LAWS OF ELECTROKINETIC FLOW THROUGH CAPILLARY-
POROUS BODY WITH MICROINHOMOGENEOUS SURFACE

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On the basis of experimental data, the applicability of existing formulas for predicting the de-
pendence of the flow rate through powder-mixture diaphragms on the mixture-component ratio
is analyzed.

As is known, applying a constant electric field to a capillary-porous body saturated by electrolytes leads
to the appearance of a flow known as the electrokinetic (or electroosmotic) flow. The laws of electroosmosia
and of flows produced by the action of other forces, for example filtration, are qualitatively different. Since
electrokinetic flow is an extremely specific phenomenon, it is of undoubted scientific interest, and offers the
possibility of fundamentally new solutions to applied problems.

The present work forms part of a series of investigations into the laws of electrokinetic flow through a
porous body with a pore space consisting of sections with different filtration coefficients, different surface
types, and different solution concentrations (below, these sections will be referred to as layers) [1-4].

The specific problem here is the investigation of flow through a diaphragm formed from mechanical pow-
der mixtures. This is the limiting version of the considered systems, where the layer has microextension
(such systems will be called microheteroporous bodies below). Note that, in principle, it makes no difference
to the conclusions given in the present work whether the diaphragm is formed of individual particles or consists
of rigidly connected sections.

The laws of flow in microheteroporous systems are particularly complex. The classical formulas (Helm-
holtz–Smolukhovskii formulas, with or without a correction for surface conductivity [5]) are inapplicable; they
are derived for systems with constant parameter values. It is perhaps possible to note only two formulas given
in [1, 6] which may be brought to bear in our problem. In [6], a formula was proposed on the basis of a deriv-
ation from qualitative considerations. For the formula for electroosmosis in multilayer diaphragms (hencefor-
ward referred to as the multilayer-electroosmosis formula) [1], the problem was solved under seriously con-
strained conditions: purely sequential arrangement of the layers, each layer of sufficiently great extent, all
parameters unchanged by the current. Note that the structural relations between sections in a microhetero-
porous diaphragm do not correspond, strictly speaking, to the structural differences on which the derivation
of the given formula rests: the layers in such a diaphragm are distributed not only sequentially, but also in
parallel.

What is meant by "sufficient extent" is that no change in the layer boundaries has any effect on the flow
as a whole. The rigidity of the condition depends significantly on the type of boundary effect [7-11]. Thus, in
the case of "inactive" diaphragms,* end effects are related to change in the velocity curves in the boundary
layers because of mechanical interaction of the fluxes. From general considerations, it is improbable that the
region with the transitional curve extends over more than hundreds of thousands of microns. However, this as-
sumption is based on approximate calculations relating only to a single cylinder of regular form [1, 7].

In active diaphragms the position is more complex. As well as steady ("mechanical") effects, unsteady
effects appear because of the presence of concentration-redistribution sources on the layer boundaries [8-11].

The change in parameters may extent over a large part of the layer, and even be of considerable extent (centi-
meters). In microheteroporous diaphragms, these sources are sited at microdistances; in addition, pronounced
polarization of the intrinsic particle field may in principle appear here [12].

*A "inactive" ("active") diaphragm is such that not one (at least one) of the parameters changes under the ac-
tion of an electric field.

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<table>
<thead>
<tr>
<th>System No.</th>
<th>Component No.</th>
<th>Component</th>
<th>Electrolyte and solution</th>
<th>$\xi_1$-10$^4$</th>
<th>$\xi_2$-10$^4$</th>
<th>$a$</th>
<th>$K_2$-10$^4$</th>
<th>$S$ (specific)</th>
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* Determined from argon absorption.
† Determined by Deryagin method.

The literature includes no secure estimates of the minimal layer thicknesses limiting the applicability of the multilayer-electroosmosis formula; this question may only be illuminated by experiment. From general considerations, it is quite impossible to expect that the formula will completely represent the features of the electroosmotic behavior of any mixed diaphragms, but it will very probably be acceptable as a first approximation.

Although the Reshetnikov formula and the multilayer-electroosmosis formula have a common form, they differ significantly in the physical meaning of the constant characterizing the dispersion of the components. The common form of the two equations is

$$q_{mix} = \frac{X + \frac{\xi_1}{\xi_2} \frac{\xi_3}{\xi_4} \frac{(1-X)K}{X + (1-X)K}}{q_1},$$

where $q_1$ is the velocity through a homogeneous diaphragm of component 1, defined by the expression $\frac{\xi_1}{4\pi \alpha_1 \eta}$; $K$ is a constant whose physical meaning differs in the Reshetnikov and multilayer-electroosmosis equations: $K = S_2/S_1$ in the first (hereafter referred to as $K_1$) and $K = K_{K1}/K_{K2}$ in the second (hereafter referred to as $K_{M1}$).

The investigation centers on three pairs of powders. The parameter values of layers obtained in working with diaphragms consisting entirely of the given element are given in Table 1.† The basic requirement is choosing the pairs is a strong difference in the electrosurface characteristics of the components. In the first pair, the $\xi$ potentials are of the same sign and significantly different in size; the diaphragms are inactive. In the two other pairs the $\xi$ potentials are of different sign; one pair has inactive diaphragms and the other active diaphragms. In the latter case, the conditions were limiting rigorously; as well as the activity of the "layers" and the difference in signs of the $\xi$ potentials, those potentials were of large absolute magnitude (almost of the maximum known magnitude). Strong opposed (oppositely directed) flows around the surface of two neighboring particles led to strong oppositely directed (opposed) flows in the volume of the same pore. The distance at which change in direction of the linear velocities occurred was a few microns. Obviously, careful attention must be paid here to the flow laminar conditions.

The preparation of the experimental samples, the equipment and procedure for velocity measurement, the procedure of the electrokinetic experiments, and the measurements of the individual parameters were the same