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MULTI-CRITERIA EVALUATION OF COAL PROPERTIES IN TERMS OF GASIFICATION

WIELOKRYTERIALNA OCENA WŁAŚCIWOŚCI WĘGLA W KONTEKŚCIE JEGO ZGAZOWANIA

This paper presents a comparative analysis of two types of coal taken from the ZG Janina and ZG Wieczorek coalmines. The aim of this study has been to analyze the suitability of the coal in the context of the gasification process. The types of coal vary considerably in terms of their characteristics. Each of them was subjected to treatment in a ten-ringed annular jig. A particle size of 0-18 mm constituted the feed. The separated coal was divided into five layers, each of them containing material from two additional annular jigs. Analysis of their characteristics was carried out for each of the five layers and for both types of coal obtained, taking into account both their physicochemical properties as well as chemical ones. Each of these characteristics was then presented in three-dimensional surface diagrams, where the ordinate (or Y-axis) and abscissa (X-axis) was the particle size and height in which the material ended up in the jig (expressed as a percentage of the total height of the device). On the basis of observations, it was found that the types of coal have different potential for gasification, although both types are within the limits specified on the basis of previous studies. A correlation analysis between particle size and remaining characteristics of coal was carried out for each of the layers, allowing to determine which of the studied characteristics induced changes significant from the point of view of the coal gasification process. The entire research and observation was supported by conclusions and findings, which shall form the basis for further, in-depth analysis of coal.

Keywords: coal gasification, suitability for gasification, multivariate data analysis, correlation matrix

Proces zgazowania węgla technologią naziemną jest coraz częściej rozważanym rozwiązaniem na całym świecie. Przyczyną tego stanu jest zarówno kwestia ochrony środowiska, jak i logistyki zagospodarowania produktów przeróbki węgla. Nie inaczej jest również w Polsce, gdzie od kilku lat proces zgazowania jest jednym z głównych tematów badawczych w dziedzinie polskiego górnictwa węglowego. Efektem tego jest szereg badań i doświadczeń, jak również publikacji naukowych. W artykule dokonano analizy porównawczej dwóch typów węgla kamiennego, które pobrane były w Zakładach Górniczych

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Janina (typ węgla 31.2) oraz Zakładach Górniczych Wieczorek (typ węgla 32). Węgle te znacząco się różnią pod względem charakterystyk. Każdy z nich został poddany rozdziałowi w osadzarce pierścieniowej o 10 pierścieniach. Nadawę stanowił węgiel o uziarnieniu 0-18 mm. Rozdzielony węgiel został podzielony na 5 warstw, z których każda zawierała materiał z dwóch kolejnych pierścieni osadzarki. Dla każdej z otrzymanych w ten sposób pięciu warstw dla obu typów węgli dokonano następnie analizy ich charakterystyk, biorąc pod uwagę zarówno cechy fizykochemiczne, jak i czysto chemiczne. Do tych pierwszych zaliczono takie parametry, jak zawartość węgla pierwiastkowego, zawartość popiołu oraz ciepło spalania, do drugich zaś zawartość azotu, zawartość chloru, zawartość siarki oraz zawartość wodoru. Szczegółowe dane dla dwóch skrajnych warstw przedstawiono w tabelach 1-4. Każdą z omawianych cech przedstawiono następnie na trójwymiarowych wykresach powierzchniowych, gdzie osiami rzędnych i odciętych były wielkość ziarna oraz wysokość, na której znalazł się materiał w osadzarce (wyrażona w procentach wysokości urządzenia). Wykresy te (rys. 1-8) stanowiły bazę do analizy porównawczej obu węgli pod kątem ich przydatności do procesu zgazowania naziemnego. Wyraźnie widać, że węgle te mają inny potencjał do zgazowania, choć oba typy mieszczą się w granicach wartości ograniczających (tab. 5), określonych na podstawie wcześniejszych badań. Następnie dokonano jeszcze analizy korelacji pomiędzy wielkością ziarna a pozostałymi charakterystykami badanych węgli dla każdej z warstw. Wyniki zobrazowano w tabeli 6. Przykładowo stwierdzono, że:

- wraz ze wzrostem wielkości ziaren w warstwach zmieniają się ich związki z charakterystykami pierwiastkowymi węgli (w kolumnach (warstwach) następuje zmiana znaku współczynnika korelacji oraz miary jego istotności);
- zasadnicze różnice występują dla siarki – dla KWK Wieczorek współczynniki te są ujemne, co świadczy o tym, że siarka w tym węglu jest prawdopodobnie siarką organiczną (w warstwach najcięższych poziom siarki maleje). Przeciwnie jest w ZG Janina, gdzie dla najcięższych warstw zawartość siarki nie zmienia się (co może być spowodowane znaczącym udziałem zrostów pirytowych). Chlor w ZG Janina koncentruje się zwłaszcza w klasach najdrobniejszych niezależnie od warstwy. Inaczej układają się współczynniki dla ZG Janina, ich istotność spada a dla warstw najcięższych ilość chloru nieznacznie wzrasta wraz z wielkością ziaren. Stopień uwęglenia w warstwach najlżejszych rośnie wraz ze wzrostem wielkości ziaren dla warstw najcięższych maleje. Można powiedzieć, że w KWK Wieczorek tylko ostatnia warstwa zawiera niewielkie zrosty węgla. Analiza współczynników korelacji dla ciepła spalania i zawartości popiołu prowadzi do analogicznych wniosków (ze względu na naturalne powiązania fizyczne tych właściwości).

Współczynniki korelacji pomiędzy wielkością ziarna a zawartościami azotu w obu kopalniach układają się podobnie, przy czym zależności te są bardziej znaczące dla węgli z ZG Janina; dla obu węgli współczynniki są dodatnie dla trzech najlżejszych warstw i ujemne dla warstw najcięższych (azot występuje w większych i cięższych kawałkach węgla).

Na podstawie dokonanych analiz można stwierdzić, iż oba węgle są dostatecznie dobre aby można je było poddać procesowi zgazowania, choć więcej cech sprzyjających temu procesowi posiada węgiel z KWK Wieczorek. Dalsze badania w tym aspekcie trwają i będą przedmiotem kolejnych publikacji.

Słowa kluczowe: zgazowanie węgla, podatność na zgazowanie, wielokryterialna analiza danych, macierz korelacji

1. Introduction

Coal properties targeted for gasification must fulfill a number of limitations (Agrawal, 2011; Blaschke, 2009; Chmielniak & Tomaszewicz, 2012; Borowiecki et al., 2008; Govind & Shah, 1984; Kosminski et al., 2006; Li et al., 2005; Lee et al., 2007; Park et al., 2011; Seo et al., 2011; Sobolewski et al., 2012; Xu et al., 2012), wherein it is essential to notice that they are connected to one another. Evaluation of the suitability of coal for gasification should therefore be carried out on a multidimensional basis using multidimensional distribution features and statistics (Jamróz, 2009; 2014; b; Jamróz & Niedoba, 2014; Niedoba & Jamróz, 2013; Niedoba, 2013; 2014; Tumidajski, 1997). It is only natural that the analysis of multidimensional features and statistics begins with an analysis of the densitometry composition of grinded coal and is extended further based on the coal characteristics, especially the contents of the components and reactions to the processing stages. Analysis of the distribution of coal in terms of the so-called class-fraction is deemed as preliminary information in respect of coal capabilities in developing the specific surface area and concentrating combustible, volatile and ash components. Determining the remaining properties allows for additional distinction of the relationships of these properties with each other as well as the aforementioned geometrical and physical features.

The paper presents an approach method to analyze these issues and this is documented in the coal databases of the ZG Janina and KWK Wieczorek coal mines. The preliminary analysis was based on the results of the initial separation of coal in the annular jig of the laboratory – analysis of fractions contained in the next annular column jig obtained in the course of research carried out under the task outlined in 2.1.2 on the subject of coal cleaning tests by mechanical processing, "which was carried out between 2012-13 in the department. The multidimensional approach in obtaining results allows to evaluate the susceptibility of coal to gasification. This problem has already been the subject of other publications in the scope of NCBiR project number 23.23.100.8498/R34 entitled "Development of coal gasification technology for highly efficient production of fuels and energy" as part of a strategic program of research and development entitled "Advanced technologies in obtaining energy" (Strugała et al., 2011; 2012).

2. Established methods

The separation of the grinded material in the jig proceeds on the basis of differences in the speed of descent of individual particles (Brożek & Surowiak, 2010; Stępiński 1964; Surowiak, 2013; 2014b; Surowiak & Brożek, 2014a, b). The separation of coal from the ZG Janina and KWK Wieczorek coal mines was carried out using a laboratory annular jig ring. After jigging, the material (from the two adjacent rings) was separated into layers, which were spread, then analyzed for the content of elements in classes and evaluated in terms of heat of combustion (in accordance with Polish standards in force, including PN-80 / G-04512).

Separation of the material layer allows for the introduction of a conventional variable, which shall be called *H*, specifying the position of particles (associated with the speed of descent of particles), which will enable the two-dimensional distribution of particles (*D*, *H*) to be defined, whereby *D* is a random variable representing the particle size, and *H* – a random variable representing the position of the particle as a fraction of the height of the jig column. Such a conventional presentation of the distribution of the random variables (*D*, *H*) will allow for the evaluation of particle concentration in the coal and the breakdown of these characteristic values essential for gasification.

Based on the literature review it can be concluded that:

– the most important characteristics of coal (the key parameters) (Sobolewski et al., 2013) directed to the process of surface gasification in a pressure reactor of the circulating fluidized deposits in a CO_2 atmosphere are carbon reaction, ash content, sulphur, chlorine, melting point of ash and the viscosity of the resulting slag (Yun et al., 2007). It is worth noting that the higher content of volatile matter arising from the thermal decomposition of coal without air supply is connected with the lower degree of carbonification (Krawczykowski et al., 2013; Surowiak, 2013; 2013b; 2014);

- the reduced content of nitric oxides and sulphur in syngas reduces emissions as well as the corrosiveness of devices (Bai et al., 2010; Krawczykowski et al., 2013);
- fuel properties, particle size, reactivity and catalytic substance content affect the kinetics of coal gasification in a deposit fluidized gas generator (Łabojko et al., 2012; Nonaka et al., 2013);
- in order to obtain high-quality process gas (used as an energy component in IGCC – Integrated Gasification Combined Cycle systems, or in chemistry as a raw material) it is necessary to take additional action in the area of preliminary coal cleaning and analyze the possibility of separating minerals and undesirable substances (Pomykała & Mazurkiewicz, 2011; Surowiak, 2013).

Concentrates of different qualities are obtained depending on the form of the presence of coal contaminants, the degree of clean coal comminution, as well as the gravity separation method (in this case, the differences in sedimentation velocities of particles in an aqueous-jig) – as can be seen in Tables 1-10 (Marciniak-Kowalska et al. – research reports 2012, 2013). Not only have upgrading curves been used as the main criterion for the effectiveness of the upgrading process (Krawczykowski et al., 2013), but also a comparative analysis of primary upgraded coal. The gravity separation method in elements of coal will be possible and effective if the density of the carbonate substance containing only the so-called internal mineral substance is in the range of 1170 to about 1500 kg/m^3 (Blaschke, 2009).

3. Research methodology – comparative analysis of coal from ZG "Janina" and KWK "Wieczorek"

3.1. Preparation of test material and primary results

In order to investigate fossil fuel upgrading intended for the gasification process of fluidized layers of bituminous coals from ZG Janina (coal type 31.2), and KWK Wieczorek (coal type 32) – each of these was subjected to upgrading in a laboratory annular jig (of 10 rings – 0-18 mm coal class). After separation process has been completed, the material was divided into five layers (two rings each) and each of them was then scattered onto sieves into 10 particle classes, determining the weight recovery of layers and their classes. Afterwards, the derived product i.e. particle classes, was subjected to a preliminary chemical analysis, after separation of analytical samples and a technical analysis of coal for the purpose of characterizing the properties affecting the gasification processes. Due to the fact that this data formed the characteristic basis of three-dimensional graphs of the coal examined (Figs. 1-8), only the results for the extreme layers of both coal types (Tables 1-4), which best characterize the dispersion in the quality of the layers of the separated coal, are presented.

In the first 3 layers, coal from ZG Janina contains less than 1% sulphur, which is twice as much as coal from the KWK Wieczorek coalmine. In the case of nitrogen content of coal from ZG Janina, it is about 1% in four successive layers, whereas coal from KWK Wieczorek has an average of more than 1.5%. In the case of chlorine content of coal from ZG Janina, it is 2 times lower than that of ZG Wieczorek. Therefore, it can be seen that coal from the Wieczorek coalmine is more burdensome for the environment in terms of precursors that cause acidification of the atmosphere (acidic oxides). However, in terms of higher efficiency of coal gasification, the coal from KWK Wieczorek is better because it has a higher hydrogen content of above 5%, more than 80% carbon element and more than 32.6 MJ/kg heat of combustion. The results summarized in Tables 1-4 can be interpreted in three-dimensional graphs, i.e. designated variables $F(d, h)$ and surfaces, depending on D and H, and particular characteristics of coal.

The overview of results shall begin with the analysis of the physical properties of coal.

TABLE 1

Primary analysis of coal in layer I after jigging – ZG Janina
(Marciniak-Kowalska et al. – research report 2012, 2013)

Class d [mm]	Total sulphur content S_t^a [%]	Hydrogen content H^a [%]	Nitrogen content N^a [%]	Chlorine content Cl^a [%]	Total carbon content C^a [%]	Heat of combustion Q_s^a [kJ/kg]	Ash content A^a [%]
< 1.00	1.20	3.70	0.97	0.134	61.70	24 060	12.90
1.00-2.00	0.84	4.12	1.09	0.111	67.70	26 657	4.30
2.00-3.15	0.83	4.15	1.02	0.122	67.60	26 610	4.40
3.15-5.00	0.83	4.16	1.07	0.105	67.70	26 639	4.80
5.00-6.30	0.83	4.17	1.05	0.099	67.60	26 630	4.60
6.30-8.00	0.82	4.28	1.13	0.096	67.20	26 523	4.80
8.00-10.00	0.78	4.10	1.10	0.084	67.70	26 525	4.10
10.00-12.50	0.93	4.21	1.12	0.079	67.20	26 529	4.90
12.50-16.00	0.82	4.22	1.10	0.099	67.30	26 711	5.40
16.00-18.00	0.87	4.36	1.11	0.10	68.00	27 066	5.00

TABLE 2

Primary analysis of coal in layer V after jigging – ZG Janina
[Marciniak-Kowalska et al. – research report 2012, 2013]

Class d [mm]	Total sulphur content S_t^a [%]	Hydrogen content H^a [%]	Nitrogen content N^a [%]	Chlorine content Cl^a [%]	Total carbon content C^a [%]	Heat of combustion Q_s^a [kJ/kg]	Ash Content A^a [%]
< 1.00	2.56	3.44	0.84	0.171	57.90	23 003	13.70
1.00-2.00	1.19	3.88	1.07	0.137	61.90	24 422	10.70
2.00-3.15	3.87	2.58	0.67	0.122	40.30	15 718	38.20
3.15-5.00	4.22	2.47	0.55	0.090	36.10	14 392	42.90
5.00-6.30	5.28	2.45	0.60	0.087	33.70	13 284	46.10
6.30-8.00	2.87	2.47	0.62	0.099	33.30	13 042	47.00
8.00-10.00	3.52	2.56	0.63	0.099	37.00	14 442	41.60
10.00-12.50	5.03	2.83	0.59	0.099	40.20	15 951	38.30
12.50-16.00	2.10	2.71	0.56	0.084	35.90	14 207	44.30
16.00-18.00	2.16	3.29	0.70	0.099	46.20	18 216	32.40

TABLE 3

Primary analysis of coal in layer I after jigging – KWK Wieczorek
(Marciniak-Kowalska et al. – research report 2012, 2013)

Class *d* [mm]	Total sulphur content S_t^a [%]	Hydrogen content H^a [%]	Nitrogen content N^a [%]	Chlorine content Cl^a [%]	Total carbon content C^a [%]	Heat combustion Q_s^a [kJ/kg]	Ash Content A^a [%]
< 1.00	0.42	4.83	1.5	0.199	77.95	31 493	3.30
1.00-2.00	0.42	4.96	1.62	0.196	80.63	32 423	1.60
2.00-3.15	0.43	5.03	1.58	0.190	80.60	32 502	1.50
3.15-5.00	0.44	5.06	1.58	0.172	80.91	32 741	1.60
5.00-6.30	0.44	5.00	1.64	0.169	80.40	32 632	1.70
6.30-8.00	0.43	5.19	1.60	0.170	80.84	32 737	1.40
8.00-10.00	0.43	5.20	1.58	0.170	80.85	33 009	1.70
10.00-12.50	0.44	5.17	1.57	0.170	81.22	32 724	1.60
12.50-16.00	0.44	5.17	1.65	0.165	80.79	32 707	1.60
16.00-18.00	0.45	5.29	1.64	0.145	79.88	32 515	2.10

TABLE 4

Primary analysis of coal in layer V after jigging – KWK Wieczorek
(Marciniak-Kowalska et al. – research report 2012, 2013)

Class *d* [mm]	Total sulphur content S_t^a [%]	Hydrogen content H^a [%]	Nitrogen content N^a [%]	Chlorine content Cl^a [%]	Total carbon content C^a [%]	Heat of combustion Q_s^a [kJ/kg]	Ash content A^a [%]
< 1.00	0.54	4.55	1.49	0.296	72.05	29 048	9.60
1.00-2.00	0.44	4.64	1.52	0.156	73.52	29 735	8.20
2.00-3.15	0.69	2.60	0.81	0.097	40.12	15 437	46.40
3.15-5.00	0.31	1.67	0.52	0.057	24.46	8 788	64.80
5.00-6.30	0.34	1.52	0.46	0.036	20.56	7 260	69.30
6.30-8.00	0.26	1.48	0.45	0.028	20.27	7 134	69.10
8.00-10.00	0.22	1.91	0.59	0.069	29.00	10 567	58.90
10.00-12.50	0.39	1.76	0.54	0.049	24.00	8 838	65.40
12.50-16.00	0.28	1.80	0.58	0.075	27.08	9 600	59.80
16.00-18.00	0.53	1.31	0.38	0.366	17.57	5 811	71.40

3.2. Analysis of the physicochemical properties of coal

In proceeding to examine the distribution of coal constituents important in terms of gasification, it is necessary to pay attention to their acceptable levels. Table 5 presents a set of characteristics examined for the purposes of this article and standards by which they should be analyzed, as well as the permissible levels of characteristics examined. Generally, these parameters are divided into key and significant features (due to gasification in a pressurized gas generator with CFB circulating fluidized bed in a CO_2 atmosphere). The key features include items such as the calorific value of over 18000 [kJ/kg], ash content of less than 25%, melting point of above 1373 [K], carbonate reactivity in terms of CO_2 above 2; in terms of carbon of below 20, chlorine content of less than 0.1%; the Hardgrove's GrH grinding susceptibility in the range of 45-65;

sinterability using the Roga RI method of under 15. Significant features included the content of volatile matter, total moisture, total sulphur content, carbon content, hydrogen content, nitrogen content, oxide content, i.e., SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, P_2O_5, TiO_2, Na_2O, K_2O (Sobolewski et al., 2012; 2013). An important parameter for a given gas generator is the appropriate grinding of coal, i.e. fuel, since the fluidized reactor processes coal with a particle size from 0.5 mm to 3 mm (5 mm) (Sobolewski et al., 2012; 2013). Table 5 shows the values only for the relevant features in the experiment. It is worth noting that the graphs illustrate the full grain composition of upgraded coal, that is with a range of up to 18 mm. Material > 3 mm would be appropriate for gasification following proper fragmentation.

TABLE 5

Limitations in respect of hard coal designated for the ground gasification process for the CFB reactor (Sobolewski et al., 2012)

Parameter [unit]	**Standard**	**Fluidized bed reactor**
Calorific value [kJ/kg]	PN-81/G-04513	> 18 000
Ash content [%]	PN-80/G-451 PN-G-05460 PN-ISO 11711	< 25
Chlorine content [%]	PN-G-4534 PN-ISO 587	< 0.1
Hydrogen content [%]	PN-G-04571:1998	3.5-5.5
Nitrogen content [%]	PN-G-04571:1998	< 2.0
Carbon element content [%]	PN-G-04571:1998	> 60
Sulphur content[%]	PN-04584:2001	< 2.0

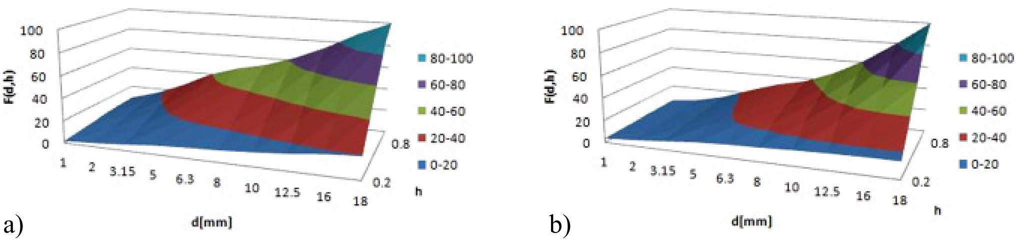

Fig. 1. $F(d, h)$ Variables for coal: a) ZG Janina; b) KWK Wieczorek

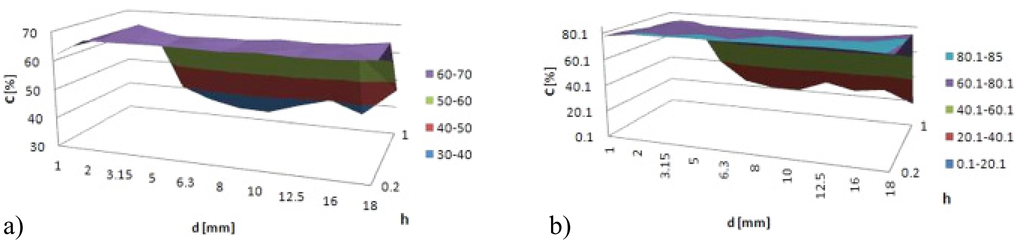

Fig. 2. Surface – coal element content = $f(d, h)$ for coal a) ZG Janina; b) KWK Wieczorek

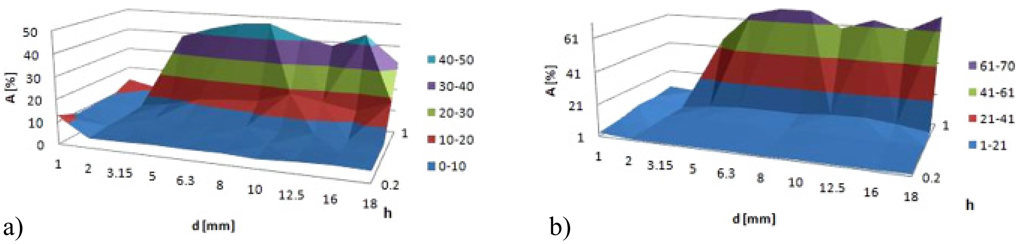

Fig. 3. Surface – ash content = $f(d, h)$ for coal: a) ZG Janina; b) KWK Wieczorek

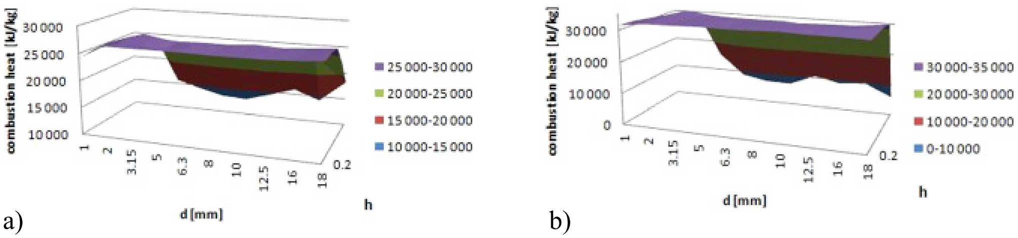

Fig. 4. Surface – heat of combustion = $f(d, h)$ for coal: a) ZG Janina; b) KWK Wieczorek

Density, particle size and the associated content of correlated carbon element, ash and heat of combustion resulting from the last two, have been accepted as physicochemical properties of coal.

In analyzing the variants $F(d, h)$ of both types of coal, it should be noted that these have different structure and texture. Coal from KWK Wieczorek contains significantly smaller amounts of fine classes, larger amounts of lighter fraction classes (with a higher carbon content). It is suspected that coal from ZG Janina is easier to break up and creates larger appropriate areas, relevant for gasification. It can be said that this is the result of lower metamorphisation of coal layers from ZG Janina.

Analyses of ash and carbon element content (Figs. 2 and 3) show the fundamental differences between the two types of coal:

- for lighter fractions, regardless of their particle size (besides the finest class), the ash content of coal from KWK Wieczorek is twice as low as that of ZG Janina, whereas the carbon element content of both types of coal is high: higher for coal from KWK Wieczorek (approximately 80%C) and by about 10% lower for coal from ZG Janina;
- in analyzing the heaviest density fractions, it can be noted that high carbon element content is present in both types of coal and significantly lower in thicker grades, indicating stone enrichment, which in turn is reflected in the analysis of the ash in individual coarser size fractions of both types of coal.
- the distribution of ash content in coal in the last layer of density (beyond the finest grade) confirms observations that there is a high concentration of ash in the previous layers (even above 60%) of coal from KWK Wieczorek – resulting from its ease of upgrading, while for ZG Janina the ash is more evenly distributed in the final three layers (between 30% and 50%).

Correlating the heat of combustion of carbon element contents and ash contents causes the graphic image to be practically identical to the image of carbon element content depending on the heat of variables *D* and *H*. Heat of combustion values for lighter fractions are lower for ZG Janina than for KWK Wieczorek and in both cases independent from the scope of the particle class.

3.3. Analysis of the chemical distribution of coal properties

Based on previous studies (section 3.2) it can be stated that obtaining coal that meets the requirements in terms of carbon element content, ash content and calorific value is not a problem, especially in the case of KWK Wieczorek. A certain problem may be ensuring appropriate carbon element content in ZG Janina. Figs. 5-8 illustrate the comparison of both types of coal in terms of the distribution of their chemical properties.

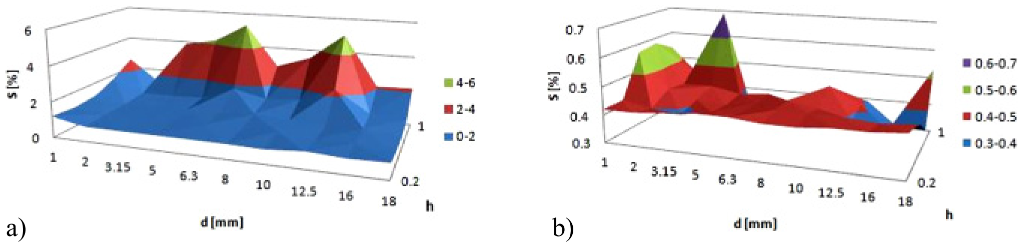

Fig. 5. Surface – sulphur content = $f(d, h)$ for coal: a) ZG Janina; b) KWK Wieczorek

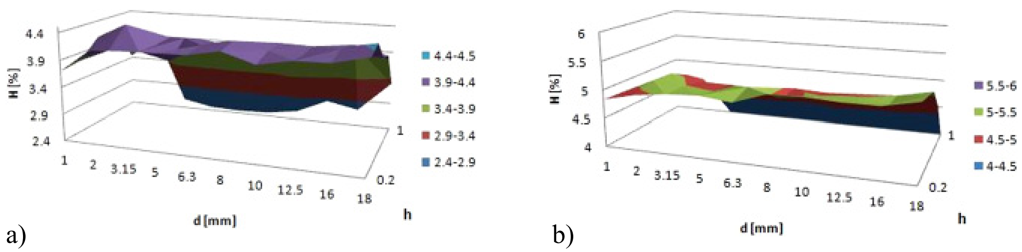

Fig. 6. Surface – hydrogen content = $f(d, h)$ for coal: a) ZG Janina; b) KWK Wieczorek

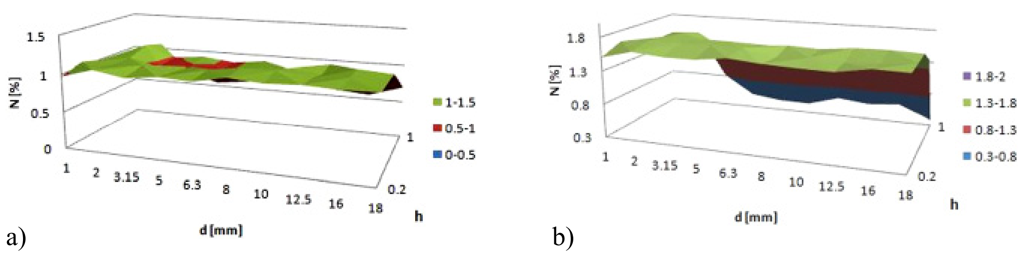

Fig. 7. Surface: the nitrogen content = $f(d, h)$ for coal: a) ZG Janina; b) KWK Wieczorek

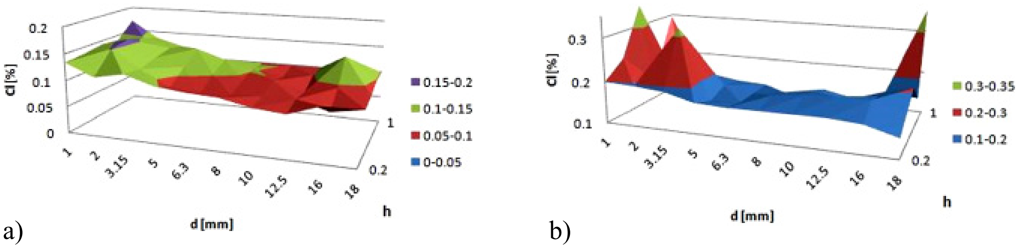

Fig. 8. Surface: chlorine content = $f(d, h)$ for coal: a) ZG Janina; b) KWK Wieczorek

In observing the distribution of nitrogen content (Fig. 7) it is clear that both types of coal fully comply with the thresholds, whereby the coal from ZG Janina has a lower N content distributed very evenly in classes and layers. Also, the distribution of hydrogen content in the coal does not cause any problems. Coal from KWK Wieczorek has a significantly larger distribution of the *H* content. In ZG Janina the heaviest layers should be removed from the gasification process (not only for this reason).

In terms of sulphur content distribution, the two types of coal vary significantly. The sulphur content in KWK Wieczorek does not exceed 1%, so there is no reason to take an interest in this issue. As far as ZG Janina is concerned, the heaviest layer, in which sulphur is bound with pyrite, should be removed in order to reduce the sulphur content. As far as the chlorine content is concerned, both types of coal slightly exceed the standards. It seems that removing the heaviest layers should lead to a chlorine balance within the normal limits.

3.4. Analysis of selected coal according to the correlation between the test characteristics

Line correlation coefficients have been determined between the particle size and characteristics of coals examined for each individual layer for the purpose of identifying the most important relationships between the parameters of the coal. In this case, with the significance level of $\alpha = 0.05$, the critical value of the correlation coefficient is $r_{kryt} = 0.63$. The results are presented in Table 6.

TABLE 6

Correlation coefficients between particle size and other characteristics of the examined coal from ZG Janina and KWK Wieczorek coalmines for each of the layers

	Sulphur	**Hydrogen**	**Nitrogen**	**Chlorine**	**Carbon**	**Heat of combustion**	**Ash**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ZG Janina							
Particle size layer 1	–0.33	0.66	0.67	–0.65	0.42	0.52	–0.34
Particle size layer 2	–0.65	0.84	0.60	–0.77	0.81	0.83	–0.46

1	2	3	4	5	6	7	8
Particle size layer 3	–0.64	0.29	0.65	–0.85	0.70	0.68	–0.49
Particle size layer 4	0.05	–0.32	–0.36	–0.58	–0.73	–0.68	0.80
Particle size layer 5	0.12	–0.32	–0.59	–0.69	–0.52	–0.51	0.55
KWK Wieczorek							
Particle size layer 1	–0.33	–0.32	0.48	–0.45	0.41	0.43	–0.40
Particle size layer 2	–0.32	0.43	0.21	–0.13	0.50	0.51	–0.54
Particle size layer 3	–0.61	0.60	0.57	–0.28	0.52	0.59	–0.54
Particle size layer 4	–0.70	–0.03	–0.49	0.23	0.24	0.10	–0.09
Particle size layer 5	–0.30	–0.69	–0.68	0.11	–0.7	–0.69	0.7

When analyzing the table of correlation coefficients, the following conclusions can be made:

- with increasing particle size, the layers change in relation to the characteristics of the carbon element content (in columns (layers), the correlation coefficient symbol and the measure of its importance change);
- fundamental differences exist for sulphur - in coal from KWK Wieczorek these coefficients are negative, which indicates that the sulphur in the coal is probably organic sulphur (sulphur level decrease in the heaviest layers). This is in contrast to the coal from ZG Janina, in which the sulphur content in the heaviest layers does not change (which may be due to a significant presence of pyrites). Chlorine contained in coal from ZG Janina is particularly concentrated in the smallest classes regardless of layer. The coefficients for coal from ZG Janina are arranged differently and their significance decreases. For the heaviest layers the amount of chlorine slightly increases with particle size. The degree of carbonification increases in the lightest layers and decreases in the heaviest layers together with the increase in particle size. It can be said that only the last layer of coal from KWK Wieczorek contains minor carbon adhesions. Analysis of correlation coefficients for heat of combustion and ash content leads to analogical conclusions (due to the natural physical connection of these properties).

The correlation coefficients between particle size and nitrogen contents in the coal from the two mines are arranged similarly, whereby these dependencies are more significant for coal from ZG Janina. In both types of coal the coefficients are positive for the three lightest layers and negative for the heaviest layers (nitrogen is present in bigger and heavier lumps of coal).

It can be assumed that extended analysis of the correlation coefficients between the characteristics of coal in classes (correlation between the columns of tables 1-4) will allow for a very precise description of the coal types and their suitability for gasification.

4. Summary and Conclusions

The proposed method of evaluating the suitability of coal for gasification is illustrative and offers a wide range of opportunities to observe the association of coal characteristics whereby certain values are significant or necessary in fulfilling the conditions in the light of their subsequent surface gasification**.** The two types of coal can be clearly differentiated on the basis of analysis. In comparing the measured values with those required, it was stated that the coal from KWK Wieczorek is better in terms of suitability for gasification, above all because it is characterized by higher heat of combustion and the values of measured properties are within the expected range. The correlation analysis also showed that it might be worth to consider eliminating the lowest layers of the material in the jig, as they can potentially generate the biggest problems during the gasification process (especially in the case of coal from ZG Janina).

The types of coal under consideration differ from each other by age and origin. Coal from ZG Janina is younger than that from KWK Wieczorek, therefore its components are not fully metamorphosed**.** Hard coal designated for the gasification process in a gas generator as a fluidized layer is a rock, which undergoes various transformations during the carbonization process, as the result of which it is characterized by a variety of mineral, petrographic, chemical and structural compositions. Therefore, there is a variety of mineral and organic carbon components depending on the petrographic type. A number of components (ash, sulphur pyrites, carbon elements, heat of combustion, and calorific value) is closely related to the density distribution of carbonaceous material and can easily be isolated by mechanical processing.

In contrast, compounds containing organic sulphur, nitrogen, chlorine, hydrogen, are those associated with coal structure as a result of geochemical, biochemical and salinity changes. Removal of these components is difficult and requires the use of chemical methods, in this case – demineralization. As multidimensional analysis individual primary components presented in the article showed, tested coal can easily be cleaned by gravitational methods and the components which correlate with the distribution of density removed. Ash and pyritic sulphur can be passed for heavy fractions (of high density). Carbon elements are concentrated in light fractions and high heat of combustion values can be observed.

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