

BARBARA BIELOWICZ<sup>1</sup>

## Petrographic composition of coal from the Janina mine and char obtained as a result of gasification in the CFB gasifier

### Introduction

Currently, coal is, and will continue to be, one of the primary energy resources in the future. As of today, coal is returning to its role, although in a slightly modified form, of a leading energy source. This is thanks to the development of the so-called clean coal technologies.

Despite the fact that the studies on petrographic and physicochemical properties of coal have a long history, there is an urgent need for a new look at the issue of the quality of coal, especially when taking its use in the combustion, gasification, and hydrogenation processes in the near future into account. However, the above-mentioned technologically advanced processes require in-depth knowledge of the fundamental relations between the petrographic composition and physicochemical properties of coal and its reactivity during the pyrolysis or devolatilization processes producing char, tar, and gases.

Gasification is a high-temperature process (above 800°C) in which the coal reacts with a gasifying agent: air, oxygen, or water vapor and, as a consequence, chemical bonds in the molecular structure of coal break up under conditions of elevated temperature and pressure to produce gas mixture of water vapor, oxygen, carbon monoxide, and hydrogen – commonly known as syngas.

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✉ Corresponding Author: Barbara Bielowicz; e-mail: bbiel@agh.edu.pl

<sup>1</sup> AGH University of Science and Technology, Kraków, Poland; ORCID: 0000-0003-2898-936X;  
e-mail: bbiel@agh.edu.pl

As of today, a number of projects on the development of coal gasification plants are being carried out in Poland. Most of them are focused on fluidized bed gasification. One of the key projects is the “Development of Coal Gasification Technology for High Production of Fuels and Energy” carried out within the framework of the National Center for Research and Development. The gasification of bituminous coal from the Janina deposit the part of the mentioned project. The discussed process was made using oxygen and CO<sub>2</sub> as a gasifying agent. A detailed petrographic analysis of the obtained char samples was conducted. The mentioned analysis allowed for the degree of gasification of coal on the basis of char composition to be determined.

## 1. Research methodology

### 1.1. Coal for gasification

The starting material, which was subjected to the gasification process, was bituminous coal from the Janina mine, Libiąż area, belonging to the Kraków Sandstone Series in the Upper Silesian Coal Basin. The mining area of the Janina coal mine is located approximately 50 km west of Kraków. The drillings have shown that the geological structure of the deposit exploited in the Janina mine contains Carboniferous, Triassic, Miocene, and Quaternary formations. The exploited coal is low rank coal (subbituminous coal) and medium rank coal (para-bituminous coal, medium rank D) occurring within the Kraków Sandstone Series in the Libiąż and Łaziska Beds (UN-ECE 1998).

### 1.2. Fluidized bed gasification

The chars that were subjected to analysis were produced as a result of the gasification. The above mentioned process involves the conversion of solid fuel, that is coal, into gas. This is carried out under atmospheric air or oxygen and appropriate temperature and pressure conditions. The conversion can be carried out in power plants or directly in the mineral deposits. The process requires energy obtained from the fuel subjected to the gasification process. This technology allows for the production of synthesis gas, which is a substitute for natural gas in power generation and chemicals production. The gasification process requires the selection and control of a number of parameters (including temperature, gas pressure, or gasifying agent) that may affect the quality and quantity of both the produced gas and unreacted material (Higman et al. 2008).

Chars are the residues of the gasification process carried out in the experimental plant of the Institute for Chemical Processing of Coal in Zabrze (IChPW). For the production of synthetic gas, a circulating fluidized bed reactor and oxygen and CO<sub>2</sub> as the gasifying agent

were used. During testing, the gasification temperature was in the range of 850–980°C. The coal flow rate was variable and ranged from 0.88 to 2.09 kg/h (Table 1). The amount of gases was also controlled and amounted to:

- ◆ for air: 43–143 m<sup>3</sup>/h,
- ◆ for carbon dioxide: 0–62 m<sup>3</sup>/h,
- ◆ for oxygen: 0–25 m<sup>3</sup>/h.

Table 1. Parameters of technological tests and the content of combustible components in process gases (Chmielniak et al. 2015)

Tabela 1. Parametry technologiczne testu i skład gazów procesowych

Parameter	Value
Gasification temperature [°C]	889–980
Coal flow rate [kg/h]	125–140
Air flow rate [m <sup>3</sup> /h]	43–143
CO <sub>2</sub> flow rate [m <sup>3</sup> /h]	0–62
O <sub>2</sub> flow rate [m <sup>3</sup> /h]	0–25
Air/coal ratio [kg/kg]	1.54–2.81
Air/CO <sub>2</sub> ratio [kg/kg]	0.19–2.39
Gas composition, dry gas, nitrogen-free, content [% vol.]	
H <sub>2</sub>	18–34.3
CH <sub>4</sub>	4.7–11.7
CO	35.9–58.1

The characteristics of the installation were already discussed in details by Chmielniak et al. (Chmielniak et al. 2015). During the gasification process carried out at atmospheric pressure, an increase in the air/coal ratio from 1.5 to 2.8 was accompanied by a decrease in the hydrogen and carbon monoxide content from 34 to 24% and from 58 to 38%, respectively.

The residues after the gasification process were subjected to a detailed petrographic, proximate, and ultimate analysis.

### 1.3. Petrographic analysis

The coal and char samples were collected before and after the gasification process, respectively. The mentioned samples were ground to a grain size of < 1 mm and used as

material for polished sections made according to standard PN-ISO 7404-2:2005. A petrographic examination was carried out in both reflected white and blue light with the use of a Zeiss microscope according to standard PN-ISO 7404-3:2001. Maceral nomenclature for both the vitrinite and inertinite maceral groups was based on the guidelines of the International Committee for Coal and Organic Petrology (Stach et al. 1982; Taylor and Glick 1998). Maceral nomenclature for the liptinite group was based on Pickel et al. (Pickel et al. 2017).

The classification scheme developed for combustion chars — Commission III Combustion Working Group of the International Committee for Coal and Organic Petrology (Lester et al. 2010) has also been used. The classification was adopted for gasification chars. The classification was based on the porosity and, to a lesser extent, on the percentage and structure of unburned organic matter.

The maceral group and char content analysis were performed using 500 equally spaced points on the surface of the polished sections.

#### 1.4. Proximate and ultimate analysis

Proximate and ultimate analysis were carried out for both coal and char. The samples were ground to a size of 0.2 mm.

The proximate analysis covered: moisture content, ash content, volatile matter content, and the Gross Calorific Value

The ultimate analysis included: carbon content and hydrogen content; the nitrogen content was determined using a Leco analyzer. The total sulphur content was determined using a Leco analyzer. The physical and chemical analyses of the coal samples and chars were made at the Institute for the Chemical Processing of Coal in Zabrze.

All chemical and technological analyses were performed in accordance with ISO standards.

## 2. Results and discussion

### 2.1. The characteristics of coal used in the gasification process

The random reflectance of vitrinite in bituminous coal from the Janina deposit subjected to the gasification process is 0.47%. The vitrinite content (mineral matter free) is around 65% vol. while the ash content (dry basis) amounts to 12.1%. According to the International Classification of In-Seam Coals (1998), the gasified coal is medium rank coal (para-bituminous coal, medium rank D), medium grade coal. Based on the ISO 11760 classification, the examined coal is Bituminous D, moderately high vitrinite and medium ash coal.

The results of the proximate and ultimate analyses of coal samples subjected to the gasification process are presented in Table 2.

Table 2. The results of the proximate and ultimate analyses of coal from the Janina deposit and the gasification char

Tabela 2. Wyniki analiz technologicznych i chemicznych węgla z kopalni Janina i karbonizatu z procesu zgazowania

Parameter	Symbol	Unit	Value Coal	Value Char
Moisture	$M^{ad}$	%	5.30	0.20
Ash	$A^{db}$	%	13.8	24.10
Volatile matter	$V^{daf}$	%	38.2	1.95
Gross calorific value	$GCV^{daf}$	MJ/kg	31.5	34.4
Carbon content	$C_t^{daf}$	%	79.93	97.30
Hydrogen content	$H_t^{daf}$	%	5.14	0.92
Nitrogen content	$N^{daf}$	%	1.30	1.60
Total sulphur	$S_t^d$	%	1.39	1.09
Aromaticity factor	$f_a$	–	0.75	0.98

The studies on the reactivity during coking have confirmed that the active site concentration in the molecular structure of chars is dependent on the aromaticity and the degree of molecular ordering in the parent maceral structure (Borrego et al. 1997). The aromaticity factor ( $f_a$ ) was obtained from the following expression in equation (1) (van Krevelen 1993):

$$f_a = \frac{1200 \cdot (100 - V^{daf})}{1240 \cdot C^{daf}} \quad (1)$$

- $f_a$  – aromaticity,  
 $V^{daf}$  – volatile matter on dry ash free basis,  
 $C^{daf}$  – carbon on dry ash free-basis.

In the examined coal, the aromaticity factor is 0.75.

The gross calorific value of coal ( $GCV^{daf}$ ) amounts to 31.5 MJ/kg (Table 2). The ash content (dry basis) is 13.8%, total moisture amounts to 5.3%, while volatile matter ( $V^{daf}$ ) is up to 38.2%. Another crucial factor in determining the suitability of coal to the gasification process is the chemical composition of coal. The sulphur content amounted to 1.39%. It is relatively high, making it necessary to monitor the movement of sulphur during the

gasification process. The carbon content amounts to 79.93%, while hydrogen and nitrogen contents amount to 4.14%, and 1.39%, respectively.

The analyzed coal is dominated by vitrinite components. In the case of the examined samples, they constitute up to 60.96% vol. (Table 3). In turn, the inertinite group (dominated by fusinite) components account for 28.97% vol. of the coal. Due to their high temperature resistance, the mentioned components are particularly undesirable during the gasification or coking processes (Wagner et al. 2008). The macerals of the liptinite group are up to 4.83% vol. These are particularly resistant to oxidation. In the early stages they are not humidified or gelified, but can be completely vitrinitized during the catagenesis (Wagner et al. 2008). The most commonly observed components of the liptinite group are spores. The mineral matter (5.23% vol.) is dominated by quartz and clay minerals. Pyrite, the source of sulphur, is up to 0.41% vol. The quantitative petrographic composition of the examined samples is presented in Table 3.

Table 3. The percentage share of macerals contained in coal from the Janina deposit and the gasification char

Tabela 3. Udział procentowy macerałów w węglu ze złoża Janina i cząstek w karbonizacie

Coal				Char	
maceral	value [% vol.]	maceral	value [% vol.]	component	[% vol.]
Telinite	4.66	Macrinite	2.14	Tenuisphere	0.45
Collotelinite	34.27	Micrinite	1.17	Crassisphere	0.9
Collodetrinite	18.81	Secretinite	0.57	Tenuinetwork	15.9
Corpogelinite	0.39	Funginite	0.88	Crassinetwork	25.11
Gelinite	2.83	Inertodetrinite	5.66	Inertoid	34.72
Sporinite	2.99	Vitrinite group	60.96	Fusinoid/Solid	4.26
Cutinite	0.71	Liptinite group	4.83	Mixed porous	12.46
Resinite	0.64	Inertinite group	28.97	Mixed dense	3.11
Liptodetrinite	0.49	Mineral matter	5.23	Mineroid	3.1
Alginite	0.0	Vitrinite (mmf)	64.33		
Fusinite	11.38	Liptinite (mmf)	5.1		
Semifusinite	7.17	Inertinite (mmf)	30.57		
Petrofactor	6.89				

Collotelinite is the main maceral of the analyzed coal. It is characterized by a smooth surface with occasional cracks and scratches. The discussed maceral originates from cells of the “woody” plant shoots. The loss of the cellular structure is a consequence of the fact that

tissues that build up the maceral are prone to destruction and gelification. Genetically, it is related to a wet environment (Stach et al. 1982).

The discussed component usually occupies large areas with dimensions up to several hundred micrometers. In the pore space of the examined samples, collotelinite chips can also be observed (Fig. 1A, B). The size of maceral clasts is highly variable and ranges from a few to several dozen micrometers. Collotelinite is often cut by fine-grained material produced from the fragmentation of components of other groups.

Occasionally, collotelinite transforms into telinite, while the boundary between the two components is fluid or very sharp. Telinite is genetically related to the abovementioned maceral but, in contrast, its cellular structure is preserved (Stach et al. 1982). In the examined coal samples, it is characterized by relatively large pores with a diameter ranging from few to several micrometers. The discussed maceral is often deformed even though the linear arrangement of cells can be observed. The intracellular space is usually filled with clay minerals or macerals from other groups, filling the pore space with, among others, resin and micrinite). What is more, telinite with closed cells can also be observed, although its content in the tested coal samples is very low. Usually, the telinite content in coal reaches up to 4.66% vol. (Table 3).

The surface of the above-mentioned macerals includes components from the liptinite group. The characteristic feature of the discussed group is its dark color, making it relatively easy to distinguish from other maceral groups.

The most commonly observed maceral from the liptinite group is sporinite (3% vol.). This term refers to spores of plants and their pollen. The aforementioned material is built of a substance referred to as sapropellin (Wagner et al. 2008). The term “sporinite” denotes two maceral groups. The first one contains microspores with a length of up to 200 micrometers, usually in the form of elongated, “safety-pin like” shapes. These are characterized by a variable degree of flattening. The spores generally have a length and width of several dozen and several micrometers, respectively. Occasionally, larger dimensions can also be observed (Fig. 1C).

Spores can reach very large sizes and form the so-called macrospores. These components are also referred to as sporinite. The observation of the examined macrospores has confirmed their thickness in the range of several dozen micrometers (40 to 80  $\mu\text{m}$ ) and to reach lengths ranging from several tens of micrometers to several millimeters. The morphology of these components allows for their easy determination. Macerals from the sporinite group are characterized by a high resistance to destructive agents (Wagner et al. 2008). Larger aggregations are associated with the air-and water transport of spores and pollen. In the examined coal samples, the sporinite content (micro- and macrospores) amounts to 2.99% vol.

In addition to the spores, other forms of elongated shape have also been found in the analyzed preparations. Cutinite, thin, longitudinal maceral consisting of fossilized epithelia, constitutes 0.71% vol. of the analyzed substances (Table 3). Its characteristic feature is the parallel arrangement with respect to the bedding surface. The thickness of the maceral is

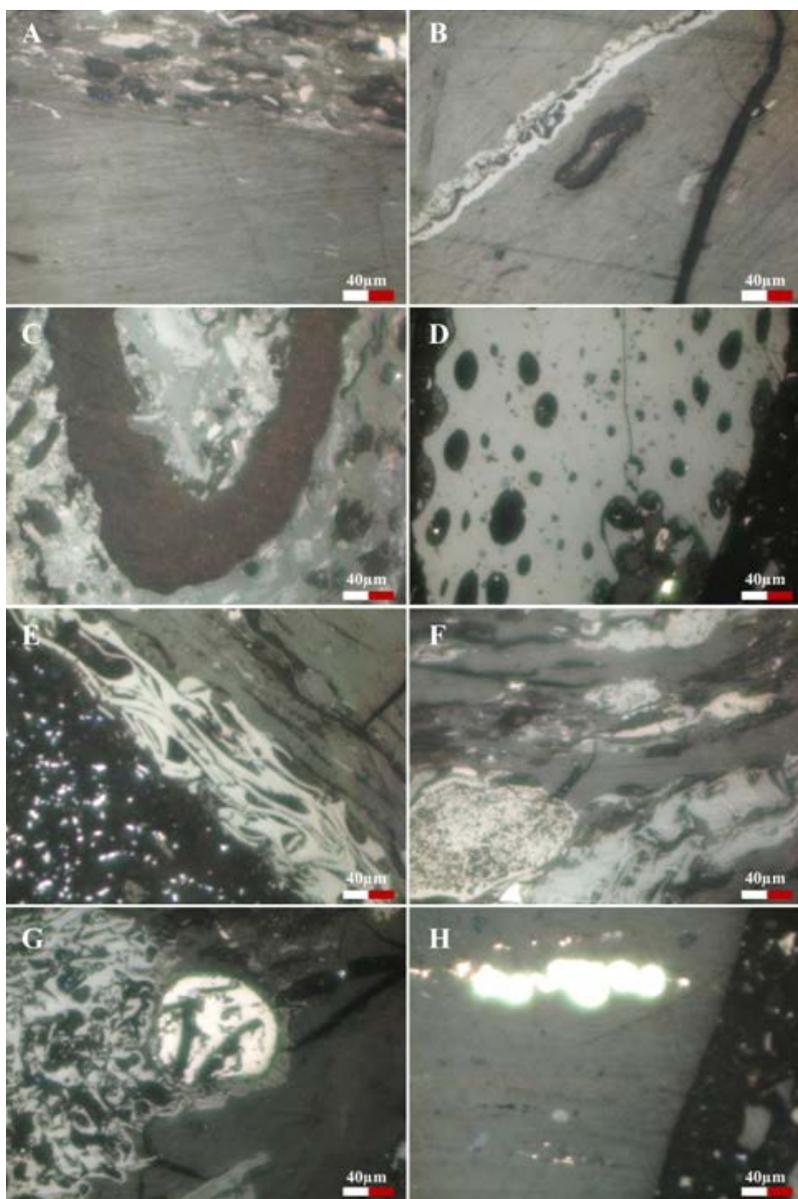


Fig. 1. Macerals in coal from the Janina coal mine.

- A) collotelinite adjacent to telinite, B) fusinite in collotelinite, C) macrosporinite,  
 D) semifusinite, with a well-preserved, thick-walled cellular structure, E) collotelinite with fusinite,  
 F) different types of fusinite and semifusinite in collodetrinite, G) pyrite and semifusinite,  
 H) framboidal pyrite in collotelinite. Reflected light, oil immersion

Rys. 1. Macerały w węglu z kopalni Janina.

- A) kolotelinit z telinitem, B) fuzynit w kolotelinicie, C) makrosporynit, D) semifuzynit,  
 E) kolotelinit z fuzynitem, F) różne typy fuzynitu i semifuzynitu w kolodetrynicie, G) piryt i semifuzynit,  
 H) piryt framboidalny w kolotelinicie. Światło odbite, imersja olejowa

highly variable. The typical thickness of the analyzed objects, resembling cracks, is several micrometers (less commonly up to twenty micrometers). In the case of cutinite, the length usually ranged from several tens to several hundreds of micrometers.

The figures 1D-F present macerals characterized by extremely bright colors resulting from their high reflectance. These are the components of the inertinite group, which are usually considered to be undesirable components of coal (Stach et al. 1982). Inertinite accounts for nearly 30% of the volume of the examined samples. The most common macerals from this group are fusinite and semifusinite. Determining the components is usually based on their reflectance (fusinite is lighter) and thickness. Macerals are usually formed as a consequence of the carbonization of plant material taking place in a dry environment and are characterized by their cellular structure (Wagner et al. 2008).

When it comes to the coal from the Janina deposit, the mentioned substances occur in different forms. Semifusinite, with a well-preserved, thick-walled cellular structure, is found in limited amounts (Fig. 1D).

The maceral is usually found in a crushed form, while the cell walls are broken, adhering to each other. Fusinite is most often adjacent to other macerals (usually collotelinite and telinite). This is probably a consequence of subjecting the walls of other macerals to the combustion process (or oxidation) (Fig. 1E, F). Unburned parts can also be found as loosely arranged fusinite particles.

Gelified, detritic, and spherical substances filling the spaces between the macerals, intracellular space, and fine grained macerals are less commonly observed. Furthermore, funginite can also be observed. Despite the small share of this maceral, it can be found in products of the gasification process.

Pyrite (0.5 % vol.) is the most important mineral in the examined coal. Iron sulphide can be found in maceral cracks and in the free space of the preparation. Occasionally, it forms cubic forms, corresponding to the morphology of the mineral (Fig. 1G, H). Iron sulphides are characterized by high reflectivity, which can be seen in microscopic images.

Based on Furimsky et al. (Furimsky et al. 1990) it has been found that the gasification reactivity appears to correlate with petrographic data of coals with a mean reflectance and petrofactor lower than 1.0 and 20.0, respectively. The fuel ratio is a good correlating parameter for coals with a mean reflectance and petrofactor greater than 1.0 and 11.0 respectively. The ignition temperature is considered a good correlating parameter for coals with the mean reflectance and petrofactor smaller than 1.0 and 11.0, respectively.

Petrofactor (Pf) has been determined based on the following formula (2):

$$Pf = \frac{R_o}{V + L + \frac{1}{3} \text{semifusinite}} \cdot 1000 \quad (2)$$

The content of reactive macerals is expressed as the sum of vitrinite + liptinite + 1/3 semifusinite. Based on the calculated petrofactor, which, in the case of coal from the Janina

deposit, is 6.89, it has been found that the examined coal is suitable for the gasification process.

## 2.2. The analysis of chars from the gasification process

Fluidized bed gasifiers are low temperature gasifiers. Their potential advantage is that low-grade coals, which are high in ash, can be processed in a more efficient way than in the case of other coal gasifiers. They generally operate below ash fusion temperatures (850–1050°C) to avoid ash melting and clinker formation (Collot 2006). In addition, low temperature gasification is the reason for a relatively low carbon conversion when compared to other types of gasifiers.

Table 2 shows the results of proximate and ultimate analyses of char, resulting from the gasification process, subjected to the petrographic, proximate and ultimate studies. As can be seen, the ash content ( $A^{db}$ ) in char has increased to 24.7%. At the same time, the volatile matter ( $V^{daf}$ ) content has decreased to 1.95%. The gross calorific value ( $GCV^{daf}$ ) has increased to 34.4 MJ/kg. The  $C^{daf}$  content is similar to the  $C^{daf}$  content in anthracite. A decrease (from 5.14 to 0.94%) in the hydrogen content can clearly be observed. These changes result from changes in the structure of coal that has been exposed to high temperature.

The aromaticity factor ( $f_a$ ) for gasification chars, amounting to 0.98, has also been determined. The results have shown an increase in aromaticity after the gasification process. The aromatic nature of the examined char increases as a result of the loss of non-aromatic side chains; this, in turn, is due to the emission of volatiles such as hydrogen and carbon monoxide, together with limited amounts of methane and carbon dioxide.

The petrographic characteristics of char were studied by (Everson et al. 2008; Hower et al. 1999; Kwieceńska and Petersen 2004; Malumbazo et al. 2012; Oboirien et al. 2012, 2011; Wagner et al. 2008).

The petrographic composition of the examined char is presented in Table 3. The most commonly found forms are inertoids and crassinetwork (Table 3). Inertoids -this term refers to macerals that have undergone minor transformations and are characterized by a relatively low porosity. Their presence indicates unfavorable properties of the starting material or insufficient conditions for carrying out the process. Inertoids constitute, on average, the third part of the material found in the examined samples (Fig. 2B, 3F). The structures related to inertoids include solids (Fig. 2C) and fusinoids (Fig. 2A, F). The former are characterized by a low porosity (up to 5%) and morphology similar to inertoids. Fusinoids are macerals (fusinite) that remained unchanged during the gasification process. Their shape, relative to that represented in coal, remains unchanged.

The most common source of inertoids are macerals of the inertinite and vitrinite group. The inertinite group is characterized by a very low suitability to gasification and coking processes. The role of semifusinite, one of the main macerals of the inertinite group, which

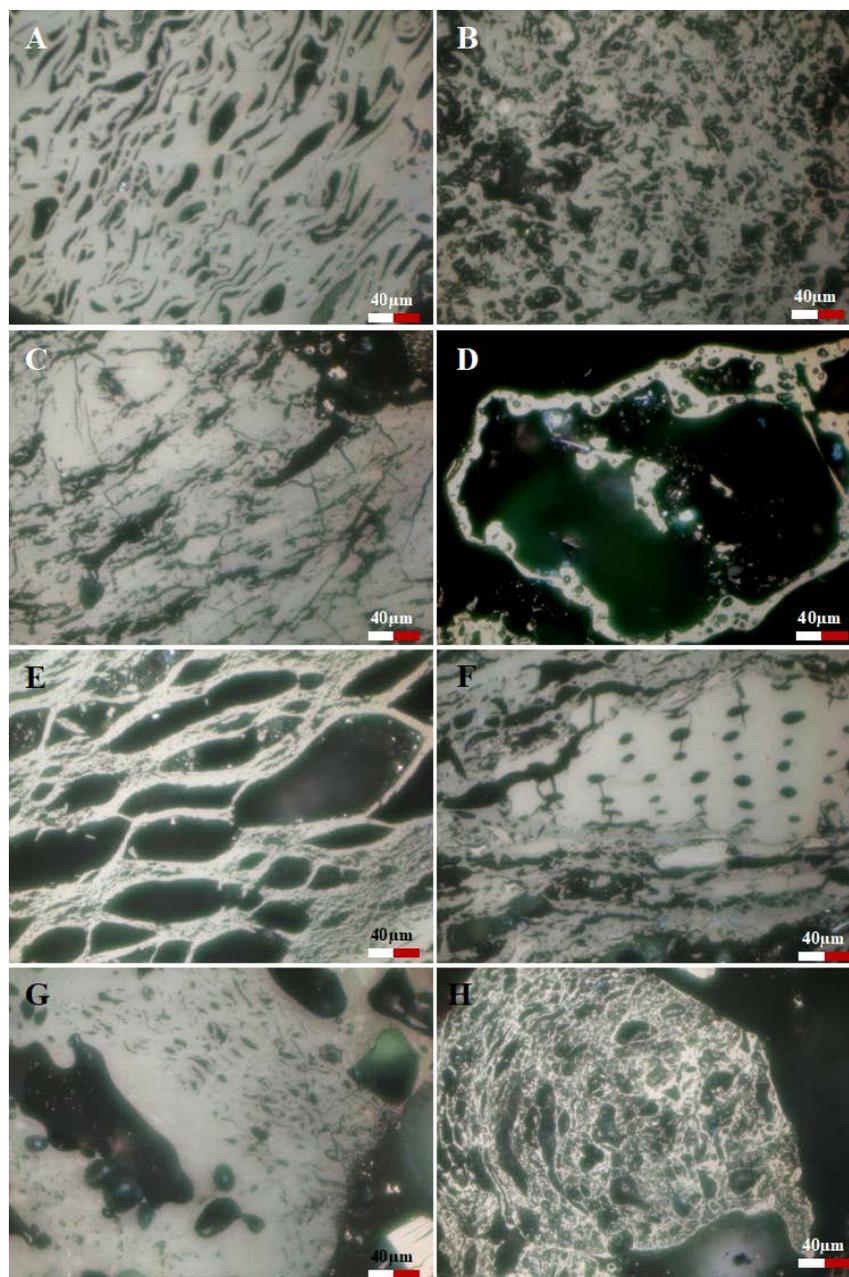


Fig. 2. Different structures observed in the char samples.

A) fusinoids, B) inertoid, C) solid, D) crassisphere, E) mixed porous probably from telinite,  
 F) fusinoid, G) mixed dense, H) mixed porous. Reflected light, oil immersion

Rys. 2. Różne formy cząstek w karbonizacie.

A) fusinoidy, B) inertoid, C) solid, D) crassisphere, E) mixed porous prawdopodobnie z telinitu,  
 F) fusinoid, G) mixed dense, H) mixed porous. Światło odbite, imersja olejowa

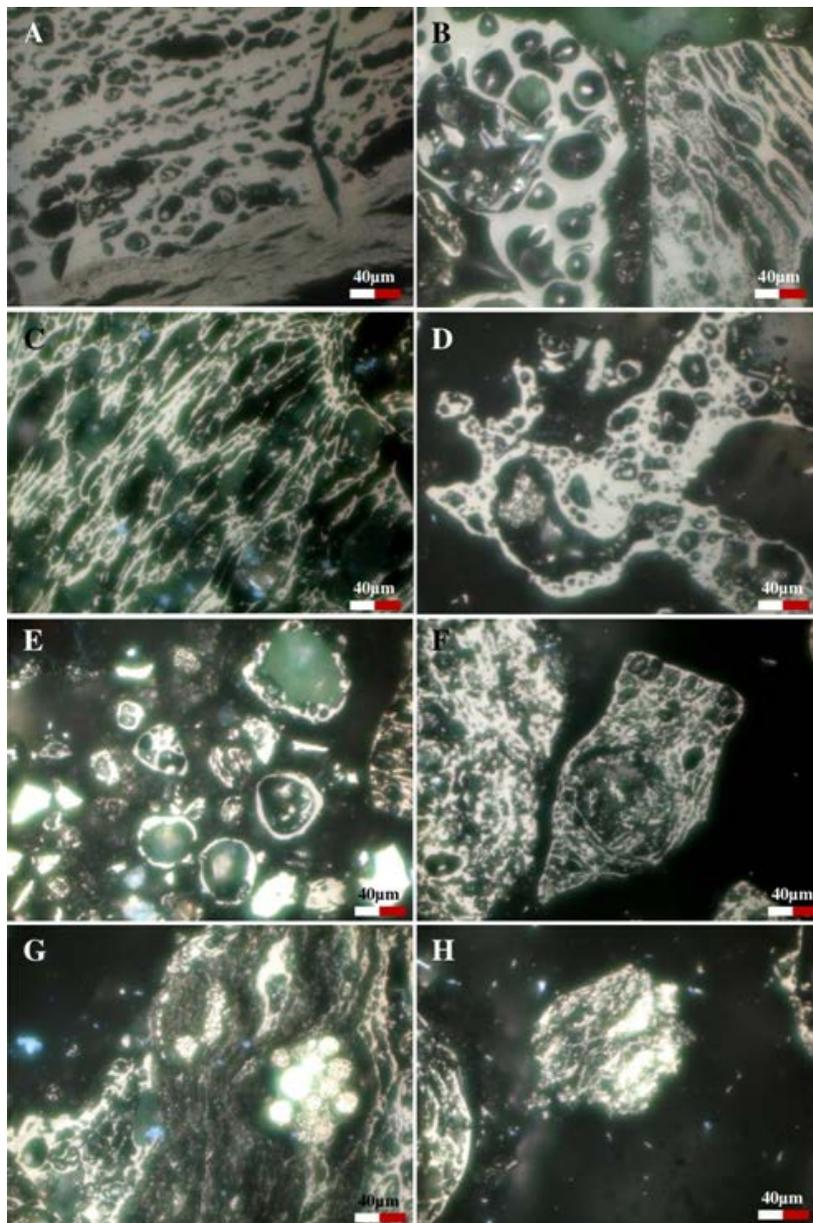


Fig. 3. Different structures observed in the char samples.

A) mixed porous, B) crassinetwork (left) and mixed porous (right), C) tenuinetwork, D) mixed porous as variable pore size, E) tenuisphere (open spheres) and crassisphere, F) inertoid, G) framboidal pyrite in mineroid, H) mineroid (with pyrite). Reflected light, oil immersion

Rys. 3. Różne formy cząstek w karbonizacie.

A) mixed porous, B) crassinetwork (z lewej) i mixed porous (z prawej), C) tenuinetwork D) mixed porous o różnej wielkości porów, E) tenuisphere (otwarte pory) i crassisphere, F) inertoid G) piryt framboidalny w mineraidzie, H) mineroid (piryt). Światło odbite, imersja olejowa

can be a reactive or inert component (Kruszewska 1998) two South African and one Polish, were examined. In all three cases collotelinite dominated over other macerals. The detailed microscopic observations revealed a close relationship between this maceral and slitted particles known as pseudovitrinite. To test the carbonizing ability of pseudovitrinite, two coking coals and one highly volatile coal (a component in coking blends, is debatable. Due to the high temperatures generated during the gasification process, collotelinite may also occur in the form of inertoids. Other components from this group are funginite and macrinite. As in the case of fusinite, their morphological features are completely preserved, which makes their identification easier than in the case of other components. The diameter of funginite is usually in the range from several dozen to 150  $\mu\text{m}$ .

An interesting fact is the occurrence of semifusinite with a very well preserved cellular structure (Fig. 2F). It occurs very rarely, but its size is relatively large – the dimensions are in the range of hundreds of micrometers. These mentioned components are characterized by a high resistance to all processes. In addition, macrinite can also be observed.

The components with network structures (tenuinetwork and crassinetwork) are other important elements. Crassinetwork (porous components with relatively thick walls of up to 30  $\mu\text{m}$ ) constitutes on average 25% of the volume of the examined material (Table 3). Empty spaces are often of irregular shape. In the case of thicknesses less than 3  $\mu\text{m}$ , these structures are referred to as tenuinetwork. They constitute on average 15% of the volume of the examined material. Their pores are usually oval and reach smaller sizes. Both components are largely related to the occurrence of macerals of cellular structure (e.g. telinite). Empty pore spaces allow for the better penetration during the gasification process, thus increasing the usefulness of the coal.

The elements described above, when occurring individually, are referred to as spheres (tenui- and crassisphere). In the case of the material subjected to the gasification process, their occurrence is extremely rare. They have oval and (in the case of crassisphere) irregular shapes. Their size is usually small (in the order of 40  $\mu\text{m}$ ), but there are exceptionally large elements, the diameter of which may exceed 200  $\mu\text{m}$  (only in the case of crassisphere (Fig. 3E). These particles are characterized by very high porosity (especially tenuisphere). When it comes to crassispheres with thick walls, they may include tiny oval pores located on the walls. They usually appear separately, but may form small local aggregations.

‘Mixed’ structures (with the dominant share of ‘porous’ structure – 12% by volume) are slightly over 15% vol. of the components. Make up slightly these elements include many smaller structures, which makes it difficult to classify them to any of the previously described groups. The mentioned mixed structures show a different degree of transformation.

Some of the components are characterized by a linear-parallel arrangement of structures, formed as a result of telinite conversion (Fig. 3E). The cell walls vary in thickness – from several up to about 30  $\mu\text{m}$ . Macerals from the liptinite group are characterized by high porosity resulting from the combustion process. Microscopic images show their longitudinal structure. Examining their cellular structure is also possible.

One of the determinants of the process is the conversion degree, which was calculated based on the following formula (3) (Ammosov et al. 1959):

$$Conversion = 100 - \left( 100 \frac{C_{char}^{daf} / A_{char}^{db}}{C_{coal}^{daf} / A_{coal}^{db}} \right) \quad (3)$$

↪ where  $C_{coal}^{daf}$  or  $C_{char}^{daf}$  is the carbon in coal or char and  $A_{coal}^{db}$  or  $A_{char}^{db}$  is the ash in the coal or the char.

Based on this formula (3), it was calculated that the carbon conversion is 30.3%. The obtained result is not very high, especially when taking into account the fact that the aromaticity factor for chars is 0.98.

The nature and type of the resulting char is related to the starting material and thus the petrographic composition of coal. Inertinites are aromatic in nature, whereas liptinite and vitrinite are more aliphatic, that is their reactivity will not be the same during gasification. The above statement is also reported by Borrego et al. (Borrego et al. 1997). This has led to the conclusion that inertinite-rich parent coals will have low reactivity as the inertinite content increases. Malumbazo et al. (Malumbazo et al. 2012, 2011) have confirmed that the higher content of inertinite in the low reactivity of coal. These results are in agreement with those obtained for coal combustion by Lu et al. (Lu et al. 2000). The difference in thermal stability resulting from the maceral composition is only significant at low temperatures. Sun et al. (Sun et al. 2003) have shown that the difference of aromaticity between vitrinite-rich and inertinite-rich fractions was larger at lower temperatures, while it became smaller at higher temperatures. When the temperature increased from 25 to 500°C, the aromaticity of vitrinite increased from 0.51 to 0.83, while in the case of inertinite it only increased from 0.76 to 0.87. At 500°C, the aromaticity of vitrinite and inertinite was very similar. This may be related to the fact that inertinite-rich coals contain lots of stable aromatic rings which are not easy broken at lower temperatures, yet could be decomposed further at temperatures over 500°C. In a similar study by Kalkreuth et al. (Kalkreuth et al. 2005), it has been found that while the vitrinite-rich coals are intrinsically more active than the inertinite rich ones at 500°C, the actual difference tended to diminish significantly at higher temperatures.

## Conclusion

Taking the vitrinite reflectance into account, the coal from the Janina mine, which was subjected to the gasification process, can be classified as borderline sub-bituminous/bituminous coal. However, other features such as the gross calorific value, black color, and the presence of macerals from the vitrinite group suggest bituminous coal. The petrographic

composition is dominated by the vitrinite group. The inertinite group accounts for almost 30%, of which around 7% is semifusinite. The share of non-reactive macerals is relatively high and is around 27%. Taking the requirements for the gasification of lignite into account (Bielowicz 2013), the coal from the Janina deposit is moderately suitable for the gasification process. However, based on the designated petrofactor equal to 6.9, it has been found that the examined coal is suitable for the gasification process. The petrographic composition of chars is dominated by particles with low porosity and network arrangement. Approximately 40% of the low porosity components in the residues after the gasification indicate a low degree of carbon conversion. This assumption is further confirmed by a relatively low conversion rate, which for the analyzed sample is 30%. It should be noted that the degree of conversion is also dependent on the type of gasification process and the gasifying agent. In the present article, the gasification temperature did not exceed 950°C, while the gasification factor was CO<sub>2</sub>, which also affected the low degree of carbon conversion. Based on the obtained results it can be stated that the petrographic composition of coal subjected to gasification is of great importance for the success of the process. Therefore, it is necessary to determine the petrographic composition of coal to be used for the gasification. A simple test will enable, to a large extent, the examination of the suitability of the coal for the gasification process and thus allow avoiding other expensive examinations.

It should, however, be noted that due to the high reactivity, the coal from the Janina mine is very useful for the gasification (Czerski et al. 2017; Porada et al. 2014, 2013).

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**PETROGRAPHIC COMPOSITION OF COAL FROM THE JANINA MINE  
AND CHAR OBTAINED AS A RESULT OF GASIFICATION IN THE CFB GASIFIER**

**Keywords**

coal gasification, char petrography, fluidized bed gasification, char classification

**Abstract**

The research was aimed at examining the impact of the petrographic composition of coal from the Janina mine on the gasification process and petrographic composition of the resulting char. The coal was subjected to fluidized bed gasification at a temperature below 1000°C in oxygen and CO<sub>2</sub> atmosphere. The rank of coal is borderline subbituminous to bituminous coal. The petrographic composition is as follows: macerals from the vitrinite (61.0% vol.); liptinite (4.8% vol.) and inertinite groups (29.0% vol.). The petrofactor in coal from the Janina deposit is 6.9. The high content of macerals of the inertinite group, which can be considered inert during the gasification, naturally affects the process. The content of non-reactive macerals is around 27% vol. The petrographic analysis of char was carried out based on the classification of International Committee for Coal and Organic Petrology.

Both inertoid (34.7% vol.) and crassinetwork (25.1% vol.) have a dominant share in chars resulting from the above-mentioned process. In addition, the examined char contained 3.1% vol. of mineroids and 4.3% vol. of fusinoids and solids. The calculated aromaticity factor increases from 0.75 in coal to 0.98 in char. The carbon conversion is 30.3%. Approximately 40% vol. of the low porosity components in the residues after the gasification process indicate a low degree of carbon conversion. The ash content in coal amounted to 13.8% and increased to 24.10% in char. Based on the petrographic composition of the starting coal and the degree of conversion of macerals in the char, it can be stated that the coal from the Janina deposit is moderately suitable for the gasification process.

**SKŁAD PETROGRAFICZNY WĘGLA Z KOPALNI JANINA I KARBONIZATU UZYSKANEGO  
W WYNIKU JEGO ZGAZOWANIA Z CYRKULACYJNYM ZŁOŻEM FLUIDALNYM**

**Słowa kluczowe**

zgazowanie węgla, petrografia karbonizatu, zgazowaniu w reaktorze fluidalnym,  
klasyfikacja karbonizatu

## Streszczenie

Celem badań była analiza wpływu składu petrograficznego węgla z kopalni Janina na proces zgazowania i skład petrograficzny powstałego karbonizatu. Węgiel poddano zgazowaniu w reaktorze fluidalnym w temperaturze poniżej 1000°C oraz w atmosferze tlenu i CO<sub>2</sub>. Stopień uwęglenia wyjściowego węgla to granica między węglem brunatnym twardym błyszczącym a węglem kamiennym. Skład petrograficzny przedstawia się następująco: dominują macerały z grupy wityrynit (61,0% obj.); a z grupy liptynit i inertynit stanowią odpowiednio o 4,8% obj. i 29,0% obj. Petrofactor w węglu ze złoża Janina wynosi 6,9. Wysoka zawartość macerałów z grupy inertynit, którą można uznać za obojętną podczas zgazowania, ma naturalny wpływ na proces. Zawartość nieaktywnych macerałów wynosi około 27% obj. Analiza petrograficzna karbonizatu została przeprowadzona w oparciu o klasyfikację International Committee for Coal and Organic Petrology. Składniki *inertoid* (34,7% obj.) i *crassinetwork* (25,1% obj.) mają dominujący udział w karbonizacie powstałym w procesie zgazowania. Ponadto badany węgiel zawierał 3,1% obj. mineroidów i 4,3% obj. fusinoidów i solid. Obliczony współczynnik aromatyczności wzrasta z 0,75 w węglu do 0,98 na karbonizacie. Konwersja węgla wynosi 30,3%. W karbonizacie znajduje się około 40% obj. składników o niskiej porowatości, co wskazuje na niski stopień konwersji węgla. Zawartość popiołu w węglu wynosiła 13,8% i wzrosła do 24,10% w karbonizacie. Na podstawie składu petrograficznego wyjściowego węgla i stopnia konwersji macerałów w karbonizacie można stwierdzić, że węgiel ze złoża Janina jest umiarkowanie odpowiedni do procesu zgazowania.