Experimental results are presented on the electroosmosis coefficient as a function of electric field strength and mean pore size for quartz sand.

Electroosmosis is widely used to consolidate and dry soils, to accelerate impregnation of finely divided systems, and so on, but some systematic studies are required to establish the relationships.

The basic electroosmotic characteristic for a porous material is the electroosmosis coefficient $k_e$, which is defined as follows [1]:

$$k_e = \frac{Z_e}{4\pi \eta} \cdot \frac{\kappa_p}{\lambda_1}.$$  

It is found [1] that $k_e$ is dependent on many factors, particularly the concentration of the equilibrium pore solution and the mean pore size. Although (1) does not show any explicit dependence of $k_e$ on pore size, such a relationship exists and makes itself felt via the dependence of $\kappa_p/\lambda_1$ on the structural characteristics [2].

The published evidence on this coefficient as a function of grain size is conflicting; for instance, it has been reported [3] that the grain size of a soil has little effect on the electroosmotic behavior, and it has also been claimed [4] that $k_e$ is not dependent on the pore size at all.

In contrast to this, other workers have claimed that the electroosmotic behavior is related to the structural characteristics; there are a few papers on the effects of porous structures in soils on electroosmosis.

Lomize used the method of dimensions to calculate $k_e$ as a function of the porous structure, for which purpose he used characteristics such as the porosity, the hydraulic radius, and the characteristic hydraulic length [5]. The result was checked by experiment on quartz sand of various grain sizes. The curve for $k_e = f(d_{av})$ had a peak for particles of mean size 70 $\mu$m.

It has been found [6] that $k_e$ increases as the grain size is reduced for fractions between 500 and 100 $\mu$m.

The published evidence thus indicates a need for systematic and thorough studies of the characteristics as regards the electroosmosis coefficient.

The mean particle diameter was used to characterize the porous structure in the above studies, whereas we consider that the mean pore size should be used for this purpose. The porosity of such a medium is not dependent on the particle size and is solely governed by the mode of packing [7], consequently, the pore size in such a system is dependent on the mean particle diameter and on the packing density and is an unambiguous characteristic of the structure.
Fig. 1. Electroosmosis coefficient $k_e \cdot 10^8$ (m$^2$/V·sec) as a function of: a) field $E \cdot 10^{-2}$ (V/m) for pore sizes (μm) of: 1) 3, 2) 1.4; 3) 4; 4) 1.0; 5) 9.1; 6) 12; b) field $E \cdot 10^{-2}$ (V/m) for strengths (M) of KCl solution: 1) $10^{-4}$; 2) $5 \cdot 10^{-4}$; 3) $10^{-3}$; 4) $5 \cdot 10^{-3}$; c) average pore size $d_{av}$ (μm) for strengths (M) of KCl solution: 1) $10^{-4}$; 2) $5 \cdot 10^{-4}$; 3) $5 \cdot 10^{-3}$.

We determine the mean pore size from the electrical resistance and the gravitational infiltration rate as measured by the method described in [2].

The materials were purified finely divided quartz-sand powders, with mean particle sizes from 4 to 80 μm.

The filters were made up from this material using a 40% suspension of the powder, which was allowed to sediment spontaneously with continuous vibration for 60 min. This provided the closest particle packing, and the resulting hydrodynamic resistance was adequate, while the structure did not change during the electroosmotic measurements.

The electrical resistance was measured in 0.1 M KCl solution, which enabled us to neglect the surface conductivity [2]. The measurements were made at 10 kHz with an ac bridge to eliminate electrode polarization effects.

The gravitational filtration rate was also measured with 0.1 M KCl solution with the instrument used for $k_e$ [8]. The instrument had a thermostatic jacket, so all measurements were made under isothermal conditions at 20°C. Three copper-constantan thermocouples monitored the temperature within the specimen.

An important point in electroosmotic measurement is to choose the electric field strength; parts a and b of Fig. 1 show our results on $k_e$ as a function of $E$. The curves for $k_e = f(E)$ have two parts (plateaux) with constant $k_e$, which are distinguished by the vertical broken lines in the figure. These plateaux are explained as follows. The actual pore channels arise from contact between nearly spherical particles, and they are therefore complicated in shape and variable in cross section, with narrower and broader parts. The above materials were therefore heteroporous not only in section but also in length.

As a first approximation, we represent a real pore as a system of series-connected cylindrical channels with two different diameters, and in that case it is readily shown that the local variations in field strength have an inverse quadratic relationship to the pores radius.

The liquid in the pores has a limiting shear stress $\tau_0$ [9, 10], so the above shows that the small local $E$ in the wide parts will mean that the shear stress $\tau$ set up by the electric field will be insufficient to overcome $\tau_0$; consequently, the liquid in these wide parts will be immobile, but the mass flow in the channels is continuous, so these parts will be excluded from the flow. They will be involved in the electroosmotic transport as $E$ is increased to the point where $\tau \geq \tau_0$.

This effect should be the more pronounced the greater the variation in pore size within the body. If the body is homogeneous in structure, no such effect should be observed. These conclusions agree well with our results. We measured the pore-size distributions for all the specimens and found that the range in pore sizes diminished as the particles became smaller. Specimens made up from the smallest particles