

A Study on the Iron Extraction from Kazakhstan Bauxite

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ABSTRACT

This study investigated the use of coke for the recovery of minerals included in the composition of ferruginous sands of the alumina production from bauxites of Kazakhstan. The granulometric and mineralogical analyses showed that that fine ferruginous sands were enriched with iron oxides (up to 67.8% Fe_2O_3), while the coarse fractions possessed higher alumina concentrations, primarily in gibbsite and kaolinite. The reduction experiments were conducted using ore-coke-lime briquettes, which were prepared from ferruginous sands (0.40 - 0.63 mm fraction), metallurgical coke, lime, and bentonite. The testing of smelting from 1200 - 1450 °C, demonstrated that the metallic iron was completely separated from slag at 1400–1450 °C, obtaining a metallic phase with 92.62% Fe. The coke content influenced the reduction efficiency, with results obtained at up to 20% coke. The product of the metallic phase was analyzed by X-Ray Fluorescence (XRF), confirming the high purity of the metallic product, while the slag phase, rich in Al_2O_3 , SiO_2 , and CaO , was successfully tested as a filler in concrete production. The analysis of the chemical composition of the resulting slag revealed the possibility of its use as a filler in the production of construction concrete.

Keywords—bauxite; iron; alumina; coke; recycling

I. INTRODUCTION

Aluminum is the second most important structural material after steel, with its use steadily growing in economic sectors including transport, mechanical engineering, construction, and electrical engineering [1]. This increasing demand is supported by extensive scientific research. Specifically, authors in [2] investigated the incorporation of aluminum with nitrogen to improve the properties of steel during heat treatment. Additionally, authors in [3] examined issues related to the metal structure production based on reinforced aluminum foams. Authors in [4] studied the formability of a sample of aluminum alloy A5010 under various deformation options. The effectiveness of these studies influences directly the request for metallic aluminum and, as a consequence, its availability on the world market. This, by turn, requires the primary aluminum producers to constantly increase the degree of metal extraction from bauxites.

The primary ore base for aluminum production is mainly represented by high-quality bauxite deposits, which enable the use of Bayer technology for the production of alumina [5, 6]. In Kazakhstan, alumina and aluminum production developing/development is based on its own deposits located in the north of the country. However, these deposits have a complex mineral composition [7-8], as displayed in Tables I and II.

TABLE I. AVERAGE CHEMICAL COMPOSITION OF BAUXITES IN KAZAKHSTAN (MAIN ELEMENTS), %

Field	Chemical composition, %					μSiO_2 , silicon module
	Al_2O_3	SiO_2	Fe_2O_3	CaO	FeO	
Belinsky	41.40	10.3	21.2	1.27	2.88	4.02
Ayatsky	44.60	10.7	18.3	0.53	2.06	4.17
Krasnooktyabrsky	42.00	10.9	19.4	0.96	5.41	3.85

TABLE II. MINERALOGICAL COMPOSITION OF BAUXITES, %

Field	Kaolinite	Chamosite	Gibbsite	Goethite	Anatase	Quartz	Siderite	Hematite
Belinsky	15.0	1.95	52.3	2.7	2.7	1.0	2.4	18.4
Ayatsky	14.4	1.65	56.6	2.6	2.3	1.2	1.4	16.7
Krasnooktyabrsky	22.6	2.0	50.9	2.8	2.4	1.2	4.7	11.5

The primary impurities in Kazakhstan's bauxites are iron minerals, which should be removed through preliminary enrichment to obtain a suitable composition for the alumina production [9-12]. The main disadvantage of this technology is the accumulation of large volumes of sludge with high contents of iron and other elements, along with the loss of Al_2O_3 . For example, at the Pavlodar Aluminum Plant, which produces 1.4 million tons of alumina per year, up to 192.5 thousand tons of Fe_2O_3 , and 65.6 thousand tons of Al_2O_3 are lost with iron-containing waste. The visual characteristics of ferruginous sands are illustrated in Figure 1 and their composition is presented in Table III.

Environmental factors have led to the development of closed production cycles in metallurgy, both in Kazakhstan and worldwide. Several studies considering this production with the development of a waste management system, including the processing of alumina production sludge, have been conducted [13-18].

Specifically, in [13], the processes of phase formation during the agglomeration of manganese ores of the Tur deposit in the presence of dolomite were studied. Authors in [14] examined methods for the utilization of red mud in order to reduce the environmental pollution in three directions - the extraction of valuable components, resource conversion, and environmental application. In [15], various methods and techniques were proposed for the consumption of large quantities of red mud to maintain a sustainable environment. Additionally, authors in [16] investigated the effect of carbothermic reduction on the physical and chemical separation of red mud components, namely Ti, REE, Fe and Al. In [17], a method of reducing the sintering of alumina and iron oxide, leaching, and the subsequent magnetic enrichment was used. The experimental results revealed that the recovery of alumina from Bayer red mud could reach 89.71%, as well as the degree of Fe recovery and the content of magnetite concentrate were 60.67% and 61.78%, respectively. Similarly, in [18], priority methods for using red mud were analyzed considering volumes, process productivity, costs, and risks.

Despite the extensive research on red mud, the reduction of ferrous sands obtained during the enrichment of Kazakh bauxites has not been fully studied. For this reason, this paper examines the characteristics of Kazakhstan bauxite enrichment tailings in the form of ferruginous sands, and the technology of reducing the iron oxides with coke to obtain metallic iron for



Fig. 1. Visual characteristics of ferruginous sands.

TABLE III. AVERAGE CHEMICAL COMPOSITION OF FERRUGINOUS SANDS (%)

Na_2O	Al_2O_3	SiO_2	CaO	Fe_2O_3	SO_3	CO_2
0.15-0.75	13-17	5.4-9.5	3.4-6.1	42-58	1-4	5.4-10.9

further steel production and "iron-free" slag for further production of construction concrete.

II. RESULTS AND DISCUSSION

At the first stage, the granulometric characteristics of ferruginous sands were investigated. Table IV portrays the distribution of aluminum and iron compounds by particle size fractions.

TABLE IV. COMPOSITION OF FERRUGINOUS SANDS BY CHEMICAL ELEMENTS IN EACH FRACTION.

№	Fraction, mm	Fraction content, %	Content, %							
			Na ₂ O	Al ₂ O ₃	SiO ₂	CaO	Fe ₂ O ₃	SO ₃	CO ₂	FeO
1	(+5)	0.43	0.98	35.4	7.4	5.9	26.9	0.95	4.9	5.2
2	(-5+3)	4.01	0.71	32.9	5.9	5.4	27.4	1.32	8.3	8.5
3	(-3+1)	24.12	0.87	27.6	6.4	5.1	36.2	2.01	9.4	9.5
4	(-1+0.63)	16.94	0.94	22.7	6.9	4.8	42.1	2.09	10.1	10.3
5	(-0.63+0.25)	28.91	1.08	14.9	7.4	4.3	48.1	2.12	10.9	10.6
6	(-0.25+0.15)	11.01	1.01	12.1	9.5	4.2	57.9	1.7	5.15	6.4
7	(-0.15)	14.24	0.81	11.9	6.2	2.4	67.8	2.1	2.28	3.5

It is obvious that the Fe₂O₃ content increased as the particle size decreased. For example, the coarse fraction (+ 5 mm) contained 26.9% Fe₂O₃, while the finest fraction (- 0.15 mm) reached 67.8%. This indicates that the smaller fractions were more enriched with iron oxide. Conversely, the Al₂O₃ content decreased with a decreasing particle size. The coarsest fraction (+ 5 mm) contained 35.4% Al₂O₃, while the smallest fraction (-

0.15 mm) had only 11.9%, demonstrating that aluminum was included to a greater extent in coarser fractions. Thus, it can be concluded that the small fractions of ferruginous sands were more saturated with iron, and the large ones with aluminum.

The mineralogical composition of ferruginous sands was studied, and the results are presented in Table V.

TABLE V. MINERALOGICAL COMPOSITION OF FERRUGINOUS SANDS, %

Kaolinite	Gibbsite	Goethite	Anatase	Quartz	Siderite	Hematite	Calcite
8-15	12-17	2.6-3.5	2.2-2.8	1.2-2.5	11-16	38-48	2-5

TABLE VI. CHEMICAL COMPOSITION OF IRON-CONTAINING SLUDGE FROM THE PAVLODAR ALUMINUM PLANT, %

Al ₂ O ₃	Na ₂ O	Fe ₂ O ₃	CaO	SiO ₂	TiO ₂	CO ₂	SO ₃	Other elements
16	0.7	51	4.5	8.3	2.4	9.1	3.2	2.2

Alumina in ferruginous sands was mainly present in the form of gibbsite and kaolinite. A part of alumina was also distributed in iron - containing compounds, which complicated the aluminum extraction since it is closely associated with iron. Iron in ferruginous sands was represented by hematite, siderite, and partly goethite. This diversity can affect the processing methods and iron extraction.

Using the granulometric and mineralogical data of ferruginous sands, a series of experiments was carried out to study the reduction of iron oxides with coke. The chemical composition of ferruginous sands from the Pavlodar Aluminum Plant is given in Table VI.

Iron was obtained from ferruginous sands using ore-coke-lime briquettes (Figure 2). The following materials were used for the briquette preparation:

- Ferruginous sands (fractions 0.4 - 0.63 mm)
- Metallurgical coke
- freshly burned lime
- bentonite



Fig. 2. General view of ore-lime briquettes.

The composition of metallurgical coke and freshly burned lime used in briquette production is illustrated in Tables VII and VIII.

TABLE VII. CHEMICAL COMPOSITION OF METALLURGICAL COKE, %

Components	C	S	Calcination losses
Metallurgical coke	79.02	0.53	20.45

TABLE VIII. CHEMICAL COMPOSITION OF FRESHLY BURNED LIME, %

Components	CaO	SiO ₂	MgO	Al ₂ O ₃ + Fe ₂ O ₃	S	Calcination losses
Freshly burned lime	89	1.9	1.2	1.3	0.12	6.48

The materials were mixed and formed into briquettes using a hydraulic press at a force of 3 kN. The raw briquettes were

then pre-dried at 110 °C for 60 min to improve the mechanical strength.

The briquettes had the following dimensions:

- Diameter: 27 mm
- Height: 20 mm
- Weight: 17 gr

Each series of experiments was carried out using briquettes with different component ratios (Table IX). The amount of metallurgical coke in the briquettes was selected considering the need for maximum iron recovery and the experience of previously conducted studies [19-25].

TABLE IX. COMPOSITION AND FRACTION OF COMPONENTS FOR DIFFERENT SERIES OF EXPERIMENTS

Name of components	No. of experiments		
	№1	№2	№3
Ferruginous sands	60	65	70
Metallurgical coke	20	15	10
Lime	10	10	10
Bentonite	10	10	10
Water (over 100%)	15	15	15

The amount of freshly burned lime was calculated to ensure the formation of liquid slag and the effective separation of slag from metal during the reduction and smelting process. Bentonite was added to provide the required green strength of the briquettes.

The briquettes were subjected to reducing melting/melting reduction in a muffle furnace at temperatures ranging from 1200 °C to 1450 °C (Figure 3).



Fig. 3. Reductive smelting of ore-lime briquettes to produce metallic iron and slag.

The temperature of the reduction process significantly affected the efficiency of the metal and slag separation.

TABLE XI. RESULTS OF XRF ANALYSIS OF SLAG, %

Al ₂ O ₃	SiO ₂	CaO	Fe ₂ O ₃	TiO ₂	MgO	SO ₂	MnO	K ₂ O	Other elements
39.1	23.5	19.08	8.18	3.87	2.5	2.06	0.83	0.37	0.51

The metallic phase contained 92.62% Fe, with minor impurities of sulfur (7.14%) and traces of P, Cr, Cu, and As. The slag phase included Al₂O₃ (39.1%), SiO₂ (23.5%), and CaO (19.08%), with smaller amounts of Fe₂O₃ and TiO₂. The increased sulfur content in the metal product was due to the initial components of the batch (ferrous sand, coke, and

Specifically, at 1200 °C, metal and slag did not melt, preventing their separation. Increasing the temperature to 1300 °C - 1350 °C led to melting, creating conditions for the separation of cast iron and slag. With a further increase in temperature to 1400 °C - 1450 °C, the separation process was fully accomplished. At 1600 °C, the melt began to boil, reducing the separation efficiency.

The amount of coke also affected the reducibility of iron. By increasing the coke content from 10% to 20%, an increase in the degree of iron reduction was observed.

In the next stage of the study, the reduced briquettes were crushed and magnetically separated on a laboratory magnetic separator SMS-20-PM1. The process involved a primary separation with permanent magnets and a secondary separation in a magnetic field of 2 Tesla. The resulting iron and slag samples were subjected to XRF analysis to determine the chemical composition (Figure 4 and Tables X and XI).

The results demonstrated that the proposed method obtained a metallized product with a metallic iron content of up to 92.62%, with the degree of reduction increasing as the temperature increases from 1300 to 1450 °C. The analysis showed that the degree of iron reduction varied from 82.2% to 92.62% depending on the amount of coke introduced.

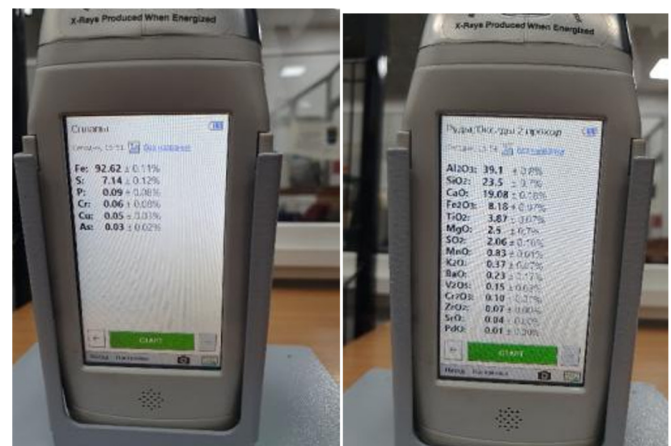


Fig. 4. XRF analysis of metallic iron and slag after magnetic separation.

TABLE X. RESULTS OF XRF ANALYSIS OF METALLIC IRON, %

Fe	S	P	Cr	Cu	As
92.62	7.14	0.09	0.06	0.05	0.03

bentonite). However, sulfur was quite easily removed during the smelting of steel in an arc steel-making furnace during the oxidation and refining processes.

The analysis of the slag composition showed the possibility of its use as a filler in the production of construction concrete, Slag was introduced into the concrete mixture in an amount of

20 to 40%. According to the test results, the tensile strength of the concrete samples of building products was 21.3 - 36.5 MPa depending on the content of Portland cement and corresponded to the class of heavy concrete.

III. CONCLUSION

This study investigated the possibility of obtaining metallic iron from ferruginous sands during bauxite enrichment in Kazakhstan. The results demonstrated the following findings:

- Ferruginous sands contained 52% - 61% Fe₂O₃, represented by such minerals as hematite, siderite, and partially goethite, while the rest of the ferruginous sands included Al₂O₃ in the form of gibbsite and kaolinite.
- At 1400 - 1450 °C, a complete separation of iron and slag was achieved producing metallic iron with up to 92.62%.
- An increase in the coke content in the briquette from 10% to 20% improved the degree of reduction.
- The chemical composition of the resulting slag, consisting of Al₂O₃, SiO₂, CaO, was successfully tested as a filler in the production of construction concrete, providing strengths of 21.3 – 36.5 MPa.

Overall, this research demonstrated that ferruginous sands could implement a closed production cycle in the processing of high-iron bauxites of Kazakhstan.

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