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INVESTIGATION OF POSSIBLE LOSSES OF COAL RAW MATERIALS DURING ITS TECHNOLOGICAL PREPARATION FOR COKING MESSAGE 1.THE ACTUAL MASS VARIATION OF COAL IN THE PROCESS OF ITS DEFROSTING

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Abstract

Particles begin to freeze when the moisture content in them exceeds the value of the maximum capacity. In turn, the magnitude of the maximum capacity depends on the degree of metamorphism and in the rank of coking coal has the maximum value or the low-metamorphosed coal.
Taking into account the fact that low-metamorphosed coals are characterized by the maximum values of water capacity, these coals may be less time in the defrosting garage compared to other coking coals. Using mathematical statistics, an equation was obtained describing the change in the mass of coal when it is thawed, depending on the moisture content, the average particle diameter of the coal, and time spent in the defrosting garage. This equation makes it possible to estimate the reduction in the mass of coal in the process of defrosting, depending on its quality indicators and the conditions in the defrosting garage.
***Keywords**: coal; maximum water holding capacity; freezing; garage defrosting; weight loss.*

1. Introduction

In the cold season, irregular coal supplies to coke plants are aggravated by the need to heat the coal cars. The individual coal particles freeze together and also bond with the floor and walls of the car. Such freezing occurs on account of heat transfer between the car and the surrounding cold air, between the car and its coal cargo, and at the open top of the car between the coal and the cold air. Freezing of the coal to the car hinders its discharge, while the freezing of the coal particles forms large conglomerates that cannot easily be manipulated.

Wet dispersed coals freeze during storage and transportation at low temperatures. The freezing and strength of the frozen coal-water-ice disperse system is due to the phase state of the water on the surface of the coal particles and the cementing effect of the ice formed.

The freezing of coal is a complex thermophysical process accompanied by the migration of moisture and temperature variation. It depends primarily on the thermal conductivity and specific heat of the coal, the duration of the low ambient temperatures, the moisture content of the coal, its metamorphic stage, the composition of mineral impurities, the granulometric composition, and the hydrophilic properties of the surface. However, the key factor is the moisture content of the charge [1].

The theory of the question of coal freezing is discussed in [2]; the main points of the theory are as follows.

A layer of strongly bound water is retained on the outer surface of the particles, which, under the influence of active surface centers, acquires special physicochemical properties. It freezes at temperatures below -70°C. When the external moisture is an adsorption layer of tightly bound moisture, the freezing of particles at normal negative temperatures is absent. The bond strength of water with the surface decreases with an increase in the thickness of its film. Layers of water adjacent to the film of tightly bound, non-freezing water are less affected by the surface. This is the so-called loose water. It, unlike strongly bound water, is capable of crystallizing into ice, but at temperatures lower than the freezing point of water in volume. In contrast to the tightly bound, this water has greater mobility, which leads to its tightening to the points of contact between the particles of coal.

At negative temperatures, part of this water freezes, adhesions form between the particles, and the system loses flowability. The amount of bound non-freezing water and the amount of water crystallizing in ice depend (ceteris paribus) on the surface energy of the coal, which is a function of their petrographic features — the stage of metamorphism and petrographic composition.

The strength of freezing coal is determined by the strength of the ice, which depends on the surface energy of the particles. With decreasing temperature, the degree of coal freezing increases with increasing humidity and decreasing particle size [3].

In order to ensure the normal discharge of coal concentrates, they must be directed to special garages for their thawing before car dumpers [4–6]. In the process of finding cars with coal in these garages, there is an intensive removal of moisture, leading to a change in the actual mass of coal.

In the course of the research, the results of which are presented in this article, the influence of various factors (ambient temperature, initial humidity of coal concentrates and their particle size distribution, duration of coal in the defrosting garage) on the change in the actual mass of coal concentrates during their defrosting were studied.

2. Results and discussions

Currently, the raw material base of Avdeevskii coke plant contains coals from both the near (Taldinsky Zapadny open pit, Taybinskaya central processing plant, Shchedrukhinskaya central processing plant, Berezovskaya central processing plant) and long-distance (Wellmore, Rocklick, Teck Premium, Pocahontas) abroad. Coal concentrates of these suppliers enter the plant with moisture ~ 10%, which in winter, at a negative ambient temperature, leads to their freezing.

The quality indicators of the investigated coal concentrates are given in Table 1–4. It is nece-ssary to dwell on the maximum moisture capacity of the coals studied [7–11]. In [2], the freezing of Kuzbass coals at various stages of metamorphism and close petrographic composition was investigated. The degree of freezing of coal of different humidity was evaluated by the strength of frozen samples with uniaxial compression.

All tested coals do not freeze when the humidity changes to the maximum capacity. Particles begin to freeze when their moisture content exceeds the maximum moisture capacity. This condition was fulfilled for all tested size classes from 0.5–1 to 5–7 mm and temperature limits from –8 to –35°C. Therefore, the maximum moisture capacity can be taken as safe moisture in relation to the freezing of coal. With a further increase in the moisture content of dispersed coal, the moisture on the outer surface of the particles freezes and the system loses flowability.

The influence of the degree of metamorphism of coal on the value of their maximum capacity can be traced in Fig. 1, obtained on the basis given Table 1 data. Taking into account the fact that low-metamorphosed coal of the gas group is characterized by the maximum values of water capacity, these coals may remain less time in the defrosting garage compared to other coking coals.

The study of the dependence of the freezing temperature of coal on its granulometric composition and the level of working moisture is an urgent task, the solution of which will optimize the operation of the coal preparation plant as well as reduce the cost of heating the frozen coal.

Table 1. Technological properties of coal concentrates

Component; country	Coal rank	Proximate analysis, %				Thickness of plastometric layer, mm		Maximum moisture-holding capacity, %	Oxidation index, °C
		W^a	A^d	S^d_t	V^{daf}	x	y	W_{max}	Δt
Shchedrukhinskaya coal, Russia	G	3.3	7.5	0.53	38.2	32	10	4.12	1
Section Taldinsky West coal, Russia	G	4.0	8.5	0.44	37.0	33	10	3.79	4
Taybinskaya coal, Russia	G	2.9	9.0	0.50	34.1	30	10	3.14	3
Wellmore coal, USA	Zh	1.3	7.5	0.98	34.2	17	24	3.16	2
Rocklick coal, USA	Zh	1.3	7.5	0.98	34.2	17	24	3.17	2
Svyato-Varvarinskaya coal, Ukraine	K	1.1	9.1	0.73	26.8	14	14	2.33	2
Teck Premium coal, Canada	K+KO	1.1	8.6	0.56	26.2	18	14	2.22	5
Berezovskaya coal, Russia	KO	1.5	5.1	0.40	24.2	30	9	2.34	5
Pocahontas coal, USA	OS	0.8	8.03	0.85	18.3	11	12	2.91	2

Table 2. Petrographic characteristics of coal concentrates

Component; country	Coal rank	Petrographic composition (without mineral impurities), %					Mean vitrinite reflection coefficient, %	Distribution of vitrinite reflection coefficient, %					
		Vt	Sv	I	L	ΣFC	R_o	0.50 – 0.79	0.80 – 0.89	0.90 – 1.19	1.20 – 1.49	1.50 – 1.69	1.70 – 2.59
Shchedrukhinskaya coal, Russia	G	74	0	24	2	24	0.69	96	4	0	0	0	0
Section Taldinsky West coal, Russia	G	69	0	29	2	29	0.64	100	0	0	0	0	0
Taybinskaya coal, Russia	G	66	0	31	3	31	0.72	94	6	0	0	0	0
Wellmore coal, USA	Zh	73	0	24	3	24	0.99	0	11	89	0	0	0
Rocklick coal, USA	Zh	69	0	26	5	26	0.97	2	18	79	1	0	0
Svyato-Varvarinskaya coal, Ukraine	K	83	1	14	2	15	1.20	0	0	48	52	0	0
Teck Premium coal, Canada	K+KO	70	0	29	1	29	1.09	0	6	80	14	0	0
Berezovskaya coal, Russia	KO	37	1	62	0	63	1.05	0	11	83	6	0	0
Pocahontas coal, USA	OS	77	0	23	0	23	1.60	0	0	0	12	76	12

Table 3. Ultimate composition of coal concentrates

Component; country	Coal rank	Ultimate composition, %				
		C^{daf}	H^{daf}	N^{daf}	S_t^d	O_d^{daf}
Shchedrukhinskaya coal, Russia	G	83.10	5.77	2.40	0.53	8.20
Section Taldinsky West coal, Russia	G	81.51	5.25	2.29	0.44	10.51
Taybinskaya coal, Russia	G	84.32	5.39	2.30	0.50	7.49
Wellmore coal, USA	Zh	86.94	6.15	1.66	1.10	4.15
Rocklick coal, USA	Zh	86.10	7.70	1.68	0.98	3.54
Svyato-Varvarinskaya coal, Ukraine	K	87.52	5.45	1.65	0.73	4.65
Teck Premium coal, Canada	K+KO	88.20	4.96	1.36	0.56	4.92
Berezovskaya coal, Russia	KO	84.14	4.85	2.30	0.40	8.31
Pocahontas coal, USA	OS	91.56	4.85	1.40	0.85	1.34

Table 4. Granulometric composition of coal concentrates

Component; country	Coal rank	Granulometric composition (%) by class (mm)									Mean particle diameter, mm
		>50	25–50	13–25	6–13	3–6	1–3	0,5–1	<0,5	0–3	
Shchedrukhinskaya coal, Russia	G	2.1	2.3	6.4	18.6	23.3	22.0	8.8	16.6	47.4	6.64
Section Taldinsky West coal, Russia	G	4.1	21.1	22.9	19.8	12.0	8.4	3.7	8.0	20.1	17.33
Taybinskaya coal, Russia	G	1.6	6.8	12.8	19.5	20.2	18.2	8.1	12.8	39.1	8.92
Wellmore coal, USA	Zh	0.0	2.8	7.6	22.8	20.6	18.4	8.6	19.2	46.2	5.61
Rocklick coal, USA	Zh	0.0	2.3	7.6	15.0	18.6	20.4	10.0	26.1	56.5	4.78
Svyato-Varvarinskaya coal, Ukraine	K	0.0	5.0	9.8	16.6	16.1	17.2	9.3	26.0	52.5	6.12
Teck Premium coal, Canada	K+KO	0.0	0.2	2.7	5.4	10.0	19.0	11.5	51.2	81.7	2.02
Berezovskaya coal, Russia	KO	10.3	21.5	16.4	13.1	8.4	7.6	4.4	18.3	30.3	20.31
Pocahontas coal, USA	OS	0.0	0.0	1.0	3.8	10.3	26.8	23.8	34.3	84.9	1.83

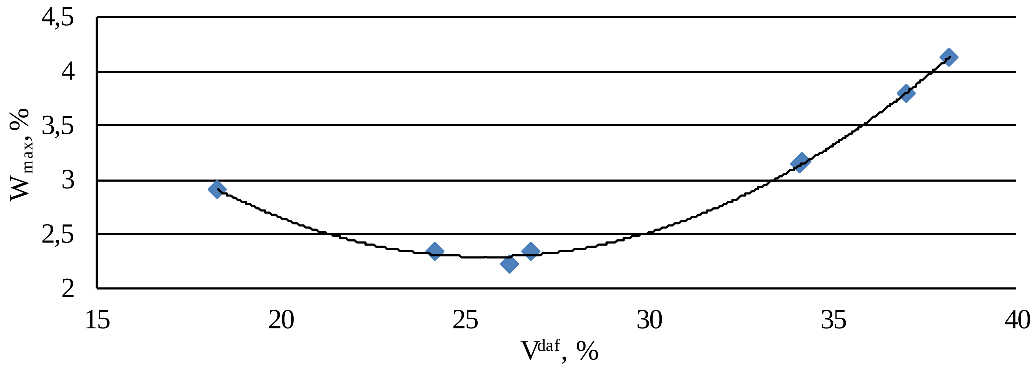

Fig. 1. Dependence of the maximum moisture-holding capacity of the index of the volatile matter of the investigated coal

A sample of coal from the company Wellmore (coal rank «Zh») was used as a model sample in laboratory studies. Data on the maximum capacity of its size classes – Table 5.

Table 5. Values of the maximum moisture-holding capacity of the coal sample Wellmore

Size class, mm	Maximum moisture-holding capacity Wmax, %
<0,5	5.2
<3	3.0
3–6	2.8
6-13	2.1
13–50	1.8

Analyzing the data given Table 5, it can be concluded that the value of the maximum water capacity decreases with an increasing particle size of the coal classes studied. Consequently, it can be expected that coal particles with a particle size of less than 3 and, especially, less than 0.5 mm will be characterized by the highest working moisture content and freezing conditions.

To determine the influence of the humidity level (6, 10 and 12%) on the freezing capacity of various classes of the coal sample examined, a special study was conducted.

Samples of coal of various sizes were loaded into metal forms with a diameter of 150 mm and a height of 150 mm, after which they were kept in a freezer with a gradual decrease in temperature to -15°C for 2 days. Then the sample was removed and the degree of coal freezing at temperatures of -5C, -10C and -15°C was determined as the ratio of spilled coal to the total mass of coal taken for the experiment. The results of determining the freezing capacity of various classes of coal size are summarized Table. 6

Table 6. Results of the determination of freezing

Size class, mm	W^r_t , %	Degree of freezing, %		
		-5ºC	-10ºC	-15ºC
	6	80	88	100
0–3	10	88	96	100
	12	100	100	100
	6	48	56	81
3–6	10	64	76	96
	12	80	96	100
	6	20	28	49
6–13	10	36	48	64
	12	48	68	88
	6	4	8	36
13–50	10	6	16	45
	12	20	32	64

Analyzing the data given in Table 6, it can be concluded that with decreasing temperature, the degree of coal freezing increases with increasing its humidity and decreasing the particle size.

To determine the quantitative effect of the content of small classes on the value of coal freezing, mixtures containing a different amount of class 0–3 mm were prepared (Table 7). All samples were characterized by humidity equal to 12%.

Table 7. Composition of coal blends

Size class, mm	Samples composition of coal blend, %			
	1	2	3	4
0–3	25	50	75	75
3–6	25	25	0	25
6–13	50	25	25	0
Total	100	100	100	100
Mean particle diameter, mm	6.00	4.13	3.38	2.25

The results of determining the freezing capacity of mixtures containing different amounts of a class of 0–3 mm are shown in Table 8.

Table 8. Dependence of the degree of freezing of coal blends on its granulometric composition

Coal blend	Degree of freezing, %		
	-5°C	-10°C	-15°C
1	35.2	68.8	90.0
2	82.0	82.0	92.3
3	88.6	83,2	94.8
4	94.8	98.0	100.0

The data Table 8 shows that with an increase in the content of small classes in the coal, which is expressed by a decrease in its average diameter, there is an increase in the degree of freezing of coal over the entire range of temperatures studied.

Experimental data to determine the mass loss of coal during its defrosting are given in Table 9. In particular, it presents the name of the suppliers of the investigated coal, their brand identity, the date of the experiment, the average daily temperature on that day, as well as the number of the list for which the coal was received.

Analyzing the data presented, it can be concluded that 14 measurements of the mass loss of coal were made while it was in the defrosting garage, and the ambient temperature varied from -3.5 to +6.5°C.

Analysis of the results obtained suggests that during the stay of the coals in the garage of defrosting there is a loss of their mass (from 0.01 to 0.63%), which can be explained by evaporation or drainage of available moisture.

The maximum mass loss is observed in Wellmore coal concentrates (coal rank "Zh"), Rocklick (coal rank "Zh") and Pocahontas (coal rank "OS"), which amounted to 0.50–0.63%.

Due to the fact that coal freezing capacity largely depends on the working moisture content and its granulometric composition, and the only variable parameter when coal was in the defrosting garage was time, the change in the actual mass of coal was estimated from the change in these three factors.

Based on the Table 1 data, it can be stated that the working moisture content in the coals that took part in the industrial experiment varied from 8.5 to 11.6%, the average particle diameter varied from 2.02 to 20.31 mm, and their residence time in the defrosting garage changed from 170 to 475 minutes. At the same time, the mass loss of coal in the process of defrosting was 0.01–0.63% of the mass.

Table 9. Results of researches

Component; country	Coal rank	Moisture W_{rt}, %	Average daily temperature t, °C	Time spent in the garage defrosting, min	Mass variation of coal, Δm, %
Shchedrukhinskaya coal, Russia	G	11.6	4.5	220	0.03
Section Taldinsky West coal, Russia	G	10.2	4.5	195	0.08
Taybinskaya coal, Russia	G	9.5	-2.0	190	0.03
		10.5	-1.0	375	0.29
Wellmore coal, USA	Zh	8.9	0.5	310	0.50
		8.9	0.5	475	0.27
Rocklick coal, USA	Zh	8.5	-3.5	245	0.10
		8.9	1.0	195	0.63
Svyato-Varvarinskaya coal, Ukraine	K	9,7	2.5	230	0.34
		10.3	0.5	310	0.04
Teck Premium coal, Canada	K+KO	9,7	0.5	265	0.16
Berezovskaya coal, Russia	KO	8.9	6.5	250	0.03
Pocahontas coal, USA	OS	10.5	0.5	170	0.50
		10.1	1.0	300	0.01

Using the methods of mathematical statistics, equation (1) was obtained that describes the change in the mass of coal when it is thawed, depending on the moisture content in it, the average diameter of its particles, and the time it spent in the defrosting garage.

$$\Delta m = 1{,}161723 - 0{,}00033\tau - 0{,}007677W_t^r - 0{,}01529d_{me} \quad (1)$$

Figure 2 shows the graphical dependence of the calculated (by equation 1) and the actual values of the mass loss of coal in the process it's defrosting.

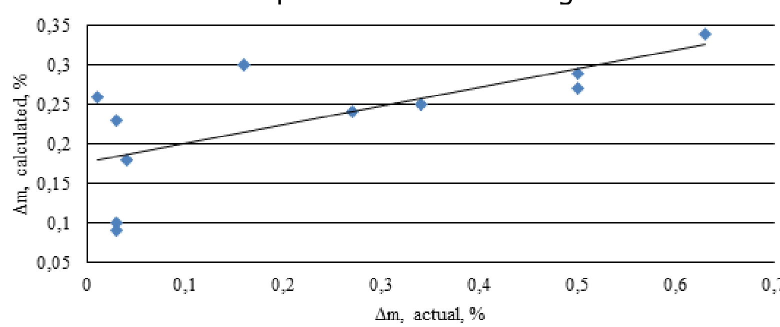

Fig. 2. Graphic dependence of the calculated and actual values of change in the mass of coal in the process of defrosting

Equation (1) makes it possible to estimate the decrease in the mass of coal in the process of defrosting, depending on the indicators of its quality and the conditions in the defrosting garage. In general, it can be noted that an increase in the initial moisture content, the average diameter of the coal particles and the residence time in the defrosting garage leads to an increase in the loss of the actual mass of the coal concentrates when they are thawed.

3. Conclusions

Based on the laboratory and pilot studies, the following main conclusions can be formulated:

1. The freezing of particles begins when the content of moisture in them exceeds the value of the maximum capacity. In turn, the magnitude of the maximum capacity depends on the

degree of metamorphism and in the rank of coking coal has the maximum values for the low-metamorphosed coal of the gas group.

Taking into account the fact that low-metamorphosed coals of the gas group are characterized by the maximum values of water capacity, these coals may be less time in the defrosting garage compared to other coking coals.

2. With decreasing temperature, the degree of coal freezing increases with increasing humidity and decreasing particle size.

3. Using mathematical statistics, an equation was obtained describing the change in the mass of coal when it is thawed, depending on the moisture content in it, the average diameter of its particles and the time it takes to defrost the garage. This equation makes it possible to estimate the reduction in the mass of coal in the process of defrosting, depending on its quality indicators and the conditions in the defrosting garage.

Symbols

W^r_t	*water content in coal, as received state, %;*
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;*
C^{daf}, H^{daf}, N^{daf}, O_d^{daf}	*carbon, hydrogen, nitrogen, oxygen in the dry, ash-free state, %;*
W_{max}	*maximum moisture-holding moisture capacity, %;*
d_{me}	*mean particle diameter, mm;*
Δt	*oxidation index, °C;*
τ	*the residence time of coal in the defrosting garage, min.*

References

[1] Matasov SF, Kurtunov LM, and Khorunzhii AS. Bor'ba so smerzaemost'yu pri perevozke po zheleznym dorogam (Prevention of freezing in railroad transportation), Moscow: Metallurgiya, 1974.

[2] Eremin IV, Lebedev VV, and Tsikarov DA. Petrografiya i fizicheskie svoistva uglei (Petrography and physical properties of coal), Moscow: Nedra, 1980. 263 p.

[3] Kormer MV, Lyalyuk VP, Uchitel AD, Shmeltser EO, Lyakhova IA. Dependens of coals freezing point on its granulometric composition. Coke and Chemistry, 2015; 58(1): 9–14.

[4] Starovoit A, Chemerinskii M, Malyi E. Mechanisms of gas-coal thermal preparation in electromagnetic field. Chemistry and Chemical Technology, 2014; 8(4): 475–478.

[5] Brodsky EV, Babitsin SM, Fedorov AP. Improving the efficiency of convective defrost garages. Koks I Khimiya, 1990; 3: 4–6.

[6] Zashkvara VG, Vvozny GF, Baydalinov PA. Coal and Chemistry, Foulness and Unloading of Coals, 1966; 1: 1–3.

[7] Balaeva YS, Kaftan YS, Miroshnichenko DV, Kotlyarov EI. Influence of coal properties on the gross calorific value and maximum moisture content. Coke and Chemistry, 2018; 61(1): 4–11.

[8] Balaeva YS, Miroshnichenko DV, Kaftan YS. Moisture-holding capacity of coals. Solid Fuel Chemistry, 2017; 51(6): 337–348.

[9] Balaeva YS, Miroshnichenko DV, Kaftan YS. Moisture-holding capacity of coal. Pet coal. 2017; 59(3): 302–310.

[10] Balaeva YS, Miroshichenko DV, Kaftan YS, Shmalko VM. Relation between the maximum moisture content of coal and its porous structure. Coke and Chemistry, 2016; 59(11): 407–410.
[11] Balaeva YS, Miroshnichenko DV, Kaftan YS. Predicting the classification charac-teristics of coal. Part 2. Maximum moisture content. Coke and Chemistry, 2015; 58(12): 459–464.

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