Computer Simulation of the Physical Processes of Electroosmotic Soil Treatment

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Abstract. An algorithm for determining the electrical and hydrodynamic parameters of soils during their electroosmotic treatment is presented. The results of computer simulation of non-stationary physical processes occurring in clay soils during the flow of electric current without the introduction of active solutions are given.

1 Introduction

The physical parameters characterizing the process of electroosmotic soil treatment are the velocity of electroosmosis, coefficients of filtration k_f, electroosmosis k_e and electroosmotic activity ($k_a = k_e/k_f$).Determining these characteristics by various methods requires multi-stage cumbersome measurements, the availability of special laboratory equipment [1-8], therefore, it is advisable to increase the efficiency and accuracy of assessments using an experimental-analytical research method, including computer modeling, experimental data obtained at various stages of electrical processing

2 Materials and Methods

On Fig. 1 the algorithm of a software package developed to implement a methodology of experimental computer simulation of nonstationary physical processes occurring in the soil treatment zone by means of electroosmosis is shown [10-12].
The initial data were the results obtained during a laboratory study of electroosmotic and electrochemical processes on an experimental model. The model is made as the form of a section of a clayey array, in which the electrodes-injectors are immersed. The model is made in full size, in accordance with the technological parameters of electroosmotic soil treatment. The dimensions of the model and the equipment used are given in [9].

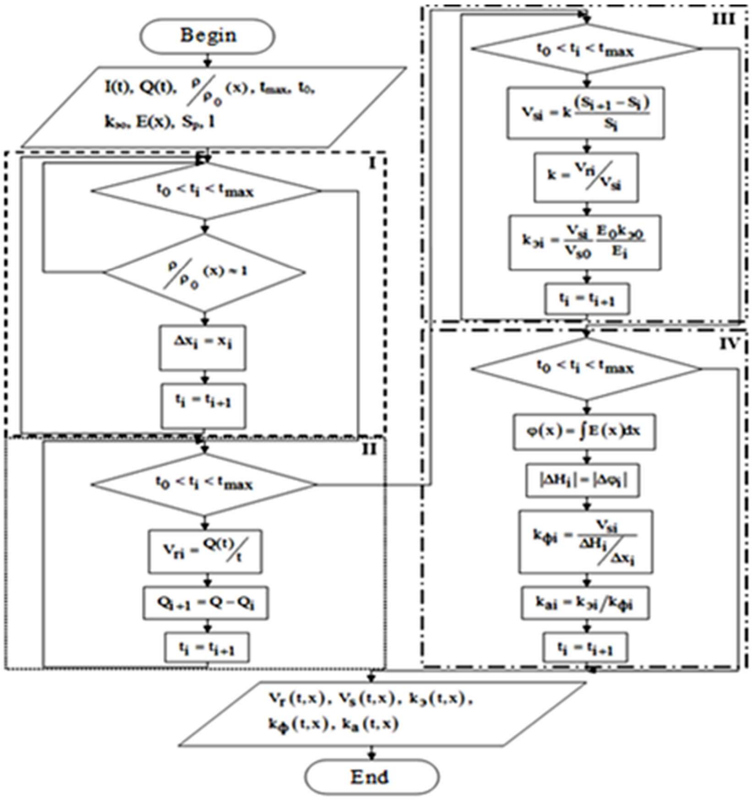

Fig. 1. Block-diagram of the method of calculating the parameters of the process of electroosmotic soil treatment (I, II, III, IV - the stages of calculation).

I(t), *Q(t)* - the flow rate of the electric current and the liquid outlet, respectively; $\rho/\rho_0\,(x)$ - change in the relative resistivity; t_{max}, t_0 - time of the last and first measurement, respectively; k_{e0} - the value of the coefficient of electroosmosis, taken as the initial; *E(x)* - the change in the electric field strength obtained during the simulation; *Sp*, *l* - the cross-sectional area and length of the model being processed, respectively; V_{si} - velocity of change of the process, determined from the graphs of the relative resistance; V_{ri} - velocity of the electroosmosis process, determined by the output of the liquid

3 Results and Discussions

The algorithm is implemented in four stages.

The initial data for the first stage were the graphs of changes in the value of the relative resistivity (Fig. 2) [7, 9]. The stage is responsible for determining the size of the characteristic zones formed during the processing of the soil (Fig. 3).

At the second stage, the velocity of electroosmosis is defined and taken as the standard. The initial data for the calculation are the liquid output *Q* from the electrode and the magnitude of the current *I* passing through the soil during the experiment [7, 9].

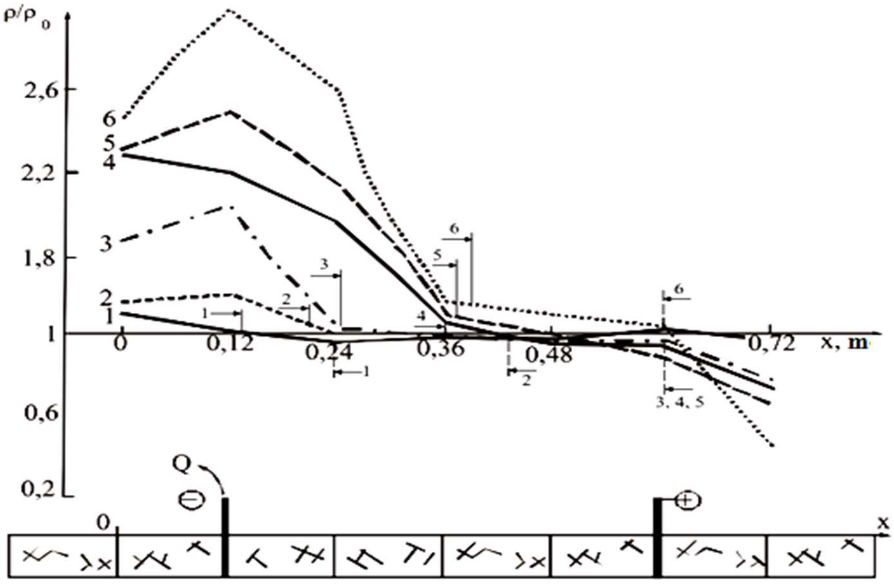

Fig. 2. Dependence of the relative resistivity ρ/ρ_0 from current consumption *I·t* and coordinates *x* of the sensor installation in the electroosmotic treatment area: 1 - *I·t* = 5,6 A·h; 2 - 8; 3 - 18; 4 - 22; 5 - 30; 6 – 54.

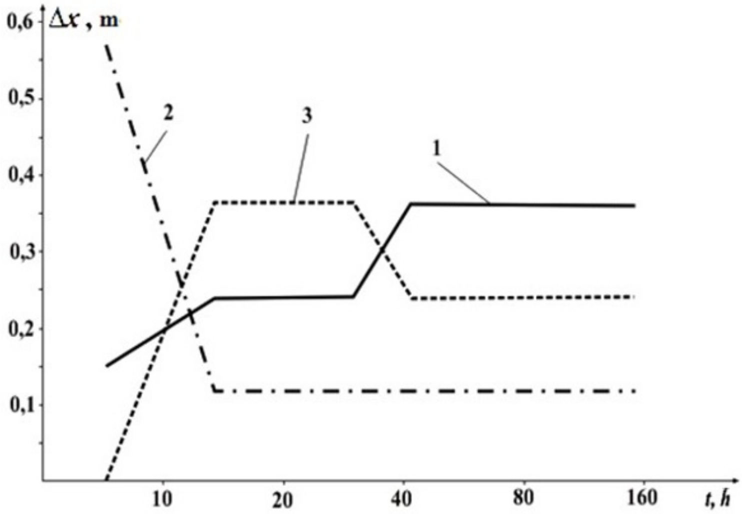

Fig. 3. Graphs of the change in the sizes Δ*x* of the zones of electrical treatment of the soil with the passage of time *t*:1 - in the drainage zone; 2 –in the zone of moisture accumulation; 3 - in the transition zone.

The third stage is responsible for determining the rate of change of the electroosmosis process according to Fig. 2. At the same time, the main characteristic of the process change is the difference of the areas located under the graphs of relative resistivity.

The velocity of change of the process is determined by the following relationship:

$$V_{Si} = k\,\frac{(S_{i+1}-S_i)}{S_i}, \tag{1}$$

where S_i and S_{i+1} - corresponding to the subsequent and previous time measurement area under the graphs (integral values of the function) relative resistivity ρ/ρ_0; k - correction factor determined from the ratio of the reference and calculated by the formula of the velocity (1) (Fig. 4, a).

The next parameter calculated in the third stage is the coefficient of electroosmosis k_e. For this purpose, the processing zone has been modeled by means of MATLAB library programs implementing the finite element method.

The assumptions adopted during the simulation are given in [7].

The relative filtration velocity was taken as the main design parameter determined through the modulus of the electric field [7]

$$\frac{V(x;z)}{k_e(x;z)} = E(x;z), \tag{2}$$

where V - effective velocity of electroosmotic filtration, m/s; k_e - coefficient of electroosmosis, m^2/B·c; E - the electric field strength, V/m.

Taking into account dependence (2) and average values of filtration velocity over the zones, and also assuming the initial value k_e = 1,3·10^{-4} cm^2/V·s [10], k_e is calculated for each zone over time (Fig. 4 b).

The fourth step in the calculation is the determination of coefficients of the filtration k_f and electroosmotic activity k_a in the characteristic zones.

Typical calculation results are presented on Fig. 4.

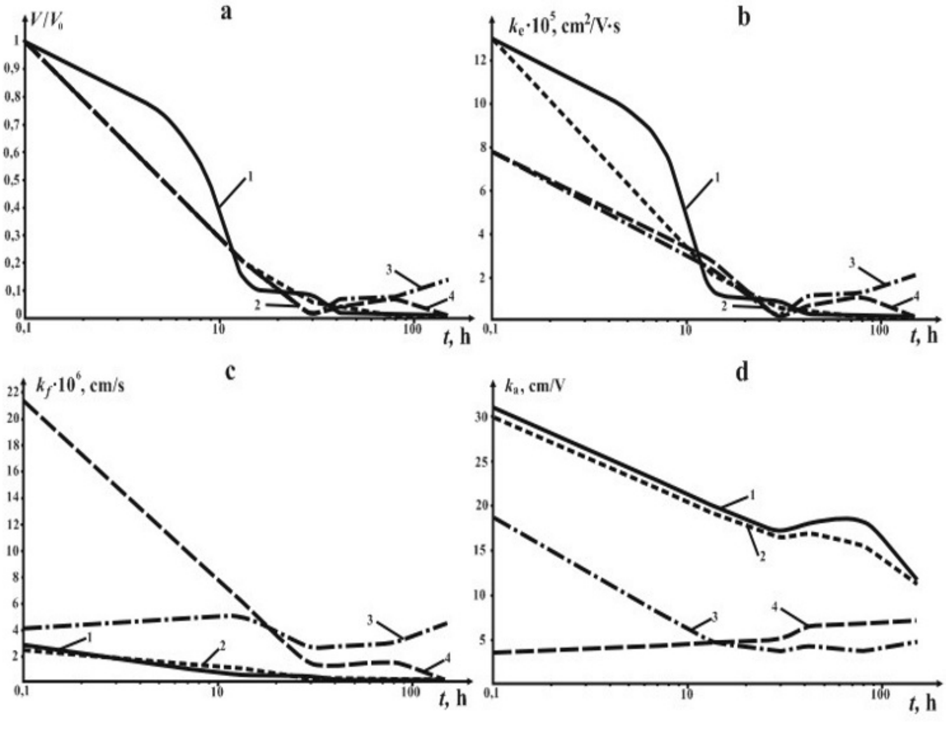

Fig. 4. Dependence of the relative velocity of electroosmosis (a), electroosmosis coefficient k_e (b), filtration coefficient k_f (c) and coefficient of electroosmotic activity k_a (d) from time 1 - calculation for the output fluid; 2 - in the drainage zone; 3 –in the transition zone; 4 - in the zone of moisture accumulation.

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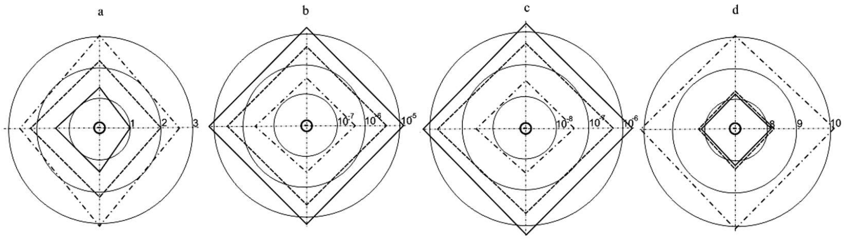
The filtration coefficient was determined using dependence [9]

$$V = k_f \cdot gradP = k_f \cdot \frac{\Delta P}{\Delta x}, \tag{3}$$

where V - velocity, cm/s; k_f - coefficient of filtration, cm/s; ΔP- value of pressure drop, cm; Δx - the length of the filtration path, cm.

The pressure drop and the length of the filtration path were determined using the simulation results [7, 9], from which follows the equality $|\Delta P_i| \sim |\Delta \varphi_i|$.

On fig. 5 diagrams of changes in resistivity, coefficients k_e, k_f, k_a in the cathode area are shown. Analysis of the calculation results shows that electrical resistivity during electroosmosis develops relatively evenly in all directions.



ρ/ρ_0 (a), k_e, cm^2/V·s (b), k_f, cm/s (c), k_a, cm/V (d):
——— - I·t = 8 A·h; ------- I·t = 22 A·h; —·—·— - I·t = 54 A·h

Fig. 5. The diagrams of change of relative resistivity Conclusion.

4 Conclusion

1. The above algorithm determines the methodology for modeling the processes of electrokinetic soil treatment in a linear pattern, in the plane and in space, depending on the obtained experimental data.
2. As the soil drains, the electroosmosis coefficient k_e decreases, while the accumulation of moisture causes its growth, with full moisture saturation of clay soils, and it is accompanied by an increase in k_e to $4 \cdot 10^{-4}$ cm^2/V·s.
3. The effectiveness of electroosmotic processing of the array decreases as it is drained. The process is characterized by a drop in the calculated value of the electroosmotic filtration velocity from 19 cm/h after 7 hours of treatment to 0.2 cm/h after 150 hours of treatment. At the same time, coefficients of the filtration and electroosmotic activity are decreasing with an insignificant increase in the zone of moisture accumulation.
4. The electrochemical processes occurring during electroosmotic treatment in soil (electrolysis, metabolic processes, changes in the physicochemical state of the soil) slow down and, as a result, lead to the attenuation of electroosmosis. The uniform nature of changes in electrical and hydrodynamic parameters in the active electroosmosis zone confirms the relative uniformity of fluid movement in the electrode zone in all directions [13].

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