage between the electrodes and energy consumption are determined depending on the soil resistivity and the electrodes location geometry.

This article presents the calculation of the electrical parameters of the electrochemical cleaning of oil-contaminated soils, which allows to determine the number of electrodes, amperage and the voltage depending on soil properties, area, contamination depth, electrodes geometric parameters and the required cleaning efficiency.

2. **Practical part**

The calculations were carried out on the basis of the analysis of experimental data about cleaning of the model medium by passing of low voltage electric current [5]. The model medium were different soil types polluted with oil and reservoir water. Electric current treatment was carried out in open plexiglas cell of a parallelepiped shape with the prepared model soil. The amperage with the different density was passed through the soil during time intervals 30 - 90 minutes. Measurement of the petroleum hydrocarbons concentration before and after the treatment was carried out by the method of infrared spectrometry. Additionally soil current-voltage characteristics and physic-chemical parameters (for example, electrical conductivity, density, etc.) were determined.

3. **Research results and discussion**

Electrochemical processes in contaminated soil are complex and multifactorial. The cleaning efficiency largely depends on the electrodes characteristics (material, size and shape, location in the ground).

The depth of the electrodes immersion depends on the depth of pollutants penetration into the soil.

One of the defining parameters is the electrodes material. Steel electrodes have sufficient strength, but they can be destroyed by the corrosion due to oxidation processes (especially it is actual for anodes). Therefore it is more rational to produce graphite anodes. It has been established that the use of carbon electrodes creates optimal conditions for the electro-oxidation of petroleum hydrocarbons [6]. To intensify electrocoagulation the anodes can be made of iron or aluminum, which can be dissolved and turn into the hydroxides. The electrochemical cleaning is highly effective with the use of platinum, lead oxide, titanium electrodes [7, 8]. However the high cost, the possibility of damage in the soil and the need for a large amount of material makes it economically impractical to use them.

Electrodes shape and location has great influence on the cleaning efficiency too. The electric fields features were studied for the different electrodes locations [9, 10].

Flat electrodes create a uniform electric field, which contributes to greater efficiency of electrochemical processes, but their installation in the ground is difficult. The most technologically advanced is the use of cylindrical electrodes, which can be immersed into the wells with use of mobile drilling equipment or manual motor drills with the required auger diameter. The arrangement of cylindrical electrodes (anodes and cathodes) should ensure that the electric field in the polluted soil is close to homogeneous. This problem is solved by consistently placing anodes and cathodes connected by separate tires (figure 1 [5]).
The electrodes location scheme shown in figure 1 allows reducing the resistance between the electrodes by creating an electric field close to homogeneous. The structure of the electric field is shown in figure 2.

This type of connection allows to skip the required number of electric charges at the voltage safe for the environment and living objects (up to 6-12V).

It was previously established [11] that for effective cleaning of various types of oil-contaminated soils, it is necessary to pass a certain amount of electric charges through the soil (for clay - $0.63 \cdot 10^7$ C/kg of oil products, for loam - $0.93 \cdot 10^7$, for sand - $1.34 \cdot 10^7$ C/kg of oil products. Therefore it is necessary to determine the current-voltage dependence for this method of electrodes placement which relates the electrodes geometric parameters and the process properties.

The density of the electric current flowing between the electrodes is determined by the resistivity of the soil $\rho$ and the electric field strength $E$:

$$j = \frac{1}{\rho} E$$ (1)

To determine the electric field generated by the electrodes, we use the first Maxwell equation:

$$\int \vec{E} d\vec{S} = \frac{\Sigma q}{\varepsilon \varepsilon_0}$$ (2)

where $q$ - the charge covering the surface;
$\varepsilon$ - relative dielectric constant of the medium (soil);
$\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m is the electric constant.

The integration is carried out along a cylindrical surface with radius $R \leq r \leq L$, the symmetry axis of which concurs with the symmetry axis anode, and the height is equal to the electrode immersion depth.

The next equation is based on the symmetry of the power lines of the electric field strength:
\[ E \cdot 2\pi r H = \frac{\sigma 2\pi R H}{\varepsilon \varepsilon_0}, \]  \hspace{1cm} (3)

where \( \sigma \) - the surface charge density of the electrode; 
\( R \) - the electrode radius.

The last equation shows that
\[ E = \frac{\sigma R}{\varepsilon \varepsilon_0 r}, \]  \hspace{1cm} (4)

The surface charge density is determined by the electric field potential of the electrode.

\[ E = -\text{grad} \varphi, \]  \hspace{1cm} (5)

Considering that the strength and potential of the electric field are related by equation (5), where \( \text{grad} \) is a gradient operator, taking into account symmetry axial (in the cylindrical coordinate system), we obtain:

\[ \Delta \varphi = \frac{\sigma R}{\varepsilon \varepsilon_0} \ln \frac{r}{R}, \]  \hspace{1cm} (6)

When the distance between opposite electrodes is \( r = L \), the potential difference is \( \Delta \varphi = U \), where \( U \) is the voltage between the electrodes:
\[ U = \frac{\sigma R}{\varepsilon \varepsilon_0} \ln \frac{L}{R}. \]  \hspace{1cm} (7)

So the electric field strength between the electrodes can be estimated by the equation (8):
\[ E = \frac{U}{r \ln \frac{L}{R}}. \]  \hspace{1cm} (8)

Thus the density of electric current in the interelectrodes space is determined by the ratio
\[ j = \frac{U}{\rho r \ln \frac{L}{R}}, \]  \hspace{1cm} (9)

and the amperage of one anode is:
\[ I = \int j ds \approx \frac{2\pi H}{\rho \ln \frac{L}{R}} U. \]  \hspace{1cm} (10)

The last dependence shows amperage increase with increasing distance \( L \), and increases with increasing depth of immersion.

Figure 3 shows the current-voltage characteristic (dependence of the anode current on the voltage between the electrodes) at different distances between the electrodes.
The resistivity of soils depends on contamination quantity, moisture and soil type. In real conditions it can depend on the season, weather conditions (precipitation abundance, temperature and air moisture, intensity of evaporation, etc.). Soils with the 40% moisture containing more than 1000 mg of oil products per kg have resistivity, which varies from 0.93 $\Omega \cdot m$ for sand to 1.069 $\Omega \cdot m$ for loam.

As can be seen at figure 2, the “elementary” cell with an area of $2L \times 2L$ contains 5 anodic and 4 cathodic electrodes. Consequently for the treatment of a section of soil contaminated with oil products with an area of $S$, the number of required cells is:

$$k = \frac{S}{4L^2}$$

(11)

In this case the number of anodes is

$$Z_A = 5k = \frac{5S}{4L^2}$$

(12)

The total amperage between the electrodes is determined by the equation:

$$I_s = \frac{5\pi SH}{2L^2 \rho \ln R} U,$$

(13)

So the power consumption is

$$W_s = I_s Ut,$$

(14)

where $t$ is the time of the electrochemical treatment of the oil-polluted area, which is depended on the concentration of oil products in the soil [12].

**Summary**

The correlations allow us to calculate the number of electrodes, voltage between them, the treatment time depended on polluted area, contamination depth, the properties of contaminated soil and the required cleaning efficiency.

The use of electrochemical treatment to reduce the concentration of pollutants in the soil has great interest because of large cleaning depth and the equipment mobility. However, the introduction of this technology requires a systematic approach based on the analysis of many factors, which is a significant challenge. The selection of the process optimal conditions requires preliminary laboratory tests before the full-scale field work often. The materials obtained in this research and the calculations of the electrical parameters can simplify the electrochemical process implementation.

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