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Metallurgy

Investigation of the possibility of using depleted bauxite in alumina production at the Pavlodar aluminum plant

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ABSTRACT

The topic of processing low-grade or low-quality bauxite is highly relevant in modern conditions due to the gradual depletion of high-quality bauxite reserves. Consequently, there is an increasing need to explore alternative sources of raw materials for aluminum production and its derivatives. Processing low-quality bauxite ores can become an effective solution, reducing dependence on limited high-quality resources and ensuring production stability in the long term. Such research has significant potential for developing technologies capable of optimizing aluminum production processes and enhancing its competitiveness in the global market. Bauxites from the Krasnooktyabrsky bauxite ore management with low aluminum oxide content (37 – 40% by mass) and a silicon module up to 2.0 are considered as potential blending materials for sintering bauxite in alumina production due to the depletion of high-quality bauxite reserves. This article presents the results of research on their processing into alumina at the Pavlodar Aluminum Plant. Laboratory and pilot-scale studies were conducted to assess the feasibility of using low-quality bauxite in alumina production and to determine the techno-economic indicators of processing. The research results confirmed the technological feasibility of processing depleted bauxites with a silicon module of 1.95 - 2.0 in the sintering section while maintaining the quality of sinter and extracting useful components. The maximum proportion of blending of depleted bauxites with the main bauxite was determined not to exceed 50%.

Keywords: depleted bauxite, alumina production, sintering process.

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Introduction

The impending shortage of natural raw materials with acceptable quality for processing, such as bauxite, is a prerequisite for the involvement of depleted or substandard bauxite of the lowest quality in the production of alumina, which will compensate for the technological shortcomings of the raw materials.

At ore deposits, rich and easily accessible areas have always been developed first, leading to a sharp decrease in metal content in recoverable reserves in recent years, while extraction costs have increased [1].

In these conditions, the relevance of issues related to the extraction and processing of unbalanced ores increases, with reserves on certain deposits reaching tens of millions of tons [1].

The criterion for the feasibility of including unbalanced ores in processing is the metal grade. Its determination is influenced by technical, technological, and economic factors. The effectiveness of combined extraction and processing of balanced and unbalanced ores depends on specific indicators unique to each deposit [1].

Bauxite ores show various forms under geological and physical-chemical effects [2]. While various bauxite classifications had been proposed in the past, the current consensus tends to divide bauxite into karstic and lateritic bauxite [3]. Kazakhstan's bauxites are characterized by an unstable lithological and phase composition, elevated content of ferruginous minerals, carbonates, and organic impurities. Additionally, Kazakhstan possesses other types of alumina-bearing raw materials, such as nepheline syenites, clays, kaolins, and coal ash, which are potential sources for alumina production [[4], [5], [6], [7]].

Most of Kazakhstan's bauxite deposits are complex. Alongside high-grade bauxites, bauxite-bearing formations include alites, which contain a large amount of gibbsite, high-alumina, and basic refractory clays [8].

Reserves of off-balance sheet ores have been formed in metal deposits, the content of which is close to the balance value, but does not ensure profitability with gross mining. At metallic deposits, reserves of unbalanced ores have formed, the content of which is close to the balanced value, but gross extraction does not ensure profitability. Unbalanced reserves include mineral resources that, due to their quantity, quality, complex extraction or processing conditions, are not utilized, but may become the subject of development in the future [1].

Depleted or off–balance bauxite is a low-quality bauxite-like ore with a silicon module ($M_{Si}=Al_2O_3/SiO_2$) below 2.0. Such substandard ores make up the main part of the contact zone of the bauxite deposit, which is formed during mining during the stripping of the ore body, they enter the dumps together with the overburden and are not listed as ore raw materials. A fairly large amount of substandard bauxite is formed; therefore, studies have been conducted on the possibility of involving these bauxites in processing using the Pavlodar aluminum plant sintering method.

Figure 1 – The charging yard on the PAP

Bauxites from Kazakh deposits themselves are low-grade raw materials and abroad are classified as bauxite-like clays, unsuitable for processing into alumina [9].

At one time, thanks to the improvement and development of technologies, as well as the modernization and improvement of the basics of alumina production, it became possible to process low-quality bauxite [10]. It was for the processing of such bauxites that the Pavlodar Aluminum Plant was designed.

The Pavlodar aluminum plant occupies a special place in the global hierarchy of alumina producers and has positive experience in processing low-quality bauxite raw materials into alumina using the world's only technological scheme, the 'Sequential-Parallel Bayer-Sintering' method, achieving satisfactory economic indicators [11].

The Bayer process, currently dominant in alumina production, is suitable only for low-silica bauxites [12]. However, through the sintering process, not only various bauxites but also clays, kaolins, sericites, and other aluminosilicate rocks, whose reserves are inexhaustible, can be processed into alumina [13].

According to the existing technological scheme of the plant, bauxite is processed using the parallel–sequential Bayer-Sintering method. The distribution of bauxite by branches is ~ 91% (Bayer) and 9% (Sintering).

The alkaline sintering method is used for processing bauxites with high silica content, whose silica modulus typically does not exceed 5. This method involves sintering bauxite with soda and limestone. During sintering, the interaction between the alumina of the bauxite and the soda forms sodium aluminate, while the silica is bound by calcium oxide into insoluble dicalcium silicate. Sodium aluminate is leached from the resulting sinter with water [14].

At the Pavlodar Aluminum Plant, an important technological problem was solved for the first time in global practice, involving the large-scale industrial production of high-silica and high-iron bauxites from Kazakhstan [15].

However, according to the mining plan for the Krasnooktyabrsky bauxite ore management from 2020 to 2030, a deterioration in the quality of the ore base is expected in terms of a decrease in the quality of bauxite and an increase in the stripping coefficient, which creates significant risks of an increase in the cost of both bauxite and alumina. Therefore, the topic of involving depleted or substandard bauxite raw materials in the production of alumina has now become relevant.

Partial replacement of bauxite from the Pavlodar aluminum plant Sintering branch with bauxite-like bauxites from the Krasnooktyabrsky bauxite ore will reduce the production of "basic" bauxite by ~ 111 thousand tons per year.

Previously, the Pavlodar aluminum plant Sintering branch had already processed lignite bauxites with a silicon module of ~ 2.0 with optimal technological performance. However, currently, due to the depletion of these bauxite reserves, the Krasnogorsk Ore Management bauxite with M_{Si} 3.5, which is suitable for use in the Bayer branch, serves as a "sintering" one. Therefore, the search for alternative raw materials as "sintering" bauxite was continued.

This paper presents the results of testing an alternative type of bauxite raw materials from the Sintering branch of the Pavlodar aluminum plant – dining bauxite to reduce the cost of alumina production.

Table 1 presents a comparative analysis of bauxite from Kazakhstani deposits with various qualitative indicators:

Table 1 - Chemical composition of Kazakhstani bauxite

Deposits	Al_2O_3	SiO_2	CO_2	M_{Si}
	%			
Krasnooktyabrskoye	42.0	10.9	3.70	3.85
Ayatskoye	44.6	10.7	1.26	4.17
Belinskoe	41.4	10.3	1.79	4.02
Depleted A	37.3	18.9	3.51	1.97
Depleted Б	40.3	20.7	0.31	1.95

Kazakhstan's bauxite deposits, such as Belinskiy, Ayatskiy, and Krasnooktyabrskiy, have Al_2O_3/SiO_2 ratios ranging from 3.0 to 8.0 [16]. Depleted bauxites are characterized by a low content of alumina and an increased content of silicon oxide, and, accordingly, a low silicon modulus of up to 2.0.

Depending on the content of aluminum oxide and silicon modules, bauxites are divided into grades and grades. There is a certain standard corresponding to GOST – 972-74. According to the qualitative characteristics, depleted bauxite does not comply with this GOST.

As a rule, schemes (methods) with its preliminary enrichment are used for low-quality raw materials.

For instance, the method of processing poor and low-grade bauxites with Al_2O_3 content less than 37%, SiO_2 content over 5.5%, and silicon modulus of 2.1 - 3.5, as well as the processing of old tailings of unbalanced ores, which includes ore transportation, their express analysis by radiometric methods, ore quality averaging, nuclear-physical sorting, and lump separation using relay separator, heap bacterial-chemical leaching of SiO_2 with silicate bacteria (Silucius) [17].

In work, it is mentioned about the radiometric enrichment of various types of bauxites from the Middle Timan region, namely unbalanced bauxite, calcining, and Bayer [18]. Radiometric separation from unbalanced bauxite allows the extraction of 36.3% of enriched product with a silicon modulus of 4.2, which is suitable for further calcining.

The article describes the thermochemistry – Bayer method, which allows the processing of various substandard bauxite raw materials, this method may well "compete" with the Sintering method [19].

These methods ensure efficient separation of harmful gangue minerals from bauxite during the raw ore preparation stage. However, despite the promising nature of these methods, the capital and operational costs for bauxite beneficiation are quite high, and in some cases, it is still not possible to obtain concentrates of the desired quality [20].

A method is known for the hydrochemical processing of low-quality aluminosilicate raw materials in the Bayer branch with the addition of lime [21].

The work describes the results of studies of the decomposition of aluminium-containing ores: mudstones and kaolin clays of the Ziddy and Chashma-Sang deposits of the Republic of Tajikistan by mineral acids and chlorine methods [22].

The proposed method allows the processing of substandard bauxite-like raw materials according to the existing Pavlodar aluminum plant scheme without changing and using additional resources while maintaining output. Such a scheme has no analogues in the world practice of producing alumina.

There are relatively few theoretical and technological data in the literature on the processing of bauxite-like raw materials used according to a similar scheme for the production of alumina Pavlodar aluminum plant.

However, a similar technology for processing nephelines with additions of bauxite using the Sintering method is known at the Achinsk Alumina Plant. The depletion of the raw material base of the

Kiya-Shaltyr mine served as a prerequisite for involving non-conforming and unbalanced ores in the processing of nephelines. This allows for reducing capital costs and maintaining quality indicators for extracting useful components without changing the technological scheme of the Achinsk Alumina Plant [23].

Off-balance bauxites (allites) are intended for use as a correlating additive in the processing of nepheline concentrates [8].

The extraction of valuable components from aluminosilicate natural and man-made materials by sintering on Achinsk Alumina Combine was described in one of the articles [24].

Experimental part

Chemical and X-ray fluorescence analysis methods were used in the research.

Chemical analysis of technological samples was carried out by the complexometric method for determining the mass concentrations of aluminum oxide in solutions ranging from 1.0 g/dm^3 to 300 g/dm^3 and sodium oxide in solutions ranging from 1.0 g/dm^3 to 500 g/dm^3.

X-ray fluorescence analysis of the samples was carried out on a wave-dispersive X-ray fluorescence spectrometer Simultix 14 («Rigaku Corporation», Japan).

Figure 2 - Simultix X-ray fluorescence spectrometer

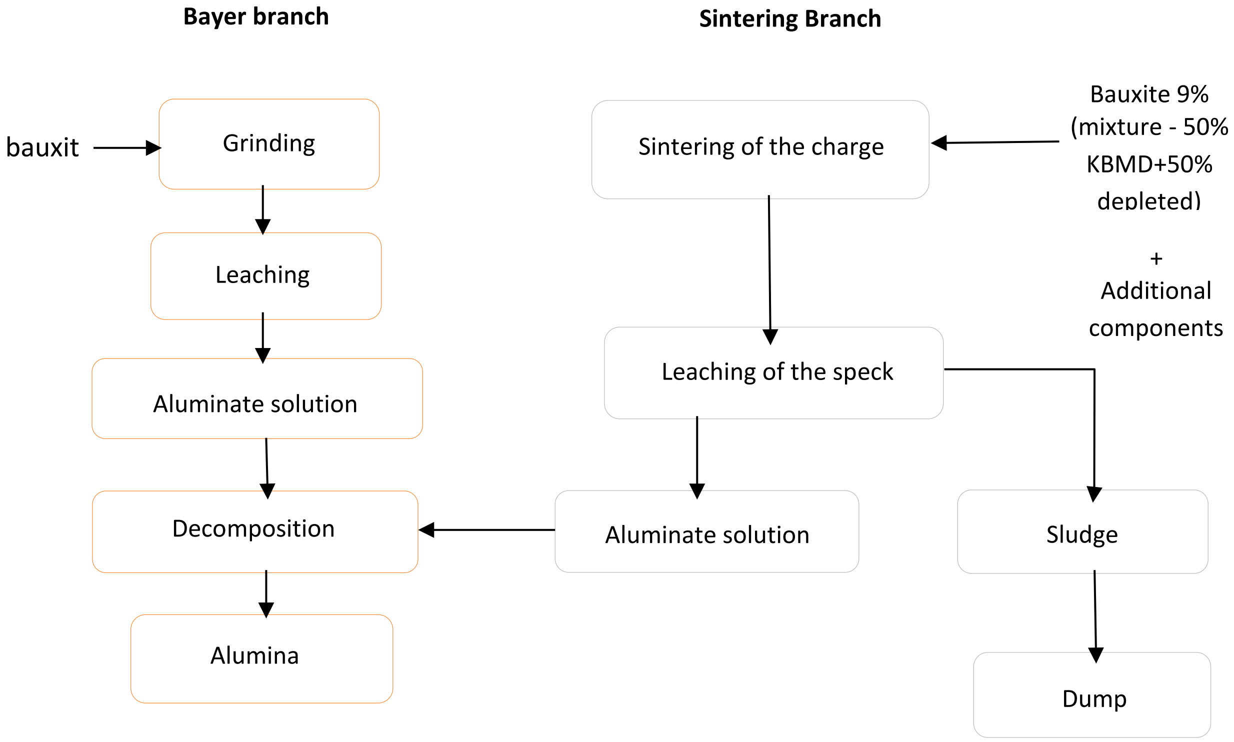

Figure 3 - Block diagram of Bayer-Sintering

Results and Discussion

As mentioned earlier, the Pavlodar aluminum plant works according to a parallel–sequential Bayer–Sintering scheme.

Figure 3 shows the existing block diagram of Bayer Sintering using depleted bauxite in the charge.

Depleted bauxites from the Krasnogorsky bauxite mine (A) and the Vostochno – Ayatskoye (B) deposit were selected for research. In the process of mining ordinary bauxite ore, point (selective) excavation of these bauxites with a silicon module of 1.6 – 2.0 was carried out.

The research methods included pilot industrial tests and standard leaching of industrial sinter in the laboratory.

Laboratory leaching of the sinter was carried out under strictly defined conditions regulated by the standard of the PAP enterprise.

The amount of extraction during laboratory leaching shows how completely Al_2O_3 and Na_2O are converted into soluble compounds during sintering [25].

Preparation for laboratory work.

The leaching of the sinter was carried out in 100 ml of sodium hydroxide solution with a concentration equivalent to 0.5 mol/dm^3 at (L:S) = 10:1 for 15 minutes at a temperature of 75 ˚C under isothermal conditions. After leaching, the chemical composition of the solid precipitate was determined.

The chemical reactions occurring during the leaching of the sinter are presented below:

$$Na_2O \cdot Fe_2O_3 + 2H_2O = 2NaOH + Fe_2O_3 \cdot H_2O \quad (1)$$

$$2Na_2O \cdot nAl_2O_3 \cdot (1-n)Fe_2O_3 + 3H_2O = \\ = 2NaOH + Na_2O \cdot nAl_2O_3 + (1-n)Fe_2O_3 \cdot H_2O + H_2O \quad (2)$$

$$2CaO \cdot SiO_2 + 2NaOH + H_2O = Na_2SiO_3 + 2Ca(OH)_2 \quad (3)$$

$$2CaO \cdot SiO_2 + 2Na_2CO_3 + H_2O = 2CaCO_3 + Na_2SiO_3 + 2NaOH \quad (4)$$

The extraction of aluminum oxide from the sinter into the solution proceeds by reaction 2 in an alkaline (caustic) medium with a pH of 10 to 12. The increase in pH is mainly due to the extraction of caustic alkali from the sinter into a solution by reaction 1 and partially by reaction 4.

Pilot tests on the use of depleted bauxite were carried out in the raw material preparation shop and the PAP sintering shop.

During the testing period, the sinter was selected from all operating furnaces, and the sieve composition and extraction of useful components were determined based on the results of laboratory leaching.

Depleted bauxites were delivered to the Pavlodar aluminum plant with the following qualitative characteristics, presented in Table 2:

Table 2 – Chemical composition of bauxite

Name	Al_2O_3	SiO_2	Fe_2O_3	M_{Si}
	%			
Current sintering bauxite	43.3	10.9	18.8	**3.98**
Depleted bauxite A	37.3	18.9	19.3	**1.97**
Depleted bauxite B	40.3	20.6	17.2	**1.95**

As can be seen from Table 2, depleted bauxites are characterized by a low silicon modulus and a reduced content of Al_2O_3.

Depleted bauxite A was tested first. At the initial stage, this bauxite was supplied with the lowest proportion of charge, which amounted to 18.4 %. Further, its share in the mixture with the current bauxite was gradually increased to 47.1 %. Depleted bauxite B was supplied immediately with the maximum fraction in the composition of the charge - 48.2 %.

As a result of the polythermal high-temperature treatment of the wet initial charge in rotating furnaces, a poly mineral sinter was obtained from newly synthesized solid phases.

The finished product was evaluated according to the quality categories of the sinter: by chemical composition, by the content of fractions -1.0 mm not more than 30 % and by the level of extraction of Al_2O_3 and Na_2O into solution during hydrochemical leaching of the sinter according to [9].

The chemical composition of the charge and sinter is usually determined mainly by the molar ratios of the main oxides – this is an alkaline (alumina) module (M_{al})=[Na_2O]+[K_2O·0,66]/[Al_2O_3] и limestone module ($M_{limestone}$)=[CaO]/[SiO_2] [25]. It is important to withstand such physico–chemical conditions so that other compounds are not formed during sintering, which reduces the extraction of useful components during the leaching of sinters.

Figure 4 below shows the alumina and lime sintering modules during the EIT period:

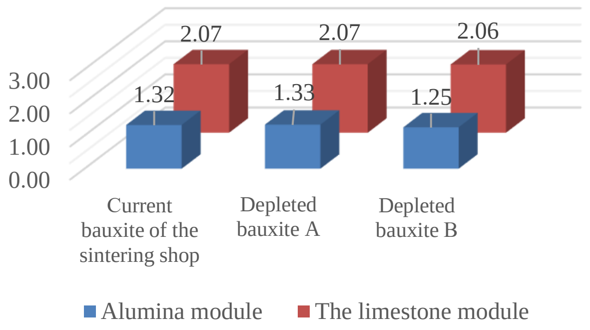

Figure 4 – Alumina and limestone sintering modules

When testing depleted bauxite B, the alumina sinter modulus decreased to 1.25. This was due to a technological violation unrelated to the pilot testing, which led to some deterioration in the quality of the spec (Fig. 4).

During the period of supply of depleted bauxite A to the sintering charge, the sintering quality was maintained in the regulatory values and remained at the level of the control period.

The process of transferring useful components from the sinter to the solution during leaching depends on the size of the sinter crushing and subsequent grinding of the sinter sludge.

Table 3 shows the main indicators for the chemical composition of the solid phase of the dump sludge during the period of the pilot testing.

Table 3 - The main indicators for the chemical composition of the dump sludge during the EIT period

Name	Na_2O	Al_2O_3
	%	
Current sintering bauxite	1.11	4.58
Depleted bauxite A	1.14	4.58
Depleted bauxite B	1.19	5.81

Exceeding the regulated value for the content of Al_2O_3 in the dumped sludge (< 5.0) during the charge period of depleted bauxite B is associated, as shown above, with a decrease in the alumina sintering modulus during the test period.

As follows from the production practice of sintering alumina charges, when the stoichiometry of the preparation of the charge is violated, namely, with a decrease in the alumina module or a lack of alkalis, the content of Al_2O_3 in the dump sludge increases [[4], [26]].

The indicators for the content of useful components in the dumped sludge during the period of charging depleted bauxite A were without deviations.

Further, Table 4 shows the results of the extraction of useful components Al_2O_3 and Na_2O during the pilot testing period.

Table 4 - Indicators for the extraction of Na_2O and Al_2O_3 during the pilot testing period

Name	Na_2O	Al_2O_3
	%	
Current sintering bauxite	95.2	84.6
Depleted bauxite A	95.2	84.9
Depleted bauxite B	95.0	82.2

As we can see, the fact associated with a decrease in the alumina sintering modulus (from 1.32 to 1.25) also affected the recovery of useful components during the charging period of depleted bauxite B, thereby reducing the extraction of Al_2O_3 to 82.2%.

At the stage of mixing depleted bauxite A, there were no deviations in the extraction of useful components.

Also, during the pilot testing period, in comparison with the current sintering bauxite, data on laboratory (standard) leaching of sinter during the charging of depleted bauxite A were analyzed.

Table 5 shows the chemical composition of the sinter/sludge after laboratory leaching during the supply of depleted bauxite A.

Laboratory tests showed that the results of the standard leaching of the sinter of the experimental period were on the same level as the control one, both in terms of the chemical composition of the dumped sludge and in the extraction of useful components (Al_2O_3 and Na_2O).

Based on the results of the pilot testing, the possibility of processing depleted bauxite according to the existing technological scheme was determined. During the mixing of depleted bauxite A, equivalent technological indicators were noted for the quality of sintering and the extraction of useful components (Al_2O_3 and Na_2O) in comparison with the control period – on the current bauxite of the sintering branch.

During the charge period of depleted bauxite B, a violation was noted that was not related to the extraction of bauxite, and with failures within the technological cycle - a decrease in the alumina module ($M_{silicon}$) in the sinter, as a result of which there was a slight decrease in the extraction of alumina from the sinter, amounting to 82.2%.

Table 5 - chemical composition of the sinter/sludge after laboratory leaching

Stage	Name	Chemical composition of the sinter/sludge, %		$M_{alkaline}$	$M_{silicon}$	Extraction of useful components, %	
		Na_2O	Al_2O_3			Na_2O	Al_2O_3
Current bauxite of the sintering shop (control)	Speck	15.18	19.74	1.27	2.07	-	-
	Sludge	0.92	3.58	-	-	95.83	87.67
Depleted bauxite A	Speck	14.85	18.77	1.30	2.09	-	-
	Sludge	0.86	3.41	-	-	96.04	87.48

Conclusions

According to the results of the conducted research, it was determined that, depleted bauxite A and B are characterized by a low flint modulus of 1.97 and 1.95, respectively, in comparison with the current sintering bauxite, the flint modulus of which is 3.98. Such bauxites can only be processed in Sintering branches, chemical analysis of sinters and slurries after laboratory leaching showed a complete correlation in the content of the components. However, there was a slight decrease in Al_2O_3 and Na_2O.

The content of useful components Al2O3 and Na2O during the processing of depleted bauxite remained at the level of the current basic bauxite.

Based on the conducted pilot testing, the technological possibility of processing depleted bauxite A and B with an optimal proportion of charge to the current bauxite was confirmed - no more than 40-50 %.

The involvement of depleted bauxite with such a proportion of charge maintains optimal technical and economic indicators of Sintering conversion, as well as such a balance amount is recommended for continuous use on the Pavlodar aluminum plant.

Conflicts of interest. On behalf of all authors, the correspondent author declares that there is no conflict of interest.

Author Contributions CRediT**: G. Abikenova:** Management, conceptualization, data curation. **D.Dauletov:** Author's supervision, reviewing and editing. **S. Tverdokhlebov:** Methodology, research, supervision, reviewing. **I. Danchenko:** Research, writing - original draft preparation.

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Павлодар алюминий зауытында алюминий өндірісінде жұтаңдаған бокситтерді пайдалану мүмкіндігін зерттеу

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ТҮЙІНДЕМЕ

Жоғары сапалы боксит қорының бірте-бірте таусылуына байланысты қазіргі жағдайда төмен сортты немесе сапасыз бокситті өңдеу тақырыбы өте өзекті болып табылады. Демек, алюминий және оның басқа өнімдерін өндіру үшін шикізаттың баламалы көздерін іздеу қажеттілігі артып отыр. Төмен сортты боксит кендерін қайта өңдеу шектеулі жоғары сапалы ресурстарға тәуелділікті азайту және өндірістің ұзақ мерзімді тұрақтылығын қамтамасыз ету үшін тиімді шешім бола алады. Мұндай зерттеулер алюминий өндірісінің процестерін оңтайландыруға және оның әлемдік нарықтағы бәсекеге қабілеттілігін арттыруға қабілетті технологияларды әзірлеу үшін маңызды әлеуетке ие. Алюминий оксиді төмен (масса бойынша 37 – 40%) және кремний модулі 2,0-ге дейінгі Краснооктябрь боксит кен басқармасының бокситтері жоғары сапалы боксит қорының таусылуына байланысты алюминий оксиді өндірісінде бокситті күйежентектеу үшін әлеуетті араластырғыш материалдар ретінде қарастырылады. Бұл мақалада Павлодар алюминий зауытында оларды алюминий оксидіне өңдеу бойынша жүргізілген зерттеулердің нәтижелері берілген. Глинозем өндірісінде сапасы төмен бокситті пайдаланудың орындылығын бағалау және өңдеудің техно-экономикалық көрсеткіштерін анықтау үшін зертханалық және тәжірибелік-зерттеу жұмыстары жүргізілді. Зерттеу нәтижелері 1,95 - 2,0 кремний модулі бар жұтаңдаған бокситтерді агломераттың сапасын сақтай отырып және пайдалы компоненттерді бөліп алу кезінде өңдеудің технологиялық мүмкіндігін растады. Жұтаңдаған бокситтерді негізгі бокситпен араластырудың максималды үлесі 50%-дан аспайтыны анықталды.

Түйін сөздер: жұтаңдаған боксит, алюминий оксидін өндіру, күйежентектеу процесі.

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Исследование возможности использования обедненных бокситов в глиноземном производстве на Павлодарском алюминиевом заводе

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АННОТАЦИЯ

Тема переработки низкосортных или низкокачественных бокситов весьма актуальна в современных условиях в связи с постепенным истощением запасов высококачественных бокситов. Следовательно, растет потребность в поиске альтернативных источников сырья для производства алюминия и его производных. Переработка низкокачественных бокситовых руд может стать эффективным решением, снижающим зависимость от ограниченных высококачественных ресурсов и обеспечивающим стабильность производства в долгосрочной перспективе. Подобные исследования имеют значительный потенциал для разработки технологий, способных оптимизировать процессы производства алюминия и повысить его конкурентоспособность на мировом рынке. Бокситы Краснооктябрьского бокситового рудоуправления с низким содержанием оксида алюминия (37–40 % по массе) и кремниевым модулем до 2,0 рассматриваются в качестве потенциальных шихтовых материалов для спекания бокситов в глиноземном производстве в связи с истощением запасов высококачественных бокситов. В данной статье представлены результаты исследований по их переработке в глинозем на Павлодарском алюминиевом заводе. Проведены лабораторные и опытно-промышленные исследования с целью оценки возможности использования низкокачественных бокситов в глиноземном производстве и определения технико-экономических показателей переработки. Результаты исследований подтвердили технологическую целесообразность переработки обедненных бокситов с кремниевым модулем 1,95-2,0 в отделении агломерации с сохранением качества агломерата и извлечением полезных компонентов. Установлено, что максимальная доля смешения обедненных бокситов с основным бокситом не превышает 50%.

Keywords: обеднённый боксит, производство глинозема, процесс спекания.

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