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Using indices of the current industrial coal classification to forecast hazardous characteristics of coal seams

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Abstract

Purpose is to identify changes in the basic indices of vitrinite reflection as well as content of volatile matter in the process of seam underground transformation influenced by high temperature and pressure and define nature of the changes in the classification indices and their correspondence to grades, groups, and subgroups of similar metamorphic coal transformations to determine hazardous characteristics of seams while mining.

Methods. Selection of the most adequate basic index, evaluating metamorphism degree of coal seam and forecasting of their hazardous characteristic demonstration while mining, is based upon the average data of coal composition in Donbas depending upon the stages of seam metamorphism.

Findings. Analysis of indices of the current industrial classification and normative base has shown the following. They cannot characterize directly the coal metamorphism connected with changes in composition and properties of the original organic substance. It has been mentioned that volatile matter do not demonstrate specifically ultimate composition of the organic matter and phase coal composition while fluid extraction from seams during their metamorphic transformations. Only the total release of gaseous products without identification of the released gases is defined by its value. Average vitrinite reflection has been defined experimentally along with other indices to identify the coal grades. For that reason, values of the index not always correspond to coal metamorphism degree in their grade ranking.

Originality. Nature of changes in the classification indices of industrial coal ranking has been defined to identify hazardous characteristics of coal seams while mining.

Practical implications. Possibilities to improve a normative base for safe mining have been defined while determining the classification indices characterizing directly the changes in ultimate composition during metamorphic processes.

Keywords: *coal, metamorphism, ultimate composition, humidity, hazardous properties*

1. Introduction

Safe mining within seams, having a tendency to demonstrate their hazardous properties, is regulated by a number of legal instruments [1]-[4]. According to them, the stage of technical documentation development should involve a forecast of gas emission into mine workings. In addition, potential for gas dynamic phenomena, endogenous fires, and tendency of coal seams to dust release is determined. Accuracy of such forecasts effects heavily upon the efficiency of the applied measures to prevent or reduce the probability of emergency situations connected with the manifestation of hazardous properties of coal seams. Recurrent accidents in coal mines with grave consequences support the idea to improve the normative base concerning safe coal mining.

It is supposed [1]-[4] that metamorphism of fossil carbon is among the basic reasons of manifestation of hazardous properties of coal seams. According to the official definition [5], metamorphism is a process of consistent lignite transformation into hard coal and anthracite resulting from underground changes in chemical composition, structure, and physical properties. Mainly, high temperature and pressure originate the procedure.

While forecasting the manifestation of hazardous coal seam properties, evaluation of a coal metamorphism degree has no adequate scientific substantiation in line with the determination of technological features according to the industrial classifications proposing coal systematization depending upon their applicability for commercial use [6]. For the purpose, coal grades are established. They are symbols of their varieties being close in the genetic characteristics as well as in the basic energy and technological characteristics.

Initially, the basic criteria of coal metamorphic transformations included coke percentage (*K*) per organic substance [7]. Later, identification of coal grades (*M*) substituted the index for volatile matter of thermal airless decomposition per dry ashless mass (V^{daf}) of an organic substance [6], [8]. Use of *K* and V^{daf} indices helped determine similar number of metamorphism stages. The abovementioned has made it possible to substitute *K* for an aggregate of several indices being less labour-intensive for determination. Furthermore, they provide a way to grade coal more differentially in terms of technological and energy characteristics. According to [7], [8], the current classification [6] makes it possible to

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identify 81 types of all fossil coal (inclusive of lignite, hard coal, and anthracite) instead of 10 grades (*M*). Substantially, the success of the industrial classification [6] improvement results from the use of a new basic classifying index, i.e. average vitrinite reflection (R_o). In addition, nine additional indices were applied. They involve volatile mass output (V^{daf}) to determine consumer properties of hard coal as well as volatile matter (V_v^{daf}) to determine anthracite grades, groups, subgroups, types, and subtypes. The two indices (i.e. V^{daf} and V_v^{daf}) are also the basic criteria to evaluate coal metamorphism degree while forecasting hazardous properties of coal seams.

The methods to forecast hazardous properties of coal seams [1]-[4] remain unchangeable for the last decades. In combination, V^{daf} and V_v^{daf} are added by two extra indices, i.e. a plastic seam thickness (y) and a logarithm of specific anthracite electric resistance (lg ρ).

It should be mentioned that none of the indices, applied to evaluate metamorphism degree [1]-[5], [7], [8], corresponds to the basic description of classic metamorphism. The inconsistencies are nonavailability of indices characterizing directly the changes in composition of an organic substance. For the reason, it is of scientific and practical interest to consider the potential to apply relatively new index of average vitrinite reflection (R_o) while forecasting hazardous properties of coal seams.

The research object is a process of coal metamorphism and its impact on the manifestation of hazardous properties of coal seams.

The research purpose is to identify changes in the basic R_o and V_v^{daf} indices in the process of underground seam transformation influenced by high temperature and pressure.

To that end, following tasks have been set:

– to establish a relationship between the basic classifying indices; namely, between those ones characterizing hazardous properties of coal seams inclusive of spontaneous combustion of coal;

– to identify the indices helping characterize fossil coal in the context of the whole transformation series;

– to substantiate the use of the classifying indices, characterizing directly an element composition during metamorphic processes, for forecasting hazardous properties of coal seams.

2. Methods

The research relies upon statistical averages of Donbas coal composition at different stages of seam metamorphism [8].

Accuracy of determination of the average component composition in the organic substance is supported by the coincidence with the results of statistical [9], [10] data [7], [11]-[14] processing for coal types from different deposits.

Currently, coke output per organic substance is the only as well as the key index according to which stages of metamorphic coal seam transformation have been identified [8]. First of all, index K is the criterion evaluating the processing properties of coal rather than the hazardous properties of coal seams manifesting themselves while mining. Paper [8] has determined ten stages of seam metamorphism. The seams were separated uniformly depending upon the coke output from 52 to 100% (Table 1). Graphite ($K \approx 100\%$) was supposed to be the end product of the metamorphic transformations. A value of average coke output $\left(\bar{K}\right)$ at each metamorphism stage makes it possible to define the average fluid number $\left(\bar{V}_K\right)$ extracted from the organic substance of the coal seams:

$$\bar{V}_K = 100 - \bar{K}\text{, \%.} \quad (1)$$

Table 1 demonstrates $\bar{K}$ and $\bar{V}_K$ values at the different metamorphic stages of coal seams as well as corresponding components of the organic substance, carbon $\left(\bar{C}_0\right)$; hydrogen $\left(\bar{H}_0\right)$; nitrogen $\left(\bar{N}_0\right)$; sulfur $\left(\bar{S}_0\right)$; and oxygen $\left(\bar{O}_0\right)$.

Table 1. Data on the metamorphism stages of coal seams (I-X), coal metamorphism degrees according to [6], and industrial classifications [7], [8]

Source	Indices of metamorphism degree, %	Metamorphism degrees									
		I	II	III	IV	V	VI	VII	VIII	IX	X
[6]	K	52-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	9095	95-100
	$\bar{K}$	53.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5
	V_K	48-45	45-40	40-35	35-30	30-25	25-20	20-15	15-10	10-15	5-0
	$\bar{V}_K$	46.5	42.5	37.5	32.5	27.5	22.5	17.5	12.5	7.5	2.5
	$\bar{C}_0$	80.19	81.57	84.29	86.43	88.33	89.53	90.43	91.46	92.67	93.65
	$\bar{H}_0$	5.34	5.31	5.31	5.21	5.10	4.81	4.60	4.30	3.75	1.93
	$\bar{N}_0$	1.73	1.44	1.44	1.46	1.52	1.51	1.51	1.38	1.32	1.05
	$\bar{S}_0$	2.28	1.83	1.42	1.24	1.10	1.04	1.06	1.03	1.00	0.74
	$\bar{O}_0$	10.76	9.85	7.54	5.66	3.95	3.11	2.40	1.83	1.26	0.63
	$\bar{W}$	7.34	6.44	2.59	1.59	1.15	0.99	0.88	0.78	1.29	3.32
[7]	Coal type	*LF*	*Fa*	*FF*	*Fi*	*CBT*	*C*	*2C**	*SLS*	*LC*	*L*
	V^{daf}	50-35	46-33	40-31	37-25	33-13	27-17	25-17	27-14	37-17	20-8
	$\bar{V}^{daf}$	42.5	39.5	35.5	31.0	23.0	22.0	22.0	20.5	27.0	14.0
[8]	Coal type	*LF*	*Fa*	*FF*	*Fi*	*CBT*	*C*	*2C**	*SLS*	*LC*	*L, A*
	R_o	0.4-0.79	0.5-0.79	0.5-0.99	0.8-0.99	0.9-1.29	1.0-1.29	1.3-1.69	≥ 1.7	0.7-1.79	1.5-4.5
	$\bar{R}_0$	0.595	0.745	0.745	0.895	1.095	1.145	1.495	1.700	1.245	3.0
	V^{daf}	40-28	38-30	36-30	36-28	30-24	30-24	28	20	34-16	18-8
	$\bar{V}^{daf}$	34	34	33	32	27	27	28	20	25	13

Note to Table 1: *2C** is a group of coal grade.
Coal type:
LF – long-flaming;
Fa – fairy;
FF – fairy fat;
Fi – fat;
CBT – common bituminous coal;
C – coking;
2C – second coking;
SLS – semi-lean sintering;
LC – low-caking;
L – lean;
A – anthracite;

Moreover, average moisture content $\overline{W}$ has been identified. Since the methods of $\overline{W}$ determination are quite specific, they belong to the total mass of the initial coal samples rather than to ashless dry organic substance.

Separation of the seam metamorphism processes into ten stage depending upon coke output [8] coincides completely with the initial coal gradation in ten ranks (i.e. *LF*, *Fa*, *FF*, *Fi*, *CBT*, *C*, *2C*, *SLS*, *LC*, *A*) in terms of its consumer properties [7]. The current industrial classification divides all types of fossil coal into 17 grades inclusive of lignite and anthracite [6]. The basic ten grades, determined initially [7], remains almost unchangeable in the context of the modern classification [6] (Table 1). The abovementioned has made it possible to consider simultaneously changes in $\overline{V}_K$, $\overline{V}^{daf}$, $\overline{R}_0$ and $\overline{C}_0$ indices depending upon coke output $\overline{K}$; metamorphic degree of seams (I-X); and coal grades from *LF* to *A*. (Table 1, Fig. 1).

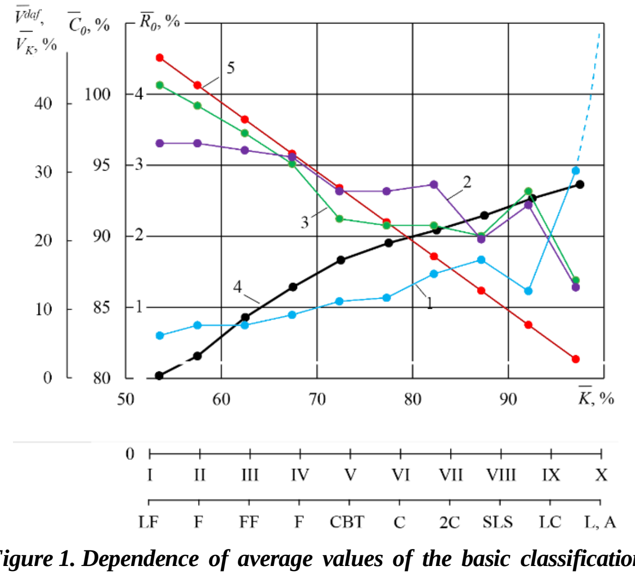

Figure 1. Dependence of average values of the basic classification indices of coal metamorphic degree upon coke output $(\overline{K})$; coal grades (M); and stages of geological transformations of seams (I-X); 1, 2 – curves of changes in the average vitrinite reflection $(\overline{R}_0)$ and volatile matter $(\overline{V}^{daf})$ respectively according to the current industrial classification [6]; 3 – curve of a volatile matter $(\overline{V}^{daf})$ according to the current industrial classification [7]; 4, 5 – curves of changes in average carbon content within organic substance $(\overline{C}_0)$ and fluid extraction $(\overline{V}_K)$ respectively at the different stages of seam metamorphism [8]

Relying upon the nature of changes in the dependences (curves 1-5) and following the classic metamorphism description [5], selection of the most adequate basic index was considered to evaluate metamorphism degree of seams, and forecast manifestation of their hazardous properties while mining.

3. Results and discussion

According to metamorphism definition [5]-[7], [9]-[11], [14], increase in ultimate carbon content in the organic substance as well as decrease in other components is its basic intensification index. None of ($\overline{V}^{daf}$, $\overline{R}_0$) indices inclusive of other ones, applied by the current industrial classification [6] and normative documents [1]-[4] corresponds to the common geological metamorphism idea.

The indices cannot represent immediate changes in the ultimate coal composition during metamorphic processes of the coal seam transformation.

According to the determination methods [15], volatile matter during thermal airless coal decomposition per ashless dry mass of an organic substance (V^{daf}) cannot be among the direct factor of a seam metamorphism resulting from several reasons:

– thermal decomposition is the artificial continuation of underground coal seam transformation during geological processes. Thermal coal decomposition takes place at 900ºC temperature [15] being much higher than 300-650ºC tempe-rature range for hard coal and anthracite formation [10]. V^{daf} value depends upon the temperature of coal thermal decomposition influencing heavily accuracy of the index determination;

– volatile content cannot reflect directly the elemental composition of an organic substance. Its value defines only the total output of gaseous products with no identification of the released gases;

– according to the determination methods [15], gaseous products of coal decomposition belong to dry ashless mass of an organic substance. Hazardous properties are manifested if moisture and mineral impurities are available within the seams;

– in the context of thermal decomposition, V^{daf} index does not consider the yields of pyrogenetic moisture and coal-tar resin. The abovementioned cannot correspond to the processes of fluid extraction from seams during their metamorphic transformations;

– due to low accuracy of V^{daf} determination for lignite, corresponding to the initial stages of seam and anthracite transformation, the final stages cannot involve the index as the key one within the whole metamorphism period.

Average index of vitrinite reflection (R_o) characterizes the petrographic coal composition [16]. Its basic advantage is the possibility to define accurately the values during each stage of coal and seam metamorphism. Its disadvantage is the relatively poor mutual correlation with C_0, H_0, O_0) content per dry ashless mass as for the ultimate analysis data. The paired correlation coefficients (r) are 0.769; -0.839; and -0.672 respectively [17]. The correlation between R_0 and V^{daf} indices is some higher (r = -0.883). The nonlinear inverse proportion connects them; a determination coefficient is R^2 = 0.9409) [18]. Hence, R_o and V^{daf} indices characterize different parts of organic substance metamorphism. Intensification of the latter (i.e. during coherent transition from D grade to A grade) increases $\overline{R}_0$ value and decreases $\overline{V}^{daf}$ (Fig. 1). The broken nature of 1 and 2 curves supports the idea of artificial selection of the indices while identifying the coal grades. Analogously,

V^{daf} value was selected for industrial classification of previous years [7]. The abovementioned is proved by the broken curve 3 nature and position. Average $\bar{C}_0$ content and amount of the extracted fluid $\bar{V}_K$ experience smoother variations (curves 4 and 5) at the different stages of seam transformation [8]. In addition to carbon, hydrogen ($\bar{H}_0$); nitrogen ($\bar{N}_0$); sulfur ($\bar{S}_0$); and oxygen ($\bar{O}_0$) are the basic elements of the organic substance. At all stages of seam transformation, the total of $\bar{C}_0$, $\bar{H}_0$, $\bar{N}_0$, $\bar{S}_0$ and $\bar{O}_0$ is almost 100%. 70% of them belong to the ultimate carbon composition [9]-[11]. The total of other components, i.e. $\sum \bar{H}_0, \bar{N}_0, \bar{S}_0$ and $\bar{O}_0$ decrease functionally during unilateral increase in $\bar{C}_0$ content and seam metamorphism intensification:

$$\sum \bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0 = 100 - \bar{C}_0 \text{ , \%.} \qquad (2)$$

Hence, taking into consideration the definition of metamorphism [5], [7], [9]-[11], [14] makes us possible to refer $\bar{C}_0$ index to one of the basic criteria evaluating the degree of metamorphic transformations of coal seams together with other components, i.e. $(\bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0)$ as well as with humidity $(\bar{W})$. The carbon content almost completely identifies changes in the organic substance at all the stages of seam metamorphism. Its minimum value for hard coal is about 70% [9], [10]. In terms of the considered ten stages of seam metamorphism, average carbon values $(\bar{C}_0)$ varied as follows: 80.19-93.65% [8].

From the viewpoint of such a definition of $\bar{V}_K$, in Equation 1 its values will exceed slightly the average volatile content in the process of thermal decomposition of coal ($\bar{V}^{daf}$). $\bar{V}^{daf}$ takes into consideration only gaseous decomposition products; the extracted fluid may involve pyrogenetic moisture and coal-tar resin. It supports the idea that $\bar{V}^{daf}$ index cannot correspond to metamorphic transformations of seams. Along with the metamorphic process intensification (i.e. $\bar{K}$ increase), unilateral increase in carbon took place (Fig. 2).

Simultaneously, the processes also demonstrated decrease in the total of other components of the organic substance, i.e. $\sum \bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0$ (Fig. 2b; curve 7). Individual changes in the components of the organic substance were of diverse nature. Oxygen demonstrated the most intensive decrease (stages I-IV). Smother decrease almost down to zero showed stages V-X (Fig. 2b; curve 2). Hydrogen content remained nearly unchanged at stages I-VI. Then it decreased nonlinearly (Fig. 2b; curve 3). Nitrogen and sulfur experienced minor changes (Fig. 2b; curves 5 and 4). In addition to the considered components of the organic substance, i.e. $\bar{C}_0, \bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0$, it also contains formation moisture $(\bar{W})$. The methods, determining moisture, prevent from its consideration together with other abovementioned components within a 100 percent composition of the organic substance. $\bar{W}$ percentage is related to the reference coal sample. The moisture content reduction was an intensive process at the initial I-III stages of coal seam transformation (Fig. 2; curve 6). Then it turned out to be insignificant (stages IV-VII; Table 1).

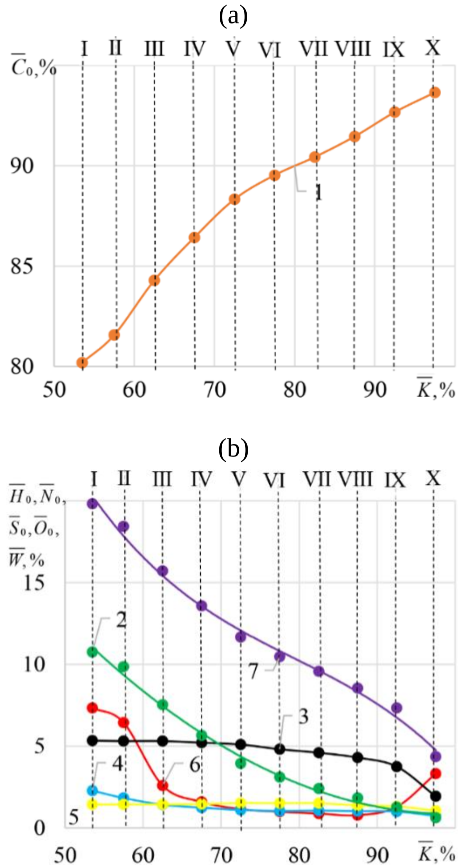

***Figure 2.** Changes in the average content of organic substance elements resulting from coke yield at the different stages of metamorphic transformations in the coal seams [8]; 1, 2, 3, 4, 5, 6 – curves of average carbon $(\bar{C}_0)$; oxygen $(\bar{O}_0)$; hydrogen $(\bar{H}_0)$; sulfur $(\bar{S}_0)$; nitrogen $(\bar{N}_0)$; and moisture (W) content in the organic substance; 7 – curve of changes in the total of components of the organic mass $(\bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0)$; I-X – stages of metamorphic transformations of seams depending upon the coke yield*

VIII-X stages demonstrated its intensification. Certainly, such ambiguous changes in $\bar{W}$ index impact metamorphism processes as well as manifestation of hazardous properties of coal seams.

Carbon content dominates at all the stages of seam transformation. Moreover, the availability of other components being $\bar{C}_0, \bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0$ and moisture $(\bar{W})$ within the organic substance depends heavily upon carbon. Hence, characteristic of coal seam metamorphism stages may apply changes in ratios between the content of carbon and other components instead of coke yield. The ratio between $\bar{C}_0$ and the total hydrogen $(\bar{H}_0)$ and oxygen $(\bar{O}_0)$ content is defined as a carbonization index. Use of only components for the carbonization index (C_n) does not provide a full picture of effect by nitrogen $(\bar{N}_0)$, sulfur $(\bar{S}_0)$, and moisture $(\bar{W})$ on carbon increase $(\bar{C}_0)$ in the process of metamorphism intensification. It is more expedient to consider all the basic components of an organic substance, i.e. $(\bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0)$ and moisture $(\bar{W})$ while determining C_n index. Carbonization index C_n^Σ, corresponding to the total of organic substance components is as follows:

$$C_n^\Sigma = \frac{\bar{C}_0}{\bar{H}_0 + \bar{N}_0 + \bar{S}_0 + \bar{O}_0}. \quad (3)$$

Similarly and approximately (since $\bar{W}$ is not among one hundred percent of an organic substance components) carbonization index for moisture content was identified like this:

$$C_n^W = \frac{\bar{C}_0}{\bar{W}}. \quad (4)$$

The total carbonization index (C_n) is linked with C_n^Σ and C_n^W by means of the Expression 5:

$$\frac{1}{C_n} = \frac{1}{C_n^\Sigma} + \frac{1}{C_n^W}. \quad (5)$$

Taking C_n^{-1} value as a unit for each stage of seam metamorphism has helped identify participation rates of the total of components of an organic substance $\left(\Delta C_n^\Sigma\right)$ and moisture $\left(\Delta C_n^W\right)$:

$$\Delta C_n^\Sigma = \frac{1}{C_n^\Sigma} \cdot \frac{1}{C_n}; \quad (6)$$

$$\Delta C_n^W = \frac{1}{C_n^W} \cdot \frac{1}{C_n}. \quad (7)$$

In the carbonization process, the participation rates of the total of components of an organic substance (ΔC_n^Σ) and moisture $\left(\Delta C_n^\Sigma\right)$ vary significantly along with the increase in carbon content (Fig. 3a).

Oxygen $\left(\bar{O}_0\right)$ and moisture $\left(\bar{W}\right)$ content were the key components influencing carbonization at the early (I, and II) metamorphism stages. Following stages demonstrated dominance of oxygen and hydrogen (stages III, IV); hydrogen and oxygen (stages V-VIII); hydrogen and oxygen, and moisture (stage IX); and moisture hydrogen (stage X). In terms of coke yield and carbonization index, the compared characteristics of the organic substance components are almost equal as for the placement of other members of the series. For instance, their placement at the final (X) stage is similar: $\bar{W}, \bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0$.

Hence, while defining metamorphism degree of seams and taking into consideration their classical definition (inclusive of that one according to GOST [5]), it is quite possible to use a value of carbon content $\left(\bar{C}_0\right)$ in the organic substance rather than coking index $\left(\bar{K}\right)$.

Individual graphs of mutual changes in the organic substance components, shown in Figure 4, can be considered as an additional reason to assume carbon content in the capacity of the key criterion for the separation of metamorphism stages of seams.

Intersections of curves, characterizing individual changes in the organic substance components, speak for certain changes in the chemical composition as well as for changes in the physical and mechanical properties.

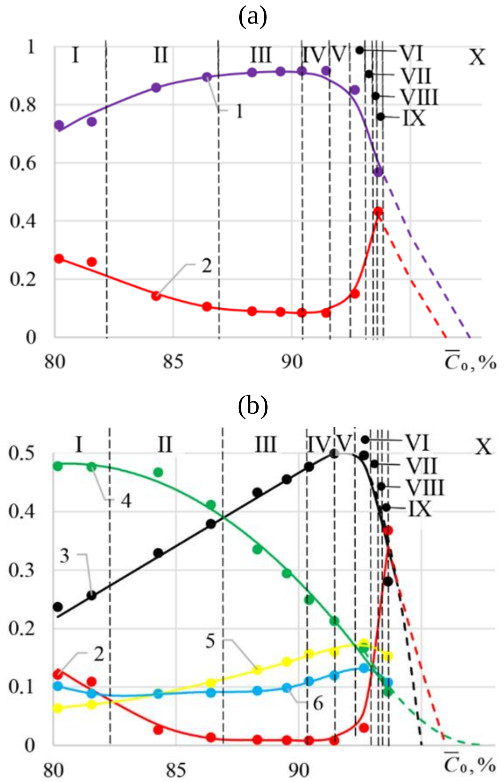

Figure 3. Dependence of changes in rates of the components of an organic substance, participating in seam carbonization, upon average carbon content $\left(\bar{C}_0\right)$ according to [8]; 1, 2 – changes in participation rates while carbonizing: the total $\left(C_n^\Sigma\right)$ of components of an organic substance, i.e. $\left(\bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0\right)$ and moisture $\left(\Delta C_n^W\right)$; 3, 4, 5, 6 – curves of changes in participation rates of hydrogen $\left(\Delta C_n^H\right)$, oxygen $\left(\Delta C_n^O\right)$, nitrogen $\left(\Delta C_n^N\right)$ and sulfur $\left(\Delta C_n^S\right)$ while carbonizing; and I-X – stages of seam metamorphism

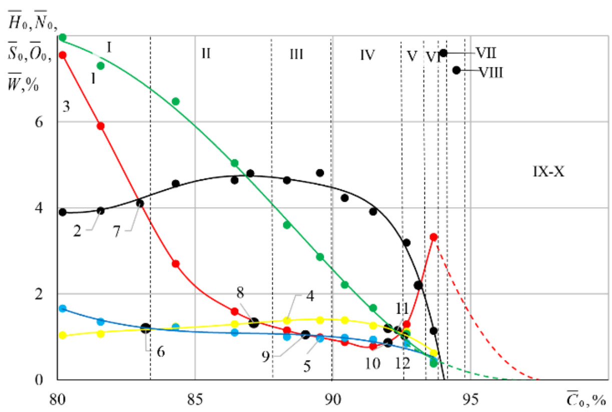

Figure 4. Dependence of the average values of component content in the organic substance upon carbon according to [8]; 1, 2, 3, 4, 5 – curves of average content of oxygen $\left(\bar{O}_0\right)$, hydrogen $\left(\bar{H}_0\right)$, moisture $\left(\bar{W}\right)$ and sulfur $\left(\bar{S}_0\right)$ in the organic substance; 6, 7, 8, 9, 10, 11, 12 – characteristic intersections of curves to identify boundaries of seam metamorphism stages; I-X – stages of seam metamorphism determined with the help of characteristic intersections of curves

From the viewpoint, less than 83% of carbon corresponds to the initial stage of seam metamorphism. The upper 83% boundary is determined by means of 6 and 7 points as well as intersection of 4, 5 and 2, 3 curves. 4 and 5 curves characterize the changes in nitrogen $\left(\bar{N}_0\right)$ and sulfur $\left(\bar{S}_0\right)$ content respectively. 2 and 3 curves characterize the content of hydrogen $\left(\bar{H}_0\right)$ and moisture $\left(\bar{W}\right)$. Similarly, the upper boundary $\left(\bar{C}_0 = 87\%\right)$ of stage II was identified by means of 8 point. Intersection of 3 and 4 curves, defining the moisture $\left(\bar{W}\right)$ and nitrogen $\left(\bar{N}_0\right)$ content, corresponds to the point. Figure 4 does not represent the scale for $\bar{O}_0$.

The upper boundary of stage III $\left(\bar{C}_0 = 89\%\right)$ has been identified through point 9 of intersection of 3 and 5 curves. Intersection point 10 corresponds to the stage IV termination (curves 3 and 5). Point 11 corresponds to the intersection of curves 3 and 4 (stage V). Intersection of curves 1 and 5 within point 12 defines stage VI. Stages VII and VIII differ in tenths of carbon percentage. It is estimated that the boundaries of stages IX and X cannot be defined since in terms of the considered case carbon content is less than 93.6%. If $\bar{C}_0 > 93.6\%$, then the seam metamorphism stages may differ significantly from each other as for their properties due to the unpredictable ratio between components of an organic substance. At the stages, even minimal difference between the components can result in the origination of new properties of coal seams. Intensification of metamorphism gives rise to the narrowing of stage boundaries determined by the carbon percentage.

Relying upon the abovementioned methods (Eq. 3-7), the corrected rate of individual participation of hydrogen $\left(\Delta C_n^H\right)$, oxygen $\left(\Delta C_n^O\right)$, nitrogen $\left(\Delta C_n^N\right)$, sulfur $\left(\Delta C_n^S\right)$ and moisture $\left(\Delta C_n^W\right)$ in carbonization were identified. Their values varied significantly in the process of metamorphic transformation of seams.

There are also certain differences in ranking series as for the participation of components in carbonization comparing with the series ranked on the ultimate composition of an organic substance. Moisture is quite important for early (i.e. I and II) stages of seam transformation. Following stages (i.e. III and IV) minimizes its rate to compare with other components. At the final (i.e. X) stage, moisture becomes important again becoming among dominating ones within the ranking series.

When carbon content becomes more than 93.6%, sharp decrease of participation in carbonization of all other components (i.e. $\bar{H}_0, \bar{N}_0, \bar{S}_0, \bar{O}_0$ and $\bar{W}$) is forecasted (Fig. 3b). In this context, their total share in the organic substance will not be more than 6.4%. Undoubtedly, that impacts the characteristics of coal seams while mining.

The determined stages of seam transformation as for the individual rate of component participation in carbonization are almost similar to the boundaries of stages identified according to the ultimate composition of an organic substance (Fig. 3b). It should also be mentioned that in the majority of cases average carbon content within the stages of seam metamorphism, defined on coke yield, do not coincide with $\bar{C}_0$ ranges, identified either on the individual content of the components or on their participation in carbonization. Impermanent nature of the boundaries of seam metamorphism stages prevents from using coke yield as the basic criterion to evaluate coal transformation. Furthermore, it concerns manifestation of hazardous characteristics of the seams.

4. Conclusions

The research has made it possible to draw conclusions connected with the selection of classifying indices forecasting the hazardous characteristics of coal seams, and use provisions of the current industrial classification for the purpose:

– coke yield per organic substance is one of the first indices upon which industrial classifications are based. Currently, it is the only index which knowledge helps separate all the metamorphic processes of seam transformation into stages, and identify the components of ultimate composition of an organic substance;

– a current industrial classification supposes separation into 81 types depending upon the technological characteristics of lignite, hard coal, and anthracite. Such a thin gradation is supported by the use of average vitrinite reflection together with nine other extra indices. The average vitrinite reflection has been defined for all grades of coal metamorphism;

– none of the indices, applied by the current industrial classification, represents direct changes in the ultimate composition of an organic substance;

– during metamorphism, the mass output of gaseous products during thermal coal decomposition cannot correspond to the ultimate composition of an organic substance. It characterizes the total volatile content per ashless mass without any identification. The abovementioned prevents from consideration of the effect by analytical moisture, pyrogenetic water, and mineral impurities on the manifestation of hazardous properties of coal seams;

– average vitrinite reflection has been selected experimentally together with other indices to determine coal grades. For the purpose, values of the index cannot always correspond to a coal metamorphism degree in terms of ranking series. The index of average vitrinite reflection can be applied to forecast hazardous properties of coal seams only after determination of its dependence upon the physicomechanical coal characteristics. Relying upon the methods of its definition, it characterizes a petrographic composition of an organic substance;

– content of carbon together with hydrogen, nitrogen, sulfur, oxygen, and moisture defines functionally the ultimate content of an organic substance at each stage of coal seam metamorphism. The abovementioned helps use them to forecast hazardous properties of the coal seams.

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ЗАСТОСУВАННЯ ПОКАЗНИКІВ СУЧАСНОЇ ПРОМИСЛОВОЇ КЛАСИФІКАЦІЇ ВУГІЛЛЯ ДЛЯ ПРОГНОЗУ НЕБЕЗПЕЧНИХ ВЛАСТИВОСТЕЙ ШАХТОПЛАСТІВ

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Мета. Встановити зміну основних показників середнього відбиття вітриніту і об'ємного виходу летких речовин у процесі перетворення пластів в надрах під впливом підвищеної температури і тиску. Встановити характер зміни класифікаційних показників та їх відповідність маркам, групам і підгрупам однакового ступеня метаморфічних перетворень вугілля для виявлення небезпечних властивостей шахтопластів при веденні гірничих робіт.

Методика. Вибір найбільш відповідного основного показника для оцінки ступеня метаморфізму пластів і прогнозу прояву їх небезпечних властивостей при веденні гірничих робіт засноване на середньостатистичних даних складу вугілля Донецького басейну на різних стадіях метаморфізму пластів.

Результати. Аналіз показників сучасної промислової класифікації і нормативної бази показав, що вони безпосередньо не характеризують метаморфізм вугілля, пов'язаний зі зміною складу і властивостей вихідної органічної речовини. Відзначено, що вихід летких речовин безпосередньо не відображає елементний склад органічної речовини і фазовий склад вугілля в умовах видалення флюїдів з пластів при їх метаморфічних перетвореннях. Його значення визначає лише сумарний вихід газоподібних продуктів без ідентифікації газів, що виділилися. Середній показник відбиття вітриніту підібраний дослідним шляхом в сукупності з іншими показниками для встановлення марочної приналежності вугілля. З цієї причини значення цього показника не завжди відповідають ступеню метаморфізму вугілля в їх марочному ряду ранжирування.

Наукова новизна. Встановлено характер зміни класифікаційних показників промислової класифікації вугілля для виявлення небезпечних властивостей шахтопластів при веденні гірничих робіт.

Практична значимість. Можливість вдосконалення нормативної бази безпечного відпрацьовування шахтопластів, шляхом встановлення класифікаційних показників, безпосередньо характеризують зміну елементного складу при метаморфічних процесах.

Ключові слова: *вугілля, метаморфізм, елементний склад, волога, небезпечні властивості*