UDC 662.741.3.022

DOI: 10.15372/CSD20180604

Assessment of Coal Cokeability According to Petrographic Composition

A. N. ZAOSTROVSKY[1], N. A. GRABOVAYA[1], N. I. FEDOROVA[1], E. S. MIKHAILOVA[1], and Z. R. ISMAGILOV[1,2]

[1]Federal Research Centre of Coal and Coal Chemistry, Siberian Branch, Russian Academy of Sciences, Kemerovo, Russia

E-mail: iccms@iccms.sbras.ru

[2]Boreskov Institute of Catalysis, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia

E-mail: IsmagilovZR@iccms.ru

Abstract

The paper investigated petrographic characteristics of seam commercial samples of gas coal collected in various Kuznetsk Basin mines. Reflectogram analysis identified petrographic peculiarities that determined coal cokeability during high-temperature coking. According to the results of the additional assessment made for coal physicochemical properties, significant gas coal reserves might be used as valuable raw materials for the coke-chemical industry.

Key words: gas coal, coal petrographic analysis, vitrinite reflectance, coal macerals, reflectogram, coal cokeability

INTRODUCTION

Cokeability is comprehended as the ability of coal to form lump coke of certain fineness and strength upon heating without the access of air.

An attempt to establish the inter-linkage among the petrographic composition of coal and technological characteristics of the latter was first attempted by Zh. V. Ergol'skaya [1]. In this connection, a new parameter, *i. e.* gelified matter content ($\sum$V), was suggested in addition to parameters of coal cokeability being the thickness of a seam layer and volatile matter yield.

Gelified matter is a collective term that covers various types of vegetable residues exposed to gelification at the step of their biochemical transformation under variable redox potential conditions.

Nevertheless, it is hard to determine the functional relationship among coal cokeability and the quantitative content of individual types of gelified matter due to the impossibility to individualize the latter for separate research. For this reason, total gelified matter content, a measure of cokeability, acts as a classification parameter.

The thickness of the plastic layer separating surfaces of coal and semicoke, Y (in mm), is a parameter characterising sinterability (the terms cokeability and sinterability are not different in this paper). This indicator has entered research and factory practices over the time (about 90 years) of its existence. It is worth noting that the plastic layer heated to a certain temperature without the access of air is matter saturated with gas bubbles. Thus, it is impossible to present the Y value as a measure of the amount of gas matter in the dense form.

Coal cokeability primarily depends on its physicochemical properties but also on technology factors, such as particle size (degree of grinding) and volume density that is the mass of the single loading of coal charge into the coking chamber. After addressing the issue of determining the cokeability of macerals or their group vs metamorphism, various attempts were made to predict or calculate properties of high-temperature coke according to microscopic analysis data. Two kinds of microcomponents, such as reactive (vitrinite group) and inert (intertinite one) groups, stood out in all proposed methods relying on content data for macerals or microlithotypes (used in addition to the crucial procedures for determining degree of metamorphism). The main properties of vitrinite that is prevailing in humic coal readily determine the position of coal (grade) in a series of metamorphism. Unlike inert microcomponents in coal, all reactive ones, suitable for coking, pass the plastic layer phase upon heating without the access of air.

Intertinite or fusainized components are relatively little changed upon metamorphism, and according to their content in coal of a certain grade (index of reflection), one may judge properties of this coal. In this regard, fusainized components content ($\sum$FC) is accepted to be regarded as the main parameter of petrographic composition. The term itself "fusainized" testifies that this classification parameter primarily indicates properties of this coal upon coking.

The objective of the research work was to determine the inter-linkage between petrographic composition and coal cokeability based upon petrographic characteristics (vitrinite reflectance and microcomponent composition) and comparatively assess technological properties using a series of standard methods utilised in Russia to predict the cokeability of Kuznetsk Basin gas coal.

EXPERIMENTAL

Currently, there is a shortage of strongly coking coal, such as Zh grade (fat). Under these conditions, it is expedient to involve additional resources of coal (gas), especially those of G17 technology group (gas), coal plastic layer thickness, Y = 17 mm into coking. In combination with fat coal and other coking coals, they yield solid metallurgical coke that meets requirements of the modern blast-furnace production.

Gas coal is diverse according to its properties [2, 3]. Not any gas coal may be exposed to coking with the same success. Differentiation of Kuznetsk gas coal according to technological properties should facilitate its correct separation in mines and feasible use in coke-chemical enterprises. When gas coke is assessed as raw materials for the coke-chemical industry, it is crucial to determine coal cokeability not resourcing to expensive semi- and pilot-scale coking. Currently, prediction methods of the cokeability of coal according to its petrographic characteristics, i.e. microcomponent composition and vitrinite reflection ability, have been developed and industrially tested. They may be used to assess the mechanical strength of metallurgical coke that may be produced in industrial coke furnaces according to bed samples [4–6].

Seam commercial samples of G grade coal (gas coal) at four seams (Baykaimsky, Breevsky, Polenovsky, and Boldyrevsky) of Lenin mine in the Kuznetsk Basin developed by five mines, such as named after 7 Noyabrya, Zarechnaya, Komsomolets, Polysayevskaya and named after Kirov, were selected as research objects.

RESULTS AND DISCUSSION

The primary qualitative assessment of coal according to elemental (Table 1) and plastometric (Table 2) analysis data allows roughly evaluating coal suitability for coking.

The mine named after 7 Noyabrya: Baykaimsky seam is being developed. Coal has lower sinterability (X = 40 mm, Y = 7 mm). As a whole, the plastic layer thickness (Y) varies within 7 and 12 mm.

Zarechnaya mine: according to a stratigraphic horizon, coal is referred to Baykaimsky one, in a similar fashion to the mine named after 7 Noyabrya,

TABLE 1

Characteristics of the investigated gas coal (coal is enriched according to a specific weight of 1.4)

Mine, seam	Technical analysis, %				Elemental analysis, % per daf		
	W^a	A^d	V^{daf}	S^d_t	C	H	(O + N + S)
Named after 7 Noyabrya, Baykaimsky	2.2	3.2	45.7	0.3	81.8	5.4	12.8
Zarechnaya, Baykaimsky	1.8	3.7	44.4	0.3	81.9	5.4	12.7
Komsomolets, Breevsky	1.5	4.6	44.2	1.1	82.7	5.7	11.6
Polysayevskaya, Breevsky	2.0	2.9	42.4	0.8	82.0	5.5	12.5
Named after Kirov, Polenovsky	1.2	2.7	43.6	0.3	84.3	6.0	9.7
Named after Kirov, Boldyrevsky	1.4	2.8	41.6	0.3	83.0	5.8	11.2

TABLE 2

Plastometric indices and plastic properties of coals

Mine, seam	Plastometric indices, mm		Plastic properties (according to Giselher method)				
			F, cd/min	Temperature, °C			ΔT, °C
	y	x		Softening (T_s)	Maximum fluidity (T_f)	Cure (T_c)	
Named after 7 Noyabrya, Baykaimsky	7	39	3	405	423	439	34
Zarechnaya, Baykaimsky	10	43	4	392	420	436	44
Komsomolets, Breevsky	13	43	78	388	427	452	64
Polysayevskaya, Breevsky	12	43	5	398	424	442	44
Named after Kirov, Polenovsky	17	44	19 334	372	423	466	94
Named after Kirov, Boldyrevsky	14	48	3058	384	425	458	74

Note. F and ΔT are maximum fluidity and plastic range, respectively.

which is indicated by the monotony of the petrographic composition (Table 3).

Komsomolets mine: Breevsky seam is being developed. As demonstrated by Table 2 data, coal possesses higher sinterability, as the plastic layer thickness is 13 mm. Coal may be used as raw materials for coking.

Polysayevskaya mine: Breevsky seam is being elaborated. Coal seam thickness is 12 mm. Coal may be used as raw materials for cooking; it is notable for higher total sulphur content (0.8–1.1 %) compared to other coal (a sulphur concentration of 0.3 %, see Table 1).

Mine named after Kirov: Polenovsky and Boldyrevsky seams are being developed. They are referred to Listvyazhnaya and Lenin horizons. Unlike coal from the layer Baykaimsky, the former of most seams has high sinterability (the plastic layer thickness of 14–17 mm). Coal sinterability is changed in the section of a mine field, raising, judging by coal seam thickness, with the stratigraphic depth from Breevsky seam to Boldyrevsky one. The coal therein is suitable for cooking; primarily that of Polenovsky seam, with the plastic layer thickness of 17 mm and plastic range (94°).

Petrographic analysis is of great importance when exploring the genesis of coal, determining the position of the latter in series of carbonization with a view to assessing the stage of metamorphism and development prospects of the coke-chemical industry at the expense of gas coal.

Sample collection and preparation, and also technical and elemental analysis were carried out according to the standard methods [7, 8]. In order to comparatively assess petrographic characteristics and technological properties, the investigated coal was pre-enriched according to a specific weight of 1.4 in a solution of carbon tetrachloride and benzene.

Petrographic analysis was performed according to State Standards GOST P 55662–2013 (ISO 7404-2.2009), GOST P 55663–2013 (ISO 7404-2:2009), GOST P 55659–2013 (ISO 7404-5:2009), and GOST 12112–78 [9–12]. The research work used the automated SIAMS 620 analyser of petrographic characteristics of coal in automatic and manual (expert) modes [13, 14].

The stage of metamorphism of coal, the maceral and microlithotype composition of the latter, and also the distribution of mineral compounds therein may be judged relying on the results of petrographic analysis of individual coals. Vitrinite reflectance ($R_{o,r}$) that is one of the main genetic parameters was determined in immersion oil (in order to increase picture contrast range, which improves the diagnostics of individual macerals) upon a fixed wavelength of 546 nm. Oil with GOST 13739 and index of refraction n_e = 1.5180±0.0004 was used as an immersion liquid at (23±3) °C.

The essence of the petrographic method consisted in determining the quantitative content of groups of macerals in coal by the point contact method under a microscope, in reflected light almost under the straight angle of the polished surface of a metallographic specimen, with 300× magnification. Coal macerals are different among themselves according to the index of reflection: the highest one is typical for macerals of the intertinite group, the lowest one – for those of the liptinite unit, vitrinite ranks intermediate in this row.

The content of groups (in percentage) is calculated in coal. The former is as follows: vitrinite (Vt), semivitrinite (Sv), intertinite (I), and fusainized components content (∑FC). Micrographs may provide some idea about the appearance of

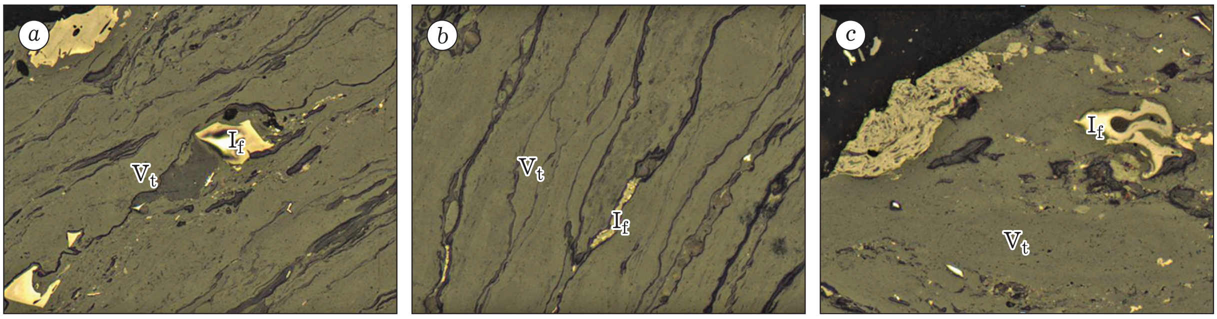

Fig. 1. Micro components of humic coal. Vt and I_f are vitrinite and intertinite groups; reflected light, oil inversion; 300×

microcomponents that are being united into the listed groups (Fig. 1). The pronounced structure of coal is visible under a microscope: there is an abundance of small snippets of fusinized plant tissue among vitrinized matter. Macerals of the vitrinite group are uniform; as a rule, they are quantitatively prevailing, therefore their indicator has been accepted as the major one (estimative) in determining coal grade and the corresponding stage of metamorphism.

The ratio of points of the determinable component to the total amount of points upon calculation was used to compute groups of macerals and mineral inclusions. At the same time, the petrographic composition of the sample and standard deviation (σ_r) may be identified using an analyser. The latter characterises the inhomogeneity of the samples under scrutiny. Furthermore, the analyser allows plotting reflectograms of the $R_{o,r}$ indicator. The reflectogram mode is meant for collecting the required number of vitrinite fields with which reflectance is measured and included in case if upon scanning polished microsection with a given number of fields with measured reflectance turns out to be lower than required (which may be due to the quality of preparing polished microsection or vitrinite properties in this sample) [15].

It is known that the sintering ability of coal is driven by the coking property of vitrain. Due to the homogeneity of the investigated coal and the prevalence of vitrinized matter therein, there is no dramatic difference in the coking property.

The petrographic composition of coal is a crucial characteristic of modern charge mixtures of coke-chemical enterprises. With comparable (0.642–0.740) average values of $R_{o,r}$, the investigated seam production samples of coal are slightly different according to vitrinite reflectograms (Fig. 2) that has a distinct maximum in the field of vitrinite of 06 and 07 grades and vitrinite of 08 grade of GGh coal (gas fat). Gas coal is notable for high petrographic homogeneity, but some species yield more viscous matter (coal from Baykaimsky and Breevsky seams). The viscosity of plastic matter of gas coal is increased with increasing the O/H ratio, which is linked to a decrease in their degree of metamorphism and restorability.

In particular, the highest viscosity of plastic matter (see Table 3) is typical of coal from mines named after 7 Noyabrya, Zarechnaya, Komsomolets, and Polysayevskaya; the lowest one – of coal from the mine named after Kirov, Polenovsky and Boldyrevsky seams. According to the stage of metamorphism, coal in these seams is similar to

TABLE 3
Petrographic composition of coal

Mine, seam	Petrographic composition, %				$R_{o,r}$ %	σ_r
	Vt	Sv	I	∑FC		
Named after 7 Noyabrya, Baykaimsky	97	0	3	3	0.642	0.04
Zarechnaya, Baykaimsky	96	1	3	3	0.647	0.04
Komsomolets, Breevsky	93	2	5	6	0.664	0.05
Polysayevskaya, Breevsky	91	2	7	9	0.699	0.05
Named after Kirov, Polenovsky	94	2	4	5	0.713	0.05
Named after Kirov, Boldyrevsky	91	1	8	9	0.740	0.05

Note. Vt, Sv, I, ∑FC, $R_{o,r}$ and σ_r are vitrinite, semivitrinite, inertinite, the total amount of fusainized components, vitrinite reflectance (in measured oil, of random orientation) and standard deviation, correspondingly.

gas fat (GF) and fat (G) ranks and are different according to petrographic composition and plastometric parameters. For example, Y = 17 mm, X = 44 mm for Polenovsky seam upon vitrinite content of 94 %, whereas for Boldyrevsky one with the latter of 91 %, fusainized components content are 5 and 9 %, respectively, and the range of residence in plastic state is 94 and 74°, correspondingly. Coal in these seams has almost identical temperature of maximum fluidity (423 and 425 °C) under maximum softening conditions. Hence, favourable conditions are developed for mutual diffusion and solution of any coal particles upon softening.

As demonstrated by comparative analysis of petrographic and technological parameters of gas coal from Baykaimsky and Breevsky seams, its technological properties are lower with close petrographic compositions and homogeneities. Coal from mines named after 7 Noyabrya and Zarechnaya, when developing the same Baykaimsky, has the lowest CSN index: Y = 7 mm and Y = 10 mm, respectively. This is indicated by reflectogram analysis (see Fig. 2).

It can be seen that reflectogram histograms of seams Baykaimsky and Breevsky are shifted towards lower vitrinite reflectance. In other words, coal is found in a lower degree of metamorphism than that from seams Polenovsky and Boldyrevsky. Linked to this are moderate sintering properties of coal in seams Baikaimsky and Breevsky, though it has the performance of gas coal according to grading [9]. Gas coal from seams Baykaimsky and Breevsky are least thermally stable owing to a low degree of metamorphism and significant oxygen content. The lowest softening temperature and a narrow temperature range are typical for the former.

Thus, coal seams in Lenin mine are characterised by mainly simple composition and the monotony of the petrographic composition driven by the prevalence of shiny kinds and high (91–97 %) vitrinized matter content. Due to this, the main difference between seams is related to changes in the degree of metamorphism. The microscopical analysis is the only efficient method when the degree of metamorphism is determined. The former is also suitable for determination of the average degree of metamorphism of coal (coal charges) according to vitrinite reflectance and the total amount of fusainized components or in case when it is required to determine the quantitative ratio of various petrographic components in the mixture. This analytical method is now accepted by not only coal petrography and coal chemistry specialists in laboratory research but also by production workers to control the content of coal charges and reveal their behaviour during coking [16].

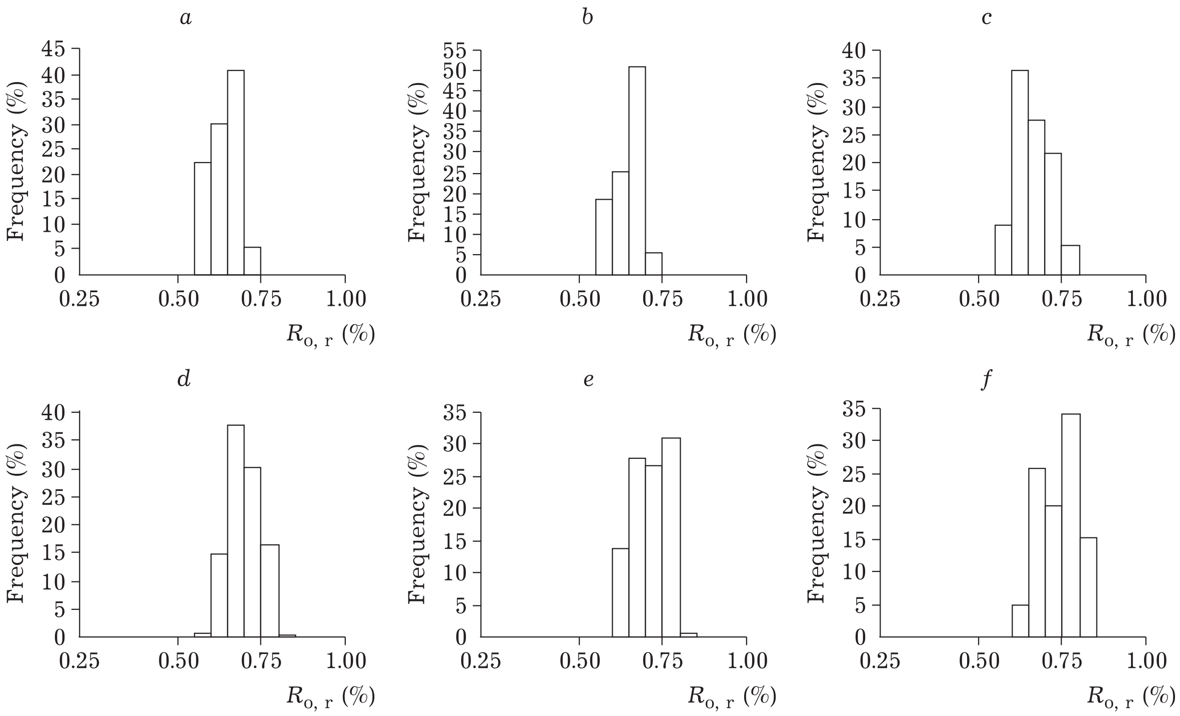

Fig. 2. Reflectograms of Kuznetsk Basin gas coal (X axis – frequency of occurrence of vitrinite, Y axis – vitrinite reflectance in the measured oil). Mines are as follows: a – named after 7 Noyabrya, b – Zarechnaya, c – Komsomolets, d – Polysayevskaya, e – named after Kirov, Polenovsky seam, f – named after Kirov, Boldyrevsky seam.

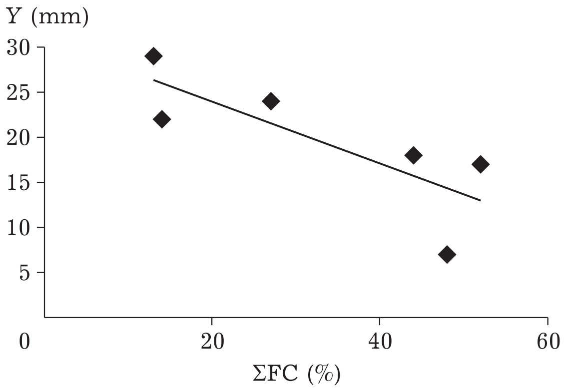

Fig. 3. Coal seam thickness (Y) *vs.* fusainized components content (ΣFC) in coals.

Petrographic and reflectogram analysis allows differentiating gas coal according to technological properties ensuring its rational use in the coke-chemical industry.

When Kuznetsk coal of each stage of metamorphism was positioned in order of increasing fusainized components content therein, there was a distinct trend of changing its cokeability (Fig. 3) [17].

It is known from experience that in order to produce metallurgical coke with high mechanical strength, it is required to have a charge mixture with a layer of a minimum of 17 mm. Out of the investigated coals, this requirement is met by coal with fusainized components content of about 30 % (see Fig. 3). In order to predict the cokeability of coal mines, it is required to have a number of additional coal characteristics. The most important one out of the latter is the optimum ratio of sintering (vitrinite content) components and fusainized components content of 2.34 for this stage of metamorphism. Hence, when the latter is 30 %, the contents of sintering agents should be equal to 70 %.

CONCLUSION

There are certain optimum ratios between meltable and fusainized components for each stage of metamorphism with the modern technology of coking that provide obtaining the best coke.

Vitrinite reflectance as the indicator of the degree of metamorphism has advantages compared to any other parameter. Nevertheless, technological classifications of coal are constructed on the basis of volatile-matter yield. This is likely to be linked to the lack of standardized methods for determination of vitrinite reflectance and the clear gradation of coal according to the index of reflection. Furthermore, experts believe that volatile-matter yield acts as the technological parameter and allows prediction of coal behaviour upon coking.

Technological properties of coal are primarily determined by its genetic peculiarities, i.e. by those that determine varying reflectance.

For example, the cokeability of coal may be more reliably judged according to its petrographic peculiarities (vitrinite reflectance) and the total amount of fusainized components than to volatile-matter yield and plastometric indices.

Acknowledgements

The authors are grateful to T. G. Vychikova (elemental analysis of coal) and V. A. Zubakina (sintering properties of coal) from the Federal Research Centre of Coal and Coal Chemistry, Siberian Branch, Russian Academy of Sciences for their help and experimental data discussion.

REFERENCES

1 Ergol'skaya Z. V. Khim. tv. top., 8, 2 (1937) 97.
2 Zolotuxin Yu. A., Kiselev B. P., Ol'shaneczkij L. G., and Stankevich A. S. Koks i Khim., 1 (1986) 4.
3 Fedorova N. I., Mikhajlova E. S., Ismagilov Z. R., Koks i Khim., 7 (2017) 2.
4 Eremin I. V., Arcer A. S., Bronovecz T. M. Petrologiya i khimiko-tekhnologicheskie parametry uglej Kuzbassa. Kemerovo, 2001.
5 Zhemchuzhnikov Yu. A., Ginzburg A. I. Osnovy petrologii uglej. M., Izd. AN SSSR. 1960.
6 Eremin I. V., Lebedev V. V., Cikarev D. A. Petrografiya i fizicheskie svojstva uglej. M., Nedra, 1980.
7 Tajcz E. M., Andreeva I. A. Metody analiza i ispytaniya uglej. M., Nedra, 1983.
8 Avgushevich I. V. Standartnye metody ispytaniya uglej. Klassifikaciya uglej. M: NTK "Trek", 2008.
9 GOST 9414.1. Ugol' kamennyj i antracit. Metody petrograficheskogo analiza. Chast 1. Slovar terminov. M.: Izdatel'stvo standartov, 1995.
10 GOST 9414.2-93 "Ugol' kamennyj i antracit. Metody petrograficheskogo analiza. Chast' 2. Metod podgotovki obrazczov uglya".
11 GOST R 55662–2013. Metody petrograficheskogo analiza. Chast' 3. Metody opredeleniya maceral'nogo sostava. M.: Standartinform, 2014. 14 P.
12 GOST 12113–94 (ISO 7404-5–85) "Ugli burye, kamennye, antracity, tvyordye rasseyannye organicheskie veshhestva i uglerodistye materialy. Metod opredeleniya pokazatelej otrazheniya".
13 Zaostrovskij A. N., Zhuravleva N. V., Potokina R. R., Grabovaya N. A., Ismagilov Z. R. Chem. Sustain. Devel., 23 (2015) 131.
14 Zaostrovskij A. N., Grabovaya N. A., Ismagilov Z. R. Chem. Sustain. Devel. 24 (2016), 363.
15 Gajnieva G. R., Boyarchikova R. L. Koks i Khim., 5 (2005) 18.
16 Tajcz E. M. Svojstva kamennykh uglej i process obrazovaniya koksa. M., Metallurgizdat. 1961.
17 Zaostrovskij A. N., Grabovaya N. A., Ismagilov Z. R. Vzaimosvyaz' petrograficheskogo sostava i koksuemosti uglej. VII Mezhdunarodnyj Rossijsko-Kazaxstanskij simpozium, Kemerovo, 2018, P. 109