10. Hossain, S. S., Mathur, L., Roy, P. K. (2018). Rice husk/rice husk ash as an alternative source of silica in ceramics: A review. *Journal of Asian Ceramic Societies, 6 (4)*, 299–313. doi: https://doi.org/10.1080/21870764.2018.1539210
11. Li, S., Bao, C., Ma, H., Dong, W., Song, S., Wang, Q. et al. (2022). Fabrication and properties of diatomite ceramics with hierarchical pores based on direct stereolithography. *Ceramics International, 48 (5)*, 6266–6276. doi: https://doi.org/10.1016/j.ceramint.2021.11.169

Irina Subbota, *PhD, Associate Professor, Department of Chemical Technology of Ceramics and Glass, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-1581-8513*

✉***Larysa Spasonova,*** *PhD, Associate Professor, Department of Chemical Technology of Ceramics and Glass, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, e-mail: L_Spasonova@kpi.ua, ORCID: https://orcid.org/0000-0002-7562-7241*

Anastasia Sholom, *Department of Chemical Technology of Ceramics and Glass, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, ORCID: https://orcid.org/0000-0003-2043-5389*

✉*Corresponding author*

UDC 622.82:54-3
DOI: 10.15587/2706-5448.2022.266455
Article type «Reports on Research Projects»

Yevhen Rudniev, Mykola Antoshchenko, Elvira Filatieva, Mykhailo Filatiev, Vadym Tarasov

ANALYSIS OF METAMORPHISM AND TENDENCY OF COAL SEAMS AND THEIR HAZARDOUS PROPERTIES

The object of this study is coals of different stages of metamorphism. Currently, a situation has arisen when indicators developed to establish the consumer qualities of coal are used to predict the manifestation of hazardous properties of mine seams during mining operations. The need to consider the fuel for its working condition is due to different end goals between the establishment of consumer qualities of coal and the manifestation of the hazardous properties of mine seams. The condition and quality of coal after its preparation for use is significantly different from the condition in the mining area. Appropriate sample preparation changes the physical and chemical properties of coals, which determine the manifestation of the hazardous properties of mine layers during mining. To eliminate such a discrepancy, the quality indicators of coals were recalculated for their working condition, taking into account the yield of ash and moisture content for the mined mine seams, followed by an analysis of changes in the correlations be-tween the indicators. The indicators of the manifestation of the hazardous proper-ties of mine layers are borrowed from the characteristics of the quality of the fuel, reduced to a dry, ash-free state. Using these indicators, additional errors are introduced in advance into the accuracy of the prediction of the manifestation of hazardous properties during mining operations. The values of the indicators of the organic (combustible) part of the fuel serve as general reliable characteristics of its quality for the entire set of mine seams, but they cannot be used to predict the hazardous properties of a particular mine seam due to a decrease in the accuracy of their determination due to the unpredictable content of mineral impurities and moisture. The initial experimental data, which have been accumulated over several decades based on the experience of using coal for industrial purposes, are analyzed. On the basis of the conducted researches the peculiarities of the choice of indicators of metamorphic transformations of coal, which are used in parallel respectively to establish the quality of fuel and forecast the dangerous properties of coal seams, have been established. The discrepancies between the indicators of the degree of metamorphism used in the current regulatory framework for the safe conduct of mining operations, the state of fuel during mining operations in underground conditions.

Keywords: *physico-chemical properties of coal, hazardous properties of mine seams, coal quality, ash yield, moisture content.*

Received date: 17.09.2022
Accepted date: 24.10.2022
Published date: 31.10.2022

How to cite
Rudniev, Y., Antoshchenko, M., Filatieva, E., Filatiev, M., Tarasov, V. (2022). Analysis of metamorphism and tendency of coal seams and their hazardous properties. Technology Audit and Production Reserves, 5 (3 (67)), 11–14. doi: https://doi.org/10.15587/2706-5448.2022.266455

1. Introduction

Coal fires pose great threats to valuable energy resources [1], the environment [2], and human health and safety [3]. They occur in numerous countries in the world. Not only do coal seam fires [4, 5] harm the environment and human health by burning uncontrolled, they also deplete non-renewable resources. Estimates of coal lost

ISSN 2664-9969

to these fires range from 20 to 600 million tons of coal annually [6].

Previous studies [7] made it possible to assess the validity of using individual indicators [8, 9] of the degree of metamorphic transformations of coals to predict the manifestation of hazardous properties of mine seams. Some of the recommendations for improving the regulatory framework for safe mining are as follows:

– based on the definition of coal metamorphism, it is necessary to control the increase in carbon content and the reduction of other components with a parallel change in the physical and mechanical properties and structural structure of the transformed substance;
– each, taken separately, classification indicator reflects, as a rule, one side of the metamorphic transformations of coals;
– in most cases, when determining the hazardous properties of mine seams, researchers used one or two indicators that one-sidedly characterized the diversity of metamorphic transformations of coals and served as a general measure of the degree of metamorphism. In particular, such properties, without sufficient scientific justification, were attributed to the release of volatile substances during the thermal decomposition of coals and their grades;
– ranking of coal properties by grade does not coincide with the degree of their metamorphic transformations in past geological periods;
– different methods, methods, accuracy of determining classification indicators and their non-linear interdependence among themselves do not allow their complete interchangeability in determining the hazardous properties of mine seams;
– modern industrial classification does not consider the simultaneous change in the organic and mineral components of coal, which makes it impossible to use it unchanged to predict the hazardous properties of mine seams.

The elemental content of carbon in the organic (combustible) mass [10, 11] is a more informative indicator for establishing the hazardous properties of mine layers compared to the release of volatile substances [12]. The advantage lies in the possibility of its reliable determination in the entire range of metamorphic transformations of coals and 100 % control of the content of the sum of the remaining main components in the organic (combustible) mass O_o, H_o, N_o, S_o (O_c, H_c, N_c, S_c). In terms of the ability to control the amount of other components in an organic or combustible mass, the C_o (C_c) indicator also has an advantage over one of the main indicators of modern industrial classification [8].

Solving this problem will help to improve the regulatory framework for creating safe conditions in coal mines.

Thus, *the object of research* is the coals of different stages of metamorphism.

The *aim of research* is determination of general methodological approaches to the selection of classification parameters for assessing the degree of coal metamorphism when establishing their propensity for spontaneous combustion.

2. Research methodology

The methodology provides for the establishment of changes in the classification parameters of the degree of metamorphism, characteristic of the whole series of coalification. In parallel, identify indicators that exist only in some ranges of a number of degrees of metamorphism. Comparison of changes in indicators in individual intervals will allow for a more detailed gradation of the properties of coals by their tendency to spontaneous combustion.

3. Research results and discussion

The direction and nature of the change in the average oxygen content in the combustible part of the fuel were confirmed by the results of statistical processing of the initial data [13, 14] (Fig. 1).

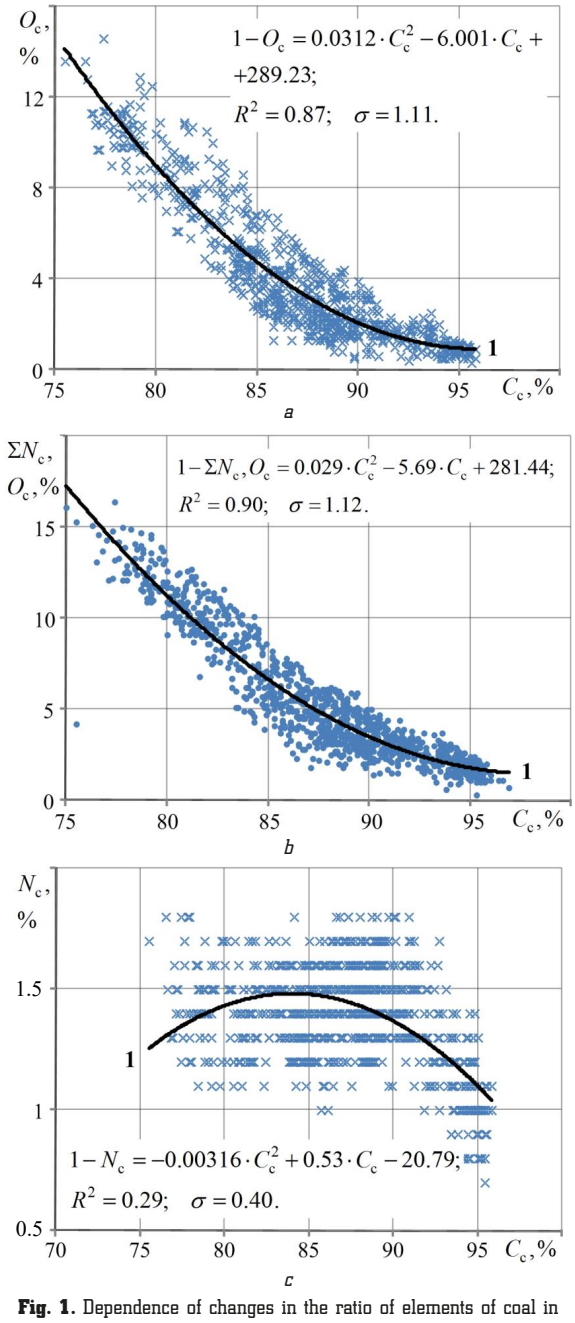

Fig. 1. Dependence of changes in the ratio of elements of coal in combustible part of the fuel: *a* – the ratio between the content of carbon and oxygen; *b* – the ratio between the content of carbon and a mixture of other components (ΣN_c, O_c); *c* – the ratio between the carbon content and nitrogen; 1 – averaging curves; ×, ● – experimental data for mine formations, respectively, according to [13] and [14]; R^2 и σ are, respectively, the coefficients of determination and standard deviations from the averaging curves

When processing the data [13], a close nonlinear correlation dependence of the oxygen content in the combustible part (O_c) on the carbon of the C_c was established (Fig. 1, *a*). It is characterized by a high value of the coefficient of determination (R^2=0.87). A similar dependence was obtained when the sum of nitrogen and oxygen (ΣN_c, O_c) was processed from the carbon of the C_c for the data given in the document [14] (Fig. 1, *b*). Insignificant differences between the coefficients of determination (0.87 and 0.90) and standard deviations (1.11 and 1.12 %) from the averaging curves (Fig. 1, *a*, *b*) are due to the low nitrogen content (0.7÷1.8 %) at all stages of the metamorphic transformation of the combustible part of the fuel (Fig. 1, *c*). The oxygen content in this case varied within 0.3÷14.6 % [13]. The relatively low nitrogen content in the combustible part and its slight change compared to the reduction in oxygen content as metamorphic transformations intensified predetermined approximately the same indicators of correlation dependences (Fig. 1, *a*, *b*).

The non-linear dependence of hydrogen in the combustible part of the fuel (H_c) was established (Fig. 2) as the influence of metamorphism processes (growth of C_c) intensifies.

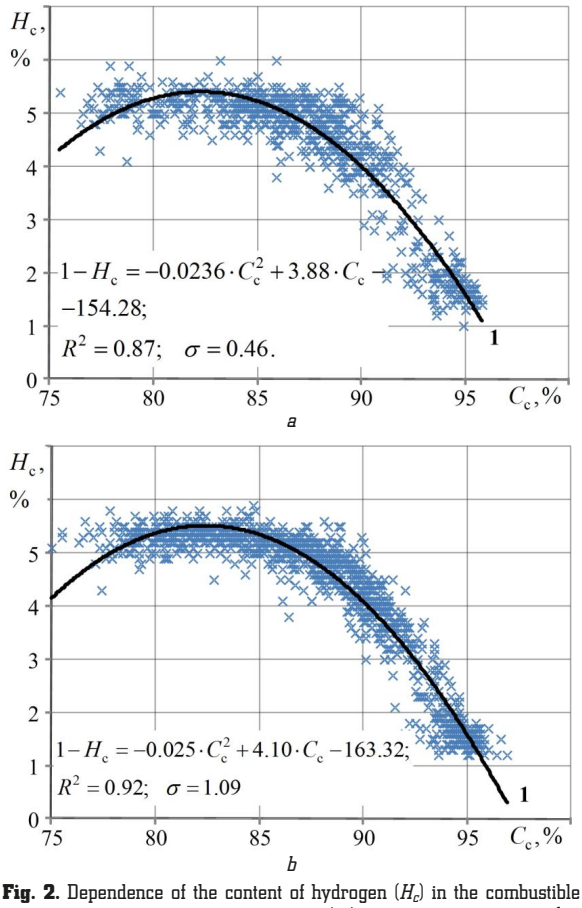

Fig. 2. Dependence of the content of hydrogen (H_c) in the combustible part of the fuel on the content of carbon (C_c): *a* – experimental data [13]; *b* – experimental data [14]; 1 – averaging curves; × – experimental data; R^2 и σ are, respectively, the coefficients of determination and standard deviations from the averaging curves

The coefficients of determination (R^2) for the considered dependences of the change in the hydrogen content of 0.87 and 0.92 approximately equally characterize the closeness of the correlation dependences in comparison with the dependences of oxygen reduction, with an increase in the influence of the degree of metamorphism (Fig. 1, *a*, *b*). Despite the similarity of the tightness of the correlation dependences, the reduction in the content of hydrogen and oxygen occurs according to completely different dependences. The decrease in the oxygen content at all stages of the transformation of the initial substance occurs more or less evenly.

When the carbon content in the combustible part is approximately less than 85 %, based on the graphs of the average hydrogen content and its individual values (Fig. 2), the hydrogen content does not decrease and remains approximately constant for a separately considered mine seam. A noticeable decrease in hydrogen occurs if, as a result of metamorphic transformations, the carbon content in the combustible part of the fuel exceeds about 85 %. Obviously, the different nature of the dependences and the rate of decrease in the content of oxygen and hydrogen in the combustible part of the fuel can have an ambiguous effect on the manifestation of the hazardous properties of mine layers at all stages of their metamorphic transformations.

The change in the sulfur content (S_c) in the combustible part of the fuel from carbon (C_c) is not subject to a certain type of correlation. To some extent, it can only be argued that there is a tendency for the sulfur content in the combustible part to decrease as metamorphic transformations intensify. This trend is characterized by negative, insignificant in magnitude, values of the correlation coefficients (–0.58 and –0.43) (Fig. 3).

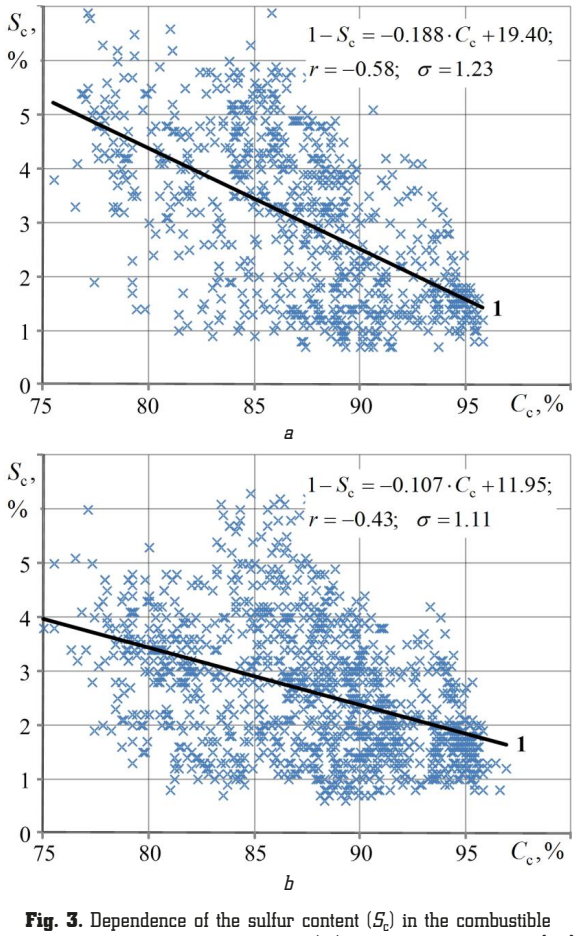

Fig. 3. Dependence of the sulfur content (S_c) in the combustible part of the fuel on the carbon content (C_c): *a* – experimental data [13]; *b* – experimental data [14]; 1 – averaging straight lines; × – experimental data; *r* and σ are the correlation coefficients and standard deviations from the averaging lines, respectively

ISSN 2664-9969

Based on the studies carried out, the features of the choice of indicators of metamorphic transformations of coals were established, which are used in parallel, respectively, to establish the quality of fuel and predict the hazardous properties of mine seams.

All indicators related to the determination of product quality are based on the analysis of analytical samples. Their preparation consists in preliminary enrichment until the ash yield, as a rule, to a level of less than 10 %, coal grinding to a fineness of 0–0.2 mm (–212 mcm) and drying to dry, close to air dry. Such a state of analytical samples of coal fundamentally does not correspond to the conditions of its presence in the mining area, since the presence of mineral impurities and moisture is neglected.

To improve the normative documents for safe mining, it is necessary to consider indicators that characterize not only the organic (combustible) part of the fuel, but also the presence of mineral impurities and moisture in coals in the mining area.

Discrepancies between the indicators of the degree of metamorphism used in the current regulatory framework for the safe conduct of mining operations and the state of fuel during mining operations in underground conditions are revealed.

4. Conclusions

The research results show that at present, based on the basic genetic signs of metamorphism, there is no reliable regulatory framework for determining the hazardous properties of mine plastics, including the tendency of coal to spontaneously ignite. Based on the statistical processing of the dependence of the main components of the combustible part of the fuel on the carbon content, close correlations were established only for oxygen and hydrogen. For the sulfur content, tendencies to its decrease were established with significant standard deviations from the averaging straight lines (σ=1.11÷1.23 %). With the absolute maximum values of sulfur in the combustible part of about 6 %, using the «three sigma» rule, it follows that for any mine formation, the sulfur content can fluctuate unpredictably over the entire range of its possible change. The random sulfur content in the combustible part significantly affects the change in the ratio between other main components, and with them the manifestation of the hazardous properties of mine seams. A similar effect on the redistribution of the ratio between the main components of the combustible part, but to a lesser extent, due to the insignificant absolute content, is exerted by nitrogen at all stages of metamorphic transformations. Its role is especially great at the later stages (at a carbon content of about 95 %), when the content of the main components (hydrogen, sulfur, nitrogen, and oxygen) is approximately equal to each other and individually less than two percent.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

The manuscript has no associated data.

References

1. Williams, F. A. (1977). Mechanisms of fire spread. *Symposium (International) on Combustion, 16 (1)*, 1281–1294. doi: https://doi.org/10.1016/s0082-0784(77)80415-3
2. Stracher, G. B., Taylor, T. P. (2004). Coal fires burning out of control around the world: thermodynamic recipe for environmental catastrophe. *International Journal of Coal Geology, 59 (1-2)*, 7–17. doi: https://doi.org/10.1016/j.coal.2003.03.002
3. Du, J., Chen, J., Pu, Y., Jiang, D., Chen, L., Zhang, Y. (2021). Risk assessment of dynamic disasters in deep coal mines based on multi-source, multi-parameter indexes, and engineering application. *Process Safety and Environmental Protection, 155*, 575–586. doi: https://doi.org/10.1016/j.psep.2021.09.034
4. Song, Z. (2022). Modelling oxygen-limited and self-sustained smoldering propagation: Underground coal fires driven by thermal buoyancy. *Combustion and Flame, 245*, 112382. doi: https://doi.org/10.1016/j.combustflame.2022.112382
5. Niu, H., Sun, Q., Bu, Y., Chen, H., Yang, Y., Li, S. et al. (2022). Study of the microstructure and oxidation characteristics of residual coal in deep mines. *Journal of Cleaner Production, 373*, 133923. doi: https://doi.org/10.1016/j.jclepro.2022.133923
6. Kolker, A., Engle, M., Stracher, G., Hower, J., Prakash, A., Radke, L. et al. (2009). Emissions from coal fires and their impact on the environment. *Fact Sheet, 3084*. doi: https://doi.org/10.3133/fs20093084
7. Antoshchenko, M. I., Tarasov, V. Y., Rudniev, Ye. S., Zakharova, O. I. (2021). On the Issue of Establishing the Stages of Coal Metamorphism for Predicting the Hazardous Properties of Coal Seams. *Nature Environment and Pollution Technology, 20 (4)*, 1495–1503. doi: https://doi.org/10.46488/nept.2021.v20i04.011
8. *GOST 25543-2013. Mezhgosudarstvennyi standart. Ugli burye, kamennye i antratcity. Klassifikatciia po geneticheskim i tekhnologicheskim parametram*. (2014). Moscow: Standartinform, 19.
9. ASTM International (2012). *Standard Classification of Coals by Rank: D388-15*. ASTM International West Conshohocken, 7. doi: https://doi.org/10.1520/d0388-15
10. Liu, F. (2022). A comparison between multivariate linear model and maximum likelihood estimation for the prediction of elemental composition of coal using proximate analysis. *Results in Engineering, 13*, 100338. doi: https://doi.org/10.1016/j.rineng.2022.100338
11. Thomas, L. (1992). *Handbook on practical coal geology*. N. p., United States, 338.
12. Grzebyk, W., Stolecki, L. (2015). Volumetric changes of rock massif preceding mining seismic events. *International Journal of Rock Mechanics and Mining Sciences, 80*, 147–154. doi: https://doi.org/10.1016/j.ijrmms.2015.09.020
13. *Spravochnik po kachestvu i obogatimosti kamennykh uglei i antratcitov Ukrainskoi SSR (Donbass v granitcakh USSR, Lvovsko-Volynskii bassein)* (1965). Kharakteristika kachestva kamennykh uglei i antratcitov Ukrainskoi SSR. Moscow: Nedra, 204.
14. *Spravochnik po kachestvu kamennykh uglei i antratcitov Donetckogo i Lvovsko-Volynskogo basseinov* (1972). Donetckii nauchno-issledovatelskii ugolnyi institut. Moscow: Nedra, 168.

Yevhen Rudniev, *PhD, Associate Professor, Department of Electrical Engineering, Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, ORCID: https://orcid.org/0000-0002-4236-8407*

Mykola Antoshchenko, *Doctor of Technical Sciences, Professor, Department of Pharmacy, Production and Technology, Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, ORCID: https://orcid.org/0000-0001-8901-8263*

Mykhailo Filatiev, *Doctor of Technical Sciences, Professor, Severodonetsk, Ukraine, ORCID: https://orcid.org/0000-0001-5608-6737*

Elvira Filatieva, *PhD, Severodonetsk, Ukraine, ORCID: https://orcid.org/0000-0002-1041-0535*

✉ ***Vadym Tarasov,*** *Doctor of Technical Sciences, Associate Professor, Department of Pharmacy, Production and Technology, Volodymyr Dahl East Ukrainian National University, Severodonetsk, Ukraine, e-mail: tarasov@snu.edu.ua, ORCID: https://orcid.org/0000-0003-3614-0913*

✉ *Corresponding author*