

About Possibility to Use Industrial Coal-Rank Classification to Reveal Coal Layers Hazardous Characteristics

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Abstract The research is concerned with all the fossil coal metamorphism series based on their rank classification. Currently, based on the genetic characters of metamorphic coal conversions, no proved regulatory definition of the coal layer hazardous characteristics is available. For mining forecasts, the regulatory framework uses a limited number of the classificatory parameters with properties, which have not been determined for the whole multiplicity of coals metamorphic transformation. Special features of each coal rank shall be specified using their proxy parameters. It proves that they specify different aspects of the metamorphic coal conversions, as well as other classificatory parameters. For proved forecasting the coal layer hazardous characteristics, it is necessary to use some combinations of the classificatory parameters. It is testified that any alterations of coal properties due to their inner structure conversions may be characterized by maximum and minimum values of different parameters for the same coal rank. The limit for possible alteration of the K rank coals volatile mass yield has been established in lower than normal level. It is noted that coals with the same consumer performance may in some cases be characterized by different values of the classificatory parameters, and in other cases—the coals with different values of the classificatory parameters may have the same processing

behavior. It is proposed, when establishing any hazardous properties of the coal layers in addition to the industrial classificatory parameters, one should use alterations of the organic part elemental composition, mineral impurities and moisture in the whole range of metamorphism series.

Keywords Gas-Dynamic Phenomena, Coals, Geological and Genetic Factors, Elemental Composition

1. Introduction

Worldwide, issues of the coal layer mining activities [1] continue to be challenging currently. It is proved by the routine hard-hitting accidents in coal mines [2, 3]. In many cases, natural disasters are the consequence of the coal layer hazardous characteristics manifestation, when mining [4]. Such characteristics are gas bearing capacity [5] and layer liabilities to gas-dynamic phenomena [6], coal ignitability [7], and its ability to dust production [8] and its explosibility [9].

When mining, the regulatory framework uses a limited number of the coal metamorphism series classificatory parameters to forecast their gas emission [10], occurrence

of spontaneous fires [11] as evaluation criterion for hazardous characteristics of coals. Only 4 classificatory parameters are currently used in the regulatory documents [12] to assess the possibility of coal layer hazardous characteristics during the coal metamorphic conversions. The main one is their volatile mass yield during the coal thermal decomposition in an anaerobic environment (V^{daf}). In some degree, V^{daf} specifies the organic matter elemental composition of bituminous coals only. In addition, to describe the anthracites, the volatile volume yield (V_v^{daf}) or specific electrical resistivity logarithm ($\lg\rho$) is used. When establishing the coal layer liability to gas-dynamic phenomena, jointly with V^{daf} and $\lg\rho$ parameters, the parameter of their plastic layer thickness (y) shall be used. The main criterion of their liability to ignitability shall be their ranking as bituminous coals of anthracites. When mining, assessment of all the possible manifestations of coal layer hazardous characteristics is limited by this list.

To assess the characteristics of coals appeared during their metamorphic conversions, more than 20 classificatory parameters are known [13, 14]. Nevertheless, up to now, the challenging need to unify the coals for different purposes [15] exists. There is no doubt in relevance of such researches to improve the mining regulatory framework.

Now, the classification of coals by their genetic and process parameters [16] is the most perfect. In addition to V^{daf} , V_v^{daf} , $\lg\rho$, and y , it uses 6 more classificatory parameters are applied. The main of them is an average reflectance of vitrinite. As distinct from V^{daf} , V_v^{daf} , $\lg\rho$, and y , the limits of its alterations are established for the whole range of metamorphism series of fossil coals as per their ranking.

The purpose of the study is to find interrelation between the fossil coal qualification parameters and possibility of their use to forecast the coal layer hazardous characteristics, when mining.

2. Materials and Methods

Exception for vitrinite (R_o), all the qualification parameters in the coal metamorphism series have their quantitative values in its separate ranges only. Having determined qualification parameters in these ranges, we may suppose any possible manifestations of the hazardous characteristics of coals of some metamorphism series. When developing the international GOST for classification of coals as per their genetic and process parameters [16], 10 parameters: V_v^{daf} ; V^{daf} ; R_o ; maximum water capacity for ash free state (W_{\max}^{daf}); gross calorific value for wet ash (Q_s^{daf}); total fusainized components for clean coal ($\sum OK$); semi-coking resin yield for dry ash free state (T_{SK}^{daf}); plastic layer thickness (y), free swelling index (SI); and vitrinite reflectance anisotropic index (A_R). By ten classificatory parameters, the coals are divided by

types, ranks, grades, sub-grades, orders, sub-orders.

Ranking the fossil coals by types shall be performed as per different combination of three parameters R_o , Q_s^{daf} , and V^{daf} :

- brown coal (B) – $R_o < 0.60\%$, $Q_s^{daf} < 24$ MJ/kg;
- bituminous coal (between D and T ranks) – $0.40 < R_o < 2.59\%$, $Q_s^{daf} = 24$ MJ/kg and more, $V^{daf} > 8\%$;
- anthracites (A) – $R_o \geq 2.20\%$, $V^{daf} < 8\%$.

As per main (R_o) and proxy parameters, 17 coal ranks have been specified (B, D, DG, G, GZh, OG, Zh, Zh, KZh, K, KO, KSN, KS, OS, TS, SS, T, A). In turn, the coal ranks have been divided by 27 grades, 44 sub-grades, and 49 classes.

To establish any possible ranges of the proxy parameters alteration as per [16], their dependencies on R_o have been considered, which has its qualitative evaluation of the coal metamorphism series based on their rank classification.

Classification concept supposes the metamorphic conversion intensification along with R_o increasing and arrangement of coals in their ordered series by rank classification between B and A. Having determined their qualitative composition of the main and proxy parameters, one may find the special factors, which determine the identity of rank under consideration. The parameters established in such a way may be used for detailed elaboration of the coal layer hazardous characteristics manifestation forecast.

3. Results

Analysis of the regulation [16] has shown absence of certain recommendations to select the value of $\sum OK$ parameter, upon determination of the coal category. For all the ranks, grades, and sub-grades are recommended to be assumed less than 39 % or more than 40 %. For this reason, to reveal any hazardous characteristics of coal layers using $\sum OK$ parameter is impossible as per [13]. Similarly, when establishing the order of brown coals and anthracites, it is recommended to use their maximum water capacity for ash free state (W_{\max}^{daf}) and volatile volume yield (V_v^{daf}). For 1B grade, W_{\max}^{daf} value is more than 60 %; for sub-grades 2BV and 2BF—30÷50 %; and for 3B grade (sub-grades 3BV and 3BF)—less than 30 %. The same uncertainty of gradation use to be observed upon determination of the anthracites grades and sub-grades by their volatile volume yield. For AV sub-grade, it is more than 200 cm³/g; for sub-grades 1AF, 2AV, 2 AF—100÷150 cm³/g and more; and for 3A grade (sub-grades 3AB and 3AΦ)—150÷200 cm³/g. It is impossible to determine the analytical dependencies of $\sum OK$, W_{\max}^{daf} , and V_v^{daf} on R_o as per [16].

Independent of the big quantity of sub-grades (44), they have no distinct boundaries determined by the parameters

R_o and V^{daf} .

In many cases, no lower and upper boundaries of V^{daf} alteration have been established. The experimental data statistical processing [16, 17, 19] has allowed to fix this disadvantage. To make it possible to use in analysis V^{daf} values along with R_o , their alteration boundaries have been established using the coal ranks (Table 1).

Table 1. Relation between R_o [16] and V^{daf} [19] alteration limits values as per coal ranks

Coal rank	R_o limit value [16], %		V^{daf} limit value [19], %	
	lower	upper	lower	upper
B	0.20	0.59	45.0	64.0
D	0.40	0.79	34.4	50.0
G	0.50	0.99	27.2	44.3
Zh	0.80	1.19	14.4	40.6
K	1.00	1.69	2.7	31.3
OS	1.30	1.79	9.4	28.2
T	1.50	2.59	4.1	19.5
A	2.20	4.5	0.8	10.9

Almost all the values of V^{daf} lower and upper alteration limits as per [16] are within area located between the boundaries (Fig. 1, curves 1 and 2). The experimental data analysis [15, 17-19] has revealed the abnormal low limit (2.7 %) of possible V^{daf} alteration for K rank coals. Plastic layer thickness parameter (y) shall be used to establish the ranks, grades, orders, and sub-orders of the bituminous coal. No definite correlation of this value on R_o is observed (Fig. 2, a).

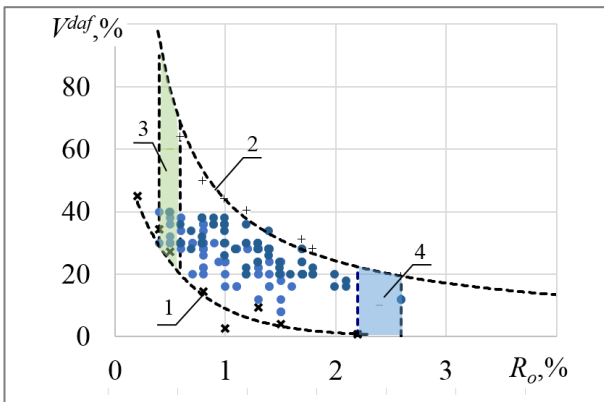


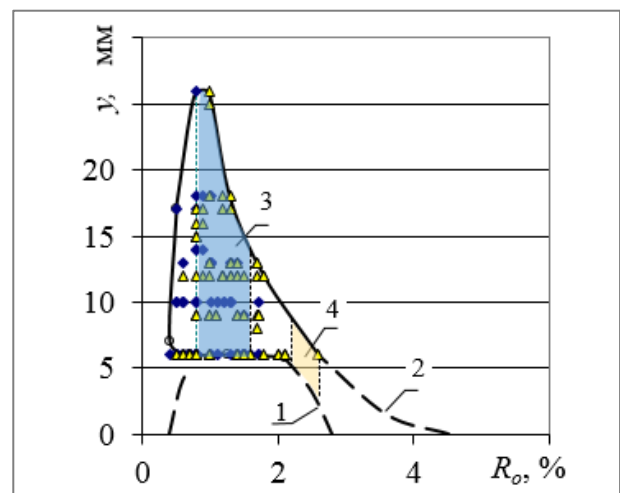
Figure 1. Study of volatile mass yield (V^{daf}) from the mean value of reflectance of vitrinite (R_o) as per classification [16]: 1,2 – lower and upper alteration boundaries V^{daf} ; 3,4 – alteration ranges of R_o [16] for fossil coals upon transition from B and K (0.40-0.59 %) and from K to A (2.20-2.59 %) accordingly; ×, + – data of V^{daf} and R_o as per [17, 19]

Only lower (1) and upper (2) alteration boundaries of y may be considered depending on R_o . Within alteration range $R_o=0.80\div 1.60$ % value of y increases from 6 to 28 mm [16]. Its minimum values, including those equal to 0,

are within alteration range $R_o =2.00\div 2.60$ %. Thus, depending on nature of y , one may suppose presence of several possible ranges R_o , where the metamorphic conversions led to different consequences in the elemental composition and properties of the organic matter of coals. This is evidenced by increasing of y from 6 to 22 mm with values of $R_o=0.40\div 0.80$ % (Fig. 2, a). Upon alteration of R_o within 0.80-1.60 % interval, y parameter is within limits of 6-12 mm. Nature of y range alteration at $R_o=1.60\div 2.20$ % is similar to y alterations at $R_o=0.40\div 0.80$ %. Obviously, it is related to the approximately same conversion of organic constituents by chemical composition and different restructuring the inner structure of coals. This is evidenced by the different alteration ranges R_o equal to 0.60-0.80 % and 1.60-2.20% respectively.

The identical nature of alteration of interrelation between y and R_o is established as [15]; and for the plastic layer—from the volatile yield (Fig. 2, b). Maximum y value of 37 mm is achieved at V^{daf} equal to 32 %. It is little more than the maximum values of y (26 mm) by the classification. V^{daf} alteration boundaries (Fig. 1) require to be specified due to as per [16], the minimum possible value of V^{daf} is about 10 %. And the experimental data diagram, dependence of V^{daf} on V_v^{daf} evidences that minimum V^{daf} values are within range of 1.0-4.0 % (Fig. 3).

Free swelling index value (SI) exists for some coal ranks only. They include D, TS, SS, and T coal ranks. They are significantly different between them by main parameter R_o . For D rank coals, $R_o=0.40\div 0.79$ %; and for TS, SS, TT ranks, the main parameter values are 1.40-1.99 %, 0.70-1.79 %, and 1.50-2.59 % respectively. As per main classificatory parameter of coal rank, coals of D and TS, SS, T are on opposite ends of the fossil coals geological conversion series.



a

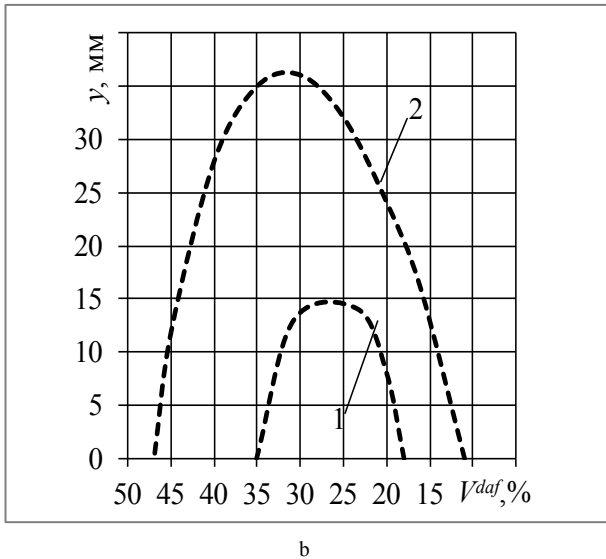


Figure 2. Fossil coals plastic layer thickness (y) study: a – from the mean value of reflectance of vitrinite (R_o) as per [16]; b – from the volatile yield (V^{daf}) [19], 1,2 – lower and upper boundaries of y ; 3,4 – alteration ranges of y depending on R_o as per [16]

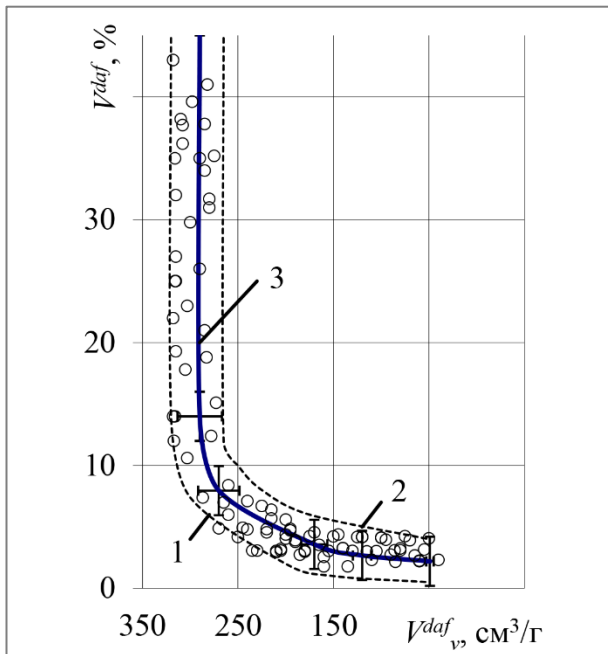


Figure 3. Interrelation between the mass V^{daf} and volume V_v^{daf} volatile yield, [12]: 1, 2, 3 – lower, upper alteration boundaries of parameters, and averaging curve, respectively; \circ – experimental data

SI parameter evidences that there are common attributes, which are the same for the coal ranks under consideration. Herewith, they are expressly different against each other with their main parameter (R_o) that evidences any possible differences, which specify the hazardous characteristics of coal layers.

4. Discussion

The studies performed have confirmed the conclusions

that the rank classification has narrow separation of K rank coals by their consumer properties. It is obviously that such an approach to the coal gradation using V^{daf} and R_o will not be sufficiently accurate for establishing the coal layer hazardous characteristics as well. It is confirmed by availability of the transition zones (3,4) (Fig. 1) of alteration ranges V^{daf} and R_o upon transition from the brown to bituminous coals and from the bituminous coals to anthracites. All these zones include almost all the coal metamorphism series by their ranks.

As classificatory parameters to establish the coal layer hazardous characteristics, it is not possible to use T_{SK}^{daf} and A_p as per [16] due to no indications of their certain alteration limits. For the coals of 1B grade and 2BV, 3BV sub-grades, T_{SK}^{daf} is less and more than 20 %. For 2 BF sub-grade, the recommended parameter value shall be less than 20 %; and for 3BF—less than 15 %.

A_p parameter for 1A anthracite grade (1AV, 1AF sub-grades) shall be 70 % and lower; for 2A grade (2AV, 2AF sub-grades)—40 % and more; for 3A grade (3AV, 3AF sub-grades)—50 % and more.

The alteration range of $R_o=2.20\div 2.60$ % corresponds to transition from the bituminous coals to anthracites. In this R_o alteration interval, y values are less than 6 mm. It is supposed that the same its values may be specific for the anthracites as well.

The composition and characteristics of anthracites within their alteration range of $R_o=2.60\div 4.50$ % and more are the least researched from the point of view of coal layer hazardous characteristics appearance. This alteration range of R_o is almost a half of size of the whole fossil coal metamorphic conversion series by their ranks. The proxy parameters are insufficiently used to characterize the consequences of such conversions.

5. Conclusions

The top-down analysis of the current industrial coal classification has allowed establishing its particularities and identifying its peculiar provisions to establish the coal layer hazardous characteristics, when mining:

- no recommendations on selection of the classificatory parameter certain limits for volatile yield, maximum water capacity for ash free state, etc. does not allow their use to establish the coal layer hazardous characteristics;
- possible range boundaries of the mass volatile yield alterations have been determined; nonlinear relationship of the reflectance of vitrinite with the mass volatile yield has been noted, which evidences that they characterize different aspects of the coal metamorphic conversions;
- the established abnormally low limit for the fossil coal mass volatile yield alterations has shown that coal ranks do not allow making the coal layer

gradation by their hazardous characteristics manifestation;

- alterations of the anthracite properties during their geological conversions have been the least understood. At the maximum width of range of the vitrinite reflectance alteration, no certain alteration limits for proxy parameters are available;
- availability of the free swelling index for coal ranks in diametrically opposite parts of the ordered series shows presence of the same properties with their different degree of metamorphic conversion;
- for reliable establishing the coal layer hazardous characteristics manifestation, when mining, it is necessary to consider the indices, which may directly characterize such properties in addition to the industrial classification. They should include the elemental composition alterations of mineral impurities and moisture in the whole coal metamorphism series.

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