Monocathode installation for electrochemical cleaning of oil-contaminated soils

V P Meshalkin\textsuperscript{1,2}, N S Shulaev\textsuperscript{2}, R R Kadyrov\textsuperscript{2} and V V Pryanichnikova\textsuperscript{2}

\textsuperscript{1}Dmitry Mendeleev University of Chemical Technology of Russia, Miusskaya Square, 9, Moscow, 125047, Russia
\textsuperscript{2}Ufa State Petroleum Technological University, Branch in the Sterlitamak, Pr. Oktyabrya, 2, Sterlitamak, 453118, Bashkortostan, Russia

E-mail: r_kadyrov@mail.ru

Abstract. One of the promising solutions for soil remediation is the impact on oil-contaminated areas with a constant electric current of small magnitude. The features of this method in comparison with others that require soil excavation or treatment with sorbents are ease of implementation, energy efficiency and economic feasibility. The cleaning process is carried out directly on the contaminated site. Electrochemical cleaning occurs when the electrodes are submerged into the soil to a depth of contamination and electric voltage applied to them. In this case, the pollutants transfer processes of under the influence of electric current and redox reactions are initiated. However, the traditional realization of the electrochemical method of cleaning soils contaminated with oil and oil products is accompanied by a high material consumption due to the large number of electrodes used, various energy losses depending on the materials of the cathode and anode and their relative position in the contaminated area, as well as insufficient environmental efficiency due to the accumulation of contaminated liquid in the cathode area. In view of the indicated disadvantages, the practical application of the method requires scientifically grounded engineering, the purpose of which is to design new energy-efficient, environmentally friendly, mobile installations.

1. Introduction

Analysis of modern research in the field of electrochemical cleaning of oil-contaminated soils makes it possible to single out a number of areas. For example, Russian scientists determine the state of the soil after electrochemical cleaning from gasoline and used oil with a solvent by measuring electrical resistivity, moisture, density, and size of soil fractions [1, 2]. Romanian and Italian scientists are developing techniques that combine electrokinetic cleaning and bioremediation [3, 4]. Some analytical articles are devoted to electrokinetic processes and anodic oxidation for cleaning soils with various pollutants, as well as the analysis of materials used for electrodes [5]. Separate works highlight the issues of using renewable energy sources in electrochemical cleaning processes [6, 7].

Consideration of the above-described works shows that traditionally the electrochemical method of soil cleaning is carried out by deepening cathodes and anodes, which are rods or plates, alternating in a certain order, but the disadvantages of this arrangement are the high material consumption and the difficulty of removing contaminated liquid from the near-cathode areas. So practical application of the the electrochemical method requires scientifically grounded engineering, the purpose of which is to design new energy-efficient, environmentally friendly, mobile installations.
2. Practical part

In contrast to the above studies, we analyzed the spatial distribution in the interelectrode zone of the main physicochemical parameters of oil-contaminated soils during the electrochemical cleaning process. In particular, the distribution of temperature, humidity, acidity in the near-cathode, central and near-anode zones was studied [8]. However, the indicated material and environmental problems require improved approaches to the design of new installations, the implementation of modern engineering.

Therefore, there is a need to reduce material consumption and organize the removal of contaminated liquid. We propose installing a negative electrode in the center of the contaminated area as one of the problem’s solutions. Cathode is a hollow perforated metal pipe with a drainage fitting in the inner area, through which the contaminated liquid is collected into the container.

Also positive electrodes made of cylindrical graphite rods and installed along the periphery of the contaminated area at an equidistant distance from the cathode (figure 1). The electrodes are connected to a direct electric current source and are immersed into the soil to the depth of pollution.

Figure 1. Cathode construction scheme.

Figure 2 shows the electrodes placement scheme for cleaning oil-contaminated soils and removing contaminated liquid.
Figure 2. Electrodes placement scheme.

The proposed placement of the electrodes makes it possible to create an electric field in the oil-contaminated area that is close to homogeneous and ensures uniform cleaning of oil products throughout the entire volume of the soil. The electric current between the anodes and the cathode is determined by the equation:

\[ I = \frac{USN}{\rho l} \]  

where \( U \) - the voltage between the anodes and the cathode;  
\( \rho \) - soil resistivity;  
\( N \) - the number of anodes;  
\( S \) – effective area of the electric current channel between the anode and cathode;  
\( L \) - interelectrode distance.

\[ S = \frac{d_k + d_a}{2} H \]  

\[ l = R_{ak} - \frac{d_k + d_a}{2} \]

\( R_{ak} \) is the distance between the centers of the anodes and the cathode;  
\( d_k, d_a \) are the diameters of the cathode and anodes.

It is known that it is required to spend a certain amount of electric charge when passing an electric current to remove 1 kg of oil products. This charge \( (q_{sp}) \) is \( 0.7 \times 10^7 \text{ C/kg} \) for black soil, \( 0.63 \times 10^7 \text{ C/kg} \) for clay soil, \( 0.93 \times 10^7 \text{ C/kg} \) for loam, \( 1.34 \times 10^7 \text{ C/kg} \) for sandy [9]. Therefore, for each type of oil-contaminated soil, the required amount of electric charge \( Q \) will be determined by the concentration of oil products \( C \) [kg/m³].

\[ Q = q_{sp} CV \]  

where \( V \) is the volume of oil-contaminated soil.

Then the cleaning time will be proportional to the amperage between the anodes and the cathode

\[ t \approx \frac{Q}{I} \]  

The processing time depending on the volume of contaminated soil can be estimated by the equation.
\[ t = \frac{q_u d_n R^2 a_k H \rho l}{U S N}, \]  

(6)

from which it follows that the design parameters of the electrodes \((d_k, d_a, R_a)\) and the depth of contamination significantly affect the processing time.

The installation in figure 2 contains an electric current source connected to terminals 1; cylindrical graphite anodes 2 and cathode 3, which is a steel cylindrical pipe, inside which there are fittings 4 to remove contaminated liquid.

The installation works as follows: an electric voltage is applied between the electrodes, a directional movement of positive and negatively charged ions (electric current) occurs, affecting the soil contaminated with oil products. Due to electrokinetic phenomena, part of the oil products in the liquid phase with the pore solution or formation water moves to the cathode and is removed using drainage fitting, while the other part is oxidized at the anodes and in the soil mass.

Oxidation of hydrocarbons occurs due to oxygen, hydrogen peroxide and hydroxyl radicals. This substances formation is initiated by electrochemical processes occurring in the soil under the action of an electric current. The production of graphite anodes helps to block the processes of corrosion and destruction, as well as to intensify the electrooxidative reactions.

The magnitude of the amperage and the voltage \(U\) for the given dimensions of the cathode and anodes is set based on the required cleaning efficiency and soil treatment time.

The studies showed that energy consumption of the proposed installation is much less than with the use of cathode and anode in the form of plates at the opposite boundaries of the contaminated area.

The main advantages of the proposed design of the installation for electrochemical treatment of oil-contaminated soil include:

- simplicity of the arrangement of the anodes and cathode at the treated area;
- the possibility of removing the contaminated liquid in a concentrated manner inside the cathode volume;
- high energy efficiency due to the creation of an electric field close to uniform in the interelectrode zone;
- ease of installation, dismantling and transportation.

3. Conclusion

The studies carried out made it possible to establish that the proposed location of the hollow perforated metal cathode with drainage fitting in the center of the contaminated area and anodes installation at an equidistant distance from the cathode increase energy efficiency and improve ecological parameters of the electrochemical process. These results allow design environmentally friendly, mobile installation used for oil-contaminated soils cleaning in the oil-extracting and oil-refining industries.

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