Metallurgist, Vol. 53, Nos. 3–4, 2009

IMPROVED QUALITY OF RAW-MATERIAL MIXTURE FOR COMPREHENSIVE PROCESSING OF NEPHELINE ORE AND CONCENTRATES BY SINTERING AT THE ACHINSK INTEGRATED ALUMINA PLANT

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UDC 669.712:553.492.1

This paper describes partial replacement of nepheline raw material with bauxites in order to increase alumina production at the Achinsk Integrated Alumina Plant.

Key words: *alumina production, out of balance ores, nepheline raw material, bauxite additives, sintering of briquettes.*

Integrated processing of nephelin-based ores began in Russia in the 1950s. Using the developed process, all components of the raw material (without any residue) could be used for production of alumina, Portland cement, and soda/potash products. As a result nepheline was, and remains competitive relative to bauxite, as indicated by operations at the Achinsk Integrated Alumina Plant (AGK) [1].

Integrated processing, which is the primary advantage of nepheline as a raw material, has certain drawbacks, the most important of which is the need to have a profitable market for all products produced, either in the immediate vicinity of the enterprise or within a reasonable distance of the enterprise, with the volume and ratio being determined by the natural composition of the nepheline ores. However, it has now become necessary to change the ratio of alumina to soda products so that it favors alumina, due to the fact that domestic alumina is currently meeting on the order of 50% of the needs of the Russian aluminum industry [2].

This change in the process can be achieved by adding an alkali-free raw material to the charge; in particular, sintering-grade bauxite can be used as such a component. The idea that an artificial alumina ore could be processed by mixing natural alumina ores of various composition was first advanced by V. A. Mazel in 1932 [3].

In this and subsequent papers [4, 5], it was shown that when necessary alumina production can be noticeably (by 10–15%) increased, with some reduction in soda and potash production, without substantial changes to the equipment and process flow, based on market conditions at the time. In this approach, both the nepheline and bauxite components of the charge can be adjusted. Moreover, the use of bauxite as an additive means that low-quality nepheline can effectively be used in the production process.

AGK is currently using nepheline ore from the Kiya-Shaltyr Deposit, which is located in Kemerovo Oblast 265 km from Achinsk. This deposit has been continuously operated since 1970, and the reserves have undergone a substantial decrease. Over the period of time that the mine has been in operation, the content of useful components has been observed to decrease: Al_2O_3 has decreased from 27.3% to 26.5%, and R_2O (Na_2O and K_2O) has decreased from 13.3% to 12.7%. At present, the sections of the deposit with the highest concentration of aluminum oxide have been worked out. The ore at the Goryachegorsk Deposit, the backup raw materials source for the AGK are poorer in Al_2O_3 than the Kiya-Shaltyr Deposit,

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TABLE 1. Chemical Compositions of Materials Used

Description of material	Mass fraction, %								M_{alk}	f/a	μ_{Si}
	Al_2O_3	SiO_2	Fe_2O_3	CaO	Na_2O	K_2O	R_2O	Calc. loss			
Kiya-Shaltyr nepheline ore (KSO)	26.2	39.0	4.8	8.0	9.8	3.0	11.8	3.0	0.74	0.12	0.67
Goryachegorsk nepheline ore (GGO)	23.6	42.7	7.7	9.5	8.2	1.5	9.2	2.9	0.64	0.21	0.55
Goryachegorsk nepheline concentrate (CGGO)	27.4	43.5	2.2	8.4	10.1	1.7	11.2	4.3	0.67	0.05	0.63
North Onega bauxite (NOB)	51.2	18.0	7.8	0.5	0.1	0.2	–	17.3	–	0.10	2.84
Mazulskii limestone	0.5	1.4	0.4	53.3	0.15	0.15	–	43.7	–	–	–

Notes. 1) M_{alk} is the alkali modulus, the molecular ratio $R_2O:Al_2O_3$; 2) f/a is the ferrite ratio, the molecular ratio $Fe_2O_3:Al_2O_3$; 3) μ_{Si} is the silicon modulus, the mass ratio $Al_2O_3:SiO_2$.

TABLE 2. Composition of Ore Mixtures

Description of ore material	Mass fraction, %					M_{alk}	f/a	μ_{Si}
	Al_2O_3	SiO_2	Fe_2O_3	CaO	R_2O			
GGO (86%), NOB (14%)	27.05	39.6	9.0	6.7	8.9	0.54	0.21	0.68
CGGO (88%), NOB (12%)	30.3	40.5	2.88	7.5	9.9	0.54	0.06	0.75
GGO (46%), KSO (46%), NOB (8%)	28.9	40.3	3.6	6.3	11.2	0.64	0.08	0.72

TABLE 3. Composition of Nephelin-Bauxite Charges

Ore components of charge	Chemical composition of charge, %					Moduli of charge			f/a
	Al_2O_3	SiO_2	Fe_2O_3	CaO	R_2O	M_{Ca}	M_{alk}	M_{alk}^{a+f}	
KSO (100%)	11.8	17.0	2.0	31.8	8.1	2.02	1.12	1.0	0.11
GGO (100%)	9.4	17.0	3.4	31.7	7.16	2.0	1.25	1.02	0.23
CGGO (100%)	11.2	17.6	1.0	33.0	7.7	2.01	1.13	1.07	0.05
GGO (86%), NOB (14%)	11.0	15.5	3.3	30.2	8.4	2.07	1.25	1.06	0.19
CGGO (88%), NOB (12%)	12.0	16.1	1.3	31.1	8.2	2.07	1.12	1.05	0.07
GGO (46%), KSO (46%), NOB (8%)	11.5	16.3	3.0	30.6	8.3	2.01	1.18	1.02	0.17

Notes. 1) M_{Ca} is the calcium modulus, $CaO:SiO_2$ molecular ratio; 2; M_{alk}^{a+f} is the alkali modulus (total), molecular ratio $R_2O:(Al_2O_3 + Fe_2O_3)$.

meaning that use of this ore will lead to a reduction in the basic statistics for the integrated plant, even when the ore is pre-enriched [6].

TABLE 4. Composition of Resulting Cake and Leaching Results

Ore component	Sintering temperature, °C	Cake composition, %							M_{alk}^{a+f}	M_{alk}^{a}	f/a	Extraction, %	
		Al_2O_3	SiO_2	Fe_2O_3	CaO	Na_2O	K_2O	R_2O				Al_2O_3	R_2O
KSO (100%)	1275	16.4	24.0	3.5	44.4	9.4	2.0	10.7	0.95	1.08	0.14	88.8	88.9
GGO (100%)	1250	13.3	24.1	4.9	44.7	9.0	1.5	10.0	1.00	1.23	0.235	90.3	89.5
CGGO (100%)	1325	15.4	24.2	1.6	45.2	9.1	1.2	9.9	0.99	1.06	0.066	90.0	92.3
GGO (86%), NOB (14%)	1275	15.3	21.9	5.2	41.4	9.2	1.9	10.4	0.92	1.12	0.217	89.5	91.7
CGGO (88%), NOB (12%)	1325	16.9	22.9	1.9	43.3	9.8	1.3	10.7	0.97	1.04	0.071	90.5	90.4
GGO (46%), KSO (46%), NOB (8%)	1275	16.1	23.4	4.4	42.7	9.6	2.0	10.9	0.95	1.11	0.174	90.9	94.3

In this connection, successful operation of the enterprise without any reduction in production capacity will require implementation of measures to increase the aluminum oxide content of the sintering charge [7]. Adding bauxite to the charge will not only enable optimization of the content of the nepheline cake but also enable use of substandard and out-of-balance ore from the Kiya-Shaltyr Deposit and serve as advance work for switching the integrated plant over to its alternate resource base [8].

Thus, the primary subjects of this paper are the Kiya-Shaltyr nepheline ore (KSO), the Goryachegorsk nepheline ore (GGO), concentrate of Goryachegorsk nepheline ore (CGGO, produced by magnetic separation), and Mazulskii limestone. Bauxite from the North Onega Deposit (NOB) was selected as a bauxite additive. The chemical compositions of the materials used are listed in Table 1.

In addition to sintering the Goryachegorsk and Kiya-Shaltyr ores, we also studied a mixture of these ores with the North Onega bauxites as an additive (Table 2).

The charge was prepared via the following procedure. All the components were first milled to a size of minus 0.088 mm, and then mixed in the specified ratios. The mixture was carefully stirred and eventually blended in a rotating drum (25 rpm) for 5 h.

The homogeneity of the charge was determined from the CO_2 content of hourly samples processed them in hydrochloric acid. When two hourly samples in succession provide identical results, the charge is presumed to be homogeneous (Table 3).This generally occurred within 4 h. The resulting charge was dry-pressed into cylindrical briquettes (18 mm dia. × 35–40 mm).

The briquettes were sintered at 1225–1325°C in a silicon-carbide laboratory furnace equipped with a programmable temperature control. The charges were heated at a rate of 10–11°C/min. The primary temperature sensor consisted of a TPP T 01.01-4-400 platinum-rhodium alloy thermocouple with a maximum operating temperature 1400°C.

The resulting cake was ground up in a metal mortar to a size of minus 0.25 mm and leached by stirring in an aluminate alkali solution at 75°C for 30 min (Na_2O_O – 53.9; Na_2O_c – 39.9; Na_2O_y – 14.0; Al_2O_3 – 31.2 g/liter, α_c – 2.1) with a liquid-to-solid ratio L:S = 2.7.

The slurry was filtered amd washed with hot water (with a water-to-slurry ratio of approximately 15 (by mass)) in a vacuum funnel.

A post-leaching x-ray spectroscopic analysis was performed to determine the main components of the cake and slurry.

The sintering temperature was determined as a function of the ferrite ratio in the charge on the 1250–1325°C temperature interval. The composition of the resulting cake and the cake leaching results (in the form of useful component extraction as a function of charge composition) are described in Table 4.

TABLE 5. Comparative Results of Balance Calculations for Alumina Production from Various Alumina-Containing Charges

Ore, concentrate, or ore mixture	Composition of ore component, %				Production %	
	Al_2O_3	SiO_2	R_2O	Fe_2O_3	Alumina	Soda products
KSO (100%)	26.5	40.7	12.6	4.4	100	100
GGO (100%)	22.5	44.3	9.5	10.0	83	75
CGGO (100%)	26.5	46.7	10.4	2.0	92	62
GGO (85%), NOB (15%)	27.0	40.3	8.1	9.6	100	28
CGGO (90%), NOB (10%)	30.4	42.4	8.8	2.8	106	23
GGO (46%), KSO (46%), NOB (8%)	26.8	40.5	10.2	7.2	99	58

As we see, sintering of Goryachegorsk nepheline ore, which contains up to 7.7% Fe_2O_3, with a ferrite ratio of 0.21 under laboratory conditions, may enable production of cake with high Al_2O_3 and alkali extraction (to the 90% level) on the 1250–1275°C temperature interval. However, due to the low Al_2O_3 content of the ore (23.0–23.5%) and the lower silicon modulus relative to the Kiya-Shaltyr ore the Al_2O_3 content of the cake is 13.3%, i.e., an absolute percentage of 2% (or a relative percentage of 15%) lower than when using the Kiya-Shaltyr ore (see Table 4). This means that if the amount of cake produced in the sintering furnaces at the combine remains the same, this implies a corresponding reduction in alumina production capacity, and a corresponding increase in the specific fuel consumption of the sintering facility. In this case, the iron in the ore will cause the resulting cake to have higher fusability, which may lead to substantial difficulties when the charge is sintered in a rotating furnace.

When Goryachegorsk ore concentrate is sintered, the Al_2O_3 content of the cake increases to a level similar to that obtained using Kiya-Shaltyr ore. However, the low concentration of Fe_2O_3 in the charge ($f/a = 0.07$) means the cake formation temperature is higher – approximately 50°C, which may lead to a slight reduction in sintering furnace productivity and an increase in operating costs for maintenance of these furnaces.

Sintering the Goryachegorsk ore with 14% (of the ore mixture) being North Onega bauxite will bring the Al_2O_3 content of the cake up to 15.3%, i.e., approximately equivalent to processing Kiya-Shaltyr ore. The sintering temperature remains 1250–1275°C. However, it should be kept in mind that when processing unenriched Goryachegorsk ore and ore enriched with the North Onega bauxite, the increase in the ferrite ratio leads to an increase in charge fusibility, which may cause certain difficulties in operation of sintering furmaces.

In order to eliminate these deficiencies, most of the iron can be removed from the ore throught magnetic separation or flotation (or a combination of magnetic separation and flotation). The resulting concentrate will have an Al_2O_3 content equivalent to that of the Kiya-Shaltyr ore, but a higher silica content, meaning that the cake produced from this concentrate will have identical alumina content cake obtained from the Kiya-Shaltyr ore (15.2%–15.4% Al_2O_3 instead of 15.8–16.0%), but be somewhat poorer in aluminium oxide, as noted above. However, the low concentration of iron in the concentrate means that sintering the concentrate with lime will require a higher temperature (approximately 50°C higher); addition of bauxite will also be useful in the case where Goryachegorsk ore is used. If North Onega bauxite (10–12%) is used for this purpose, there will be a noticeable increase in Al_2O_3 concentration and a slight improvement in ferrite ratio (see Table 4 for an 86% GGO–14% NOB mixture).

A mixture of Kiya-Shaltyr ore and Goryachegorsk ore (1:1) with bauxite as an additive also provides good results. In this case, good cake quality can be achieved with the bauxite additive reduced to 8%. This type of ore mixture may be promising during the transition period from the primary to the backup ore.

Thus, increasing the concentration of aluminum oxide in the cake to its current level requires that bauxite or another raw material (containing more alumina than nepheline ore or concentrates) be added to the charge. If North Onega bauxite is used for this purpose, it is sufficient to add bauxite (to make approximately 10% of the ore mixture bauxite) to a charge based on Goryachegorsk concentrate.

In order to determine the primary feasibility statistics for sintering and leaching of the ore mixtures studied, an approximate material balance calculation was performed for processing of these mixtures. All versions of the balance calculations used similar input data for process values and distribution of production losses, and bunker fuel was arbitrarily adopted as fuel for calculation purposes.

Since laboratory results for all options involving the raw material under study indicate that alumina extraction from the cake is approximately the same, an identical pay yield was arbitararily assumed for all cases – 80%.

The basic results from these balance calculations (Table 5) should be treated as comparative (referenced against the values calculated for Kiya-Shaltyr ore).

Analysis of the results contained in Table 5 indicates the following:

1) when unenriched Goryachegorsk ore (Al_2O_3 22.5%; SiO_2 44.3%; R_2O 9.5%; Fe_2O_3 10.0%) is used, the productivity of the enterprise with respect to alumina and soda/potash products will be substantially reduced (by 17% and 25%, respectively); the specific cake consumption will increase from 8.5 metric ton/metric ton to 10.2 metric ton/metric ton; the specific fuel consumption for sintering will increase in the same proportion; and the high iron oxide content of the ore (as high as 10%) will cause the resulting cake to have higher fusibility, which will inevitably lead to additional difficulties during the sintering process;

2) Goryachegorsk concentrate produced by two-stage magnetic enrichment (Al_2O_3 26.5%; SiO_2 46.7%; R_2O 10.4%; Fe_2O_3 2.0%) is quite different from the unenriched ore; the alumina concentration in the concentrate is identical to that in the Kiya-Shaltyr ore, however, the concentrate is inferior to the Kiya-Shaltyr ore, when Goryachegorsk concentrate is used, the productivity of the enterprise is decreased by 8% with respect to alumina and 28% with respect to soda products;

3) if a mixture of 85% Goryachegorsk ore and 15% North Onega bauxite is used (Al_2O_3 27.0%; SiO_2 40.3%; R_2O 8.1%; Fe_2O_3 9.6%), the productivity of the enterprise can remain at its existing level; negative factors include the fairly high cost of the bauxite component and the increased soda content of the charge, which may require conversion of the sintering furnaces to sputtering feed;

4) a mixture of 90% Goryachegorsk concentrate and 10% North Onega bauxite (Al_2O_3 30.4%; SiO_2 42.4%; R_2O 8.8%; Fe_2O_3 2.8%) only differs from the preceding option in that the combine has a higher productivity for alumina; and

5) a mixture of Goryachegorsk ore (46%) and Kiya-Shaltyr ore (46%) with 8% North Onega bauxite as an additive (Al_2O_3 26.8%; SiO_2 40.5%; R_2O 10.2%; Fe_2O_3 7.2%) will support current alumina production levels. Soda and potash production will be 40% lower than current production; this option might be acceptable during the transition period prior to start-up of the enrichment plant.

Thus, the only way to maintain productivity of the enterprise at the level achieved using the Kiya-Shaltyr ore is by adding bauxite raw material to the nepheline charge in various ratios, depending on the chemical composition of the initial components. It should be noted that the process for sintering nepheline-bauxite charges (with 8% North Onega bauxite as an additive) has been tested on a large industrial scale at the AGK, with favorable results.

Conclusions

1. The raw-material base for the Achinsk Alumina Combine (the Kiya-Shaltyr Nepheline Deposit) is close to exhaustion. As a result, it will become necessary to bring non-balanced ore from this deposit into production and switch over to the backup raw materialsn source – nepheline from the Goryachegorsk deposit.

2. If only low-quality raw materials can be used for expansion of raw materials sources for AGK, this will lead to a reduction in the basic statistics for AGK.

3. Research showed that the processing efficiency for low-quality nepheline can be improved by adding expensive sintering-grade bauxites (with Al_2O_3 concentrations almost two times those of the nephelines) to the nepheline-lime charges.

4. It was shown that the largest bauxite additive (up to 15% of the ore mixture) is required for processing the unenriched Goryachegorsk ore; the smallest bauxite additive (8%) is required for processing a mixture of Goryachegorsk ore concentrate and North Onega bauxite. An optimum version of enterprise operations using out-of-balance Kiya-Shaltyr and Goryachegorsk nepheline ore will need to be developed in order to perform the feasibility study for construction of the ore enrichment facility based on the actual costs of the ores, concentrates, and other components.

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