Petroleum and Coal

Article **Open Access**

MOISTURE-HOLDING CAPACITY OF COAL

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Received March 15, 2017; Accepted May 2, 2017

Abstract

The moisture-holding capacity of metamorphically distinct coals does not depend on their ash content (in the range 3.7–35.3 %) nor on the chemical composition of the ash, expressed by the basicity index B_b (in the range 1.24–27.18) and the base/acid ratio I_b (in the range 0.198–1.832). Although the oxidation of coal also increases the moisture-holding capacity, this change is less than the error in its determination (0.5 %). The oxidation of practically 30 % of the coal´s organic mass increases the moisture-holding capacity by no more than 0.4 %. Analysis of 63 samples of coal concentrates (from Ukraine, Russia, the United States, Canada, Australia and Poland) currently employed at Ukrainian coke plants indicates that the prediction of the moisture-holding capacity of coal may expediently be based on R_0 and Q_s^{af} determined, respectively, in plant laboratories and in power station laboratories.

Keywords: *coal; moisture-holding capacity; oxidation; basicity index; mathematical equations; statistical estimates*.

1. Introduction

The moisture-holding capacity indicates the rank of hard coals and is used in coal classification (*ASTM D 388–15 Standard Classification of coals by Rank*) for collecting the calorific value of the sample to the moist mineral matter-free basis. The full moisture-holding capacity is that of the coal in equilibrium with atmosphere saturated with water vapor. Since there are insuperable experimental difficulties in working with such an atmosphere, the determination is carried out at 96 % relative humidity.

2. Experimental

Accordingly *ISO 1018:75 (en) Hard Coal – Determination of moisture-holding capacity*, a representative sample of crushed coal is mixed with distilled water for 3 h. The excess water is removed and a subsample is placed in a vacuum desiccator with the pressure set at 4 kPa (30 mm Hg), the humidity set at 96–97 %, and the temperature set at 300°C for up to 72 h (or until equilibrium is attained). For some low-rank coals, equilibrium may take up to 7 days to attain. The coal is weighed and then dried to constant mass at 105°C. The mass loss is consiered the Moisture-holding capacity, Equilibrium moisture or Bed moisture. The result for moisture-holding capacity is given as the mean of duplicate determination, reported to the nearest 0.1 %.

It is expedient to investigate the influence of the content and chemical composition of the ash on the moisture-holding capacity in coal at different metamorphic stages, since there is no indication of the sample´s ash content in ISO 1018:75.

Table 1 presents the results of proximate analysis of the coal samples, together with the moisture-holding capacity. Table 2 presents the chemical composition of the ash, basicity index (eq. 1) and base/acid ratio (eq. 2) of enriched (to a density of 1500 kg/m^3) and enriched coal samples at different metamorphic stages.

$$B_b = \frac{100A^d(Fe_2O_3+CaO+MgO+Na_2O+K_2O)}{(100-V^{daf})(SiO_2+Al_2O_3)}, \quad (1)$$

$$I_b = \frac{Fe_2O_3+CaO+MgO+Na_2O+K_2O}{SiO_2+Al_2O_3}, \quad (2)$$

According to point 6 Preparation of sample of ISO 1018:75 it is essential that the coal be in fresh, unchanged state. If the sample cannot be examined immediately, it shall be protected from oxidation by storing under water'.

Table 1. Properties of coal samples

Supplier	Rank	Sample	Proximate analysis, %				Moisture-holding-capacity,%
			A^d	S^d_t	V^d	V^{daf}	W_{max}
Ernakovskaya mine	G	Unenriched	25.7	0.38	29.9	40.2	3.6
		Enriched	6.2	0.34	35.4	37.7	3.8
Uskovskaya mine	G	Unenriched	17.8	0.46	34.4	41.8	4.1
		Enriched	4.8	0.45	37.3	39.2	4.1
Esaul'skaya mine	G	Unenriched	33.5	0.73	28.4	42.7	3.4
		Enriched	5.8	0.65	36.9	39.1	3.1
Osinnikovskaya mine	G	Unenriched	35.3	0.49	24.0	37.1	3.4
		Enriched	6.9	0.58	30.9	33.2	3.1
CCI Lubelia mine, bed *n*9	Zh	Unenriched	10.0	5.33	29.3	32.6	2.6
		Enriched	4.5	3.19	30.0	31.6	2.2
CCI Lubelia mine, bed *n*7	Zh	Unenriched	7.1	0.95	25.7	27.6	1.9
		Enriched	3.7	0.73	25.9	26.9	1.9

Table 2. Chemical composition and basicity of coal samples

Supplier	Rank	Sample	Chemical composition of ash, %								Basicity	
			SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	B_b	I_b
Ernakovskaya mine	G	Unenriched	56.78	21.47	6.98	2.65	3.16	0.89	1.79	5.19	8.50	0.198
		Enriched	47.94	29.01	6.73	2.14	3.68	1.68	1.04	2.78	1.97	0.198
Uskovskaya mine	G	Unenriched	60.37	18.56	7.48	2.39	2.63	0.93	2.40	3.39	6.13	0.201
		Enriched	36.20	26.40	8.98	2.77	9.81	1.12	1.06	7.37	2.99	0.379
Esaul'skaya mine	G	Unenriched	55.25	20.30	5.74	2.52	7.01	1.02	1.99	5.19	14.15	0.242
		Enriched	46.68	25.53	11.97	2.02	4.91	1.66	1.35	2.69	2.89	0.303
Osinnikovskaya mine	G	Unenriched	61.01	17.40	4.99	2.39	5.08	1.26	1.83	4.54	11.13	0.198
		Enriched	47.26	20.30	11.47	3.91	6.48	1.05	1.26	6.12	3.70	0.358
CCI Lubelia mine, bed *n*9	Zh	Unenriched	18.48	13.63	48.13	1.51	8.41	0.32	0.45	8.31	27.18	1.832
		Enriched	16.18	16.24	49.88	1.26	6.66	0.48	0.43	8.11	11.91	1.811
CCI Lubelia mine, bed *n*7	Zh	Unenriched	45.15	26.11	8.23	1.89	8.94	0.46	1.06	7.05	2.83	0.289
		Enriched	43.54	27.56	6.98	1.39	7.54	0.65	0.87	9.14	1.24	0.245

The influence of oxidation on the moisture-holding capacity of coal was studied in [1]. Zasyad'ko bituminous coal (Donetsk Basin), crushed until it consists entirely of the <3 mm class, was oxidized in a drying chamber at 60°C, with free access of atmospheric oxygen. The 60°C temperature was chosen on the basis of the results in [2–4]. In the course of the experiment, the coal was constantly mixed so as to ensure uniform oxidation. At fixed inter-vals, coal samples were taken for measurement of the oxidation index Δt. With 2–3°C variation in Δt, samples were taken for proximate analysis (A^d, V^{daf}) and determination of the moisture-holding capacity W_{max} and the degree of oxidation d_0. Table 3 presents the variation in W_{max} on oxidation.

Table 3. Variation in coal properties during its oxidation

Oxidation time, h	Proximate analysis, %			Moisture-holding-capacity, %	Coal oxidation (Ukrainian State Standard DSTU 7611:2014	
	A^d	S^d_t	V^{daf}	W_{max}	Δt,°C	d_{0}, %
0	7.4	1.84	31.2	1.6	3	9.3
271	7.4	1.87	30.3	1.7	5	15.6
608	7.1	1.87	31.5	1.9	7	21.9
680	6.6	1.88	31.6	2.0	10	29.4

3. Results and discussion

The error in determining the moisture-holding capacity is 0.5 %, according to ISO 1018:75. Therefore, in the range 3.7–35.3 %, the ash content of the sample has no significant influence on the moisture-holding capacity. Likewise, the chemical composition of the ash has no influence, within the ranges B_b = 1.24–27.18 and I_b = 0.198–1.832.

On the basis of Table 3, we may conclude that increase in oxidation of the coal is associated with increase in its moisture-holding capacity. In Figs. 11 and 12, we plot the moisture-holding capacity against Δt and d_0.

Analysis of Table 3 and Figs. 1 and 2 indicates that, although oxidation of the coal increases the moisture-holding capacity, the increase is smaller than the error in determining the oxidation (0.5 %). The oxidation of practically 30 % of the coal´s organic mass increases the moisture-holding capacity by no more than 0.4 %. However, despite the results, we believe it is necessary to uphold the requirement in ISO 1018:75 the moisture-holding capacity must be determined for a freshly prepared coal sample.

In the present work, we have developed formulas for predicting the moisture-holding capacity $W_{\max}$ of coal from Ukraine, Russia, the United States, Canada, Australia and Poland based on data for the sample in [5].

We have calculated pair correlation coefficients between the coal properties and the moisture-holding capacity of the coal. The significance of the correlations is verified by comparing the absolute magnitude of the product $|r|\sqrt{n-1}$ with its critical value H for specified reliability P of the conclusion [6]. With P = 0.999, the critical value H for 63 samples is 3.183. Table 4. present the correlation coefficients for each pair of variables. Comparison of the actual values with the tabular values indicates that, with P = 0.999, W_{max} is correlated with W^a, V^{daf}, R_0, C^{daf}, cA, f_a, C_{ar}, and δ. In Figs. 3–12, we plot the moisture-holding capacity as a function of the other properties of the coal. Analysis indicates that these relationships are primarily quadratic.

Table 4. Pair correlation coefficients $|r|$ and $|r|\sqrt{n-1}$ for the moisture-holding capacity and other variables

Coefficients	W^a	V^{daf}	R_o	Vt	ΣFC	C^{daf}	O_d^{daf}	Q_s^{daf}	cA
r	0,930	0,649	-0,729	0,020	-0,056	-0,731	0,770	-0,844	-0,647
$\lvert r\rvert\sqrt{n-1}$	7,322	5,110	5,740	0,157	0,441	5,756	6,063	6,086	5,094

Coefficients	f_a	C_{ar}	δ
r	-0,667	-0,686	-0,645
$\lvert r\rvert\sqrt{n-1}$	5,252	5,402	5,079

Table 5 presents Eqs. (3) – (12) and statistical estimates of their validity. Analysis shows that satisfactory prediction of the moisture-holding capacity (with the permissible discrepancy $\sigma \leq 0.5$ %) is possible by means of W^a, R_0, O_d^{daf} and Q_s^{daf}: specifically, σ = 0.33, 0.49, 0.42, and 0.36 %, respectively. It is expedient to predict $W_{\max}$ on the basis of Eq. (5), since the analytical moisture content in the fuel depends on the temperature and the relative air humidity within the laboratory [7], while the oxygen content in the coal´s organic mass is not determined at coke plants. For power-plant laboratories where the heat of combustion is determined, the moisture-holding capacity may be determined with high precision from on the basis of Eq. (8).

Table 5. Formulae and corresponding statistical characteristics

Eq.	Formulae	Statistical characteristics		
		r	*D*,%	*σ*, %
3	$W_{max} = 0.4251 \cdot (W^a)^2 + 0.5694 \cdot W^a + 1.2954$	0.94	88.5	0.33
4	$W_{max} = 0.0113 \cdot (V^{daf})^2 - 0.5779 \cdot V^{daf} + 9.2706$	0.80	63.4	0.60
5	$W_{max} = 7.1136 \cdot (R_0)^2 - 18.643 \cdot R_0 + 13.987$	0.86	74.1	0.49
6	$W_{max} = 0.0844 \cdot (C^{daf})^2 - 15.004 \cdot C^{daf} + 668.97$	0.85	73.1	0.55
7	$W_{max} = 0.1122 \cdot (O_d^{daf})^2 - 0.7123 \cdot O_d^{daf} + 3.1635$	0.87	76.2	0.42
8	$W_{max} = 0.1116 \cdot (Q_s^{daf})^2 - 9.1173 \cdot Q_s^{daf} + 185.73$	0.90	80.6	0.36
9	$W_{max} = 195.5 \cdot (cA)^2 - 323.2 \cdot cA - 135.4$	0.70	48.6	0.58
10	$W_{max} = 241.9 \cdot (f_a)^2 - 356.9 \cdot f_a + 133.6$	0.72	52.3	0.68
11	$W_{max} = 0.013 \cdot (C_{ar})^2 - 0.797 \cdot C_{ar} + 13.39$	0.77	59.5	0.73
12	$W_{max} = 0.363 \cdot (\delta)^2 - 7.319 \cdot \delta + 38.38$	0.67	45.3	0.60

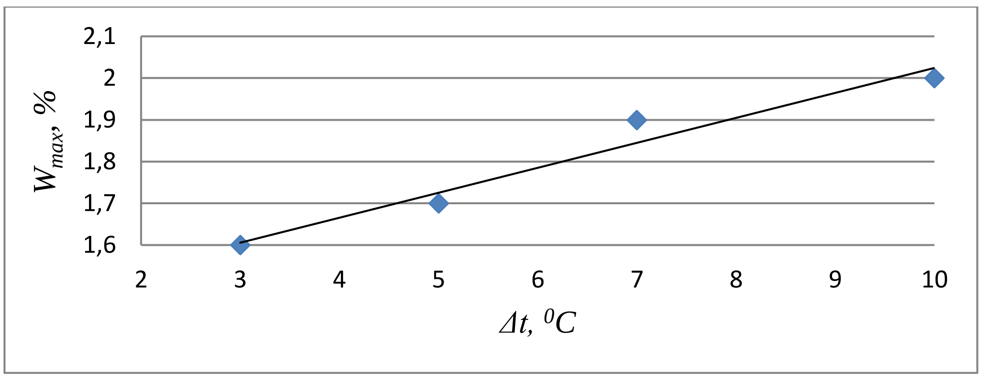

Fig.1. Relation between W_{max} and Δt

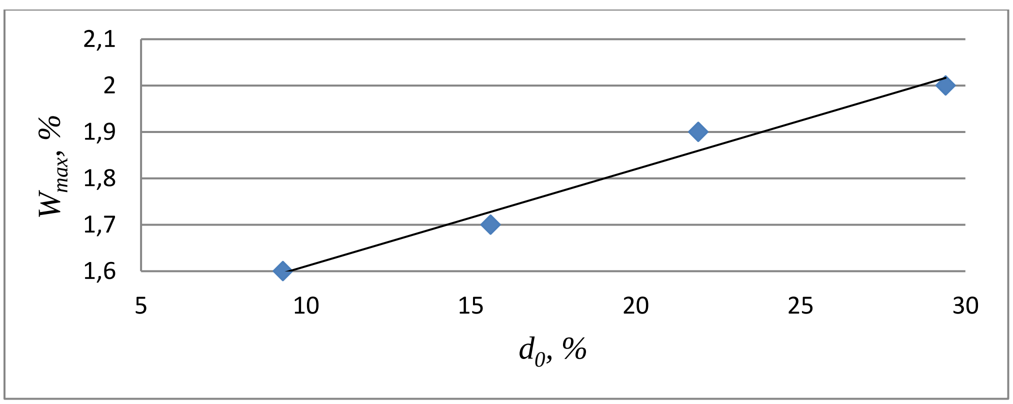

Fig.2. Relation between W_{max} and d_0

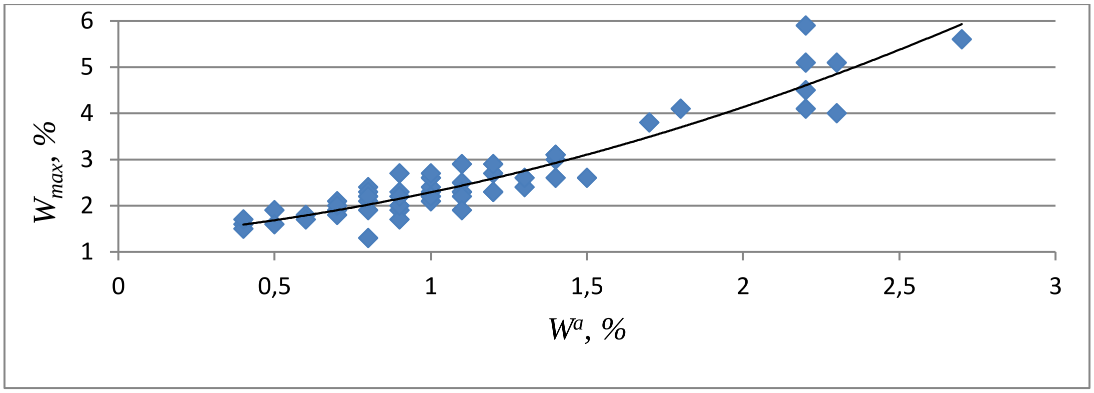

Fig.3. Relation between W_{max} and W^a

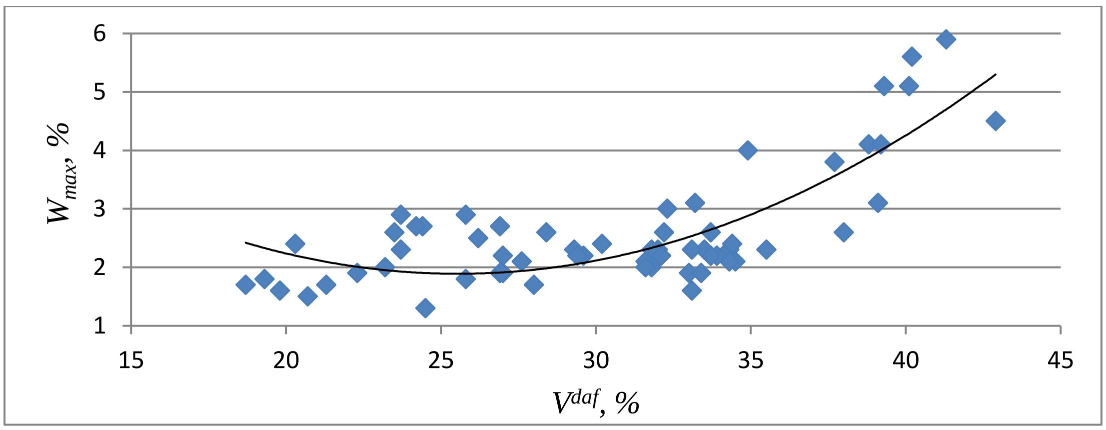

Fig.4. Relation between W_{max} and V^{daf}

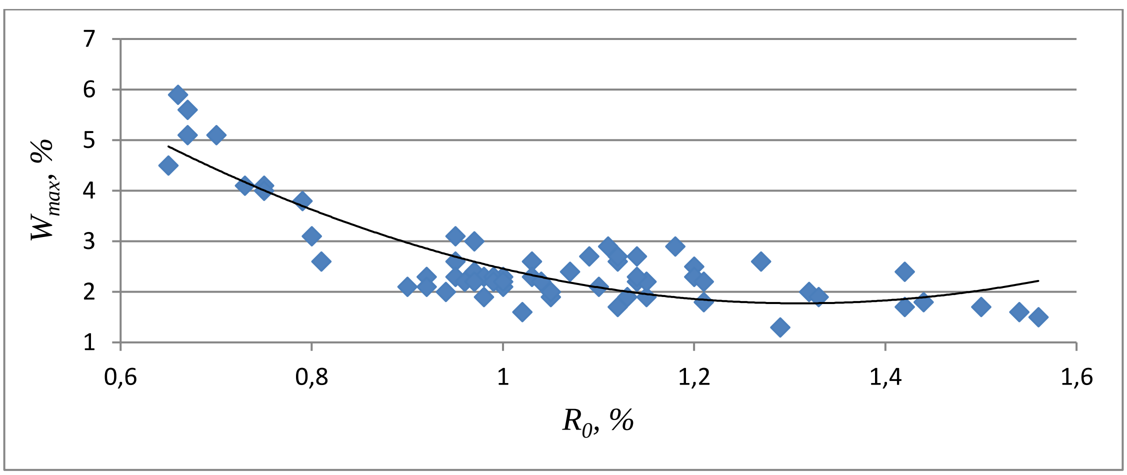

Fig.5. Relation between W_{max} and R_0

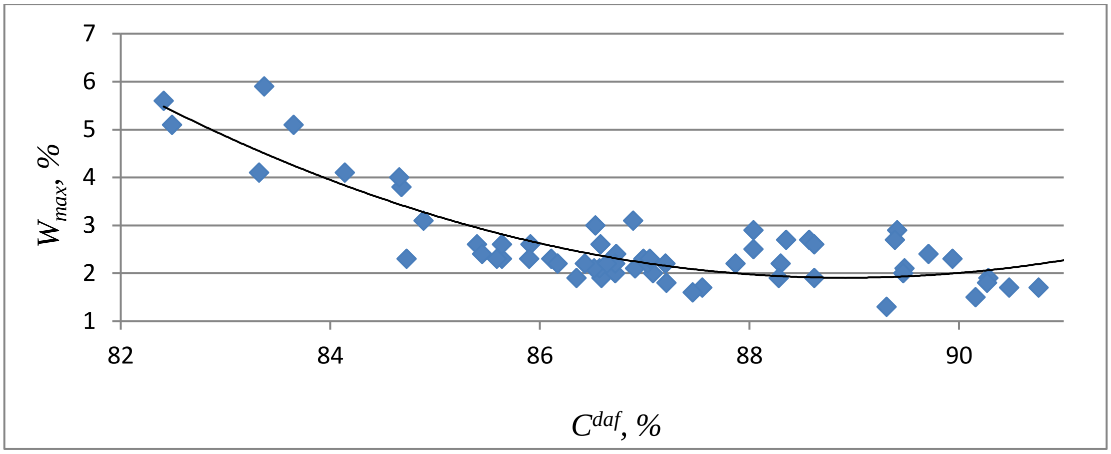

Fig.6. Relation between W_{max} and C^{daf}

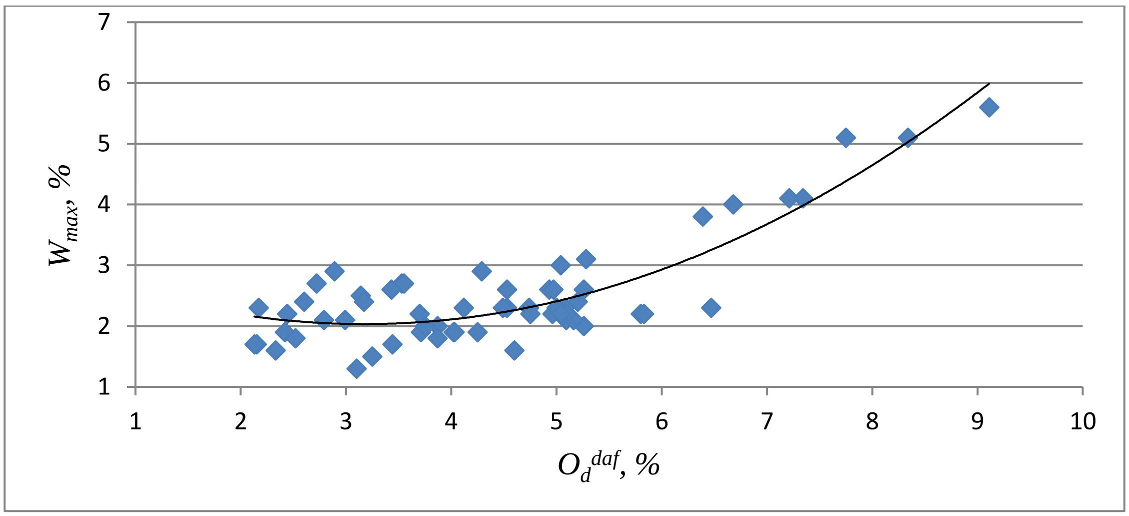

Fig.7. Relation between W_{max} and O_d^{daf}

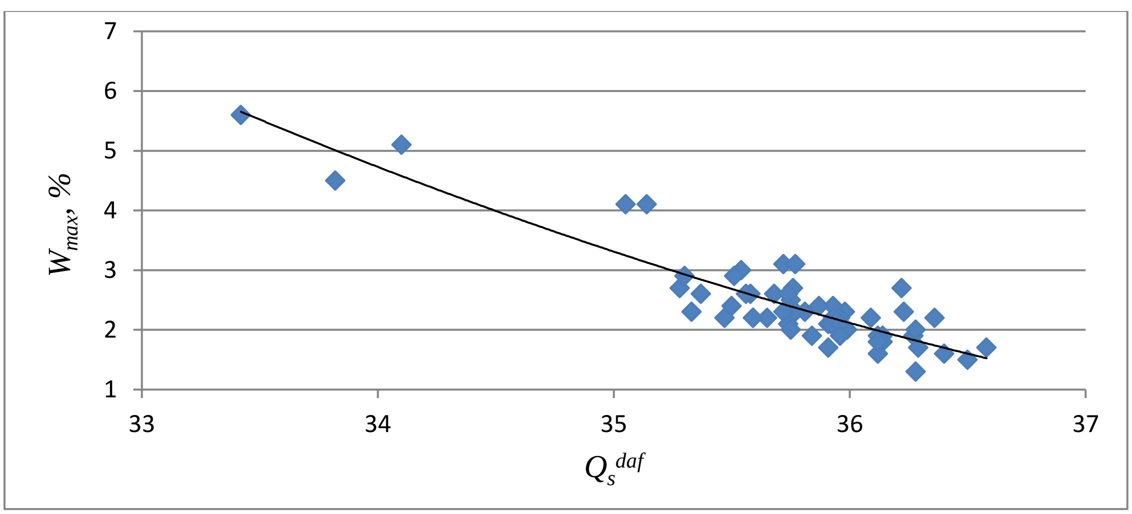

Fig.8. Relation between W_{max} and Q_s^{daf}

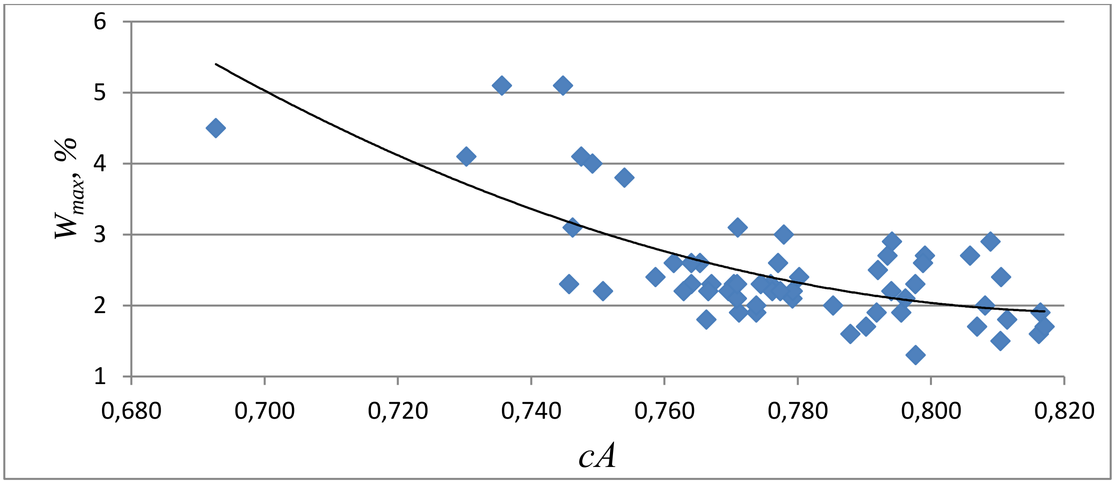

Fig.9. Relation between W_{max} and cA

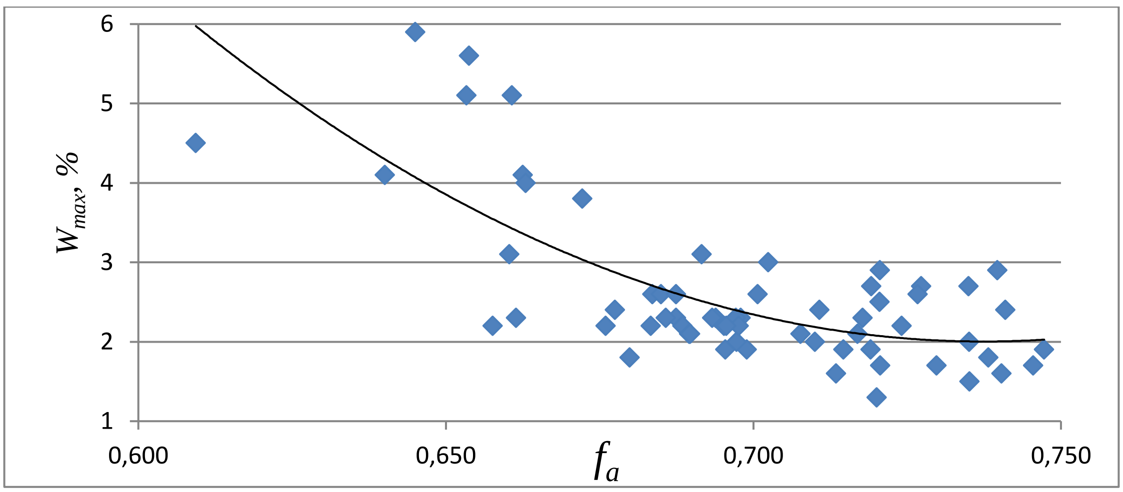

Fig.10. Relation between W_{max} and f_a

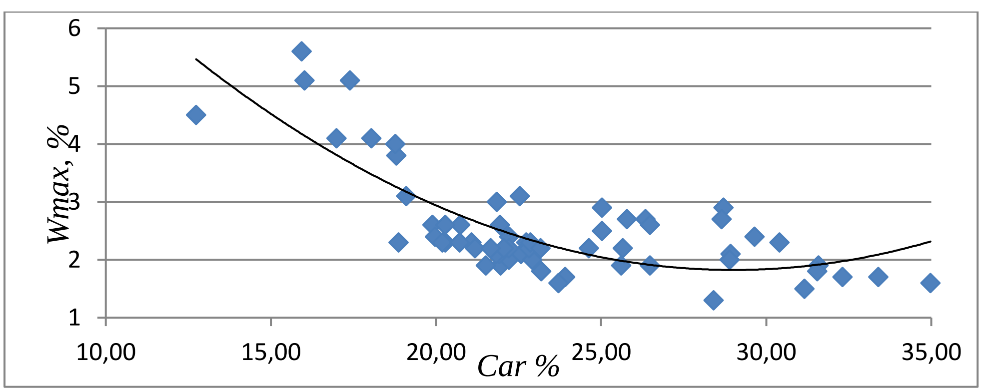

Fig.11. Relation between W_{max} and C_{ar}

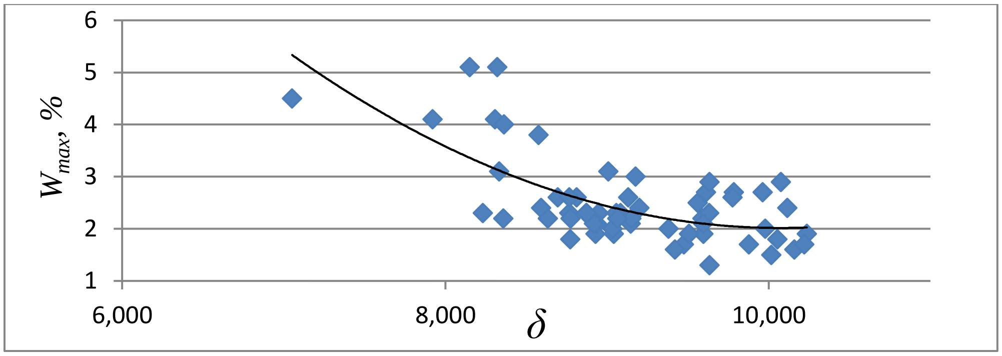

Fig.12. Relation between W_{max} and δ

4. Conclusions

The moisture-holding capacity of metamorphically distinct coals does not depend on their ash content (in the range 3.7–35.3 %) nor on the chemical composition of the ash, expressed by the basicity index B_b (in the range 1.24–27.18) and the base/acid ratio I_b 4 (in the range 0.198–1.832).

Although the oxidation of coal increases the moisture-holding capacity, this change is less than the error in its determination (0.5 %). The oxidation of practically 30 % of the coal´s organic mass increases the moisture-holding capacity by no more than 0.4 %.

Analysis of 63 samples of coal concentrates from Ukraine, Russia, the United States, Canada, Australia and Poland) currently employed at Ukrainian coke plants indicates that the prediction of the moisture-holding capacity of coal may expediently be based on R_0 and the gross calorific value Q_s^{daf} determined, respectively, in plant laboratories and in power-station laboratories.

Symbols

W_{max}	*moisture-holding capacity, %;*
Q_s^{daf}	*gross calorific value in the dry, ash-free state, MJ/kg;*
R_0	*mean vitrinite reflection coefficient, %;*
A^d	*ash content of coal, %;*
V^{daf}	*volatile matter, %;*
W^a	*moisture in the analysis sample, %;*
$\sum FC$	*sum of fusinized components, %;*
B_b	*basicity index;*
I_b	*base/acid ratio;*
Δt	*oxidation index, °C;*
d_0	*degree of oxidation, %;*
D	*determination coefficient, %;*
r	*correlation coefficient;*
σ	*mean square deviation, MJ/kg.*

Fe_2O_3, CaO, MgO, Na_2O, K_2O, Al_2O_3, and SiO_2 are the mass contents of the corresponding oxides in the ash, %.

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