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**Потенціал використання лужноземельних бентонітових глин
України при виробництві залізородних окатишів**

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**The potential of using of alkaline earth bentonite clays of Ukraine in
the production of iron ore pellets**

Мета: проаналізувати та визначити потенціал лужноземельних бентонітових глин України для використання в якості зв'язуючого при виробництві залізородних окатишів.

Методика: виконання реологічних досліджень зразків бентонітових глин та їх хімічний аналіз, електронно-мікроскопічні дослідження зразків.

Результати: здійснено аналіз хімічного складу і вимог до реологічних характеристик бентонітових глин, що використовуються у виробництві залізородних окатишів на металургійних підприємствах України, Росії та інших країн. Наведено показники набухання і водопоглинання моноіонних форм бентонітов деяких родовищ у воді різної жорсткості. Розглянуто якість окатишів з бентонітами, що мають різний обмінний комплекс при використанні технічної води різної жорсткості. Здійснено аналіз мінералогічного і хімічного складу, а також величини і складу обмінного комплексу лужноземельних бентонітових глин Черкаського родовища, що володіє найбільшими запасами таких глин на території колишнього СРСР. Показано, що глини, придатні для виробництва окатишів розташовані поблизу поверхні землі. Представлено порівняльний аналіз показників міцності окатишів з використанням бентонітів з лужним і лужноземельних обмінними комплексами.

Наукова новизна: показано що, незважаючи на низьке набухання лужноземельних бентонітів, якість окатишів з цими бентонітами в деяких випадках незначно нижче, а в певних умовах не поступається якості окатишів з лужними бентонітами при їх однаковій витраті.

Практична значущість: для реальних промислових умов продемонстровано, що збільшення жорсткості води призводить до часткової або повної (в залежності від величини жорсткості) заміні лужного обмінного комплексу на лужноземельний і перетворення лужної бентонітової глини в лужноземельну з відповідними реологічними характеристиками, погіршенням згрудкування шихти, характеристик сирих окатишів і необхідністю збільшення вмісту бентоніту в шихті. У разі підвищеної жорсткості води в концентраті економічно доцільно використовувати у виробництві окатишів лужноземельних бентонітової глину, якщо вона дешевше лужної.

Ключові слова: бентонітові глини, окатиші, виплавка чавуну, монтморилоніт, палігорськит, дисперсія, обмінний комплекс, набухання, міцність окатишів.

Objective: to analyze and determine the potential of alkaline earth bentonite clays of Ukraine for use as a binder in the production of iron ore pellets.

Methods: performing rheological studies of bentonite clay samples and their chemical analysis, electron microscopic studies of samples.

Results: the analysis of the chemical composition and requirements for the rheological characteristics of bentonite clays used in the production of iron ore pellets at metallurgical enterprises of Russia and Ukraine is carried out. The swelling indicators and water absorption of monoionic forms of bentonites of some deposits in water of different hardness are given. The quality of pellets with bentonites, that have a different exchange complex, during an industrial water of various hardness usage is examined. The analysis of the mineralogical and chemical composition, as well as the size and composition of the exchange complex of alkaline-earth bentonite clays of the Cherkassk deposit (Ukraine), which has the largest reserves of such clays in the CIS is carried out. It is shown that clays suitable for the production of pellets are located near the surface of the earth. A comparative analysis of the strength characteristics of pellets using bentonites with an alkaline and alkaline-earth exchange complex is presented.

Scientific novelty: it was shown that despite the low swelling of alkaline-earth bentonites, the quality of pellets with these bentonites, in some cases, is slightly lower, and in certain conditions is not inferior to the quality of pellets with alkaline bentonites at the same flow rate.

Practical significance: for real industrial conditions it is shown that the increase in water hardness leads to partial or complete (depending on the value of hardness) replacement of alkaline exchange complex with alkaline earth and conversion of alkaline bentonite clay into alkaline earth with corresponding rheological characteristics, deterioration of lumps and the need to increase the content of bentonite in the charge. In the case of increased hardness of water in the concentrate, it is economically feasible to use in the production of alkaline earth pellets bentonite clay, if it is cheaper than alkaline.

Keywords: bentonite clays, pellets, pig iron smelting, montmorillonite, palygorskite, dispersion, exchange complex, swelling, pellet strength.

Introduction. For the efficient smelting of cast iron in blast furnaces, it is necessary to use iron ore raw materials with the highest possible iron content, minimum silica content, high strength characteristics in the

cold state and during heating and reduction in the blast furnace [1].

In the pellets production binders are used as hardening additive for pelletizing finely ground iron ore

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concentrates. Generally accepted in the industrial production of inorganic binder additives are: fired pellets and bentonite clay with an alkali exchange complex (natural or artificially produced), as well as active lime (slaked or hydrated). Sodium carboxymethyl cellulose, peridur, technical lignosulfonate, sulphite-alcohol distillery distillate and other compounds have been used as organic binders in recent decades. The amount of bentonite clay in the charge is (by dry weight) 0,5-1,0%, lime – 2-5 %. The amount of organic binder additives in the charge is 0,05-0,1 %, that is, an order of magnitude lower than bentonitic clay [2].

In the USSR, all pellet factories used alkaline bentonite clay of one large deposit, divided by the border between the Armenian SSR and the Azerbaijan SSR and named, respectively, at the extraction site on each side, Sarygyuhsky and Dash-Salakhlynsky. Due to the collapse of the USSR and conservation of bentonite production at this field, all pelletizing factories switched to soda ash modified alkaline-earth bentonite clays imported from India and Greece.

Analysis of literature data and problem statement. Alkaline-earth bentonite clays of the II layer of the Cherkassky deposit, Ukraine, in previous years in a limited amount were also modified with soda ash, although using primitive technology, which did not provide them with high quality and, accordingly, demand. In addition, difficulties arose due to the need for mining and processing enterprises to pump highly mineralized water pumped from mines into the internal water cycle.

All clay minerals have a certain cation exchange capacity. This value is an important characteristic of the mineral and indicates the number of exchangeable cations (expressed in mg-equivalents) capable of being replaced by cations of another type per 100 g of

clay. Montmorillonite, the main mineral of bentonite clay, has the highest cation exchange capacity among clay minerals (up to 90–120 mEq/100 g of dry clay).

According to the composition of the exchange cations, bentonite clays are divided into:

- alkaline, where more than half of the components of the exchange complex are sodium and potassium cations ($\text{Na}^+ + \text{K}^+$, mEq/100 g clay);
- alkaline-earth (calcium, magnesium, calcium-magnesium and magnesium-calcium), where more than half of the exchange cations belong to calcium and magnesium ($\text{Ca}^{++} + \text{Mg}^{++}$, mEq/100 g clay) [2].

Moreover, for the production of pellets by rheological characteristics, bentonite clays with an alkaline exchange complex are most suitable (in an aqueous medium of a certain hardness).

By generally accepted methods, all rheological characteristics of bentonite clays clarify itself in distilled water, and the process water at different enterprises has different hardness, amount and composition of dissolved salts.

Studies have shown that increasing water hardness significantly reduces the swelling and water absorption of bentonites with an alkaline exchange complex (table 1) and practically does not affect these indicators in bentonites with an alkaline-earth exchange complex [2]. Moreover, an increase in the hardness of process water, for example, Severny GOK (SevGOK) from 8,8 mEq/dm³ in 1979 to 127,6 mEq/dm³ in 2017 led to a decrease in the swelling of bentonite from 10,2 to 4,3 times, and water absorption - from 344 to 178 %. This effect also affected the deterioration of the properties of raw pellets at the same consumption of bentonite in the charge.

Table 1 – Swellability and water absorption of monoionic forms of bentonites of different deposits in water of different rigidity

Material	Type of water	Water hardness, mg·eq/dm ³	Swelling, once	Water absorption (Enslin), %
Na-Sarygyuhsky	Distilled	0,07	13,6	371
	Industrial SevGOK* ¹	8,8	10,2	344
	Industrial SevGOK* ²	127,6	4,3	178
	Mine	274,5	3,0	160
Ca-Sarygyuhsky	Distilled	0,07	3,4	247
	Industrial SevGOK* ¹	8,8	4,8	243
	Mine	274,5	3,0	208
Na-Cherkassky	Distilled	0,07	13,2	398
	Industrial SevGOK* ¹	8,8	12,5	369
	Industrial CGOK	43,6	7,6	352
	Industrial InGOK	29,5	7,8	—
	Mine	274,5	4,0	214
Ca-Cherkassky	Distilled	0,07	4,8	215
	Industrial SevGOK* ¹	8,8	3,0	200
	Mine	274,5	2,4	180
* ¹ Technical water 1979				
* ² Technical water 2017				

Thus, an increase in the hardness of industrial water at enterprises producing iron ore concentrates worsens the rheological characteristics of alkaline

bentonite clays, which are positive for the production of pellets, to the level of alkaline-earth clays and re-

quires their increased consumption, which naturally reduces the iron content in the pellets.

There are lots of bentonite clay deposits with hundreds of millions tons of raw material reserves in Ukraine and Russia, but they are not used in industry due to the lack of systematic and in-depth studies on their suitability. For example, only recently more in-depth studies of the Tikhmenevskoye field (Sakhalin) has begun, more attention are paid now to the deposits of the Central region [4], Voronezh antecline [5], Cherkassky and others. Scattered works, devoted to these deposits showed that, for a number of qualitative characteristics, these clays do not fully meet the requirements contained in the technical specifications for bentonite clays for pelletizing factories [2], because these bentonites (table. 2) are alkaline earth, while specifications require Na-montmorillonite to be contained in the bentonite. The last leads to a high swelling of clay and the ratio of the amount of sodium with potassium to the sum of calcium with magnesium

and the ratio of sodium oxide to potassium oxide naturally exceeding unity.

This factor was the main reason why some Russian and Ukrainian bentonites were found unsuitable for pelletizing iron ore concentrates. Probably the same factor can explain the lack of relevant research work, which would deeply reveal the relationship between the properties of bentonite and the characteristics of the finished pellet, the possibility of pre-processing clay to bring it to the required conditions.

Thus, the geographical location, favorable mountain and environmental conditions for the extraction of these clays in large quantities and the prospects for the use of pellets in the production process provide reliable grounds for choosing these clays as the most worthy object of research. The most effective method for improving the rheological characteristics of alkaline-earth bentonites is their modification, that is, changing their metabolic complex in alkaline with the least cost [2].

Table 2 – Chemical analysis of bentonite clays of some deposits used in pellet production in Russia and Ukraine

Clays deposit	The content of oxides, %							
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O + K ₂ O	Puncture loss
Deposits Milos island (Greece), activated* ¹	55,7	18,7	3,9	3,8	3,2	1,6	2,8	7,8
10th Khutor (Republic of Khakassia, Russia)* ¹	59,7	18,6	3,9	2,8	2,4	0,1	2,6	8,4
Zyryanskoye deposit (Kurgan region, Russia)* ¹	57,4	19,4	6,0	1,8	3,0	0,1	1,8	9,4
Dash-Salahlinskoye, Sarygyuhskoye (Azerbaijan, Armenia)* ²	58,6	13,4	4,7	2,1	2,3	0,3	2,7	15,3
Konstantinovskoye deposit (Ukraine)* ¹	52,2	16,2	8,9	5,0	2,3	0,3	2,8	9,1
Cherkassky II layer* ¹	58,5	17,4	6,6	1,3	1,4	0,1	0,16	7,32
Cherkassky III layer* ³	55,1	17,3	6,83	0,42	7,3	0,1	1,83	10,6
Cherkassky IV layer* ¹⁺³	55,8	17,1	6,5	3,4	5,3	0,1	1,2	7,8
Wyoming (USA)* ²	64,1	14,27	No inf.	1,6	2,2	No inf.	4,0	9,33
* ¹ Alkaline earth. * ² Alkaline. * ³ Palygorskite.								

In the composition of the productive stratum, for example, Cherkassky deposit, there are three types of alkaline-earth bentonite clays: II layer, containing mainly Ca⁺⁺ ions and substantially less Mg⁺⁺ in the exchange complex; III layer, consisting of the palygorskite mineral, containing mainly Mg⁺⁺ ions in the exchange complex, is substantially less than Ca⁺⁺ and more than in the II layer of Na⁺ ions; IV layer, representing a natural mixture of II and III layers in a ratio of an average of about 1:1. Palygorskite by structural features is a kind of clay mineral with the ability to high dispersion effect even in environments with a high concentration of electrolytes. In addition, its hydrophilicity exceeds any cation-exchange modification of any clay mineral [6]. These two qualitative charac-

teristics determine the prerequisites for a positive effect in a mixture with alkaline-earth Ca-montmorillonite for the emergence of a stable coagulation dispersed structure, as is created in a dispersion with Na-montmorillonite. Palygorskite and montmorillonite in the IV layer of the Cherkassky deposit makes an even higher quality dispersion both in the sense of colloidal and structural-mechanical properties of the suspension. In addition, the higher dispersion of these two converting minerals than for particles of other layers creates a higher surface area, which is also a favorable factor in the interaction of the particles of the strengthening additive with particles of the concentrate. The location of a large number of water molecules in the zeolite-like channels of

the crystalline structure of palygorskite makes this mineral extremely moisture-resistant, supplying water molecules to the system during heating from room temperature to 400–450 °C. Considering that water molecules in crude pellets are the main agent that holds the concentrate particles together, it can be assumed that additives such as palygorskite crystals play a significant role.

The surface of the palygorskite crystals cannot provide high adhesion to the concentrate particles in a dry pellet, but when interacting with montmorillonite particles, this mineral exhibits exceptional structure-forming ability, and alkaline-earth montmorillonite in the presence of palygorskite acquires a higher surface activity, which is successfully implemented in collaboration with the edges of ore minerals.

Another important circumstance is very essential in substantiating the need for introducing finely dispersed palygorskite into the strengthening additive — the presence of magnesium cations in its structure. Palygorskite is inherently a magnesian silicate with a layered tape structure; in the palygorskite of the Cherkasy deposit, a significant part of it is replaced by aluminum. This combination of these two cations is most favorable for the formation of aluminum-magnesium spinel layers isostructural with magnetite edges, where magnetite acts as a matrix for the spi-

nel phase. This factor, apparently, plays one of the most significant roles in the hardening of dry pellets when they are heated to 1100 °C.

Thus, the choice of the bentonite and palygorskite clays of the Cherkassky deposit as the object of study was based on sufficiently compelling arguments, although the lack of clearly and comprehensively justified requirements for the quality of raw materials made it difficult to carry out work in terms of using natural forms of clay.

The purpose and objectives of research. Determination of the possibility of using bentonite clays of Cherkassky deposit as a binder in the production of pellets at Ukrainian GOK.

Materials and methods of research. The productive stratum of the Cherkassky deposit of bentonite and palygorskite clays consists of five layers clearly distinguished by macroscopic features (from top to bottom, of which layers II–IV are suitable for the production of pellets). The methods of research is rheological studies of bentonite clay samples and their chemical analysis, electron microscopic studies of samples.

Research results. The mineralogical composition of layer I consists of 30–40 % hydromica, 30–40 % montmorillonite, 20–30 % calcite and it is not suitable for use in the production of pellets.

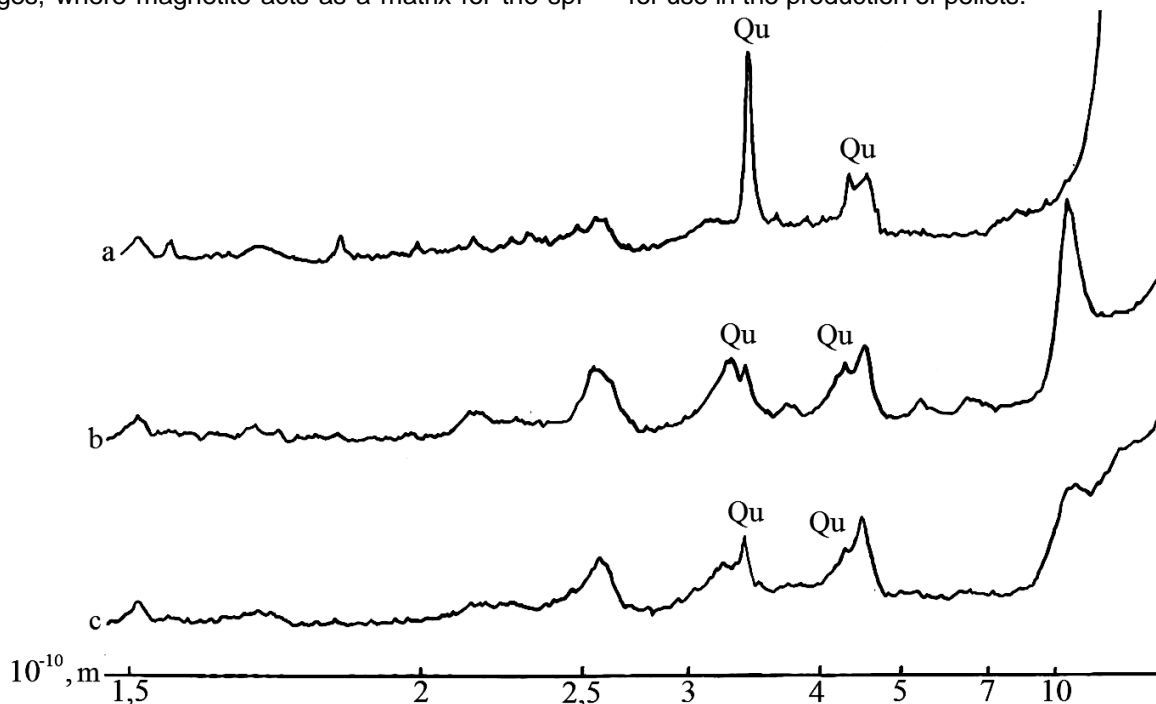


Fig. 1. X-ray diffraction patterns of productive clays the thickness of the Cherkasy deposit: a – II layer (montmorillonite), b – III layer (palygorskite), c – IV layer, Qu – quartz

The mineralogical composition of layer II consists of 95–98 % Ca-montmorillonite and 2–5 % quartz. The total distribution area of the layer is 625 km², the average thickness of the deposit is 6 m, the total clay

reserves are about 5,8 billion tons. X-ray diffraction patterns of samples from numerous wells drilled over the entire area of the field give a typical diffraction pattern for montmorillonite (fig. 1).

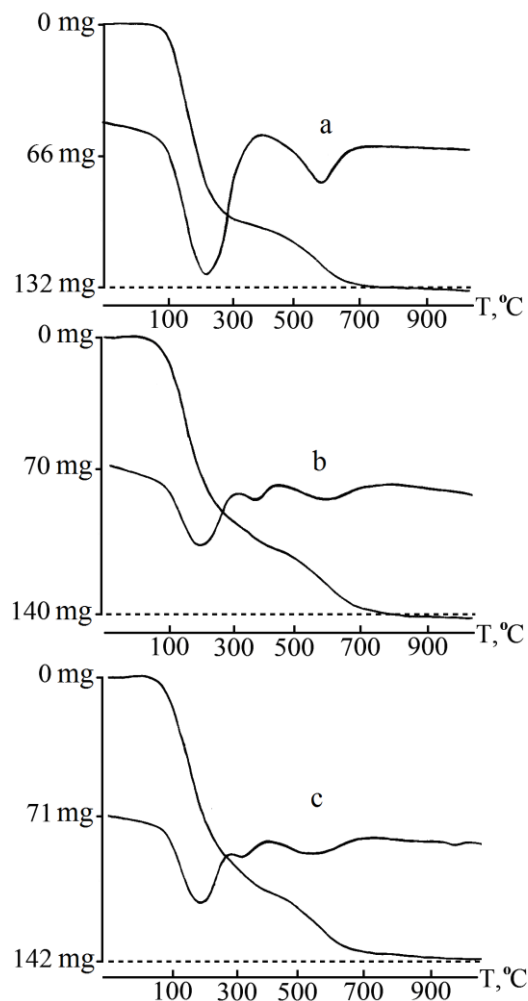
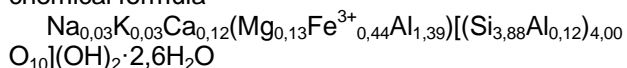


Fig. 2. Thermograms (differential and weight loss curves) of productive clays the thickness of the Cherkassy deposit: a – II layer; b – III layer; c – IV layer.

Thermograms of samples of layer II (fig. 2) have three endothermic effects: a deep endoeffect at 180 °C with an excess at 250 °C. A weaker endo effect is also observed at 500–600 °C, due to the release of the bulk of hygroscopic water, and the endoeffect caused by the loss of hydroxyl groups at 720–760 °C due to residues of removal of hydroxyl groups and recrystallization of montmorillonite. The somewhat lower temperature of the second and third endoeffects is caused by the increased iron content in the octahedral positions of the structure of Cherkassky montmorillonite.

In electron microscopic images (Fig. 3), montmorillonite is represented by small flocculent particles with fuzzy outlines.

According to chemical analysis, Cherkassky bentonite is near to the montmorillonites of other deposits presented above (see table 2). Some difference is the increased content of Fe³⁺, which in Cherkassky bentonite ranges from 5 to 8 %. The calculated crystal chemical formula



confirms the montmorillonite composition of clays of the II layer. The deficit of lattice cations is compensated by the exchange cations Ca²⁺, K⁺, Na⁺. The to-

tal exchange capacity of Cherkassky bentonite is 92,6 mEq/100 g of dry clay.

The III layer consists of four main lenses, separated by erosion of the layer by rivers. The total distribution area of clays of the III layer is 323 km², the average thickness is 3 m. In the horizontal direction, the quality of clay changes gradually: its sandiness increases to the east. The clay layer is generally uniform; sometimes in the upper part or lower parts of the formation, intercalations of limestone with a thickness of up to 3 m are observed: in individual wells, the clay is completely replaced by limestone. The total reserves of clay of the III layer are 1195,7 million tons, including 8,4 million tons in the Dashukovsky area.

Clay of the III layer is 96–98 % composed of particles less than 0,01 mm. The silt part is only 1–2 % of the rock. The main rock-forming mineral of the III layer is palygorskite (an analogue of American attapulgite). All diffraction patterns of numerous samples from wells and the Dashukovsky quarry contain reflections characteristic of palygorskite (10,48×10⁻¹⁰ m; 3,23×10⁻¹⁰ m and other), which do not change either upon heating to 300 °C or upon processing of samples with organic substances with polar molecules.

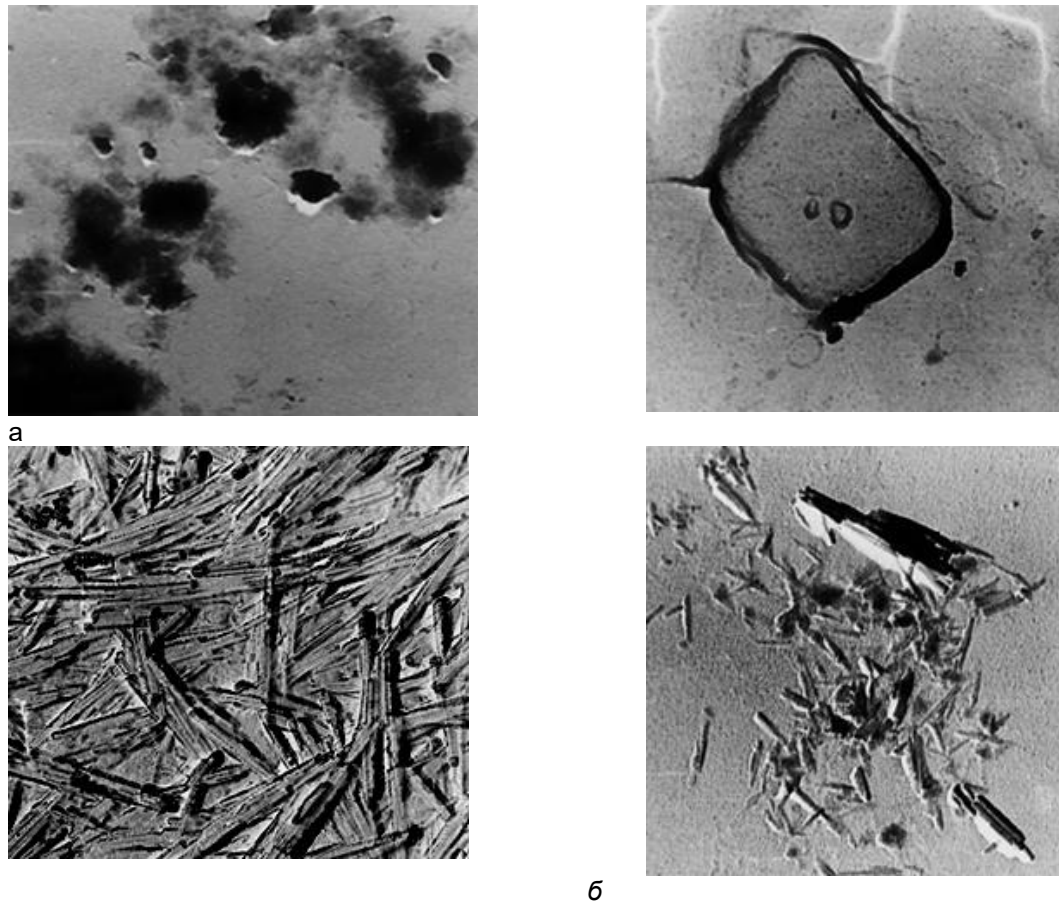
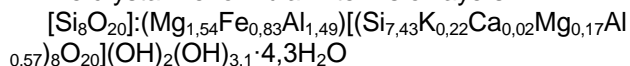


Fig. 3. Electron microscopic images of samples of productive clays the thickness of the Cherkassky deposit:
a – II layer (in suspension, in replica); b – III layer (in suspension, in replica)

The heating curves of Cherkassky palygorskite (see fig. 2, b) have two low-temperature maxima caused by the removal of hygroscopic (180 °C) and zeolite (320 °C) water. The medium temperature endoeffect (560 °C) is due to the formation of a compressed form of palygorskite-II, and the endoeffect at 720–760 °C is caused by recrystallization of it into enstatite, sillimanite and cristobalite. The electron microscopic images of all samples of layer III (see fig. 3, b) clearly show columnar crystals having the form of planks 0,2–0,5 microns long and 0,02–0,03 microns wide. On the carbon replicas of these samples, it is clearly seen that the individual trims consist of the finest parallel needles [7].

Chemical analysis of clay layer III is given in table. 2. The crystalline formula in terms of layers:



The total exchange capacity is 27–29 mEq/100 g clay.

The IV layer is distributed in the field with separate lenses, the thickness of which varies from 0,4 to 5,7 m with an average thickness of 2 m in the field. The total distribution area of the layer is 344 km².

Radiographs of clay samples of layer IV of the Cherkasy deposit (see fig. 1, c) contain reflections of

montmorillonite and palygorskite. Typically, palygorskite is 30 %, and montmorillonite is 70 %: in sandy varieties, the content of palygorskite is reduced to 10 %. Thermograms (see fig. 2, c) show a deep endothermic effect at 150–180 °C due to the removal of adsorption water and endo effects at 600 and 740–760 °C, reflecting the removal of OH groups and the recrystallization of montmorillonite.

Under an electron microscope, fibrous crystals of palygorskite and flake-like flakes of montmorillonite are visible (fig. 4). Palygorskite crystals are characterized by a significantly greater dispersion than in the case of layer III. The heat of wetting of clay of the IV layer is 21.2 cal/g, the amount of bound water is 20,9%, and the specific surface is 763 m²/g.

The V layer is represented by lower miocene sands and is not suitable for use as a binder.

The requirements for the quality of bentonite raw materials consumed for pelletizing iron ore pellets should be formulated on the basis of a study of the required technological characteristics of the pellets obtained by using one or another type of bentonite. In turn, the technological characteristics of the pellets obtained by laboratory methods should be as near as possible to the industrial conditions for the preparation of pellets at different stages of preparation.

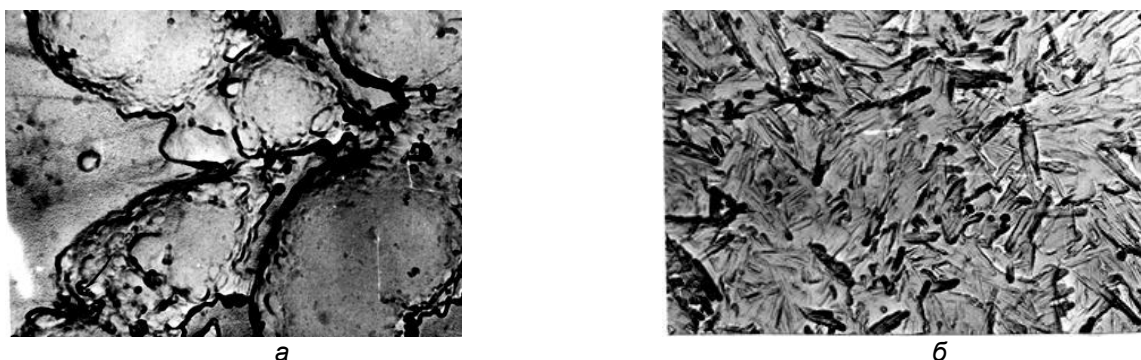


Fig. 4. Electron microscopic images of samples of productive clays the thickness of the Cherkasy deposit: a – IV layer in suspension; b – in replica

According to V.M. Vityugin and P. N. Dokuchaev [8], the increased consumption of bentonite clays under industrial conditions is caused by several reasons, the main one is the extremely uneven distribution of dry finely ground bentonite powder in wet iron ore concentrate due to the ineffective mixing equipment used, which leads to an increase in clay consumption to achieve the necessary quality characteristics of the finished pellet. For example, the authors cite information that in the American practice of pelletizing iron ore concentrates with a moisture content of not more than 10 %, the theoretical consumption of high-quality bentonite should be 0,25 %, but in fact due to insufficient mixing efficiency, this amount doubles (i.e., 0,5 and 0,8 % or even 1 %).

Various methods have been developed for using bentonite clays in the process of pelletizing, including: applying alkaline bentonite to the surface layer of pellets, preliminary mixing alkaline-earth bentonite with 7% soda ash, the use of mixed clay compositions with a small amount of high-quality bentonite, etc. These measures can reduce the percentage of bentonite additives and increase the strength of the pellets.

Nevertheless, not only the chemical composition of the binder has an effect on the formation of the corresponding binder during high-temperature firing, but also the size and composition of the cation exchange complex, which determine the quality of the raw and calcined pellets.

Thus, it becomes quite obvious that the strength characteristics of the pellets depend not only on the colloidal characteristics of the clay, but also on a number of other indicators, among which the mineralogical and chemical compositions of bentonite clay, the composition and capacity of the exchange complex, the humidity of the concentrate, the rigidity of its process water, and the physical characteristics of the iron ore concentrate are significant.

From the long-term practice of using bentonite clays of different quality in the production of iron ore pellets, requirements have been formed for the rheological characteristics of bentonite (table 3) to ensure the properties of raw and calcined pellets with this binder required by the technology (table 4), and the maximum productivity of their calcining units.

Table 3 – Requirements for rheological characteristics of the bentonite clays used in the production of pellet

The main clay mineral	Montmorillonite
Alkalinity coefficient in the exchange complex ^{*1}	More than 1,0 at Na ⁺ > K ⁺
Swelling amount ^{*2} , once	More than 12,0
Colloid ^{*2} , %	90–100
Water absorption (Enslin) ^{*2} , %	More than 250
The dynamic viscosity of the suspension ^{*2} , MPa·s	More than 9,0
Heat limit without changing physical properties, °C	More than 200
Hydrogen ion concentration (pH)	More than 9,0
Total specific surface, m ² /kg	More than 35000
^{*1} (Na ⁺ + K ⁺)/(Ca ⁺⁺ + Mg ⁺⁺).	
^{*2} By standard techniques, rheological characteristics are determined in distilled water.	

As additional characteristics for montmorillonite, thermographic and x-ray data are accepted: interval of the second endothermic effect on the thermogram 650–750 °C, the value of the first basal reflection in the x-ray for an air-dry sample – (12–13)×10⁻¹⁰ m, although it is undoubted that all of the indicated parameters of clay characteristics are largely arbitrary, since there are cases when “substandard” hardening additives create satisfactory strength characteristics of the finished pel-

lets. In the table 5 shows the quality of pellets using different binder additives when pelletizing various iron ore concentrates with different composition of process water. Analysis of these data shows that despite the low swelling of alkaline-earth bentonites, the quality of the pellets with these bentonites in some cases is slightly inferior to the quality of the pellets with alkaline bentonites. At the same time, alkaline-earth bentonites of many deposits were rejected only because they had low swelling.

Table 4 – Technological requirements for the properties of raw pellets with qualitative alkaline bentonite

Compressive strength* ¹ , kg/pellet	Compressive strength of the dried* ¹ , kg/pellet	Impact strength of the raw* ² , once	Drying temperature limit ("shock")* ³ , °C	Content of valid (8–20 mm) class, %
0,8-1,2	More than 3,0	More than 4,0	More than 400	More than 90,0
* ¹ Pellets diam. 14±2 mm.				
* ² The number of drops from a height of 500 mm onto a steel plate before the destruction of pellets diam. 14±2 mm.				
* ³ It is determined at a coolant filtration rate of 1,2 nm ³ /(m ² ·s).				

Conclusions

1. Bentonite clay is one of two (bentonite clay and active lime) important inorganic binder additives in the production of iron ore pellets, that provides the required optimal technological parameters of technical units for obtaining high-quality raw pellets and their heat strengthening, to obtain calcined product that meets the requirements of blast furnace smelting.

2. In the production of calcined pellets, it is advisable to use only bentonite clays with an alkalinity coefficient of the exchange complex equal to the ratio $Na^+ + K^+/Ca^{++} + Mg^{++} > 1,0$, wherein $Na^+ > K^+$. Moreover, it is desirable that the hardness of the technical water in the concentrate be no more than 10-30 mEq/dm³.

3. An increase in water hardness leads to a partial or complete (depending on the hardness value) replacement of the alkaline exchange complex with an alkaline-earth complex and the conversion of alkaline bentonite clay to alkaline-earth with appropriate rheological characteristics, the deterioration of the lumpiness of the mixture, the characteristics of raw pellets and the need to increase the content of bentonite in the mixture.

4. In the case of increased water hardness in the concentrate, it is economically feasible to use alkaline-earth bentonite clay in the production of pellets, if it is cheaper than alkaline.

5. Palygorskite bentonite clay can be considered as the most promising for the production of iron ore pellets. Long industrial tests should be carried out with its use.

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