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Effect of Moisture on the Flowability of the Coal Charge

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Abstract

The analysis of temporary norms of technological design of concentrators showed that the known relationship between the average diameter of coal in the range from 0.5 to 75.0 mm and the recommended angles of the gutters is logarithmic. It is shown that an increase in humidity and a decrease in the average diameter of coal leads to an increase in the values of the recommended angles of the gutters, and an increase in the degree of coal metamorphism also lead to an increase in the recommended angles of gutters. These factors act independently. Based on the processing of experimental data, the possibility of sticking the surface of the structural sheet located at different angles, using different variants of coal charge, which is characterized by different levels of humidity, particle size distribution with different productivity for the charge. It is shown that when using the technology of ramming coal charges, increasing the moisture content in the charge from 10 to 12%, the content of particles with a size of 0-3 mm from 90 to 94%, as well as increasing the load of conveyors (from 250 to 350 t/h) clearly leads to an increase in the duration of the charge, i.e. reducing the speed of its movement on the structural sheet, until the occurrence of sticking.

Keywords*: Coal charge; Moisture; Gutter; Angle of inclination; Sticking.*

1. Introduction

It is known that the scheme of preparation of coal for coking affects the quality of blast furnace coke and technical and economic efficiency of all coke production in general [1-5]. Currently, the use of technology of ramming of coal charges in the production of blast furnace coke is widely developed, both abroad and in Ukraine [6-7].

However, there are no scientifically sound recommendations regarding the use of materials for lining the gutters of coal preparation tracts, transshipment units and in the coal tower to prevent the suspension of the coal charge, which has high humidity.

In particular, in [8] it is noted that due to the low level (91±1%) of grinding and high (11.0–11.5%) humidity of the coal charge in the conditions of the coal preparation plant of CChP PJSC "ArcelorMittal Kryvyi Rih" there is a bad flowability of the coal charge along the gutters of charge facilities and the coal tower. It is established that the use of the maximum possible normative angles of inclination of gutters (60-65°) does not provide a reliable descent of the charge.

In view of the above, it was advisable to conduct special studies aimed at studying the impact of raw materials (composition of the charge, its humidity and particle size distribution) and technological (type of construction material, productivity of coal conveyors, height and angle of fall of the coal charge on the gutter) factors on the possibility of its "sticking". Based on the obtained results, it will be possible to recommend scientifically sound values of the angles of inclination of the gutters to prevent sticking of the coal charge in the gutters.

It should be noted that in the temporary norms of technological design of concentrators [9] the recommended angles of inclination of gutters for coal grades D and G (Table 1), as well as Zh, K and PS (Table 2).

Table 1. Recommended angles of inclination of gutters for coal of marks D and G

Class (average diameter), mm	Tilt angles, degrees*, humidity	
	before 7 %	after 7 %
0-100 (50.0)	41-45 (43)	45-50 (47.5)
50-100 (75.0)	25-30 (27.5)	25-30 (27.5)
25-50 (37.5)	30-35 (32.5)	35-40 (37.5)
13-25 (19.0)	35-40 (37.5)	40-45 (42.5)
0-25 (12.5)	50-55 (52.5)	55-60 (57.5)
0-13 (6.5)	50-55 (52.5)	55-60 (57.5)
0-6 (3.0)	55-60 (57.5)	60-65 (62.5)
0-1 (0.5)	75-80 (77.5)	80-85 (82.5)

* Interval and average value

Table 2. Recommended angles of inclination of gutters for coal of the Zh brands,K and PS

Class (average diameter), mm	Tilt angles, degrees, humidity	
	before 7 %	after 7 %
0-100 (50.0)	45-50 (47.5)	50-55 (52.5)
0-25 (12.5)	50-55 (52.5)	55-60 (57.5)
0-13 (6.5)	50-55 (52.5)	55-60 (57.5)
0-1 (0.5)	75-80 (77.5)	80-85 (82.5)

In Fig. 1 and 2 were shown graphical relationships between the recommended values of the angles of inclination of the gutters and the average diameter of the coal, and in Table 3 mathematical equations that describe them.

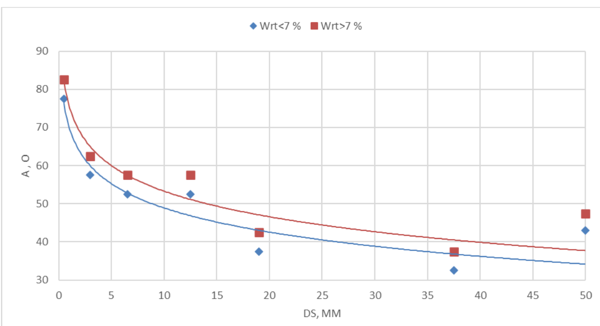


Fig. 1 Graphic relationship between the recommended values of the angles of the gutters and the average diameter of the coal grades D and G

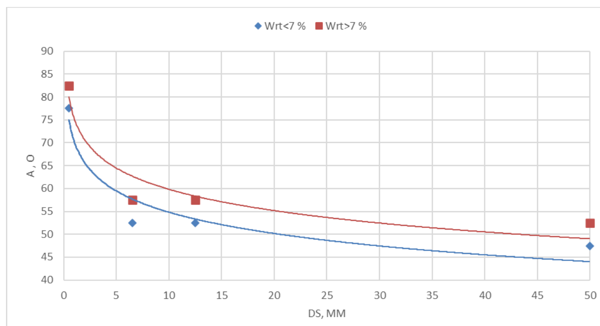


Fig. 2 Graphic relationship between the recommended values of the angles of the gutters and the average diameter of the coal grades Zh, K and PS

Table 3. Mathematical equations and statistical evaluation

No	Grade of coal	W^r_t, %	Type of equation	R^2
1	D, G	<7	$\alpha = -9.164\ln(d_s) + 70.015$	0.90
2		>7	$\alpha = -9.686\ln(d_s) + 75.606$	0.90
3	Zh, K, PS	<7	$\alpha = -6.715\ln(d_s) + 70.286$	0.92
4		>7	$\alpha = -6.715\ln(d_s) + 75.286$	0.92

Analyzing the graphical and mathematical logarithmic dependences, we can conclude that:

1. Increasing the humidity of coal leads to an increase in the recommended angles of inclination of the gutters;
2. Increasing the average diameter of the coal leads to a decrease in the recommended angles of inclination of the gutters;
3. Increasing the degree of metamorphism leads to an increase in the recommended angles of the gutters. The influence of each of the factors is almost independent of the action of others.

2. Methods and materials

2.1. Raw materials

To determine the influence of raw materials and technological factors that affect the speed of coal charges of real warehouses in the gutters of the coal preparation plant in the case of ramming technology were selected 2 variants of coal charges (Table 4), differing:
- variant 1 - high coal content of the gas group (55%);
- variant 2 - high coal content of brands KS and KP (35%).

Table 4. Component compositions of coal charges

Grade	Participation in the charge,%	
	Variant 1	Variant 2
G	25	20
GZhP	30	20
Zh	25	25
KS	10	20
KP	10	15
Total	100	100

The results of studies of technological properties, petrographic characteristics and particle size distribution of coal concentrates are given in Tables 5–7. In the Table 5 also shows the results of determining the grinding capacity according to Hardgrove. Analyzing the Tables 5-7 data, it can be stated that the selected coal samples correspond to the accepted quality indicators.

Table 5.Technological properties of the studied coal

Provider	Grade	Proximate analyses, %			Plastometric indexes, mm		Oxidation index, °C	Hardgrove grindability index, un.
		A^d	S^d_t	V^{daf}	x	y	Δt	HGI
Taldynsky incision	G	8.1	0.49	37.9	30	10	6	52
Resource	GZhP	7.3	0.36	37.4	35	13	3	57
Shchedrukhinskaya Farm	Zh	8.9	0.70	34.8	30	27	5	58
Barzas Society LLC	KS	9.4	0.27	19.5	24	9	2	69
Berezivska Foundation	KP	9.4	0.34	24.6	31	10	6	71

Table 6. Petrographic characteristics of the studied coal

Provider	Grade	Petrographic content, %					RR* %	Stages of metamorphism of vitrinite, %					
								0.50-0.79	0.80-0.89	0.90-1.19	1.20-1.49	1.50-1.69	1.70-2.59
								Coal grades, conditionally corresponding to the stages of metamorphism of vitrinite					
		Vt	Sv	I	L	∑FC	R_0	DG+G	GZhP+GZh	Zh	K	PS	P
Taldynsky incision	G	91	0	7	2	7	0.64	100	0	0	0	0	0
Resource	GZhP	75	1	23	1	24	0.68	100	0	0	0	0	0
Shchedrukhinskaya Farm	Zh	88	0	10	2	10	0.95	0	20	80	0	0	0
Barzas Society LLC	KS	24	1	75	0	76	1.19	0	0	52	48	0	0
Berezivska Foundation	KP	39	1	59	1	60	1.05	0	10	84	6	0	0

RR-The average arbitrary rate of reflection of vitrinite

Table 7. Particle size distribution of the studied coal

Provider	Grade	Particle size distribution (mm), %									Average particle diameter, mm
		>50	50-25	13-25	6-13	3-6	1-3	0.5-1	<0.5	<3	d_s
Taldynsky incision	G	0.0	0.0	3.2	12.6	20.4	24.0	12.8	27.0	63.9	3.36
Resource	GZhP	0.0	7.3	15.1	20.5	17.0	15.5	7.0	17.6	40.1	8.73
Shchedrukhinskaya Farm	Zh	0.0	3.5	9.7	18.6	20.4	17.6	8.5	21.7	47.8	6.31
Barzas Society LLC	KS	5.2	12.2	9.6	13.2	12.6	13.7	6.4	27.2	47.2	12.24
Berezivska Foundation	KP	4.6	14.0	6.7	12.9	12.2	13.9	7.8	28.0	49.6	11.90

Indicators of technological properties and petrographic characteristics of coal charge, compiled in accordance with Table 4 are given in Tables 8 and 9. Due to the increased content of gas coal in variant 1, the charge of this variant has a higher value of the volatile matter (33.8%) compared to the charge of variant 2 (31.3%).

Table 8. Technological properties of coal charges

Variant	Proximate analyses, %			Plastometric indexes, mm	
	A^d	S^d_t	V^{daf}	x	y
1	8.3	0.47	33.8	24	14
2	8.6	0.45	31.3	22	14

Table 9. Petrographic characteristics of coal charges

Variant	Petrographic content, %					RR*, %	Stages of metamorphism of vitrinite, %					
							0.50-0.79	0.80-0.89	0.90-1.19	1.20-1.49	1.50-1.69	1.70-2.59
							Coal grades, conditionally corresponding to the stages of metamorphism of vitrinite					
	Vt	Sv	I	L	∑FC	R_0	DG+G	GZhP+GZh	Zh	K	PS	P
1	74	0	25	1	25	0.83	55	6	34	5	0	0
2	65	1	32	1	33	0.90	40	7	43	10	0	0

** average arbitrary rate of reflection of vitrinite*

2.2. Methods

The charge was prepared according to the CC scheme (crushing the charge) to the required size. The coal charge was dumped from a height of ~0.5 (1.5) m on a sheet made of Steel 3, at a distance of ~0.5 m from its top. The moment of collision of the charge with the metal surface and the moment of collision of the charge with the floor surface were recorded. The duration (τ) of the charge movement on the metal sheet was calculated, sec.

In the framework of the study, the following indicators varied:
1. The humidity of the coal charge ranged from 10 to 12%;
2. The content of class 0–3 mm varied from 90 to 94%;
3. Productivity of conveyors fluctuated from 250 to 350 t/h;
4. The angle of the gutter made of Steel 3 varied from 65 to 80º.

3. Results and discussion

Table 10 shows the data showing the possibility of "sticking" (+) or "not sticking" (-) the surface of the structural sheet located at different angles, using different variants of the coal charge, which is characterized by different levels of humidity, particle size distribution, with different load.

Table 10. Possibility of "sticking" of a surface of a constructional sheet

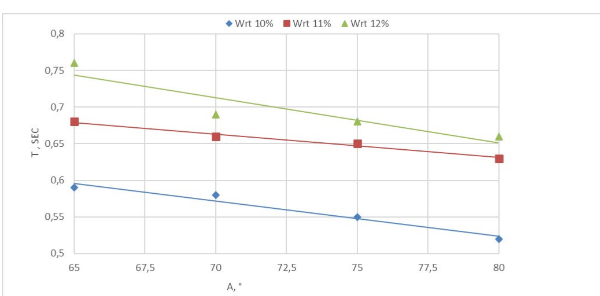
Variant	W^r_t=10%				W^r_t=11%				W^r_t=12 %			
	$\alpha = 65^o$	$\alpha = 70^o$	$\alpha = 75^o$	$\alpha = 80^o$	$\alpha = 65^o$	$\alpha = 70^o$	$\alpha = 75^o$	$\alpha = 80^o$	$\alpha = 65^o$	$\alpha = 70^o$	$\alpha = 75^o$	$\alpha = 80^o$
Load 250 t/h, grinding 90%												
1	+	-	-	-	+	-	-	-	+	-	-	-
2	-	-	-	-	-	-	-	-	+	-	-	-
Load 350 t/h, grinding 90%												
1	+	+	-	-	+	-	-	-	+	+	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-
Load 250 t/h, grinding 94%												
1	+	-	-	-	+	+	-	-	+	+	-	-
2	+	-	-	-	+	+	-	-	+	+	-	-
Load 350 t/h, grinding 94%												
1	+	+	-	-	+	+	-	-	+	+	-	-
2	+	+	-	-	+	+	-	-	+	+	-	-

According to the data obtained, the following can be stated:

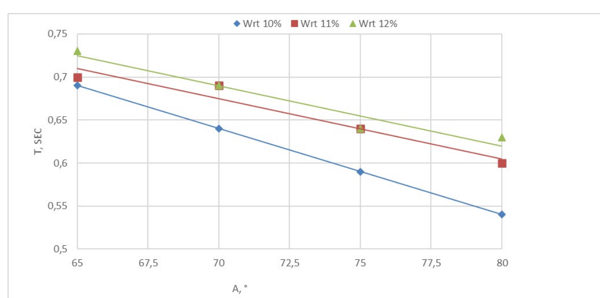
1. At W^r_t=10%, "sticking" of coal is not observed at an angle of 75-80°. At an angle of 70°, "sticking" is observed at a load of 350 t/h for variant 1 with a grinding of 90 and 94%, and for variant 2 with grinding only 94%. At an angle of 65° "sticking" is not observed only for variant 2 coal charge at 90% grinding.
2. At W^r_t=11%, "sticking" of coal is not observed at an angle of 75-80°. At an angle of inclination of 70°, "sticking" is observed when grinding 94%. At an angle of 65° "sticking" is not observed only for the variant 2 coal charge at a load of 250-350 t/h and grinding 90%.
3. At W^r_t=12%, "sticking" of coal is not observed at an angle of 75-80°. At an angle of 70°, "sticking" is not observed at 90% grinding and 250 t/h load and at 90% grinding and 350 t/h load for variant 2. At an angle of 65° "sticking" is not observed only for variant 2 coal charge at a load of 350 t/h and 90% grinding.

Thus, an angle of 75-80° can be considered safe from the point of view of the absence of "sticking" of any variant of the coal charge, any humidity and grinding.

For clarity of perception of the obtained results, graphical dependences (Fig. 3-5) of the duration of coal charge movement by structural sheet were constructed depending on the angle of its inclination at different humidity levels, class content 0-3 mm, conveyor productivity and height of charge drop on sheet.



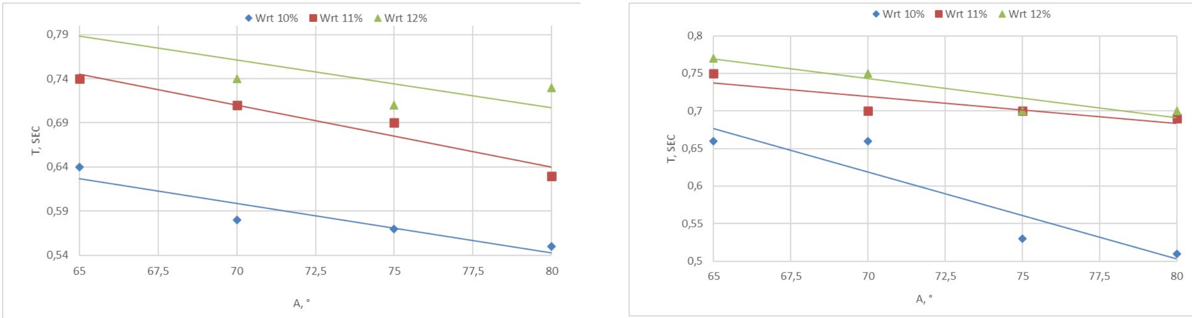
a) load 250t/h



b) load 350 t/h

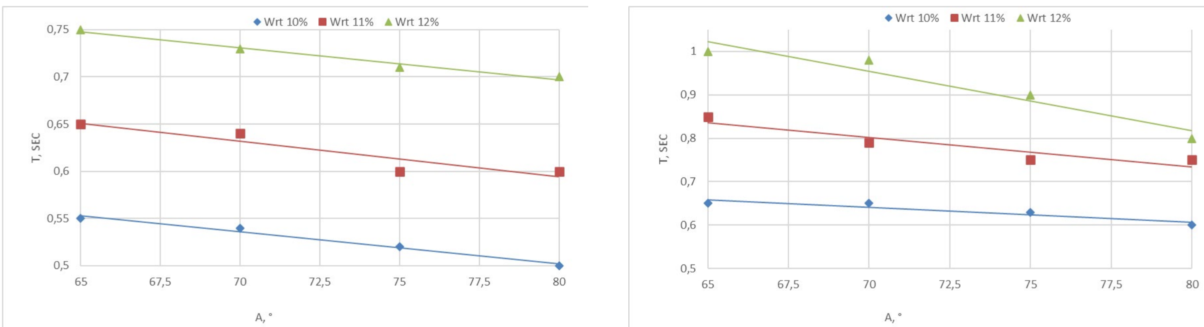
Fig. 3. Graph of the dependence of τ on the angle of the surface (variant 1, the height of the fall of the charge 0.5 m, grinding 90%)

Due to the fact that for the charge of variant 2 for 90% grinding, moisture content, angle of inclination and productivity did not affect the duration of the charge, graphic dependencies in this case were not built.



a) load 250t/h b) load 350 t/h

Fig. 4. Graph of the dependence of τ on the angle of the surface (variant 1, the height of the fall of the charge 0.5 m, grinding 94%)



a) load 250t/h b) load 350 t/h

Fig. 5. Graph of the dependence of τ on the angle of the surface (variant 2, the height of the fall of the charge 1.5 m, grinding 94%)

Based on the above dependences, we can say that increasing the moisture content in the charge, the content of particles with a size of 0-3 mm, as well as increasing the load of conveyors clearly leads to increased duration of the charge, i.e. reducing its speed on the structural sheet sticking. Table 11 shows the mathematical dependences showing the influence of various factors on the time of emergence of the coal charge on the structural sheet.

Table 11. Mathematical dependencies

No	Variant	Type of equation
5	1	$\tau = -0.3427 + 0.06125 \cdot W_t^r + 0.00005 \cdot N + 0.00857 \cdot (\Sigma 3 - 0) - 0.00653 \cdot \alpha$
6	2	$\tau = -4.9510 + 0.04125 \cdot W_t^r + 0.00078 \cdot N + 0.05552 \cdot (\Sigma 3 - 0) - 0.00315 \cdot \alpha$

4. Conclusions

The influence of various factors on the possibility of sticking coal on the gutters during the transportation of the coal charge in its preparation for coking by ramming was studied. Mathematical and graphical dependences that can be used in the preparation of coal for coking by ramming were developed.

Symbols

W^r_t – water content of coal, as received, %;
A^d – ash content of coal in the dry state, %;
V^{daf} – volatile matter in the dry ash-free state, %;
S_t^d – sulphur of coal in the dry state, %;
R_0 – mean vitrinite reflection coefficient, %;
Vt – vitrinite, %;
Sv – semivitrinite, %;

I – inertinite, %;
L – liptinite, %;
∑FC – sum of fusinized components, %;
y – thickness of the plastic layer, mm;
x – plastometric shrinkage, mm;
d_s – average particle diameter, mm;
Δt – oxidation index, °C;
HGI – Hardgrove Grindability Index, units;
α – gutter angle, °;
τ – the duration of the charge movement on the metal sheet, sec;
N – load of coal charge on the belt, t/h;
R^2 – the coefficient of determination.

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