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THE APPLICATION OF ELECTROPHORESIS TO THE IDENTIFICATION OF THE MINERAL COMPONENTS OF KAOLINS

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Abstract. Using the method of microelectrophoresis for the investigation of clay fraction ($< 2 \mu\text{m}$) of kaolinite clays, a statistical analysis was made of the frequency of occurrence of particles of definite electrophoretic mobility. The analysis yielded a number of distribution curves of electrophoretic separation, which display peaks grouping sets of particles of different electrophoretic mobility. The number of these peaks gives information on the amount of mineral components with different physico-chemical surface properties in a sample.

INTRODUCTION

The minerals exhibiting differences in their crystal structure or the degree of crystalline perfection also differ in the physico-chemical properties of the surface. This feature was used by the present author to carry out physico-chemical phase analysis.

The investigation was carried out on three samples of clay fraction obtained from kaolinite clays and kaolinite sandstones derived from mines near Bolesławiec in Lower Silesia.

Sample 1 — White silty clay from a longwall in the Bolko mine.

Sample 2 — Light-grey clay from the cross-cut 3 of the Janina mine.

Sample 3 — White loose fine-grained sandstone from the Wschód extraction gallery of the Bolko mine.

EXPERIMENTAL

The samples were subjected to investigation by the method of microelectrophoresis, described by Żbik (1980). In this method, using the external electric field, mineral particles moving in the aqueous electrolytic solution inside a capillary tube are viewed under the microscope. The microscopic image is received by a television camera and displayed on the TV monitor screen, being simultaneously recorded on video tape. The mo-

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nitor screen is divided into vertical sections of known size. Measuring the time in which the particles cover the distances between the sections, the particle velocity is calculated. With the known electric field intensity inside the capillary tube, electrophoretic mobility, i.e. the velocity of particles at an electric field potential gradient of $\text{IV}\cdot\text{m}^{-1}$, can be calculated.

The investigations were carried out on monoionic samples in sodium and potassium form in NaCl and KCl salt electrolytes of 0.0001, 0.0005 and 0.001 n concentration. The distinctive physico-chemical property in this case was the surface electric potential characteristic of each mineral phase, imparting specified motion velocities in the external electric field to the groups of particles. The process of electrophoresis was carried out for the same sample at seven different voltage values on the capillary electrodes. Due to the repeated reproduction of the process from the video tape, a velocity value could be ascribed to each mineral particle visible on the TV monitor screen. Owing to this, a large number of measuring points were obtained for different electric field intensities inside the capillary tube. Using the statistical method of „window counts”, the frequency of occurrence of particles of specified electrophoretic mobility was analysed.

RESULTS

The results of calculations in the form of distribution curves of the amount of particles against their electrophoretic mobility are presented in figures 1, 2 and 3. Each curve was a result of the summation of distribution curves obtained at different electric field intensities. This form of presentation was chosen because the systematic experimental errors had been eliminated. The summation was done after the separate curves obtained for voltage gradients were superimposed on one another. In view of the fact that due to the non-linearity of the electrophoretic process, the peaks to be summed had different electrophoretic mobility values, the distribution curves were not joined to the origin of co-ordinates.

The curves of electrophoretic separation presented by Shaw (1969) follow a Gaussian distribution, yet they were obtained not for minerals but for very regular oil droplets in water suspension. The character of the distribution curves obtained by the present author indicates that the samples studied are not homogeneous but are a mixture of several mineral phases showing different physico-chemical surface properties. Their distribution curves (Figs. 1, 2, 3) consist of a few coinciding peaks. The distribution of the amount of particles *vs.* their electrophoretic mobility for each peak follows closely the Gaussian function. There are essential differences in the shape of curves obtained for individual samples.

The curves presented in figures 1 and 2 display at least three peaks, which fact testifies to the presence of three minerals differing in physico-chemical surface properties in samples 1 and 2.

The curves presented in Fig. 3 show two peaks, one of which having a lower value of electrophoretic mobility, is very intense, and the other appears as a slight bulge on the main peak on the side of higher mobility values. Considering the wide differences in peak intensities on the distribution curves of this sample, sample 3 can be regarded as physico-chemically homogeneous.

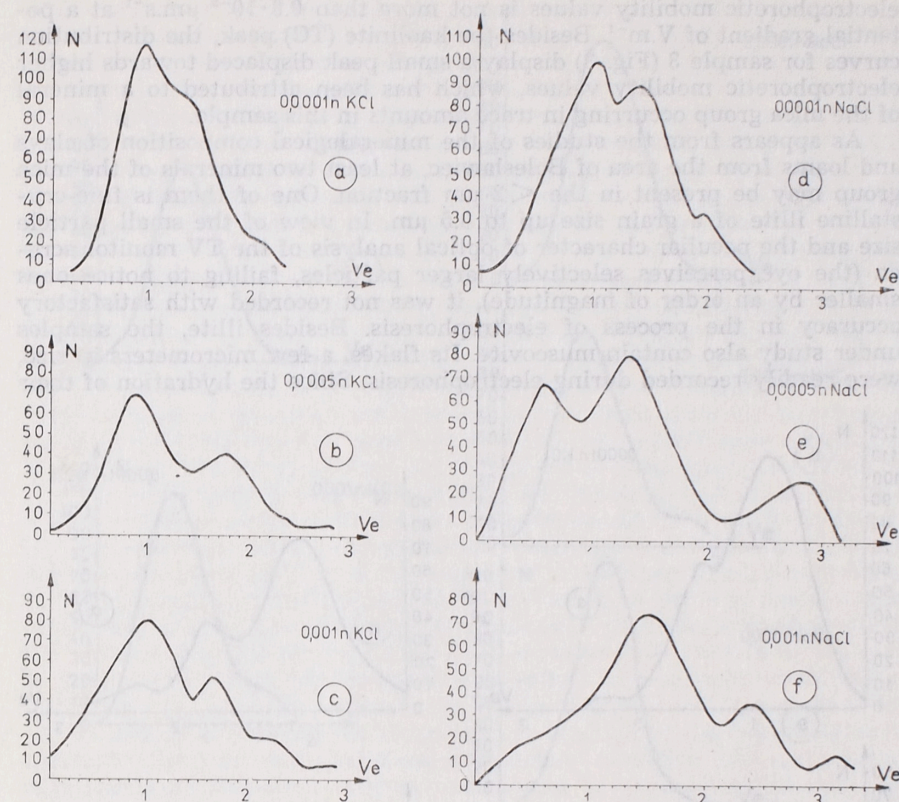


Fig. 1. Distribution curves of the amount of particles *vs.* their electrophoretic mobility (V_e) for sample 1

N — number of particles counted, V_e — electrophoretic mobility in $10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at a potential gradient of $\text{V}\cdot\text{m}^{-1}$. Curves a, b, c are for monoionic potassium form (K^+), curves d, e, f for monoionic sodium form (Na^+)

X-ray diffractometry, electron microscopy and DTA analysis have shown (Žbik 1981) that sample 3 is virtually homogeneous, consisting of kaolinite (TC) with a well ordered structure (Stoch, Sikora 1966). Judging by the index of crystallinity (IU) calculated according to Rusko (1976) from an X-ray diffraction pattern of an oriented sample (Žbik 1981), the kaolinite of sample 3 seems to have a high degree of crystalline perfection ($\text{IU}=1.33$), whereas in sample 2, where $\text{IU}=0.48$, a mineral with the poorly ordered structure predominates. According to Osipov (1979), kaolinite with a well ordered structure is characterized by high hydrophilic ability. A thick layer of water dipoles, representing the crystal structure deep into the solution, forms at the surface of this mineral. In the author's opinion (Žbik 1981), this layer is capable of generating a fairly high electric charge. Owing to the high degree of crystalline perfection of kaolinite (TC) in sample 3 and its homogeneity, the peak produced by this mineral on the distribution curves is high and sharp. For most particles the scatter of

electrophoretic mobility values is not more than $0.8 \cdot 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at a potential gradient of $\text{V}\cdot\text{m}^{-1}$. Besides the kaolinite (TC) peak, the distribution curves for sample 3 (Fig. 3) display a small peak displaced towards higher electrophoretic mobility values, which has been attributed to a mineral of the mica group occurring in trace amounts in this sample.

As appears from the studies of the mineralogical composition of clays and loams from the area of Bolesławiec, at least two minerals of the mica group may be present in the $< 2 \mu\text{m}$ fraction. One of them is fine-crystalline illite of a grain size up to $0.5 \mu\text{m}$. In view of the small particle size and the peculiar character of optical analysis of the TV monitor screen (the eye perceives selectively larger particles, failing to notice ones smaller by an order of magnitude), it was not recorded with satisfactory accuracy in the process of electrophoresis. Besides illite, the samples under study also contain muscovite. Its flakes, a few micrometers in size, were readily recorded during electrophoresis. Since the hydration of their

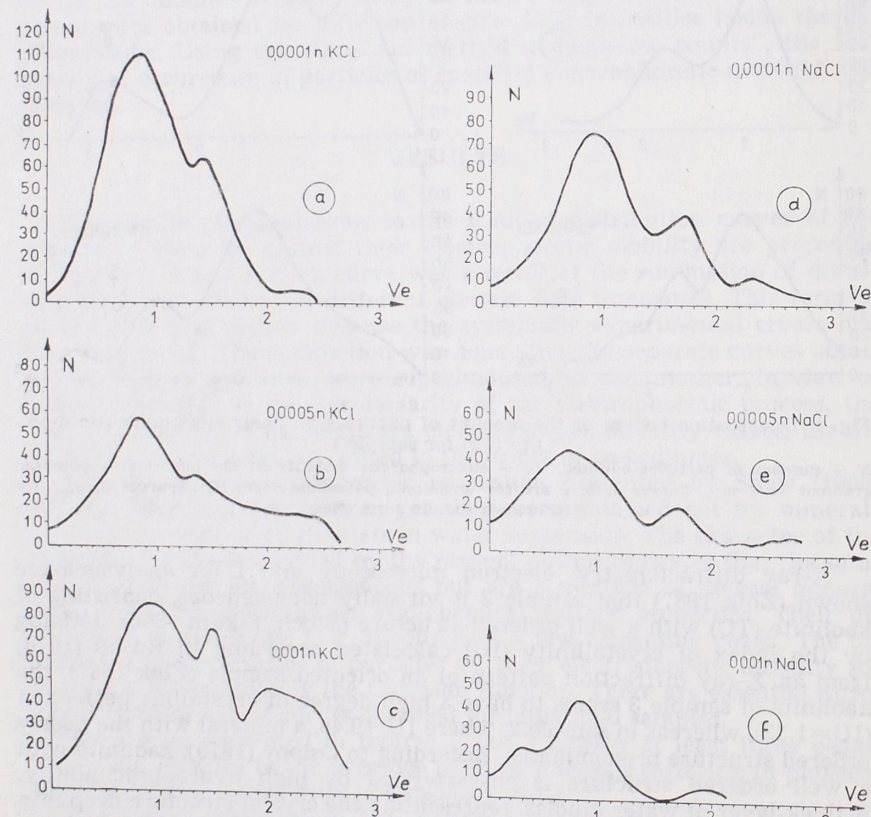


Fig. 2. Distribution curves of the amount of particles vs. their electrophoretic mobility (V_e) for sample 2

N — number of particles counted, V_e — electrophoretic mobility in $10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at a potential gradient of $\text{V}\cdot\text{m}^{-1}$. Curves a, b, c are for monoionic potassium form (K^+), curves d, e, f for monoionic sodium form (Na^+)

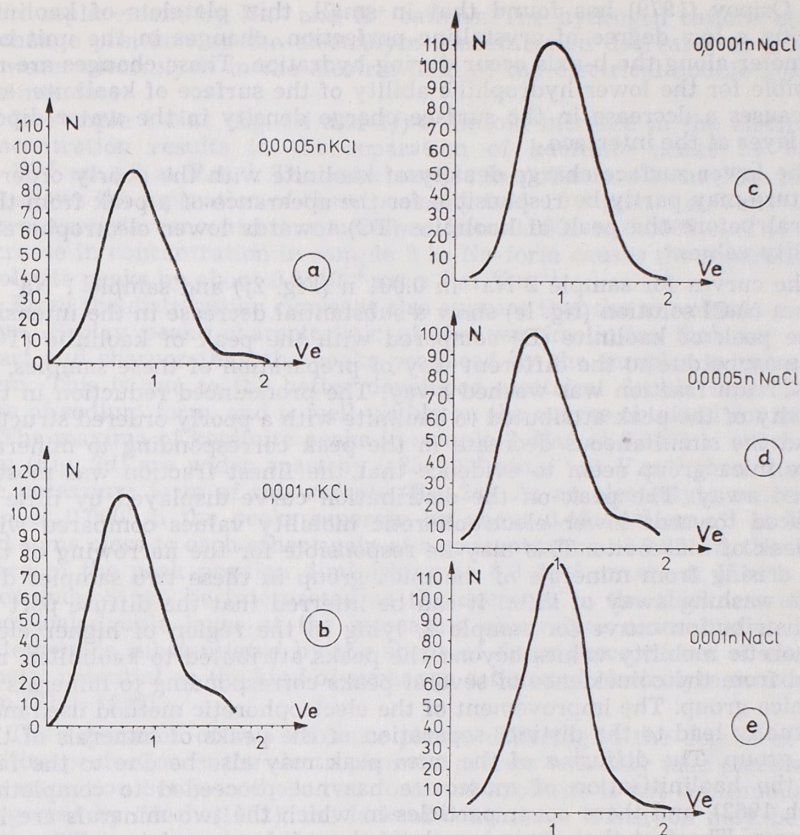


Fig. 3. Distribution curves of the amount of particles vs. their electrophoretic mobility (V_e) for sample 3

N — number of particles counted, V_e — electrophoretic mobility in $10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at a potential gradient of $\text{V}\cdot\text{m}^{-1}$. Curves a, b, c are for monoionic potassium form (K^+), curves d, e, f for monoionic sodium form (Na^+)

surface is as intense as in the case of kaolinite (TC) (Osipov 1979), and they have additionally a high negative charge on the layer, the two minerals of the mica group present in the samples studied show higher values of electrophoretic mobility and are presumably responsible for the peak displaced towards higher electrophoretic mobility values.

Besides the two peaks appearing on the distribution curves for sample 3 and attributed to kaolinite (TC) with a well ordered structure and to minerals of the mica group, the curves obtained for samples 1 and 2 display a third peak of the highest intensity, displaced towards lower electrophoretic mobility values. On the monitor screen, the group of particles with a mobility yielding this peak represents a large number of small thin platelets. On the basis of mineralogical studies (Žbik 1981), this group has been identified with kaolinite (D) with a poorly ordered structure, which was found to be present in these samples.

Osipov (1979) has found that in small, thin platelets of kaolinite showing a low degree of crystalline perfection, changes in the unit cell parameter along the b-axis occur during hydration. These changes are responsible for the lower hydrophilic ability of the surface of kaolinite, and this causes a decrease in the surface charge density in the water dipole poly-layer at the interface.

The lower surface charge density of kaolinite with the poorly ordered structure may partly be responsible for the appearance of a peak from this mineral before the peak of kaolinite (TC) towards lower electrophoretic mobility values.

The curves for sample 2 Na⁺ in 0.001 n (Fig. 2f) and sample 1 Na⁺ in 0.005 n NaCl solution (fig. 1e) show a substantial decrease in the intensity of the peak of kaolinite (D) compared with the peak of kaolinite (TC). This may be due to the different way of preparation of these samples, as the < 1 μm fraction was washed away. The pronounced reduction in the intensity of the peak attributed to kaolinite with a poorly ordered structure and the simultaneous decrease in the peak corresponding to minerals of the mica group seem to evidence that the finest fraction was mostly washed away. The peak on the distribution curve displayed by illite is displaced towards lower electrophoretic mobility values compared with the peak of muscovite. This may be responsible for the narrowing of the peak arising from minerals of the mica group in these two samples due to the washing away of illite. It can be inferred that the diffuse part of the distribution curve for sample 2, lying in the region of higher electrophoretic mobility values beyond the peaks attributed to kaolinites, resulted from the coincidence of several peaks corresponding to minerals of the mica group. The improvement of the electrophoretic method used may eventually lead to the distinct separation of the peaks of minerals of the mica group. The diffusion of the mica peak may also be due to the fact that the kaolinitization of muscovite has not proceeded to completion (Stoch 1962), and there occur particles in which the two minerals are intergrown. The fact that the minerals of the mica group do not appear in a pure form but are intergrown by kaolinite may result in the broadening of the peak along the x-axis, which is particularly pronounced on the distribution curves for sample 2.

A detailed analysis of curves obtained for samples 1 and 2 in sodium and potassium forms has shown that in the K-form samples the distances between the peak maxima are generally smaller than in sample saturated with sodium. The peaks appearing on the curves for K-form samples 1 and 2, obtained at the lowest concentration of electrolyte, are very close to one another. In the case of sample 1 (Fig. 1), the peak attributed to kaolinite with a well ordered structure appears as a bulge on the slope of the peak of kaolinite with a poorly ordered structure on the side of higher electrophoretic mobility values. As the electrolyte concentration increases, the peaks come wider apart and the distances between them are greater, making the curves easier to interpret. This fact is connected with the development of an electrical double layer and consequently, with the increase in the electric charge surface density and the electrokinetic potential. These phenomena occur in spite of the increase in the electrolyte concentration, which, according to Złoczewska et al. (1970), is a consequence of the removal of hydrogen cations from the sorption complex and

their replacement by Na⁺ and K⁺ cations. The hydrogen cations occupy exchange positions as the electrolyte concentration decreases as a result of water electrolysis in the electric field of the electrical double layer at the interface.

In sample 1 Na⁺ (fig. 1d and 1f) a tenfold increase in the electrolyte concentration results in the separation of kaolinite peaks by $0.15 \times 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at $\text{V}\cdot\text{m}^{-1}$. The same sample in potassium form (Fig. 1a and 1b) shows the separation of these peaks by $0.46 \cdot 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at $\text{V}\cdot\text{m}^{-1}$ when the electrolyte concentration increases from 0.0001 to 0.0005 n. The same increase in concentration in sample 2 in Na-form causes the separation of kaolinite peaks by about $0.2 \cdot 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at $\text{V}\cdot\text{m}^{-1}$.

From the distribution curves it also appears that the samples in sodium form display peaks characteristic of the two kaolinites that are wider apart and sharper than the peaks produced by the samples in potassium form. This is due to the better developed electrical double layer in the case of sodium form, and is well visible on the curves obtained for sample 2. The maxima of kaolinite peaks in sample 2 Na⁺ at 0.0001 n concentration (Fig. 2d) are wider apart by $0.23 \cdot 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at $\text{V}\cdot\text{m}^{-1}$ than those in the potassium form of this sample (fig. 2a). At an electrolyte concentration of 0.0005 n the peaks separate by about $0.48 \cdot 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at $\text{V}\cdot\text{m}^{-1}$ and come close to each other again at a concentration of 0.001 n, the difference in the peak position diminishing to $0.3 \cdot 10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ at $\text{V}\cdot\text{m}^{-1}$. This phenomenon can be interpreted as the decrease in the thickness of the electrical double layer at the increasing electrolyte concentration. This statement is substantiated by the shape of dependence curves of electrokinetic potential on the kind of exchange cation and electrolyte concentration (Žbik 1982).

The separation of two kaolinite phases differing in the degree of crystalline perfection in the electrophoretic process will only take place when the transition between these two forms of kaolinite is not continuous. As suggested by Stoch (1962), the lack of continuous transition may be due to the different genesis of these kaolinites, and the results obtained by the present author seem to substantiate this hypothesis.

The peaks appearing on the curves of electrophoretic separation are not affected by the slight, as it is, diversity in the grain-size distribution and the particle shape. As appears from calculations, the forces of hydrodynamic resistance exerted upon the particles during electrophoresis depend, in view of the very low values of Reynolds number (10^{-4} — 10^{-5}), on the medium viscosity alone. The flow of the liquid round clay particles is laminar. Therefore the electrochemical formulae referring to electrophoresis do not take into account the geometry of moving particles.

The differences in the peak intensities observed on the distribution curves for individual samples may be due to the method of sample preparation. Each sample was prepared separately and unintentional differences may have arisen in the procedure, e.g. repeated saturation with salt solutions, or different mixing of the suspension during sampling. Moreover, optical analysis of the TV monitor screen, however careful, has certain inaccuracies as the eye perceives more readily large particles moving at a high velocity, failing to notice the smaller and slower ones. The introduction of automatic analysis of monitor screen would yield more objective data on the composition of minerals differing in their physico-chemical

properties. It is worth noting as well that the analysis of distribution curves of electrophoretic separation would not be possible without the magnetic record on video tape, which method was used for the first time in the present studies. The magnetic record of the course of experiment also affords possibilities for the use of automatic analysis of the monitor screen, and this combination may make electrophoresis a useful method yielding supplementary data to those obtained by other methods.

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WYKORZYSTANIE ELEKTROFOREZY DO ROZRÓŻNIENIA SKŁADNIKÓW MINERALNYCH KAOLINÓW

Streszczenie

Przedmiotem badań były trzy próbki frakcji ilowej (poniżej 2 μm) ilów kaolinitowych i piaskowców kaolinitowych pobranych w kopalniach surowców ceramicznych na Dolnym Śląsku w okolicy Bolesławca. Próbkę przeprowadzono w formę monojonową, sodową i potasową, a badania prowadzono w wodnych elektrolitach soli NaCl i KCl o stężeniu 0,0001, 0,0005 i 0,001 normalnym.

Do badań zastosowano metodę mikroelektroforezy. Proces przemieszczania się cząstek w zewnętrznym polu elektrycznym obserwowano pod

mikroskopem i rejestrowano jednocześnie na taśmie magnetowidu. Badania tej samej próbki prowadzono przy siedmiu różnych wartościach napięcia na elektrodach naczynka pomiarowego. Po wielokrotnym odtwarzaniu procesu elektroforezy z zapisu magnetycznego uzyskano wartości ruchliwości elektroforetycznej wszystkich cząstek obserwowanych na ekranie monitora telewizyjnego. Statystyczną metodą „zliczeń w oknie” dokonano obliczeń częstości występowania cząstek o określonej ruchliwości elektroforetycznej. Skonstruowano krzywe zależności ilości występowania cząstek od ruchliwości elektroforetycznej.

Na krzywych tych przedstawionych na figurach 1, 2 i 3 wydzielić można szereg maksimów odpowiadających grupom cząstek o odmiennej prędkości poruszania się w polu elektrycznym wewnątrz naczynka pomiarowego. Ponieważ ruchliwość elektroforetyczna cząstek poruszających się w zewnętrznym polu elektrycznym zależy jest od jednego z ważniejszych fizykochemicznych czynników powierzchni, potencjału elektrokinetycznego, to występowanie grup cząstek o odmiennych wartościach ruchliwości elektroforetycznej wskazuje na różnorodny pod względem fizykochemicznych własności skład badanych próbek.

Krzywe przedstawione na figurach 1 i 2 składają się z trzech charakterystycznych pików. Na podstawie badań składu mineralnego próbek oraz analizy ekranu monitora telewizyjnego stwierdzono, że dwa piki o największej intensywności występujące od strony niższych wartości ruchliwości elektroforetycznej należą do kaolinitu, a trzeci pik przesunięty w kierunku wyższych wartości ruchliwości elektroforetycznej należy do minerałów z grupy mik. Ponieważ w badanych próbkach stwierdzono występowanie dwóch minerałów z grupy kaolinitu różniących się stopniem krystaliczności, pik kaolinitowy na krzywych rozdziału elektroforetycznego od strony niskich wartości ruchliwości elektroforetycznej przypisano kaolinitowi (D) o nieuporządkowanej strukturze, a pik przesunięty w kierunku wyższych wartości ruchliwości elektroforetycznej przypisano kaolinitowi (TC) o wysokim stopniu uporządkowania struktury. Gęstość powierzchniowa ładunku elektrycznego wzrasta zatem wraz ze wzrostem stopnia uporządkowania struktury sieci krystalicznej minerału.

Trzeci pik, mikowy, jest w rzeczywistości złożony z szeregu maksimów pochodzących od różnych minerałów z grupy mik. Widać to dobrze na krzywych (fig. 2), gdzie część krzywej od strony niższych wartości ruchliwości elektroforetycznej przypisać można illitowi, a część od strony wyższych wartości ruchliwości elektroforetycznej przypisać można muskowitowi. Ponadto na rozciągnięcie piku mikowego wzdłuż osi wpływać może nie zakończony proces kaolinityzacji muskowitu i występowanie cząstek, w których oba minerały przerastają się nawzajem.

Krzywe na figurze 3 reprezentują próbkę złożoną głównie z kaolinitu (TC) o wysokim stopniu uporządkowania struktury z niewielką domieszką minerału z grupy mik. Jej obecność zaznacza się jako wybrzuszenie piku kaolinitu (TC) od strony wyższych wartości ruchliwości elektroforetycznej.

Krzywe rozdziału elektroforetycznego wykazują tendencję do rozsuwania się maksimów pików wraz ze wzrostem stężenia elektrolitu co wiązać należy z rozbudową podwójnej warstwy elektrycznej w wyniku reakcji jonowymiennych.

Fig. 1. Krzywe rozdziału elektroforetycznego ilości cząstek w funkcji ich ruchliwości elektroforetycznej (V_e) dla próbki 1

N — ilość zliczonych cząstek, V_e — ruchliwość elektroforetyczna w $10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ przy gradiencie potencjału $V\cdot\text{m}^{-1}$. Krzywe a, b, c dotyczą monojonowej formy potasowej (K^+), krzywe d, e, f — formy monojonowej sodowej (Na^+)

Fig. 2. Krzywe rozdziału elektroforetycznego ilości cząstek w funkcji ich ruchliwości elektroforetycznej (V_e) dla próbki 2

N — ilość zliczonych cząstek, V_e — ruchliwość elektroforetyczna w $10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ przy gradiencie potencjału $V\cdot\text{m}^{-1}$. Krzywe a, b, c dotyczą monojonowej formy potasowej (K^+), krzywe d, e, f — formy monojonowej sodowej (Na^+)

Fig. 3. Krzywe rozdziału elektroforetycznego ilości cząstek w funkcji ich ruchliwości elektroforetycznej (V_e) dla próbki 3

N — ilość zliczonych cząstek, V_e — ruchliwość elektroforetyczna w $10^{-2} \mu\text{m}\cdot\text{s}^{-1}$ przy gradiencie potencjału $V\cdot\text{m}^{-1}$. Krzywe a, b dotyczą monojonowej formy potasowej (K^+), krzywe c, d, e — formy monojonowej sodowej (Na^+)

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ИСПОЛЬЗОВАНИЕ ЭЛЕКТРОФЕРЕЗА В РАЗЛИЧАНИИ МИНЕРАЛЬНЫХ КОМПОНЕНТОВ КАОЛИНОВ

Резюме

Предметом исследований были три образца глинистой фракции (ниже 2 мкм) каолиновых глин и песчаников, отобранных в карьерах керамического сырья в Нижней Силезии в окрестностях Болеславца. Образцы переводились в монокристаллическую, натриевую и калиевую формы, а испытания проводились в водных электролитах солей NaCl и KCl 0,0001, 0,0005 и 0,001 нормальных концентраций.

В исследованиях применялся метод электрофореза. Процесс перемещения частиц во внешнем электрическом поле наблюдался в микроскопе и одновременно регистрировался на ленте видеоманитофона. Тот же самый образец изучался при семи разных величинах напряжения на электродах измерительного сосуда. После многократного воспроизведения процесса электрофореза по магнитной записи было получено значение электрофоретической подвижности всех частиц, наблюдаемых на экране контрольного телевизора. Статистическим методом «скользящего окна» проведен подсчет частоты нахождения частиц с определенной электрофоретической подвижностью. Выведены кривые зависимости количества присутствующих частиц от электрофоретической подвижности.

На этих кривых, представленных на фигурах 1, 2, 3, можно выделить ряд максимумов, соответствующих группам частиц с разной скоростью передвижения в электрическом поле внутри измерительного сосуда. Поскольку электрофоретическая подвижность движущихся во внешнем электрическом поле частиц зависит от одного из важнейших физико-химических факторов поверхности — электрокинетического потенциала, то присутствие группы частиц с разными значениями электрофоретической подвижности указывает на разнородный в отношении физико-химических свойств состав изучаемых образцов.

Представленные на фигурах 1 и 2 кривые имеют три характерных пика. На основании исследования минерального состава образцов, а также анализа изображений на экране контрольного телевизора, обнаружено, что два пика максимальной интенсивности принадлежат к каолиниту, а третий пик, сдвинутый в сторону высших значений электрофоретической подвижности, принадлежит к минералам группы слюд. Поскольку в изучаемых образцах обнаружено присутствие двух минералов из группы каолинита, отличающихся степенью упорядоченности кристаллической структуры, то каолиновый пик на кривых электрофоретического разделения со стороны низших значений электрофоретической подвижности приписан был каолиниту (D) с неупорядоченной структурой, а пик, сдвинутый в сторону высших значений электрофоретической подвижности, приписан каолиниту (ТС) с высокой степенью упорядоченности структуры. Следовательно, поверхностная плотность электрического заряда растет с увеличением степени упорядоченности структуры кристаллической решетки минерала.

Третий, «слюдяной» пик в действительности сложен рядом максимумов, происходящих от различных минералов из группы слюд. Это хорошо заметно на кривых (фиг. 2), где участок кривой со стороны низших значений электрофоретической подвижности можно отнести на счет иллита, а отрезок со стороны высших значений электрофоретической подвижности можно приписать мусковиту. Кроме того, на растяжение слюдяного пика вдоль оси (x) может влиять незавершенный процесс каолинитизации мусковита, а присутствие частиц, в которых оба минерала взаимно сростаются.

Кривые на фигуре 3 представляют образец, сложенный главным образом каолинитом (ТС) высокой степени упорядоченности структуры с небольшой примесью минерала из группы слюд. Ее присутствие отмечается как утолщение пика каолинита (ТС) со стороны высших значений электрофоретической подвижности.

Кривые электрофоретического разделения обнаруживают тенденцию к раздвиганию максимумов пиков одновременно с увеличением концентрации электролита, что следует увязывать с расширением двойного электрического слоя вследствие ионообменных реакций.

ОБЪЯСНЕНИЯ К ФИГУРАМ

Фиг. 1. Кривые электрофоретического разделения количества частиц в функции их электрофоретической подвижности (V_e) для образца 1

N — количество подсчитанных частиц, V_e — электрофоретическая подвижность в $10^{-2} \mu\text{m}\cdot\text{сек}^{-1}$ при градиенте потенциала $V\cdot\text{m}^{-1}$. Кривые a, b, c относятся к моноионной калиевой форме (K^+), кривые d, e, f — к моноионной натриевой форме (Na^+)

Фиг. 2. Кривые электрофоретического разделения количества частиц в функции их электрофоретической подвижности (V_e) для образца 2

N — количество подсчитанных частиц, V_e — электрофоретическая подвижность в $10^{-2} \mu\text{m}\cdot\text{сек}^{-1}$ при градиенте потенциала $V\cdot\text{m}^{-1}$. Кривые a, b, c относятся к моноионной калиевой форме (K^+), кривые d, e, f — к моноионной натриевой форме (Na^+)

Фиг. 3. Кривые электрофоретического разделения количества частиц в функции их электрофоретической подвижности (V_e) для образца 3

N — количество подсчитанных частиц, V_e — электрофоретическая подвижность в $10^{-2} \mu\text{m}\cdot\text{сек}^{-1}$ при градиенте потенциала $V\cdot\text{m}^{-1}$. Кривые a, b относятся к моноионной калиевой форме (K^+), кривые c, d, e — к моноионной натриевой форме (Na^+)