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Optimal Coal Preparation Scheme in the Conditions of the Azovstal Metallurgical Plant

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Abstract

The use of the method of preparation of the blend with preliminary grinding of the group of hard coals, in comparison with the preparation method according to the CB scheme, makes it possible to improve the crushing index of M25 from 85.5 to 86.8% or by 1.3% and to reduce the abrasion index of M10 from 8.3 to 7.6% or 0.7%. Along with the improvement of the strength properties of coke as a lump material obtained according to the improved preparation scheme, there is also a tendency to improve the structural strength of the porous body of coke free from cracks from 83 to 87% and the abrasive hardness of the coke substance composing the pore walls from 72 to 78mg.

The results obtained indicate the need for further clarification of the level of grinding of the group of hard coals and the list of components included in it, as well as the level of grinding of the total blend during its final crushing.

Keywords*: Coal concentrates; Coal blend; Particle size distribution; Preliminary grinding; Preparation scheme.*

1. Introduction

AZOVSTAL is one of the largest producers of the pig iron in Ukraine. The development strategy of the enterprise provides for the use of pig iron smelting technology with replacing part of the coke with pulverized coal, which leads to increased requirements for the quality of coke. World experience shows that blast furnaces using pulverized coal most effectively operate on coke with low ash content, sulfur content, reactivity (CRI), high post-reaction strength (CSR), crushing strength (M25) and low abrasion (M10) [1].

Since 2014, the leading coke-chemical enterprises of Ukraine are almost completely deprived of domestic resources of well-caking coking coals, the use of which in coking blends is a prerequisite for the production of high-quality coke. Therefore, the coke and chemical production of AZOVSTAL operates on an inter-basin raw material base, made up mainly of imported coals [2-3].

In connection with the foregoing, work aimed at developing rational technological parameters for preparing a coal blend, depending on its technological properties, is relevant [4–8].

2. Experimental part

2.1. Raw materials

The list of coals included in the blend of the plant, and indicators of their technological properties are shown in Table 1. Table 2 shows the petrographic characteristics, and in Table 3 is the granulometric composition of these coals.

Analysis of the data given in table 1 shows that the plant's blend contains coals from Ukraine, Russia, the USA and Australia, which are characterized by a wide variety of properties.

Table 1. Technological properties of coals

Provider	Proximate analysis, %			Plastometric indicators, mm		Roga Index, units	Hardgrove grindability index, units
	A^d	S^d_t	V^{daf}	x	y	RI	HGI
Promugolservice, Russia	7.8	0.62	36.9	41	7	22	53
Dobropolskaya, Ukraine	7.5	1.50	38.8	48	10	57	57
Alpha, USA	8.5	1.05	37.2	28	17	75	60
Wellmore, USA	7.6	1.20	34.0	31	18	78	63
Svyato-Varvarinskaya, Ukraine	8.6	0.89	30.3	14	13	70	68
Berezovskaya, Russia	8.6	0.49	25.2	26	10	49	72
Oaky North, Australia	9.2	0.71	26.7	11	20	80	90
Pocahontas, USA	8.4	1.00	18.9	12	11	52	95

Table 2. Petrographic characteristics of coals

Provider	Petrographic composition, %					Ref* %	Stages of vitrinite metamorphism, %					
	Vt	Sv	I	L	∑FC	R_0	0.50–0.64	0.65–0.89	0.90–1.19	1.20–1.39	1.40–1.69	1.70–2.59
Promugolservice, Russia	78	1	20	1	21	0.71	31	66	3	0	0	0
Dobropolskaya, Ukraine	79	0	13	8	13	0.78	22	65	9	4	0	0
Alpha, USA	77	1	18	4	19	0.88	5	45	49	1	0	0
Wellmore, USA	84	0	13	3	13	0.97	0	23	76	1	0	0
Svyato-Varvarinskaya, Ukraine	88	1	9	2	10	1.09	0	3	83	14	0	0
Berezovskaya, Russia	58	1	40	1	41	1.15	0	5	68	22	5	0
Oaky North, Australia	90	0	10	0	10	1.21	0	0	50	46	4	0
Pocahontas, USA	72	1	27	0	28	1.53	0	0	0	8	87	5

**Average coefficient of reflectance of vitrinite, %*

Table 3. Granulometric composition of coals

Provider	Granulometric composition (mm),%									d_{av}, mm*
	>50	25–50	13–25	6–13	3–6	1–3	0.5–1.0	<0.5	<3	
Promugolservice, Russia	2.5	13.6	13.3	19.8	17.0	15.7	5.6	12.5	33.8	12.5
Dobropolskaya, Ukraine	0.0	13.0	15.9	19.1	15.3	17.9	7.1	11.7	36.7	10.8
Alpha, USA	0.0	4.2	9.2	17.9	17.7	20.2	6.5	24.3	51.0	6.3
Wellmore, USA	0.0	6.3	13.4	21.6	19.3	18.2	6.9	14.3	39.4	8.3
Svyato-Varvarinskaya, Ukraine	0.0	4.9	9.1	17.1	9.0	21.1	7.4	31.4	59.9	6.2
Berezovskaya, Russia	0.0	12.6	13.9	13.5	11.5	18.0	3.9	27.2	49.1	9.6
Oaky North, Australia	0.0	3.9	7.6	13.1	14.3	25.2	12.3	23.6	61.1	5.4
Pocahontas, USA	0.0	4.1	5.5	10.5	13.5	25.6	6.6	34.2	66.4	4.8

** Average diameter of particles, mm*

Low-metamorphosed coals are represented by coals from Russia (Promugolservis), Ukraine (Dobropolskaya) and the USA (Alpha). Coals vary greatly in sulfur content, plastic layer thickness, Roga index, as well as vitrinite reflectance and reflectogram. These coals also differ in the average diameter of their grains. These coals are close only in terms of the Hardgrove grindability indexes. Thus, these coals are not interchangeable and should be used as a separate component in the coal charge.

Coals of the middle stages of metamorphism Wellmore (USA), Svyato-Varvarinskaya (Ukraine), Berezovskaya (Russia) and Oaky North (Australia), like the coals of the previous group, are sharply different in the entire range of studied properties. This primarily concerns the sulfur content (S^d_t=0.41–1.20%), the volatile matter (V^{daf}=34.0–25.2%), the thickness of the plastic layer (y=10–20mm) and the Roga index (RI=49–80 units).

The coefficient of reflectance of these coals is in the range of 0.97–1.21%. In the coal of the Berezovskaya there is an increased amount of macerals of the inertinite group (I=41%), while in the other coals of this group it is only 10–13%. The considered coals also differ noticeably in the value of the grindability coefficient of Hardgrove, which increases from 63 units in Wellmore coal up to 96 units at Oaky North coal.

In terms of the average diameter of the coal grains, the coals under consideration are ranked as follows, in the order of its decrease: Berezovskaya, Wellmore, Svyato-Varvarinskaya and Oaky North, having an average diameter of 9.6; 8.3; 6.2 and 5.4mm.

Thus, coals of this group are also not interchangeable in the blend. Pocahontas high-metamorphosed coal basically meets the standardized values of quality indicators. It is characterized by the highest values of the Hardgrove grindability index (HGI=95 units) and the smallest value of the average grain diameter (d_{av}=4.8mm). The share of this coal in the blend is 15%.

Summing up the results of the analysis of the results of the analysis of quality indicators of the studied coals included in the raw material base of the plant, we can state the following.

The inter-basin raw material base of the plant and the lack of interchangeability of coals in the blend significantly complicate the maintenance of the constancy of the content of individual components in the blend, the uniformity of its quality and a stable level of grinding of groups of components and the blend as a whole. Component compositions of hard and soft groups, as well as coal blend as a whole, are shown in Table 4.

Table 4. Component compositions

Provider	Share, %		
	Group of coals		Blend
	Hard	Soft	
Promugolservice, Russia	13	0	13
Dobropolskaya, Ukraine	7	0	7
Alpha, USA	0	12	12
Wellmore, USA	0	15	15
Svyato-Varvarinskaya, Ukraine	0	15	15
Berezovskaya, Russia	10	4	14
Oaky North, Australia	0	9	9
Pocahontas, USA	0	15	15
Total	30	70	100

The hard group of coals includes low-metamorphosed coals Promugolservice, Dobropolskaya and Berezovskaya, and the soft group includes other coals: Alpha, Wellmore, Oaky North, Svyato-Varvarinskaya, Berezovskaya and Pocahontas.

2.2. Experimental equipment

The coal preparation scheme is shown in Fig. 1. The coal preparation department of the coke plant of the coke and chemical production AZOVSTAL operates according to the following coal preparation scheme. About 30% of hard low-metamorphosed and inertinite coals are crushed to a grade of 3–0 mm, equal to 75–80%. After that, the crushed product is mixed with the remaining 70% of soft coals and fed to the final grinding, where it is crushed to a level of 80–82% of the class less than 3mm in the finished blend.

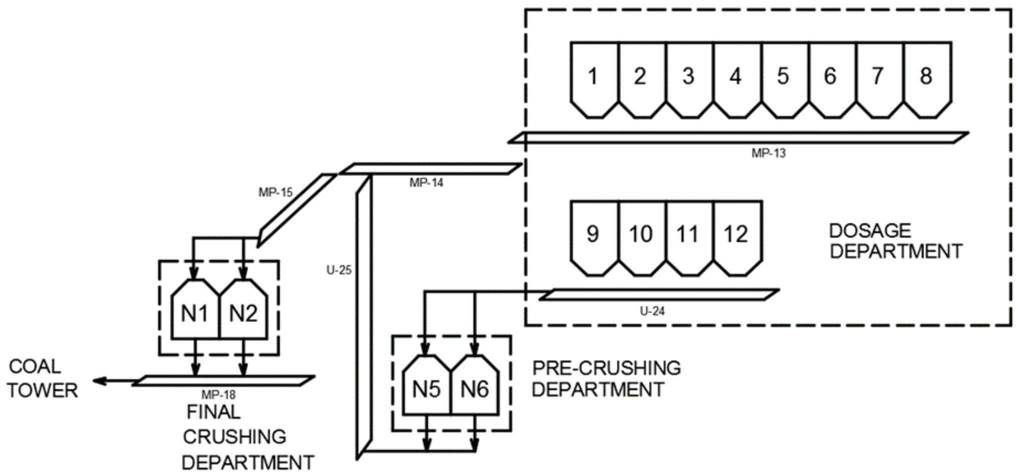

Fig. 1. Coal preparation scheme at AZOVSTAL

3. Results and discussion

Table 5–7 show the quality indicators of samples of coals of the soft group, of the hard group before preliminary grinding and the blend before its preliminary grinding.

Table 5. Technological properties

Sample	Proximate analysis, %			Plastometric indicators, mm		Roga index, units	Hardgrove grindability index, units
	A^d	S^d_t	V^{daf}	x	y	RI	HGI
Soft group	8.5	0.95	29.6	21	17	78	73
Hard group before preliminary grinding	8.3	0.69	32.2	36	9	34	63
Blend before final grinding	8.6	0.85	30.3	26	16	65	70

Table 6. Petrographic characteristics

Sample	Petrographic composition,%					$R_{o,av*}$	Stages of vitrinite metamorphism,%					
	Vt	Sv	I	L	∑FC	R_0	0.50–0.64	0.65–0.89	0.90–1.19	1.20–1.39	1.40–1.69	1.70–2.59
Soft group	85	0	13	2	13	1.14	0	16	47	19	18	0
Hard group before preliminary grinding	62	0	34	4	34	0.91	12	40	41	7	0	0
Blend before final grinding	78	1	18	3	19	1.02	9	26	42	14	7	2

**Average coefficient of reflectance of vitrinite, %*

Table 7. Granulometric composition

Sample	Granulometric composition (mm), %									d_{av*}
	>50	25–50	13–25	6–13	3–6	1–3	0.5–1.0	<0.5	<3	
Soft group	0.0	3.8	11.8	16.7	16.2	20.5	9.1	21.9	51.5	6.50
Hard group before preliminary grinding	4.8	12.3	14.3	17.4	13.2	15.0	7.1	15.9	38.0	13.60
Hard group after preliminary grinding	0.0	0.0	0.0	6.4	14.9	23.7	15.8	39.2	78.7	1.97
Blend before final grinding	0.0	1.1	7.6	13.6	15.8	23.7	11.1	27.1	61.9	4.50

**Average diameter of particles, mm*

Analysis of these data shows that mixtures of coals of soft and hard groups differ significantly across the entire range of studied parameters. This applies to sulfur content, volatile matter, plastic layer thickness, Roga index and Hardgrove grindability index.

The volatile matter is higher for coals of the hard group compared to coals of the soft group (V^{daf}=32.2–29.6%), the thickness of the plastic layer is noticeably lower (y=9–17mm), and the value of the Roga index (RI=34–78 units) and the Hardgrove grindability coefficient (HGI=63 and 73 units).

The petrographic characteristics of the considered groups of coals also differ significantly.

The vitrinite content in coals of the soft group was 85%, and in the coals of the hard group – 62%. Accordingly, the content of macerals of the inertinite group is 13 and 34%. The average coefficient of vitrinite reflection of soft coals is 1.14%, and hard – 0.91%.

The average diameter of coal grains also differs significantly between the coals of the soft and hard groups (6.5 and 13.6mm, respectively). The grinding of the total blend before its final crushing was 61.9% of the content of the class 3–0mm. This grade of 3–0mm was achieved by grinding the hard group to 78.7% of 3–0mm.

In order to assess the effect on the properties of the resulting coke using the above-described method for preparing the blend, in comparison with the method for preparing the CB (crushing of blend), the blend was prepared by the two methods described above:

- Option 1. Coal blend prepared using the technology of preliminary grinding of hard coals;
- Option 2. Coal blend prepared without using the technology of preliminary grinding of coals of the hard group.

The indicators of the granulometric composition of coal blends are given in Table. 8.

Table 8. Granulometric composition

Option	Granulometric composition (mm), %					
	>6.0	3.0–6.0	1.0–3.0	0.5–1.0	<0.5	<3.0
1	6.9	12.8	23.1	14.4	42.8	80.3
2	7.2	11.4	31.0	12.1	38.3	80.4

Table 9. Coke yield and quality indicators

Option	Proximate analysis, %			Coke yield, %	Mechanical strength coke, %		Abrasive hardness, mg	Structural strength,%
	A^d	S^d_t	V^{daf}	B^d	M_{25}	M_{10}	AH	SS
1	11.5	0.77	0.9	76.5	86.8	7.6	78	87
2	11.3	0.80	0.8	76.6	85.5	8.3	72	83

From the above data, it can be seen that in the composition of the production mixture there is an extremely high content of dusty size classes (less than 0.5 mm), equal to 42.8%. Such a high amount of pulverized fractions in the blends reduces the bulk density of the blend in the coking chamber, thereby reducing its productivity, worsens the loading conditions and leads to a deterioration in the quality of coal tar [9].

The yield of dry bulk coke from the experimental blend has a value equal to 76.5–76.6%. The use of the method of preparation of the blend with preliminary grinding of the group of hard coals, in comparison with the preparation method according to the CB scheme, makes it possible to improve the crushing index of M25 from 85.5 to 86.8% or by 1.3% and to reduce the abrasion index of M10 from 8.3 to 7.6% or 0.7%.

Along with the improvement of the strength properties of coke as a lump material obtained according to the improved preparation scheme, there is also a tendency to improve the structural strength of the porous body of coke free from cracks from 83 to 87% and the abrasive hardness of the coke substance composing the pore walls from 72 to 78mg.

4. Conclusions

The use of the method of preparation of the blend with preliminary grinding of the group of hard coals, in comparison with the preparation method according to the CB scheme, makes it possible to improve the crushing index of M25 from 85.5 to 86.8% or by 1.3% and to reduce the abrasion index of M10 from 8.3 to 7.6% or 0.7%.

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The results obtained indicate the need for further clarification of the level of grinding of the group of hard coals and the list of components included in it, as well as the level of grinding of the total blend during its final crushing.

It is necessary to work out the issue of screening out fine grades of the blend (less than 6 mm) before its final grinding, which will reduce the power consumption for grinding and optimize the particle size distribution of the production charge.

Symbols

CRI	*coke reactivity index, %;*	*Vt*	*vitrinite, %;*
CSR	*coke strength after reaction with CO_2, %;*	*Sv*	*semivitrinite, %;*
M25	*crushing strength of coke, %;*	*I*	*inertinite, %;*
M10	*abrasion of coke, %;*	*L*	*liptinite, %;*
A^d	*ash, %;*	*∑FC*	*sum of fusinized components, %;*
S^d_t	*content of sulfur, %;*	R_0	*average coefficient of reflectance of vitrinite, %;*
V^{daf}	*volatile matter, %*	d_{av}	*average diameter of particles, mm;*
x	*plastometric shrinkage, mm;*	B^d	*yield of coke, %;*
y	*thickness of plastic layer, mm;*	*AH*	*abrasive hardness, mg;*
RI	*Roga Index, units;*	*SS*	*structural strength, %.*
HGI	*Hardgrove grindability index, units;*		

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