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THE ECOLOGICAL IMPORTANCE OF PROCESSING PHOSPHATE RAW MATERIALS TO PRODUCE FINISHED PRODUCTS

Abstract. The article discusses the current problem of the phosphorus industry related to the development of technology for the production of highly effective mineral fertilizers based on substandard phosphate raw materials. Phosphorites from the Chilisai deposit are proposed as such raw materials, which are classified as low-grade due to their high carbonate content (4.56–6.34% in terms of CO_2). This creates environmental problems. Scanning electron microscopy and X-ray fluorescence analysis methods were used to study the physico-chemical properties of phosphorite samples. The results showed that phosphorites consist mainly of quartz grains of various sizes (from 0.002 to 15 mm) cemented with phosphate. Based on the conducted research, the optimal parameters of the technological process for obtaining monocalcium phosphate from this raw material have been determined.

Key words: *ecology, phosphorus industry, processing, X-ray fluorescence analysis, fertilizers, monocalcium phosphate.*

Дайын өнімді алу үшін фосфат шикізатын өңдеудің экологиялық маңызы

Аңдатпа. Мақалада фосфат өнеркәсібінің өзекті проблемасы қарастырылады, ол кондиционерленбеген фосфат шикізаты негізінде жоғары тиімді минералды тыңайтқыштарды өндіру технологиясын әзірлеуге байланысты. Мұндай шикізат ретінде Чилисай кен орнының фосфориттері ұсынылады, олар карбонаттардың жоғары болуына байланысты төмен сортты болып жіктеледі (CO_2 бойынша 4,56–6,34%). Бұл жағдай экологиялық проблемаларды тудырады. Фосфорит үлгілерінің физика-химиялық қасиеттерін зерттеу үшін растрлық электронды микроскопия және рентген-флуоресцентті талдау әдістері қолданылды. Нәтижелер фосфориттердің негізінен фосфатпен цементтелген әртүрлі мөлшердегі (0,002-ден 15 мм-ге дейін) кварц дәндерінен тұратынын көрсетті. Жүргізілген зерттеулер негізінде осы шикізаттан монокальций фосфатын алудың технологиялық процесінің оңтайлы параметрлері анықталды.

Түйінді сөздер*: экология, фосфор өнеркәсібі, өңдеу, рентген-флуоресцентті талдау, тыңайтқыштар, монокальций фосфаты.*

Экологическая значимость переработки фосфатного сырья для получения готовой продукции

Аннотация. В статье рассматривается актуальная проблема фосфорной промышленности, связанная с разработкой технологии производства высокоэффективного минерального удобрения на основе некондиционного фосфатного сырья. В качестве такого сырья предложены фосфориты Чилисайского месторождения, которые классифицируются как низкосортные из-за высокого содержания карбонатов (4,56–6,34% в пересчете на CO_2). Это обстоятельство создает экологические проблемы. Для изучения физико-химических свойств образцов фосфоритов были использованы методы растровой электронной микроскопии и рентгенофлуоресцентного анализа. Полученные результаты показали, что фосфориты состоят преимущественно из зерен кварца различного размера (от 0,002 до 15 мм), сцементированных фосфатом. На основе проведенных исследований определены оптимальные параметры технологического процесса получения монокальцийфосфата из данного сырья.

Ключевые слова: *экология, фосфорная промышленность, переработка, рентгенофлуоресцентный анализ, удобрения, монокальцийфосфат.*

Introduction

The ecological importance of processing phosphate raw materials is expressed in several key aspects that contribute to environmental protection, the rational use of natural resources and the reduction of negative impacts on ecosystems. Since phosphates are non-renewable natural resources, their reserves are gradually being depleted. The processing of phosphate raw materials allows you to reuse valuable components, extracting them from production waste or used fertilizers, which contributes to a more efficient and careful use of resources. In addition, processing reduces the burden on ecologically vulnerable areas where phosphate ores are mined, reducing the risks of destruction of natural ecosystems and reducing the need for energy-intensive and environmentally unsafe mining methods. With dwindling reserves of rich phosphate ores in Karatau, the mineral fertilizer industry is forced to process raw materials with a lower P_2O_5 content. This makes it particularly relevant to develop new ore processing technologies and create alternative schemes for obtaining fertilizers from phosphate raw materials. The Chilisai phosphorite deposit, also characterized by a low P_2O_5 content, is located in the Oktyabrsky district of the Aktobe region. In the central part of the deposit is the railway station of the phosphorite mine, located on the 17th kilometer of the Kandahach-Atyrau railway line, which crosses the deposit from northeast to southwest. The area has been actively developed economically, and the deposit itself has been explored in detail [1].

This deposit is the largest in the Aktobe phosphorous-bearing basin. The useful stratum is represented by a horizon of nodular phosphorites of Santon-Campanian age, and a slab of nodular phosphorites lies in the roof, the dimensions of which reach 7 cm. The thickness of the phosphorite-bearing reservoir varies between 0.4–1.6 m. The phosphorite layer is overlain by Campanian carbonate clays, whose thickness ranges from 0.35 to 7 m. The total area of the phosphorite formation in the deposit is 1,555 km^2. In a significant area of the deposit, the phosphorite layer reaches the daytime surface, being covered only with modern sandy loams or loams with a thickness from 0 to 1 m [2].

The average content of P_2O_5 in natural ore is 10.27%, in washed concentrate – 17.5%, and in flotation concentrate – 23.8%. Phosphorite ore contains on average from 9% to 11% P_2O_5 and impurities such as Fe_2O_3 (2–4%), Al_2O_3 (2.5–4%) and CO_2 (2–5%). Depending on the content of harmful components, the following types of ores are distinguished: easily enriched low-iron ores (Fe_2O_3 < 3%, CO_2 < 3.5%), ferruginous ores (Fe_2O_3 < 3.8%), as well as carbonate and carbonate-ferruginous ores (CO_2 4.5–5.2%, Fe_2O_3 2.7–3.6%) [3]. The phosphorite reserves of the Chilisai deposit are shown in table 1.

Note: Ore – thousand tons, P_2O_5 – thousand tons, reserves of dry phosphorite ore are calculated at volume weights of 1.92–2.12 tons/m^3. The natural moisture content of the ore is 5%.

Table 1

Reserves of Chilisai phosphorite

Кесте 1

Чилисай фосфоритінің қоры

Таблица 1

Запасы Чилисайского фосфорита

Category	Balance sheets, thousand tonnes (kt)		Off-balance sheet, thousand tonnes (kt)	
	Total	Including in the career contour	Total	Including in the career contour
A	47923 5140	47923 5140	8058 896	8058 896
B	136162 14602	136162 14602	23307 2488	23307 2486
C_1	474469 49275	201190 21562	395360 37124	118013 12346
C_2	492131 40872	3317 362	-	-

The production of phosphorous fertilizers is a critically important stage in ensuring global food security. Phosphorus, which is an essential macronutrient for plants, is present in nature mainly in the form of phosphorites, sedimentary rocks with a phosphate content ranging from 15 to 40%, although richer deposits are also found. Phosphorite mining is carried out both in an open-pit (quarry) method, which is more economical with a high concentration of minerals and favorable geological conditions, and underground (mine), which is necessary when phosphorite formations occur at great depths or with complex field geometry. The choice of extraction method directly affects the cost of the final product and the environmental impact [4, 5].

After extraction from the subsoil, phosphorites are thoroughly crushed and crushed into fractions, the size of which is determined by the technological process of obtaining fertilizers. The purpose of this stage is to maximize the surface area of phosphorite particles in order to ensure effective interaction with acid in subsequent stages. The quality of the grinding is critically important because it directly affects the reaction rate and the degree of phosphorus extraction. Various types of crushing and grinding equipment are used, from jaw and cone crushers to ball and vibrating mills, the choice of which depends on the hardness and physical properties of a particular type of phosphorite [6].

The most common method of obtaining phosphoric acid from phosphorites is the sulfate method based on the interaction of phosphorite with sulfuric acid. However, this is not the only way. There are other technologies such as the thermal method, where phosphorite is processed at high temperatures, and the extraction method using organic solvents. The choice of method is determined by economic factors, the availability of raw materials and the quality requirements of the final product.

Let's take a closer look at the sulfate method. Crushed phosphorite is mixed with sulfuric acid in special reactors, where an exothermic reaction occurs, which generates a significant amount of heat. As a result, phosphoric acid, gypsum (calcium sulfate) and other by-products are formed, the composition of which depends on the chemical composition of phosphorite. It is important to carefully control the process parameters: sulfuric acid concentration, temperature, and reaction time. The yield of phosphoric acid and its quality depend on this [7].

The resulting phosphoric acid is usually purified from impurities, after which it is used to produce various phosphorous fertilizers such as superphosphate, ammophos, nitroammophoska and others. The composition and properties of these fertilizers are determined by the ratio of phosphorus, nitrogen and other elements necessary for the proper nutrition of plants. Gypsum formed as a by-product can also be used, for example, in the construction industry or in agriculture to improve soil properties. However, its large volumes require addressing issues of its disposal or recycling, which is an important task for the environmentally responsible production of phosphorous fertilizers. In addition, the efficiency of phosphorite extraction and processing is constantly being improved in order to minimize waste and increase resource efficiency. The research is aimed at developing more environmentally friendly technologies, reducing energy consumption and increasing the efficiency of phosphorus extraction [8].

$$Ca_3(PO_4)_2+3H_2SO_4 \rightarrow 2H_3PO_4+3CaSO_4$$

Phosphoric acid is a fundamental substance in the production of phosphorous fertilizers, which play a critical role in modern agriculture. These fertilizers make up for the lack of phosphorus in the soil, a vital element for plant development. Phosphorus is involved in a variety of biochemical processes, providing root system formation, flowering, fruiting and, importantly, increasing plant immunity to diseases and pests. Phosphorus deficiency manifests itself in slow growth, pale leaf color, poor root development, and decreased yield. Therefore, the use of phosphorous fertilizers is a prerequisite for obtaining high and high-quality yields of most crops [9].

Superphosphate is one of the most common phosphorous fertilizers. Its production is based on the reaction of phosphoric acid with phosphorites, which are natural minerals containing calcium phosphates. Depending on the raw materials used, there is a distinction between simple superphosphate (obtained by reaction with phosphorite) and double superphosphate (obtained by reaction with phosphorite and sulfuric acid). Double superphosphate contains a higher phosphorus content, which makes it more cost-effective for transportation and application.

Ammophos is a complex nitrogen-phosphorus fertilizer obtained by neutralizing phosphoric acid with ammonia. It contains two main nutrients at the same time – nitrogen and phosphorus, which makes it especially effective for fertilizing plants that need both of these elements. The ratio of nitrogen and phosphorus in ammonium may vary depending on the technological process [10].

In addition to these, there are many other types of phosphorous fertilizers produced by various methods. For example, the ammonification of phosphorites can be used, which results in the formation of ammonium phosphate fertilizers. Carbonate methods of processing phosphorites are also used, which make it possible to obtain preparations with different ratios of nutrients. The choice of a specific type of fertilizer depends on the type of soil, the type of crop being grown, and its nutrient needs.

However, the production of phosphorous fertilizers is not without environmental problems. The extraction of phosphorites is accompanied by landscape disturbance and environmental pollution. Production processes are associated with greenhouse gas emissions, in particular, carbon dioxide, as well as other pollutants. Various technologies are used to minimize the negative impact on the environment, including the improvement of phosphorite extraction methods, the introduction of energy-efficient fertilizer production technologies and the development of industrial emissions treatment systems. Research is actively underway to create more environmentally friendly technologies for the production of phosphorous fertilizers, for example, the use of renewable energy sources and the development of waste-free industries. It is also an important task to develop methods for the rational use of phosphorus fertilizers in order to minimize nutrient losses and prevent their ingress into reservoirs [11].

Phosphorite treatment, especially with the use of sulfuric acid, can cause the release of dangerous gases into the atmosphere. The sulfate processing of phosphorites releases sulfur dioxide (SO_2), which can be converted into sulfuric acid in the atmosphere, contributing to the formation of acid rain. Phosgene ($COCl_2$) and compounds containing fluorine may occur among the by-products of improper phosphorite processing, especially if fluorides are present in the starting material. These substances pose a serious threat to health. Recycling also generates waste with toxic components that can pollute water sources and soil. Fluorides can affect aquatic ecosystems with their toxic effects. Calcium sulfate (gypsum) ($CaSO_4$), formed during processing, can cause difficulties with drainage, creating precipitation that degrades water quality. Additionally, mechanical processing of phosphorites can lead to the formation of dust with heavy metals, which negatively affects the health of workers and local residents. Phosphorites also contain small amounts of radioactive elements such as uranium (*U*) and thorium (*Th*), which requires special handling of radioactive waste [12].

Materials and methods

Various techniques were used in the study, such as chemical analysis, X-ray phase analysis and scanning electron microscopy. The main attention was paid to the decomposition of phosphate raw materials from the Chilisai deposit in interaction with phosphoric acid.

Chilisai phosphorites contain significant amounts of carbonates, which in equivalent results in 4.56% carbon dioxide, as well as glaconites. During the decomposition of these phosphorites, a large mass of stable and difficult-to-decompose foam is formed, caused by the release of carbon dioxide. This phenomenon complicates the decomposition of phosphate raw materials, as it reduces the useful volume of the reaction chamber by 60–80%, increases the loading time of phosphorite and the total reaction time.

It is proposed to solve the problem of foaming by pretreating phosphate raw materials in a loose state with phosphoric acid, adding a decarbonization stage before the decomposition of phosphorite. At this stage, optimal conditions (temperature, norm, acid concentration) are selected to maximize the decarbonization of Chilisai phosphorite.

To simplify the decomposition process of decarbonized phosphorite, it is necessary to determine the optimal parameters – the rate and concentration of phosphoric acid, as well as the decomposition time. At the stage of hot filtration, at 100 °C, the insoluble residue is separated from the monocalcium phosphate solution, but this process is complicated due to the content of organic matter in phosphorite. To speed up filtration, granular materials such as sand can be added to the filter surface to increase the filter area and improve the process.

After crystallization of monocalcium phosphate, the precipitate is filtered. The mother liquor is returned to the sulfatization process to obtain phosphoric acid. A neutralizing reagent is needed to neutralize the free acidity in monocalcium phosphate. In this case, calcium carbonate with a content of 88% $CaCO_3$ is used.

Results

Phosphorite samples No. 1 and No. 2 were used to analyze the elemental and mineralogical composition. The elemental analysis was performed using a JSM-6490LV scanning electron microscope, which is equipped with the INCA Energy 350 energy dispersion microanalysis system and the HKL Basic polycrystalline sample structural and textural analysis system. Figure 1 shows the energy of the dispersion analysis of phosphorites from the Chilisai deposit.

Element	Weight %
C	4.23
O	44.80
Na	0.64
Mg	0.42
AI	0.83
Si	10.91
P	10.98
S	0.56
K	0.57
Ca	24.38
Fe	1.69
Total	100

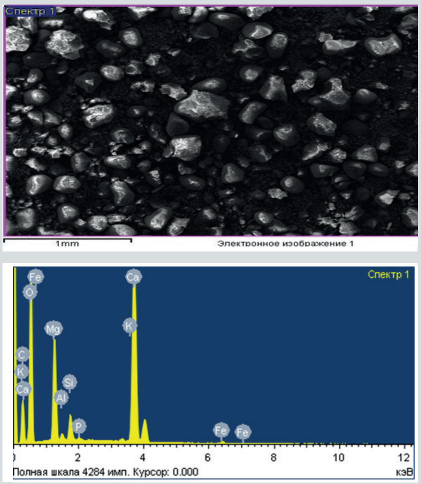

Figure 1. Energy-dispersion analysis of phosphorites from the Chilisai deposit.
Сурет 1. Чилисай кен орнының фосфориттерін энергия-дисперсиялық талдау.
Рис. 1. Энергия-дисперсионный анализ фосфоритов месторождения Чилисай.

Figure 1 shows that the elemental analysis of phosphorite differs in the content (sample No. 1) of the following elements: *P, Ca, Mg, Fe, Si, C*.

X-ray diffractometric analysis was performed on an automated diffractometer DRON-3 with $Cu_{K\alpha}$ radiation, a β-filter. Conditions for recording diffractograms: $U = 35$ kV; $I = 20$ mA; recording θ-2θ; detector 2 deg/min. X-ray phase analysis in a semi-quantitative version was carried out using diffractograms of powder samples using the method of equal weights and synthetic mixtures.Quantitative ratios of crystalline phases were established. The diffractograms were analyzed based on data from the ICDD file: PDF2 powder diffraction data base Release 2022 and diffractograms of samples without mineral admixtures. The content was calculated for the key stages. Possible impurities, the identification of which is difficult due to low concentrations and the presence of only 1–2 diffraction reflections or insufficient crystallinity of compounds. The mineralogical composition of sample No. 1 is shown in table 2.

Table 2

Results of semi-quantitative X-ray phase analysis of the crystalline phases of sample No. 1

Кесте 2

№ 1 Үлгідегі кристалдық фазалардың жартылай сандық рентгендік фазалық талдауының нәтижелері

Таблица 2

Результаты полуколичественного рентгенофазового анализа кристаллических фаз образца № 1

The mineral	Formula	Concentration, %
Quartz	SiO_2	54,8
Fluorapatite	$(CaF)Ca_4(PO_4)_3/$ $CaF_2 \cdot 3Ca_3(PO_4)_2$	26,6
Hematite	Fe_2O_3	8,2
Fluorite	CaF_2	5,7
Albit	$Na(AlSi_3O_8)$	2,4
Classes of feldspar	$KAlSi_3O_8$	2,3

X-ray analysis of the crystalline phase (table 2) revealed that sample No. 1 mainly consists of SiO_2 (54.7%), $(CaF)Ca_4(PO_4)_3/CaF_2 \cdot 3Ca_3(PO_4)_2$ (26.6%), Fe_2O_3 (8.2%), and the minerals fluorite and albite. The diffractogram of phosphate sample No. 1 is shown in figure 1.

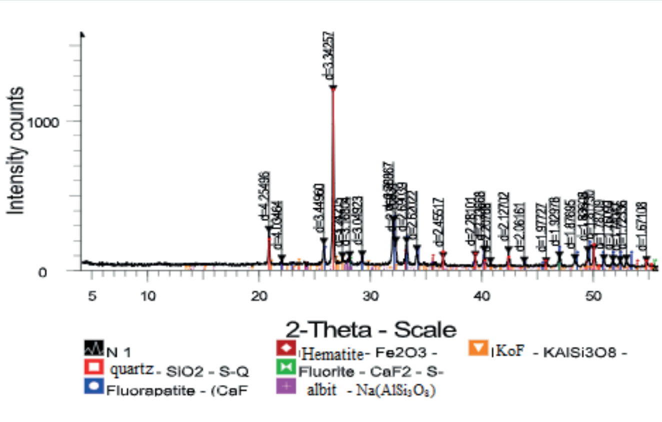

Figure 2. Diffractogram of sample No. 1.
Сурет 2. № 1 үлгінің дифрактограммасы.
Рис. 2. Дифрактограмма образца № 1.

The analysis of the data presented in Figure 1 indicates the presence of SiO_2 (quartz) in the sample with characteristic diffraction maxima at d/n = 4.25496, 4.03464, 3.34257 A^0. The diffraction maxima at d/n = 3.34257 and 3.04923 A^0 correspond to CaF_2 (fluorite). The maximum at d/n = 2.78867 and 2.76934 A^0 is identified as $Ca_5(PO_4)_3F/CaF_2 \cdot 3Ca_3(PO_4)_2$ (fluorapatite), and the peak at d/n = 2.69039 A^0 Fe_2O_3. Finally, the diffraction maximum at d/n = 3.24215 A^0 corresponds to $KAlSi_3O_8$ classes of feldspar. A more detailed mineralogical composition of sample No. 2 is presented in table 3.

Table 3

Results of a semi-quantitative X-ray phase analysis of the crystalline phases of sample No. 2

Кесте 3

№ 2 Үлгідегі кристалдық фазалардың жартылай сандық рентгендік фазалық талдауының нәтижелері

Таблица 3

Результаты полуколичественного рентгенофазового анализа кристаллических фаз образца № 2

The mineral	Formula	Concentration,%
Lizardite	$Mg_3(Si_2O_5(OH)_4$	79,1
Sjoegrenite	$(Mg_6Fe_2(OH)_{16}(CO_3)(H_2O)_4)_{25}$	12,0
Fluorapatite	$Ca_5(PO_4)_3F/CaF_2 \cdot 3Ca_3(PO_4)$	4,2
Magnesite	$MgCO_3$	6,1
Dolomite	$CaMg(CO_3)_2$	2,8

Analysis of the data presented in table 3 shows that sample No. 2 mainly consists of the mineral lizardite $(Mg_3(Si_2O_5)(OH)_4)$ – 79.1%, as well as sjoegrenite $(Mg_6Fe_2(OH)_{16}(CO_3)(H_2O)_4)$ – 12,0%. The sample also contains $Ca_5(PO_4)_3F/CaF_2 \cdot 3Ca_3(PO_4)$ in an amount of up to 4.2%, magnesite and dolomite. The results of a semi-quantitative X-ray phase analysis of the crystalline phases of sample No. 2 are shown in figure 2.

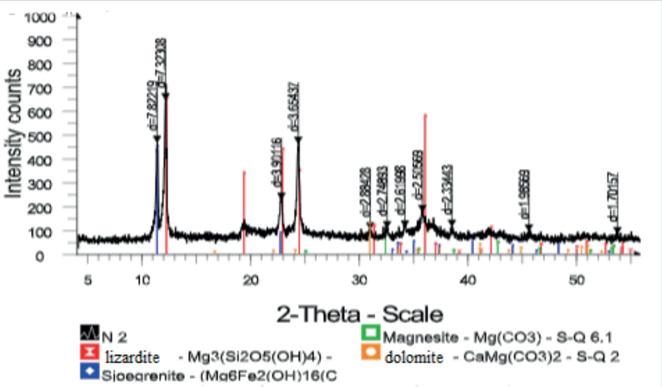

Figure 3. Diffractogram of sample No. 2.
Сурет 3. № 2 Үлгінің дифрактограммасы.
Рис. 3. Дифрактограмма образца № 2.

Figure 2 shows an analysis of sample No. 2, in which diffraction maxima were detected, indicating the presence of the following minerals: sjoegrenite $(Mg_6Fe_2(OH)_{16}(CO_3)$

$(H_2O)_4)$ with the lattice parameter d/n = 7.82219 A^{o}, lizardite $(Mg_3(Si_2O_5(OH)_4))$ with the lattice parameter d/n = 7.32308 A^{o}, dolomite $(CaMg(CO_3)_2)$ with the lattice parameter d/n = 2.88428 A^{o}, magnesite ($MgCO_3$) with the lattice parameter d/n = 2.74893 A^{o}. The intensity of the detected peaks confirms the presence of these minerals in the sample.

Analysis of sample No. 1 revealed that phosphate raw materials from the Chilisai deposit are classified as sandstone. It mainly consists of quartz grains of various sizes (0.002–15 mm) cemented with phosphate. Hydrated iron oxides, glauconite, limonite, pyrite, feldspars, gypsum, and carbonates were found in smaller quantities. Sample No. 2 is mainly represented by grains of the minerals lizardite and sjoegrenite.

Phosphorites of the Chilisai deposit are characterized by significant variability in their mineral composition. The quality of phosphorites varies significantly depending on the concentration of impurities that negatively affect the technological parameters of the products obtained. Quartz is represented by rounded platbands, as well as large and small angular grains. The grains are mainly composed of pure quartz, the surface of some of them is covered with films of limonite or hydrous mica.

Limonite is a product of the oxidation of minerals containing iron, such as pyrite and glauconite. It is found in pebble deposits in the form of large accumulations or fine powder on the surface of glauconite, pyrite and quartz. The proportion of organic matter in the phosphorites of the Chilisai deposit reaches 0.8% and is mainly associated with phosphate matter and clay materials. During the experiment, a sample of phosphorite from the Chilisai deposit was used, the chemical composition of which is described in detail in table 4.

Table 4

Chemical composition of phosphorite from the Chilisai deposit (sample No. 1)

Кесте 4

Чилисай кен орнының фосфоритінің химиялық құрамы (№ 1 үлгі)

Таблица 4

Химический состав фосфорита Чилисайского месторождения (образец № 1)

Component	Content, %	The mineral
P_2O_5	26,40	Apatite
CaO	37,16	Feldspar
MgO	0,75	Hydrosludes
Na_2O	0,95	Glauconitis
Al_2O_3	1,69	Glauconitis
Fe_2O_3	2,35	Glauconitis
SO_3	1,45	Pyrite, goethite
CO_2	4,56	Kurskite
F	3,39	Fluorite
K_2O	0,76	Glauconitis
SiO_2	25,04	Kurskite
Total	100	

An analysis of the data presented in table 4 shows that phosphorite from the Chilisai deposit is characterized by the following chemical composition: 26.40% P_2O_5, 37.16% CaO, 25.04% SiO_2 and up to 4.56% CO_2. During the research, phosphorite samples were subjected to thermal decomposition at a temperature of 95–1000 ° C for 40–50 minutes. The duration of the process varied depending on the specific sample and the required amount of phosphoric acid. To obtain monocalcium phosphate from Chilisai phosphorite, a mixture of extraction and thermal phosphoric acid with a concentration of 50–56% H_3PO_4 was used. The sulfatization of the solution, followed by the formation of gypsum, was carried out using 93% sulfuric acid.

Discussion

Phosphoric acid of a certain concentration was used in the first cycle. Decomposition was carried out in a thermostatically controlled reactor equipped with a stirrer. At the end of decomposition, the pulp is filtered on a heated vacuum filter through a filter cloth (2 layers) at a dilution of 0.6–0.7 kg / cm^2, the filtration time was measured. The precipitate was washed with a certain amount of water heated to 75–80 °C. The washed precipitate was dried, weighed, and analyzed for total P_2O_5 and digestible P_2O_5 content. The phosphate decomposition coefficient and the filtration rate of the residue were determined.

After separating the insoluble impurities, the filtrate was placed in a thermostatically controlled reactor equipped with a stirrer. During cooling to a temperature of 40–45 °C and subsequent exposure for 60–90 minutes with slow stirring, crystals formed. The formed crystals were separated by filtration on a vacuum filter. The resulting precipitate was weighed and analyzed for the content of total P_2O_5, $Ca(H_2PO_4)_2$ and H_3PO_4. Wet crystalline monocalcium phosphate (MCF) was treated with limestone to neutralize free acid. After drying, the precipitate was weighed and analyzed for the content of all forms of P_2O_5.

The sulfatization process of the initial sulfuric acid solution was carried out in a thermostatically controlled reactor equipped with a mechanical mixer. The temperature of the solution was maintained at no higher than 60 °C. After 20 minutes after mixing the reagents, the formed calcium sulfate crystals were separated by vacuum filtration. The resulting precipitate was washed with hot water (75–80 °C), after which weighing, drying until a constant mass was reached, and laboratory analysis for total P_2O_5, and P_2O_5 aqueous, F, Fe_2O_3, Al_2O_3, CaO, and SO_3 were performed.

After separating the calcium sulfate, the filtrate was weighed and analyzed to determine the content of free H_3PO_4, H_2SO_4, MgO, Al_2O_3, and F. After that, the filtrate was sent back to the decomposition stage in the next cycle. The second washing of the insoluble residue and gypsum was carried out first with previously obtained filtrates from the first washing of n.o. and gypsum, and then with water. In the third and subsequent cycles, the washing of oil and gypsum was carried out in three stages: in the first two stages, filtrates obtained at previous stages of washing in the previous cycle were used, and in the third stage, water was used. The filtrate obtained after the first washing of the oil was added to the base solution obtained after separation of the crystals in the corresponding cycle. The filtrate obtained after the first washing of gypsum was mixed with recycled phosphoric acid (the main filtrate) obtained after the separation of calcium sulfate crystals in the same cycle. Thus, the implemented procedure allowed the regeneration of phosphoric acid used for the decomposition of phosphorite.

In the course of the research, the optimal parameters of the technological process for obtaining monocalcium phosphate from phosphorite were established.

These parameters include:

1. Phosphoric acid concentration in the range of 36–42% P_2O_5.

2. The ratio of the amount of recycled phosphoric acid to the stoichiometric amount required for the formation of monocalcium phosphate should be 540–560%.

3. The temperature of the decomposition process should be within 95–100 °C.

4. The duration of the decomposition process is 40–50 minutes.

5. The filtration temperature of the insoluble residue varies from 85 to 90 °C.

6. Monocalcium phosphate crystallization is carried out at a temperature of 40–45 °C.

7. The duration of the crystallization process is 85–90 minutes.

8. The concentration of sulfuric acid used for sulfatization of the mother liquor should be in the range of 86–93% H_2SO_4.

9. The ratio of the amount of sulfuric acid to the stoichiometric amount required for the decomposition of $Ca(H_2PO_4)_2$ *in solution to form gypsum and phosphoric acid is 95–100%.*

The decomposition of phosphate raw materials by the circulating method using phosphoric acid of 540–560% of the stoichiometric amount to form monocalcium phosphate allowed the transfer of $Ca(H_2PO_4)_2$ into solution and impurities into a precipitate with phosphogypsum.

Thus, based on the conducted research, the optimal modes of the process of obtaining monocalcium phosphate from phosphate raw materials of the Chilisai deposit have been determined. Monocalcium phosphate is a highly effective phosphorous fertilizer widely used in the agricultural sector. This compound serves as a source of phosphorus, which plays a key role in the process of plant growth and development. One of the advantages of monocalcium phosphate is its high solubility in water, which provides plants with prompt access to phosphorus. This property is especially valuable at the stages of root system formation, flowering and fruiting. Unlike a number of other phosphorous fertilizers, such as superphosphate, monocalcium phosphate is able to slightly reduce soil acidity, which is a significant advantage in regions with predominantly acidic soils. In addition, monocalcium phosphate does not contain impurities that can pollute water resources, which makes it an environmentally friendly product compared to some other types of fertilizers.

Conclusion

Monocalcium phosphate is a highly effective fertilizer that helps to quickly provide plants with phosphorus and increase yields. Its use is especially advisable in situations requiring prompt and accurate application of nutrients, as well as in the composition of complex fertilizers. Despite this, the high cost of monocalcium phosphate and the need for precise dosage may limit its use. The production of monocalcium phosphate is characterized by significant energy consumption. Heat treatment of phosphorites, especially at high temperatures to produce phosphoric acid, can be accompanied by significant emissions of carbon dioxide (CO_2) and other greenhouse gases. The use of fossil fuels as an energy source also has a negative impact on the climate. It is important to note that, despite the effectiveness and relative safety of monocalcium phosphate for plants, its production is associated with a number of environmental problems, such as pollution of water resources and the atmosphere, accumulation of toxic waste and high energy consumption. However, the introduction of modern technologies and production methods can significantly minimize these risks, contributing to sustainable fertilizer production.

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