Chapter

The Comprehensive Utilisation of Red Mud Utilisation in Blast Furnace

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Abstract

State-of-the-art formation of red mud during industrial processing of bauxite in the Sverdlovsk region (Russian Federation) is presented. Red mud chemical composition is presented, and an analysis of existing ways in which they are utilised is executed. In the Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences, red mud is utilised by introducing it into the charge for the production of iron ore sinter and pellets following the use of sinter and pellets in the blast furnace charge. Metallurgical properties of sinter and pellets (reducibility, strength, softening and melting temperatures) with different contents of red mud in iron ore raw materials are also presented, including the technology of red mud usage in ferrous metallurgy carried out through industrial and laboratorial tests. Additionally, the main technical and economic indicators of blast furnace smelting (productivity, coke consumption, chemical composition of pig iron and slag, etc.) are presented. The possibility and expediency of utilisation of red mud in a blast furnace are shown.

Keywords: red mud, agglomerate, pellets, metallurgical characteristics, blast furnace smelting

1. Introduction

Red mud is one of the mass wastes of the aluminium industry. The exit of red mud fluctuates, depending on the structure and properties of processed bauxite raw materials, within 0.8–1.2 kg per tonne of aluminium. In the world, more than 50 million tonnes of red mud are dumped in dumps or reservoirs each year.

In 60 years of operation of the aluminous shop of the Ural Aluminium Plant, three mud storage facilities have been constructed using more than 500 hectares of area with over 63 million tonnes of red mud. A similar picture is seen with the Bogoslovsk Aluminium Plant: mud storage facilities occupy a space of more than 400 hectares with more than 40 million tonnes of mud.

Currently, about 600 million tonnes of red mud are saved in Russia, and this quantity increases annually by 5–8 million tonnes. In the Sverdlovsk region, mud storage facilities managing more than 137 million tonnes are necessary, and 3 million tonnes of dangerous waste are formed every year.

Negative environmental impact has proven the urgency of the problem of red mud usage. Moreover, there are useful components within the contents of red mud at the industrial level that increase prospects of its utilisation. However, the existence and influence of other red mud components that may variously impact technological processes in the blast furnace, structure and properties of products from blast furnace smelting still require detailed study.

2. State of the art

In works [1, 2] the technological expediency of using red mud as a ferriferous additive in blast furnace smelting has been shown. However, excepting the iron generally provided in the form of Fe_2O_3, which contains 15–20% $A1_2O_3$, the ratio of CaO/SiO_2 is close to one, which contains to 4–5% of MgO. Existence of such a quantity and a combination of slag-forming components allows red mud to be used as an additive to correct properties of final slags on physical and chemical properties.

In work [3] it is noted that the iron oxide accounts for about 50 wt% in the red mud; therefore, it is logical to consider the possibilities of red mud usage in burden structure for receiving blast furnace agglomerates. However, it is also necessary to consider that this material considerably concedes to processed iron ores according to the content of iron. Its application undoubtedly reduces productivity of blast furnaces and increases coke consumption. The specified minus is blocked by pluses from essential increases in the durability of the agglomerate. Red mud is found to prevent polymorphism of two-calcium silicate in the structure of the agglomerate. It also leads to the elimination of internal tension destroying the agglomerate. A reduction of the fraction of 0–5 mm per 1% promotes a gain of productivity of the blast furnace per 1% with the same economy of consumption as the expensive blast furnace coke. The binding properties of red mud are also revealed. The burden pelletising and its gas permeability improve. Productivity of sintering machines raises by 5–10% without capital expenditure. If the guantity of small fraction in the agglomerate is reduced by 3–5%, and reduction in the content of iron averages about 0.5%, the summary of technological efficiency in blast furnace production has a gain of 1.2–2.5% on production of cast iron and 1.5–1.8% on economy of blast furnace coke. In addition, the red mud input in the structure burden agglomerate will form a hardened aluminoferrite ligament of agglomerate and pellets. The exit of 0–0.5 mm during the heating and reduction of the agglomerate and pellets in blast furnaces is reduced by 20–40%. Therefore, iron losses with dust taken out from blast furnaces decrease and productivity grows.

In work [4] a negative factor of the ecology of the Russian blast furnace production is noted: the environmental harm from large dust output caused by low mechanical strength and durability in the reduction of blast furnace agglomerates and pellets. This shortcoming can be eliminated through the initial burden of the waste of aluminous production—red mud. Still, it can be hampered by the negative consequences of a reduction in the content of iron in blast furnace burdens. Calculations prove that the negative effect is compensated for by a reduction in the number of small-sized fractions in blast furnace burdens. Domestic agglomerates have been chosen for an assessment of the influence of additive red mud on the increase in productivity and reduction of coke consumption: Bakal with minimum 43.8%, Kachkanar with maximum 60.0% iron content and the Magnitogorsk agglomerate with an average iron content of 53.10%. Calculations establish an introduction in agglomerate burdens of 2% red mud (with mass percentages: 30.0–50.0 Fe_2O_3, 12.0–15.0 Al_2O_3, 4.0–7.0 SiO_2, 5.0–8.0 CaO, 4.0–5.0 TiO_2, 2.0–4.0 Na_2O, 2–3 others, 8–10 losses on calcination), taking into account the reduction of the content of a trifle that allows an increase in the productivity of blast furnaces in the range of 0.67–3.67%, with economy of 0.23–1.73% coke. What's more, inputting red mud in the structure of the blast furnace burden allows additional technological effects at the expense of education protective scar in a high-temperature zone of blast furnace lining with the raised content in blast furnace slag of hard titanium dioxide.

Work [5] notes a thermal agglomeration of ores and concentrates on the removal of harmful impurities of sulphur and phosphorus. It is useful that red mud is used for the improvement of the quality of iron ore agglomerates and pellets. In this work, it is established that in the agglomeration of red mud in aluminous production, it is possible to delete not less than 45% of alkalis and 65% of sulphur from the mud at an optimum consumption of solid fuel; additionally, by the oxidation-reduction roasting of pellets from red mud, it is possible to reduce the content of alkali, sulphur and phosphorus, respectively, by 58–60%, 31–38% and 10–15%. Sintering and roasting are carried out in semi-factory bowls with a 420 mm diameter, while the oxidising roasting of pellets from red mud is carried out at 1000–1200°C and reduction roasting at 1100–1200°C. Coke is used as a reducing agent at a coarseness of <1 mm, which was loaded into a crucible together with pellets in a mass ratio of 1:1 that provided protection of pellets against oxidation. After oxidising and reduction, roasting pellets were exposed to phase and chemical analysis.

Work [6] performs the development of technology for the Ural Aluminium Plant's red mud enrichment by receiving an iron concentrate of FeO = 45–50%. The structure of red mud minerals was defined when studying a polished section under a microscope using the programme "the Mineral-7". The Ural Aluminium Plant red mud enrichment methods are mainly the magnetic and gravitational methods, as well as the physical and chemical methods; a product attrition in the rotor-pulsating device with participation of processes of cavitation from surface processing by hexametaphosphate for a flocculus dispersion has been chosen. It is revealed that the general mineral content of iron in studied tests of the Ural Aluminium Plant makes 53 and 15% from chamosite with an iron content making 18%. In the structure of red mud, there is a significant amount of amorphous formations (flocculus) in which grains of iron-bearing minerals are included. The study of material structure has revealed the following directions for red mud enrichment: attrition; use of dispergators and rotor-pulsating units for flocculus disaggregation of initial red mud; high-gradient magnetic separation for separation of haematite, chamosite and goethite; and gravitational enrichment on a concentration table for operational development of magnetic products.

The results of research on properties of the monomineral fractions allocated from red mud are given in work [7]. The main fractions of red mud are haematite, chamosite and calcite. These fractions have been received by enrichment methods. At monomineral fractions the material structure and physical characteristics (signs), such as a specific magnetic susceptibility and true density, have been defined, and the factor of visibility between separate fractions on each of the physical signs is calculated. The maximum values of factors of visibility 3.75 and 2.3 on a specific magnetic susceptibility have been received, respectively, between haematite and calcite and haematite and chamosite. It has allowed the prediction of the first operations of the technological scheme of enrichment and the main and recleaning high-gradient magnetic separation with an induction of a magnetic field of 1.4–1.5 Tesla, which have been received when studying the dependence of specific magnetic moments of monomineral fractions from the set induction of a field. Further operations of the scheme (gravitational) have been predicted on the basis of the analysis of fraction visibility factors and checked with the use of a concentration table and Knelson separator. The results of research studies issue the optimum technological scheme of red mud enrichment as receiving an iron concentrate with a 50% general iron content and a 15% output.

Work [8] shows that the additive-enriched red mud in quantities of 4% in the high-basicity agglomerate burden of Kachkanarsky Mining and Processing

Integrated Works leads to growth in the quality of the agglomerate and slightly influences indicators of blast furnace smelting; this means that enriching red mud additives in agglomerative production with subsequent blast furnace repartition is a perspective technology for their utilisation. As a positive influence of red mud additives to agglomerates, the increase in the content of MgO in the final slags with 9.1 to 11.2–11.5% is noted as a slight improvement to the negative influence of mud on properties of slags. The increase of magnesia in the final slags, especially when processing high-fluxed agglomerates, leads to increased stability in their phase structure, particularly regarding areas on the border of melilite and spinel slags displaced towards pure spinel, i.e. in areas of more stable temperatures in the beginning of crystallisation. Influence of the specified factor has allowed properties of slag to be saved at the required level—despite an increase in the content of alumina in slag—and has weakened influence of red mud on its properties.

Work [9] studies the structure, thermal characteristics and composition of red mud in the current production of the Ural Aluminium Plant with the help of spectral methods (a mass fraction on solids: 46.7% Fe_2O_3, 12.8% Al_2O_3, 14.5% SiO_2, 10.85% CaO, 4.7% TiO_2, 4.7% Na_2O, 1.125% others). X-ray analysis is carried out on a diffractometer by X'Pert PRO (PANanalitical, the Netherlands) in monochromatic CuKa radiation. For the purpose of specification of the search for iron atoms in different minerals, samples of red mud have been investigated by a method of Mössbauer spectroscopy. In work MS-1104Em, a spectrometer with a source of Co57 in a rhodium matrix was used. The isomerous shift was relatively defined α-Fe. For high-quality determination of the sizes of mineral phases and distribution of elements in them, the samples of red mud have been studied on the electron microscope JXA-8100 (JEOL, Japan) with a power dispersive system, INCA Energy 400. Extant research of red mud structures shows that from the point of view of iron ore materials, the material represents a difficult system of dispersed and ultradispersed crystals of haematite surrounded by ferriferous phases in the form of a crystal phase of chamosite and amorphous iron-silica-alumina phases. Enrichment of such material through traditional means is represented as difficult to realise.

Work [10] establishes the basis of studying red mud structures in the current production of the Ural Aluminium Plant subject to reduction roasting and attempts to define the expediency of magnetic separation of roasting production on the basis of the results of complex research. For this purpose, briquetted samples of red mud in the current production of the Ural Aluminium Plant are subjected to roasting in a weak reduction environment (a gas mix CO_2 (95%) and H_2 (5%)) and the reduction environment (H_2 (100%)) at 810°C. The completed research study on red mud structure after heat treatment in reduction environments and analysis of similar research has shown that achieving effective magnetic separation will only be possible under conditions that develop physical and chemical impacts on the growth of crystals in the magnetic phases, which form during reduction roasting within the range of 800–1000°C.

The existence of alkalis in red mud represents danger for the technological process of agglomeration, especially for blast furnace smelting technology as it has harmful effects on the flameproof lining of the blast furnace.

In 2011, experts from the United Company RUSAL, together with scientists from "Uralpromenergoproyekt", Institute of Solid State Chemistry of the Ural Branch of the Russian Academy of Sciences, Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences and the Moscow Institute of Steel and Alloys, have carried out a number of research projects on red mud and its properties with

No.	Fe	FeO	CaO	MgO	SiO_2	TiO_2	Al_2O_3	MnO	P_2O_5	SO_3	R_2O	LC*
Mud 1	28.36	5.88	21.32	0.63	9.24	4.14	12.35	0.30	0.60	0.90	0.76	10.30
Mud 2	27.80	5.79	20.9	0.8	9.85	4.06	11.9	0.35	0.31	0.36	—	11.00

**LC—Losses on calcination.*

Table 1.
Chemical composition of red mud (%).

the aim of creating technology for its complex processing, including projects on dealkalisation, dehydration, enrichment and extraction of rare earth metals. Results of research studies are based on the creation of trial experimental industrial plants for red mud processing by calculating the productivity of 200,000 tonnes of mud in a year at the Ural Aluminium Plant.

The chemical composition of red mud in the current production of the Ural Aluminium Plant is given in **Table 1** (Mud 1), and alkaline-free red mud is listed after the above-stated plant (Mud 2).

3. Laboratory studies and industrial tests

Sintering was carried out on the agglomerative cap of a 320 mm diameter, established in the JSC Uralmekhanobr laboratory. The structure of alkaline-free red mud is given in **Table 2**.

The structure of agglomerative burden for the agglomerative factory of JSC Kachkanarsky Mining and Processing Integrated Works is given in **Table 2** (LC—losses on calcination).

After carrying out sintering-ready agglomerate three times, dumped from a height of 3 m according to GOST 25471-82, granulometric composition of the received agglomerate was defined, an output of suitable, drum-type durability and an abradability in accordance with GOST 15137-77. Agglomerate sampling for all types of tests was carried out in accordance with GOST 26136-84. The metallurgical properties of agglomerate, reducibility and a durability indicator at reduction were defined in accordance with GOST 19575-84. Results of tests are given in **Tables 3** and **4**.

For production pellets, Kachkanarsky Mining and Processing Integrated Works concentrates are bentonite and red mud. The chemical composition of materials is shown in **Table 5** (LC—losses on calcination). The content of particles of class in concentrate makes less than 0.071 mm—90 and 100% in bentonite and red mud.

Material	Weight fraction (%)									
	Fe	FeO	SiO_2	CaO	MgO	Al_2O_3	P	S	C	LC
Iron ore concentrate	62.1	28.1	3.6	1.06	2.06	2.44	<0.01	0.025	—	2.33
Limestone	—	—	1.39	53.2	0.32	0.71	—	—	—	42.4
Coke	—	—	—	—	—	—	—	0.54	83.8	83.8
Ash of coke	6.13	1.08	48.0	8.02	1.96	24.4	0.32	1.34	—	—

Table 2.
Chemical composition of components of agglomerative burden.

No.	Indicator/red mud (%)	0	1	2	3
1	Durability (%)	68.73	72.93	67.07	67.73
2	Abrasiveness (%)	7.13	6.07	11.00	8.27
3	Specific capacity (t/(m^2 hour))	1.13	1.07	0.65	0.86
4	Output of suitable (%)	76.83	71.32	64.08	69.68

Table 3.
Results of tests on agglomerate sintering with additives of red mud (%).

Content of red mud (%)	GOST 15137-77		GOST 17212-84	GOST 19575-84	GOST 26517-85
	Durability (+5 mm, %)	Abradability (−0.5 mm, %)	Reducibility (%)	Durability by Linder	Temperature range (°C)
0	68.7	7.1	65.2	36.5	1153–1266
1	72.9	6.1	73.7	27.4	1178–1334
2	67.1	11.0	69.6	31.5	1169–1313
3	67.7	8.27	69.0	32.1	1168–1309

Table 4.
Metallurgical properties of iron ore agglomerate when using red mud.

Material/element	Fe	FeO	Fe_2O_3	SiO_2	CaO	MgO
Kachkanarsky concentrate	61.9	28.3	57.0	3.93	1.10	2.68
Bentonite	3.6	1.3	3.7	58.5	2.43	2.86
Red mud	27.7	5.79	33.14	7.24	19.9	0.74
Material/element	Al_2O_3	TiO_2	S	LC	Σ	
Kachkanarsky concentrate	2.19	2.75	—	1.0	98.95	
Bentonite	18.3	—	—	5.0	92.09	
Red mud	12.8	—	0.36	11.1	91.07	

Table 5.
Chemical composition of burden components for receiving pellets with different contents of red mud (%).

Heat treatment of dry pellets was carried out in the vertical tubular furnace with height of isothermal zone (100–120 mm). Characteristics of the crude and burned pellets are shown in **Tables 6**–**8** (1—pellets with 0.7% of bentonite, 2—pellets with 0.7% of bentonite and 2% red mud, 3—pellets with 0.7% of bentonite and 4 mass % red mud, and 4—pellets with 0.7 mass % of bentonite and 6 mass % red mud).

Trial tests of production of agglomerate were carried out in the conditions of JSC Kachkanarsky Mining and Processing Integrated Works. Results are shown in **Table 9**.

Trial tests of production of pellets were carried out in the conditions of JSC Kachkanarsky Mining and Processing Integrated Works GOK. Results are shown in **Tables 10**–**12** (1—0.22% of binding, 1% red mud; 2—0.22% of binder, 2% red mud; 3—binder 0.44%, 4—1% red mud without binder, 5—2% red mud without binder, and 6—0.44% binder).

No. of test	Binding additives		Properties of pellets				
	Bentonite (%)	Red mud (%)	Damp pellets				Pressure (kg/dry pellet)
			Moisture (%)	Pressure (kg/pellet)	Dropping (3 m, times)	Dropping (1 m, times)	
1	0.7	—	6.87	1.15	4.0	1.0	2.81
2	0.7	2.0	7.0	1.25	4.2	1.0	2.06
3	0.7	4.0	6.85	1.15	4.5	1.0	1.84
4	0.7	6.0	7.0	1.36	4.5	1.0	1.72
5	—	2.0	6.34	1.13	2.9	0	0.57
6	—	6.0	6.9	1.31	3.6	1.0	1.0
7	0.35	6.0	7.0	1.32	3.9	1.0	1.55
8	1.0	6.0	7.0	1.88	7.4	1.0	3.45

Table 6.
Strengthening characteristics of nonfluxed pellets with different contents of binding additives in the form of bentonite and red mud.

No.	Heat treatment conditions				Durability of burned pellets (kg/pellet)	FeO (%)
	Part of layer	Time lag at 1050°C (minutes)	Roast			
			t (°C)	τ (minutes)		
1	Top	5	1300	6	325	4.17
	Middle	3	1270	3	317	2.92
	Bottom	—	1230	1	260	1.64
	Average	—	—	—	301	2.91
2	Top	5	1300	6	334	3.62
	Middle	3	1270	3	365	2.83
	Bottom	—	1230	1	330	1.89
	Average	—	—	—	343	2.78
3	Top	5	1300	6	300	3.85
	Middle	3	1270	3	376	2.2
	Bottom	—	1230	1	308	1.53
	Average	—	—	—	328	2.52
4	Top	5	1300	6	317	3.3
	Middle	3	1270	3	303	1.93
	Bottom	—	1230	1	306	1.22
	Average	—	—	—	309	2.15

Table 7.
Heat treatment conditions on air of nonfluxed pellets with additives of red mud, their strengthening characteristics and chemical composition.

No.	Binding additives		Properties of pellets					
	Bentonite (%)	Red mud (%)	Damp pellets				Pressure (kg/dry pellet)	Pressure (kg/roasting pellet)
			Moisture (%)	Pressure (kg/pellet)	Dropping (3 m, times)	Dropping (1 m, times)		
1	0.7	—	6.70	1.15	4.0	1.0	2.26	301
2	0.7	2.0	6.75	1.15	4.2	1.0	2.06	343
3	0.7	4.0	6.73	1.10	4.5	1.0	1.74	328
4	0.7	6.0	6.70	1.10	4.6	1.0	1.72	309

Table 8.
Metallurgical properties of iron ore pellets when using alkaline-free red mud.

Experience condition/burden	Base	Fe 53.3% (basicity 2.1)	Fe 54.0% (basicity 1.9)	Fe 54.0% (basicity 1.8)
Concentrate (kg)	15.0	15.0	15.00	15.00
Red mud (kg)	—	1.10	1.15	1.25
Red mud (%)	—	7.00	7.70	8.30
Limestone (kg)	2.85	2.86	2.48	2.29
Fuel (kg)	1.00	1.00	1.00	1.00
Backstock (kg)	6.00	6.00	6.00	6.00
Water (l)	2.40	2.40	2.4	2.15
Height of layer (mm)	280	280	280	280
Moisture after pelletisation (%)	7.80	7.6	8.4	7.50
Moisture after heating (%)	7.00	7.1	8.0	7.0
Burden temperature (°C)	80.0	81.0	81.0	81.0
Pelletisation degree (%)	52.8	43.4	59.6	55.8
Mechanical durability				
+5 mm (%)	56.8	49.9	58.8	59.8
–0.5 mm (%)	5.2	9.1	6.6	8.0
Granulometric structure (%):				
+40 mm	1.0	2.6	3.5	4.2
+25 mm	8.0	4.2	10	12.6
+10 mm	36.1	24.2	33.5	40
+5 mm	26.7	24.9	24.9	15.0
–5 mm	28.2	44.1	28.1	28.2
C (burden) (%)	4.49	4.66	3.89	3.72
Fe (agglomerate) (%)	53.9	53.3	53.9	54.0
FeO (agglomerate) (%)	9.1	8.17	10.68	9.29
Basicity (shares of units)	2.01	2.06	1.98	1.78
Content in agglomerate (%)				
C	0.11	0.22	0.36	0.11
V_2O_5	0.51	0.48	0.47	0.49
MgO	2.94	2.73	2.48	2.68
Al_2O_3	2.38	2.64	3.43	3.10

Experience condition/burden	Base	Fe 53.3% (basicity 2.1)	Fe 54.0% (basicity 1.9)	Fe 54.0% (basicity 1.8)
TiO_2	2.53	2.53	2.65	2.69
S	0.013	0.016	0.023	0.016

Table 9.
Test results of agglomerate production.

No.	Burden materials						
	Concentrate		Binder			Burden	
	Moisture (%)	Dissemination (%)	Moisture (%)	Dissemination (%)	Swelling ability (times)	Moisture (%)	Dissemination (%)
1	9.3	95.4	4.1	93.2	7.6	9.15	95.5
2	9.3	95.4	4.1	93.2	7.6	9.45	95.5
3	9.3	95.4	—	—	—	—	—
4	8.95	94.2	—	—	—	9.0	93.6
5	8.95	94.2	—	—	—	8.95	93.4
6	—	—	—	—	—	—	—

Table 10.
The industrial test results of burden materials.

No.	Quality of damp pellets									
	Moisture (%)	Plasticity (times)	Durability (kg/pellet)		Granulometric structure (%)					
			Damp	Dry	+20	+15	+12	+10	+8	–8
1	8.0	5.1	1.23	3.84	13.5	40.8	21.8	18.5	4.2	1.2
2	8.85	5.8	1.46	4.0	4.2	39.1	46.0	8.8	1.6	0.3
3	8.85	9.1	1.3	5.0	1.5	30.2	47.6	15.9	3.2	1.6
4	9.35	13.8	1.06	1.37	0.0	12.6	19.7	24.9	36.1	6.7
5	9.55	4.3	0.7	1.54	1.9	10.3	20.8	32.0	29.0	6.0
6	8.8	6.8	1.12	3.31	1.3	35.0	45.0	12.5	5.0	1.2

Table 11.
The industrial test results of pellets.

No.	Burned pellets			
	Compressive strength (kg/pellet)	Laboratory mill		FeO, %
		More 5.0 mm	Less 0.5 mm	
1	231.4	96.2	2.5	2.7
2	245.2	97.0	2.7	2.5
3	211.0	98.5	1.4	2.0
4	251.7	96.0	3.0	2.3
5	257.6	97.5	2.5	2.1
6	255.0	97.0	2.0	3.3

Table 12.
The industrial test results of burned pellets.

4. Calculated research

According to the received properties of experimental agglomerates in carrying out laboratory research with an introduction in burden of blast furnace, 1 and 3% of red mud have been calculated. Results of comparative calculations by means of mathematical models [11] are shown in **Table 13** [12].

The analysis of results shows that positive improvement in durability of the agglomerate when using red mud is practically levelled by a decrease in the general content of iron in the burden. To save the content of iron at the level of its base values in the burden of blast furnace smelting, it is possible to use several options: a decrease in basicity of the high-basicity agglomerate, along with a simultaneous raise in the relation of CaO/SiO_2 in Staflux, the addition of a new iron-containing component in the agglomerative burden (scale), and the replacement of part of the bentonite in mud in the production of pellets.

Indices	Unit of measure	Base	Red mud (1%)	Red mud (3%)
Useful volume of furnace	m^3	2200	2200	2200
Productivity	t/day	6241	6235	6141
General consumption of ore	kg/t pig iron	1712.9	1728.8	1742.2
Pellets	kg/t pig iron	907.8	916.3	923.4
Agglomerate, red mud (0%)	kg/t pig iron	650.9	0.0	0.0
Agglomerate, red mud (1%)	kg/t pig iron	0.0	657.0	0.0
Agglomerate, red mud (3%)	kg/t pig iron	0.0	0.0	662.0
Staflux	kg/t pig iron	154.2	155.6	156.8
Coke	kg/t pig iron	396.6	394.5	397.9
Dust exit	kg/t pig iron	39.1	39.4	39.7
Consumption of natural gas	m^3/t pig iron	125.2	125.2	125.2
Blast:				
Temperature	°C	1206	1206	1206
Moisture	g/m^3	8	8	8
Oxygen	%	28.7	28.7	28.7
Consumption	m^3/t pig iron	925.0	924.7	936.7
Top gas:				
Temperature	°C	173.9	176.7	189.5
exit	m^3/t pig iron	1474.5	1469.1	1483.7
CO	%	23.6	23.1	23.1
CO_2	%	21.9	22.4	22.3
H_2	%	9.6	9.5	9.5
N_2	%	44.9	45.1	45.2
Extent of use CO	Shares of units	0.493	0.481	0.480

Indices	Unit of measure	Base	Red mud (1%)	Red mud (3%)
Extent of use H_2	Shares of units	0.464	0.457	0.460
Theoretical temperature of burning	°C	2006	2005	2012
Composition of pig iron:				
Si	%	0.10	0.10	0.10
Ti	%	0.15	0.15	0.5
Mn	%	0.327	0.329	0.346
Cr	%	0.105	0.106	0.112
V	%	0.407	0.415	0.436
S	%	0.025	0.018	0.021
C	%	4.666	4.666	4.666
P	%	0.051	0.052	0.054
Fe	%	94.17	94.16	94.11
Temperature of metal	°C	1450	1450	1450
Slag exit	kg/t pig iron	347.0	359.0	373.0
Composition of slag				
CaO	%	34.20	34.82	33.34
MgO	%	9.34	9.58	9.77
SiO_2	%	27.97	25.27	25.84
Al_2O_3	%	15.83	16.79	17.34
TiO_2	%	10.38	11.32	11.07
MnO	%	0.41	0.41	0.43
Cr_2O_3	%	0.05	0.05	0.06
V_2O_5	%	0.25	0.23	0.26
S	%	0.80	0.77	0.76
R_2O	%	0.57	0.54	0.91
FeO	%	0.61	0.61	0.60
CaO/SiO_2		1.22	1.38	1.29

Table 13.
Calculated indicators of blast furnace smelting of agglomerate with additives of red mud.

5. Conclusion

Laboratory tests, calculations, research, and industrial tests have confirmed the possibility of red mud utilisation as a ferriferous additive (agglomerate) and binding as a bentonite substitute (pellets).

Acknowledgements

This research study was supported by the State Task of Institute of Metallurgy of the Ural Branch of the Russian Academy of Sciences, the Project No. 0396-2015-0081.

Conflict of interest

The author declares no conflict of interest.

Thanks

The author expresses gratitude to Leopold Leontyev, Galina Gazaleeva, Evgeniy Bratygin, Dmitriy Volkov and Yuriy Chesnokov.

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