

Industrial Use of Low-Phosphorus Anthracite in the Production of High-Carbon Ferrochrome

A. G. Kaliakparov^a, A. V. Suslov^b, and V. M. Strakhov^c

^aENRC Center, Astana, Kazakhstan

e-mail: Altay.RecENRC@yandex.kz

^bAksu Ferroalloy Plant, TNK Kazkhrom, Aksu-1, Kazakhstan

e-mail: info@kazkhrom1.enrc.com

^cKuznetsk Center, OAO VUKhIN, Novokuznetsk, Russia

e-mail: vuhin2013@yandex.ru

Received April 29, 2014

Abstract—The use of anthracite in the production of high-carbon ferrochrome is assessed. The theoretical and technological aspects of electrothermal production of high-carbon ferrochrome are analyzed. The physicochemical characteristics of anthracite and coke nuts are compared. It is established that the ash content of anthracite is low. More importantly, its content of phosphorus and sulfur is very low. An advantage of anthracite is its high electrical resistance. The use of anthracite in the production of high-carbon ferrochrome in 21-MV A furnaces reduces the consumption of reducing agent (by 1.9%) and electric power (by 6.8%). The extraction of chromium is practically unchanged. The production costs (per 1 t of high-carbon ferrochrome) are reduced. The use of anthracite in more powerful furnaces (63 MV A) permits significant increase in the working voltage and decrease in power consumption by 2.0–2.5%. The phosphorus content in the ferrochrome is reduced with increase in anthracite content in the batch.

Keywords: anthracite, composition, physicochemical properties, ferrochrome production

DOI: 10.3103/S1068364X14060040

In the past decade, there has been growing interest in the selection and testing of effective new carbon-based reducing agents for ferroalloy production. One simple and practical means of expanding the range of available reducing agents is to use mixtures of coke nuts, which are already used for that purpose, with various other materials, such as coal. The potential replacements for coke nuts must be evaluated in terms of technical and economic expediency.

Depending on the type of reducing agent, we may distinguish between ferroalloy production on the basis of silicon, aluminum, and carbon [1]. Carbon is used in the large-scale production of silicon, manganese, and chromium ferroalloys. As we know, the reduction of oxides by carbon is effective and economical.

Various requirements are imposed on carbon reducing agents in metallurgy [1–3]. In ferroalloy production by means of carbon, coke nuts are regarded as the main reducing agent. However, deficiencies include the low reactivity and electrical resistance of coke nuts, which reduce furnace performance and increase power consumption.

We may distinguish between two large groups of processes in electrofurnaces: those with and without slag [1, 2]. The production of high-carbon ferrochrome belongs to the first group; the carbon-based

reducing agent amounts to 38–48% of the batch (by volume) [2, 3]. In these processes, reduction occurs mainly at the surface of ore components or in melt at the boundary with solid carbon. In ferrochrome production, the main processes are wetting of the carbon by metal and slag and the solution of the carbon in the metal [1].

Carbon is mainly consumed in gasification at high temperature, without marked kinetic hindrance even in the case of very small specific surface of the reducing agent [4, 5]. Therefore, the use of anthracite with increased density, low specific surface, and relatively low chemical activity facilitates steady reduction, improves the economic efficiency, and improves the alloy quality thanks to its low content of harmful ash impurities [6, 7].

The anthracite used as a reducing agent without preliminary heat treatment must be characterized by low ash content, low phosphorus and sulfur content, and favorable chemical composition of the ash, as well as sufficient strength and thermal stability, resistance to graphite formation, optimal piece size, high reactivity, and high electrical resistivity at the furnace temperatures. We know that the electrical resistivity of anthracite is 1000–1500 times that of coke; that is a considerable advantage [1].

Table 1. Quality of anthracite and coke

Characteristic	ZAO “Sibantratsit”	OAO “Altai- Koks”
Size class, mm	25–13	25–10
Technical analysis, %:		
W^r	6.8	12.3
A^d	3.4	12.6
V^{daf}	2.5	1.1
S^d	0.17	0.45
P^d	0.010	0.059
Fixed carbon content C_{fix} , %	94.2	86.4
Elementary composi- tion (organic mass), %:		
C^{daf}	96.2	97.18
H^{daf}	1.4	0.50
N^{daf}	0.9	1.62
O^{daf}	1.3	0.24
S^{daf}	0.2	0.46
Composition of ash, %:		
SiO_2	50.80	48.50
Al_2O_3	32.10	20.10
Fe_2O_3	9.22	16.60
CaO	1.63	4.60
MgO	1.24	4.11
TiO_2	1.00	0.86
P_2O_5	0.10	0.28
SO_3	0.30	2.47
Na_2O	0.70	0.87
K_2O	2.50	1.80
Density, g/cm ³ :		
actual d_r^d	1.720	1.956
apparent d_a^d	1.520	1.082
Porosity P_r^d , %	11.6	44.7
Total pore volume W_{tot} , cm ³ /g	0.076	0.413
Reactivity (in terms of CO ₂) at 1000°C R_{CO_2} , cm ³ /g s	0.50	0.58
Electrical resistivity ρ (6–3 mm size class, $p = 0.2$ kg/cm ³), Ω cm	2.7×10^2	3.8
Structural strength, %	88.7	88.4
Thermal stability at 900°C, %	88.4	92.7

Experience with anthracite in ferroalloy production has been mixed. It is mainly used outside Russia and as an additive to coke—for example, in ferrosilicon production. In some cases, the anthracite is mixed with charcoal [1]. At Aksu Ferroalloy Plant, AM Listvyansk anthracite (size class 13–25 mm) is used to replace some of the coke nuts (Table 1).

As follows from Table 1, anthracite may be used for ferrochrome production since its characteristics are better than those of the coke nuts. The anthracite is characterized by low ash content ($A^d = 3.4\%$) and high carbon content (dry mass): 94.2%, as against 86.4% for coke. A particular benefit is the very low content of phosphorus and sulfur: $P^d = 0.010\%$, as against 0.59% for coke; $S^d = 0.17\%$, as against 0.45%.

Another advantage is that the electrical resistivity of anthracite is two orders of magnitude greater than for coke: 2.7×10^2 as against 3.8Ω cm. The chemical activity K_{CO_2} of anthracite is somewhat lower than that of coke, on account of its high density, low porosity, and small pore volume. Its structural strength is equivalent to that of coke, while its thermomechanical strength is 4.3% (abs.) lower.

The industrial use of anthracite to replace some of the coke as a reducing agent in the production of high-carbon ferrochrome has been adopted in shop 2 at RKZ-21 furnaces 21 and 22.

The experimental production period lasted 23 days. Since the size of the anthracite supplied was similar to that of industrial anthracite, no additional preparation is required before charging in the furnace.

Before the introduction of anthracite in the weighed batch samples, the furnace operated with 180–190 kg of OAO Altai-Koks coke nuts per charge. The amount of anthracite added was 30 kg per charge, with correction of the coke content to 160 kg. After five days of operation with anthracite, no impairment of furnace operation was observed. The only modification was correction of the coke mass (in the range 160–180 kg).

Stable furnace operation was observed, with uniform batch delivery to the charge hole. There was practically no change in the batch emissions. Uniform gas liberation was observed over the whole bath perimeter. The current at the electrodes remained stable.

On the basis of the normal furnace operation with 30 kg of anthracite, trials with 50 kg of anthracite were undertaken. The coke content was 160 kg. The state of the furnaces remained satisfactory. Increasing the anthracite content to 70 kg per charge slightly increased batch splashing. In this period, quiescent charge behavior and uniform gas liberation were observed. The batch fell uniformly, with very little spillage and no splashing.

No changes in tap-hole operation and electrode motion were observed after introducing the anthracite. No marked hot downtime or accidents were observed.

Table 2. Furnace characteristics when using anthracite

Characteristic	Shop 2, furnaces 21 and 25		Shop 6, furnace 62		
	baseline period (using coke)	period with anthracite	baseline period	period with anthracite	
				I	II
Anthracite content per charge, kg	—	30–50	—	70	100
Test duration, days	20	23	31	28	31
Power consumed, kW	17050	16617	31243	30720	30839
Furnace productivity, (t/day)/%	$\frac{66.0}{100.0}$	$\frac{69.0}{104.5}$	$\frac{108.5}{100.0}$	$\frac{108.7}{100.2}$	$\frac{109.8}{101.2}$
Power consumption, (kW-h/t)/%	$\frac{6200}{100.0}$	$\frac{5780}{93.2}$	$\frac{6912}{100.0}$	$\frac{6784}{98.1}$	$\frac{6741}{97.5}$
Batch consumption, kg/t:					
chrome ore	3578	3590	3591	2422	2851
metal concentrate	100	84	18	58	—
chrome wastes	500	425	299	388	388
dry coke	$\frac{640}{100.0}$	$\frac{481}{75.1}$	$\frac{832}{100.0}$	$\frac{679}{81.6}$	$\frac{519}{62.4}$
anthracite	—	172	—	124	373
Karaganda coal	60	—	16	—	—
FS slag	120	140	—	—	—
quartzite siftings	10	13	—	—	—
chrome briquets	—	—	260	1377	928
Chromium extraction, %	84.7	84.4	75.9	76.9	77.4
Power factor cos ϕ	0.84	0.89	0.88	0.95	0.96

Each shift accommodated 2–3 discharges of the slag–metal melt.

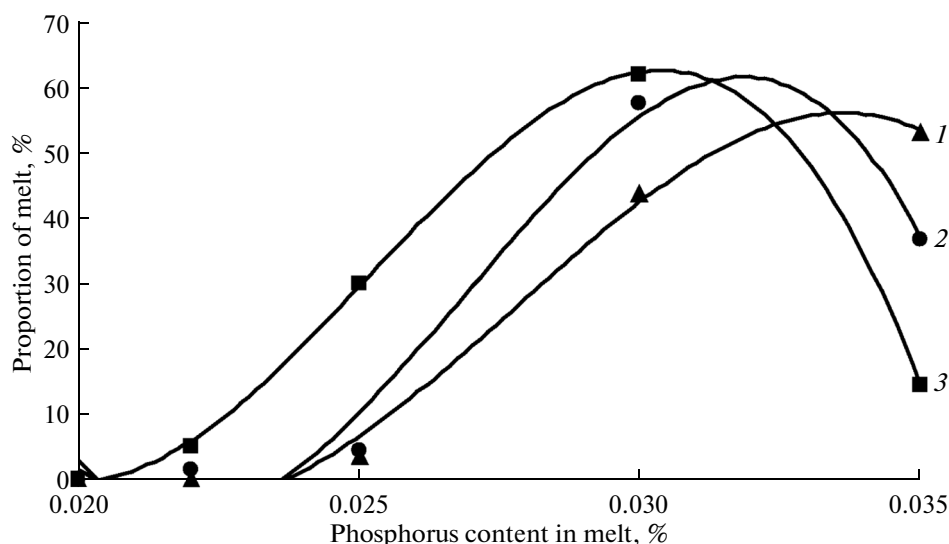
Table 2 provides information regarding furnace operation when using anthracite. Overall, positive results were obtained in the smelting of high-carbon ferrochrome.

On average, with different additions of anthracite, the consumption of reducing agent is reduced by 1.9% and the power consumption by 6.8%. The extraction of chromium is practically unchanged. When using anthracite, the production costs for high-carbon ferrochrome are reduced by \$5.4/t, on average (at current prices). The annual savings for two furnaces are \$217400, for example.

Industrial trials with anthracite have also been conducted in shop 6, at more powerful furnace 62 (63 MVA). The results are shown in Table 2.

At furnace 62, the relatively high resistivity of the anthracite permitted significant (8–9%) increase in the working voltage. The power consumption was reduced by 2.0–2.5%. The power factor cos ϕ rose by 7.9% and 9.1% (rel.), respectively, with 70 and 100 kg of anthracite per charge. Likewise, the chromium extraction rose by 1.0 and 1.5% (abs.), respectively.

The observed change in phosphorus content in the alloy for different quantities of added anthracite (over the furnace's operating period) is shown in the figure. We find that the phosphorus content in ferrochrome declines with increase in the anthracite content per charge from 50–70 to 100 kg. Thus, when using coke, 53.1% of the metal contains >0.035% P. This figure declines to 36.6% with 50 kg of anthracite and to 14.4% with 100 kg of anthracite. At the same time, 3.4% of the metal contains <0.025% P when using coke, but that figure increases to 4.4% with 50 kg of anthracite and to 15.6% with 100 kg of anthracite.



Distribution of the phosphorus content in high-carbon ferrochrome melts when using coke alone (1) and with the addition of 70 kg (2) and 100 kg (3) of anthracite.

CONCLUSIONS

(1) Anthracite may be used to replace some of the coke employed in the production of high-carbon ferrochrome, thanks to its low ash content, high carbon content, high electrical resistivity, and satisfactory reactivity. A particular benefit is the low content of phosphorus and sulfur: $P^d = 0.016\%$ and $S^d = 0.15\%$.

(2) When 30–70% of the charge consists of anthracite, no significant deviation from normal furnace operation is observed. The final alloy's phosphorus content is lowered, along with the consumption of reducing agent and power and the cost of the alloy.

REFERENCES

1. Mizin, V.G. and Serov, G.V., *Uglerodisty vosstanoviteli dlya ferrosplavov* (Carbon-Based Reducing Agents for Ferroalloys), Moscow: Metallurgiya, 1980.
2. Gasik, M.I., Lyakishev, N.P., and Emlin, B.I., *Teoriya i tekhnologiya proizvodstva ferrosplavov* (Theory and Technology of Ferroalloy Production), Moscow: Metallurgiya, 1988.
3. Nefedov, P.Ya., Quality requirements on carbon-based reducing agents for ore processing in electrofurnaces, *Koks Khim.*, 2000, no. 8, pp. 24–32.
4. Vorob'ev, V.P., Theoretical Aspects of Improving the Efficiency of Electrofurnace Ferroalloy Production, *Extended Abstract of Candidate's Dissertation*, Sverdlovsk, 1988.
5. Vorob'ev, V.P. and Vyakhireva, L.D., Physicochemical properties of carbon-based reducing agents in electrofurnace ore processing, *Izv. Akad. Nauk SSSR, Met.*, 1983, no. 5, p. 28.
6. Lavrik, S.N., Mizin, V.G., Strakhov, V.M., et al., Porous structure and reactivity of carbon-based materials, *Khim. Tverd. Topl.*, 1969, no. 3, pp. 103–109.
7. Nefedov, P.Ya., Carbon-based reducing agents in ferroalloy production: Their effectiveness, *Koks Khim.*, 2000, no. 2, pp. 27–31.

Translated by Bernard Gilbert