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Full Length Article

Change of the petrographic composition of lignite during the ex-situ lignite gasification

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HIGHLIGHTS

- Lignite from the Turów deposit was gasified in a pilot scale ex situ reactor.
- The gasification involves mainly macerals from the huminite and liptinite groups.
- The residues of the individual macerals can be observed in the resulting char.
- The examination has confirmed that a large part of lignite was only dried.

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ABSTRACT

The study examined the impact of the process of underground gasification on the petrographic composition of lignite from the Turów deposit. The lignite fed into the reactor is mainly xylodetritic and sapropelic lignite.

As a result of the gasification process in the reactor, a cavern and lignite residues were formed. The samples collected from the individual areas were subjected to a detailed petrographic analysis. On the basis of petrographic analyzes it can be concluded that lignite is being transformed as a result of thermal gasification process. Transformation areas, closely related to the temperature prevailing in the reactor, are clearly visible. Moving from the cavern, the following areas can be distinguished: ash area, coke area, degassed area containing dried lignite, cracked transversely to stratification and dried lignite area.

These areas can be easily correlated with the distribution of temperature in the reactor. A burned out cavern was formed in the place where the temperature exceeded the ignition temperature of lignite (approx. 500 degrees Celsius).

The layers of sapropelic lignite were heavily dried and degassed during the gasification process. Both gelification and fusain layers are not observed within these layers.

The ash and portions of coked lignite, characterized by the highest temperature and the largest concentration of oxygen, are mainly observed in the fire channel. The examination has confirmed that a large part of coal was only dried. The biggest changes were observed directly at the cavern and in the fire channel. Sapropelic coal has changed to a lesser extent. The changes include drying and partial degassing. In some places, a thin layer of coke can be observed.

The most commonly observed transformations include strong gelification and the formation of fusain.

1. Introduction

Despite the fact that petrographic analyses of lignite are commonly performed, modern technologies increasingly necessitate the use of petrographic methods for examining the suitability of coal in clean coal technologies. One of them is the gasification of coal. The gasification of lignite is carried out in order to obtain synthesis gas, burned as a substitute for natural gas, or used in the Fischer-Tropsch synthesis of liquid fuels [1]. The gasification can be carried out in surface gas generators or in-situ (Underground Coal Gasification – UCG) [2]. The process of underground gasification of coal is influenced by many factors. The basic, in addition to the gasifier parameters, are technological, while the most important are the geological conditions of the deposit [3–9]. The term UCG was introduced in the United Kingdom in 1868 by William Siemens, who first proposed the underground gasification of coal and waste in mines. Russian chemist Dmitri Mendeleev developed the Siemens' idea over the next years. The first experimental work

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on UCG started in 1912 [1]. Since then, a number of key studies have been carried out in many parts of the world, all of which are focused on the development of new UCG technologies. For some time, there was no interest and research on UCG due to the use of cheap natural gas [10]. Now, however, the demand for energy characterized by lower emissions, security of supply, and in light of decreasing reserves of oil and natural gas, UCG has once again become a subject of interest and research.

While the UCG studies have been conducted mainly in Australia, installations are also being built in other countries, including New Zealand, South Africa, China, USA, Spain, Turkey, India, Indonesia, Vietnam, Pakistan, and the United Kingdom. The pace of new projects continues to grow and includes large-scale commercial projects using both bituminouscoal and low-rank coal. The criteria that must be met by the coal deposit, to be qualified for the underground gasification, include both the technological and geological criteria. These criteria have been the subject of several studies [11–12]. However, it is worth noting that the criteria for installation construction sites designated by other researchers are closely related to the availability and location of deposits, which determine the geological structure. The possibility of UCG is affected by coal characteristics, particularly coal rank and reactivity, including ash content, moisture, sulfur and methane content. However, it should be noted that coal is a mixture of coalified organic matter represented by macerals and mineral matter.

The impact of petrographic composition of coal on the production of char was studied by [13–19]. The petrographic characteristics of char were studied by researchers [20–26]. However, the mentioned papers focus on the products of the surface gasification of coal, while petrographic changes resulting from underground gasification process have not yet been studied.

The paper presents petrographic characteristics of lignite before and after the gasification in the ex-situ reactor. The experimental ex-situ installation allowing to carry out the UCG process on the surface was used for the gasification of lignite sample from the Turów deposit in the "Barbara" Experimental Mine in Mikołów. The experiment was carried out under the project: "Development of coal gasification technology for highly efficient production of fuels and electricity" at the Central Mining Institute (GIG) in Katowice, Poland.

This installation is a non-pressure system designed for the maximum deposit length of 7.0 m. The design of the equipment used makes it possible to obtain similar geological conditions to those prevailing near the underground reactor, both for lignite seam and the surrounding layers, and provides the necessary technical infrastructure for conducting the gasification process [27,28].

2. Research methodology

The *ortho*-lignite samples subjected to gasification process were collected from the Turów deposit at +41 m.a.s.l. on the left side of the C – 12.4 conveyor. The Turów deposit derives from the orogenic subsidence and is located within the Zittau basin. Tertiary sedimentary formation in the Zittau Basin consists of rocks coarse-grained rocks, fine-grained clays and lignite [29].

Large, cuboid-shaped blocks of lignite, with the longest possible side dimensions of 80 × 80, were cut from the collected samples. A gasification channel with a cross section of 10 × 10 cm was cut on the bottom of each of these blocks. In addition, the material for chemical and technological examination was collected; stratigraphic sections were measured. The samples were cut to size and introduced to the reactor. The dimensions of the lignite sample fed into the reactor were 80 cm, 80 cm, and 5.7 m (W × D × H). In the examined samples, lignite lithotypes were determined on the basis of macroscopic examination.

The lithology of coal within the samples of humic lignite, was described using the scheme proposed by Kwiecińska and Wagner [30]. Lignite lithotypes include: detritic, xylo-detritic, xylitic, detro-xylitic, and fusain lignite.

Xylitic, detritic, and fusain lignite are homogenous lithotypes, while *xylo*-detritic and detro-xylitic lignite are heterogenous lithotypes. ortho-lignite (lignite) can be distinguished by its brown color, relatively low firmness, and, in the case of xylites – by their similarity to modern wood. Gelified varieties (in extreme cases – gelitic brown coal) with a brownish-black or black color, black gloss, and conchoidal, uneven fracture are undesired in the gasification process.

In the case of bituminiferous (sapropelic) lignite, semi-bituminiferous and bituminiferous (yellow) lignite were distinguished [31]. The lignite samples for microscopic examination were selected from the determined lithotypes. Grain preparations were made using a total of eight channel samples that were collected.

The lignite sample was grinded to the size of 1 mm while char samples were not grinded. The collected samples were used as material for polished blocks. Petrographic examination was performed in both reflected white and blue light, with the use of a Zeiss Axioplan microscope.

The petrographic composition of lignite before the gasification process was determined by identifying the maceral groups in accordance with the ICCP guidelines [32]. The liptinite maceral group was determined in blue light. The quantitative studies were performed using the point counter. The maceral group and char type content analysis was performed with use of 500 equally spaced points on the surface of the polished sections.

The char was characterized on the basis of the classification scheme developed for combustion chars — Commission III Combustion Working Group of the International Committee for Coal and Organic Petrology [33].

Pictures in the micro area and the EDS analysis were performed with a FEI Quanta 200 FEG Field Emission scanning electron microscope. All technological and petrographic analyses were made in accordance with the applicable ISO and Polish standards.

3. Research results

3.1. Lignite before the gasification process

Chemical and technological analysis of a channel sample from the deposit subjected to gasification process has been carried out at the Central Mining Institute (GIG) in Katowice, Poland. This analysis has been presented in Table 1.

The lignite subjected to gasification process has good chemical and technological properties. According to the ISO Coal classification [34] it is classified as Low-rank C (lignite C), high vitrinite (huminite) and low-ash lignite. In addition, low sulfur content and relatively high net calorific value have a positive effect on the possibility of its use in the gasification process. The high moisture content (46.52%) is unfavorable for the gasification process because a large part of the energy from the coal burning will be used to evaporate water contained in the raw coal. Generally, water is essential during gasification but such high content of water deteriorates the efficiency and lowers the temperature of the process [28].

3.2. Macroscopic characterization

The share of individual lithotypes of lignite in the discussed deposit is presented on the graph (Figs. 1 and 2). The lignite fed