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Full Length Article

Vitrinite reflectance as a measure of the range of influence of the temperature of a georeactor on rock mass during underground coal gasification

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ABSTRACT

Tests of coal samples collected from a borehole drilled in the surrounding of an underground coal gasification georeactor were conducted. This experiment was conducted for the first time in an active coal mine in Poland.

The aim of the tests was to determine the extent of heat penetration around the UCG cavity during a nearly two month gasification process. The method of measuring the mean reflectance of the vitrinite index (R_o), which is more generally used to measure the degree of the coalification of organic substances in coal (macerals) under the influence of temperature, was applied. The method is still used to evaluate the usefulness of coal for producing coke.

The mean reflectance of the vitrinite index determined for the collected samples and reflectograms, allowed the inference that when the georeactor was operating, the temperature in the UCG cavity reached approximately 1300 °C. Based on R_o, the point in a coal seam surrounding the georeactor corresponding to the temperature of approximately 700 °C was also identified, where there were signs of the initial stage of coal transformation. The point was located 1.94 m from the boundary of the UCG cavity. Then, at the distance of 1.73 m from the boundary of the UCG cavity the point with a temperature of approximately 1000 °C was identified. The tests confirmed that it is possible to use the method of determining the mean reflectance of vitrinite index to measure the distance of influence of georeactor temperature on the rock mass. This is particularly important for underground coal gasification conducted in active mines. In the future the results will be used to predict the time of heating needed for coal deposits to become gasified, based on laboratory tests and coal type.

1. Introduction

Underground coal gasification (UCG) is considered to be one method of economical coal deposit management. It enables both the use of the energy potential of coal and the production of a raw material in the form of gas which can be used to produce hydrogen [1–3]. Experience gained so far in UCG research facilities around the world has enabled the development of UCG technologies. Knowledge about impediments and requirements is also necessary for the development of these technologies [4–6]. Mallet [5], based on the historical analysis of nearly a hundred UCG experiments conducted so far, determined five main problems connected to the use of the UCG method in a coal seam. The most important of these are: the proper recognition of the geological conditions of the deposit, the proper selection of gasification process parameters and the occurrence of threats, e.g. toxic gases. In selected cases, the temperature of the USC process plays an important role, as it determines the behaviour of the rocks surrounding the georeactor and the quality of the gases produced.

The process of underground coal gasification in active mines presents a novel and promising challenge. The first of this kind of experiment was successfully conducted in the Wieczorek hard coal mine in Poland [7] and so far few other experiments in active coal mines have been conducted. However, the implementation of UCG in an active mine creates new problems. If it is to be done, a number of technical criteria must be met and the experiment must be economically justified [8].

One of the more important parameters of a gasification process conducted in an active coal mine is the temperature of the process. It must be controlled so as not to jeopardise operations in a coal mine. It refers to both the temperature of the coal seam and the temperature of the gas extracted to the surface and the processing facilities [9,10].

The temperature of a georeactor influences its surrounding. Initially it affects just the coal deposit, then also the rocks surrounding it. High temperatures (usually above 1000 °C) cause structural changes in the coal seam and the rock environment in the form of cracks in the rock mass, which affect both the safety of georeactor operations and the

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energy efficiency of the process [11–15]. The main aim in UCG process planning is to avoid fire hazard in neighbouring working mines, where coal is still being mined.

When planning UCG in an active mine, the maximum temperature of georeactor operations was assumed. This is usually determined based on initial tests conducted in laboratory conditions, in pilot installations, or based on mathematical modelling [16–18]. It is a known fact that different types of coal are gasified at different temperatures, depending mainly on the degree of their coalification [19,20]. The degree of coalification is a measure of metamorphic transformations which the coal was subjected to during the diagenesis process. Hence different types of coal have different susceptibility to the gasification process (reactivity) [21].

There are three groups of macerals in hard coal: liptinite, vitrinite and inertinite. From the point of view of the gasification process, possibly the content of reactive macerals, including vitrinite group macerals and liptinite group macerals, is important. As liptinite occurs in small quantities (mostly up to 10%), vitrinite content plays an important role [21].

The mean reflectance of the vitrinite index (R_o) is one of the basic parameters used to evaluate the degree of the coalification of organic substance in coal. Its value increases as the degree of the coalification of organic substances in coal increases. [21]. It is applied as one of the most important parameters when evaluating the susceptibility of a given type of coal to the coking process [22–25]. Thermal transformations of coal macerals during UCG are roughly comparable to the ones occurring during the coking process. Coal which is directly exposed to high temperatures during the gasification process changes its properties. Its structure becomes anisotropic and, depending on the distance from the oxidation zone, it transforms into coke or semi-coke, and at greater distances into degassed coal [11–15]. Both during the coking process and gasification, the process temperature determines the course of transformations and the final product.

In known literature, the problem of coal quality in underground coal gasification is frequently described, however most reports concern inactive coal mines. There is still a lack of knowledge concerning coal quality in an active coal mine, where the temperature of a georeactor is one of the most important issues for the proper recognition of geological and hydrogeological conditions in a mine where the UCG process will be conducted [9].

This article presents an attempt to use the mean reflectance of vitrinite index (R_o) to estimate the influence of temperature on the rock mass where it is located.

2. Experimental

Three types of samples were collected. For laboratory scale gasification tests, the samples were collected from the coal seam before coal gasification (PI). To estimate the mean reflectance of vitrinite index (R_o) and reflectograms, the samples were collected from a drill core made after georeactor extinction (PII). The borehole was drilled at 46° from a neighbouring mine working, driven over the seam where the gasification process was conducted (Fig. 1).

Samples were collected every 30 cm. The samples collected in the second stage were used to assess changes in the mean reflectance of the vitrinite index (R_o), as a measure of coal transformation in the surrounding of the georeactor under the influence of temperature. Additional samples were collected from the inside of the UCG cavity as a coal grain (PIII).

A PI sample was tested to determine the properties of the raw coal to be gasified. They included technical analysis parameters, such as: moisture, ash and volatiles (following standard PN-G-04560:1998) [26], elemental analysis parameters: carbon, hydrogen, nitrogen (standard PN-G-04571:1998) [27]. The type of coal was determined following Polish classification (standard PN-G-97002:1982) [28]. Moreover, microscopic examinations were conducted to determine the petrographic composition of coal (standard PN-ISO 7404-3:2001 [29], and the mean reflectance of the vitrinite index (R_o) (standard PN-ISO 7404-5:2002) [30]. The tests were conducted on polished sections prepared following PN-ISO 7404-2:2005 [31].

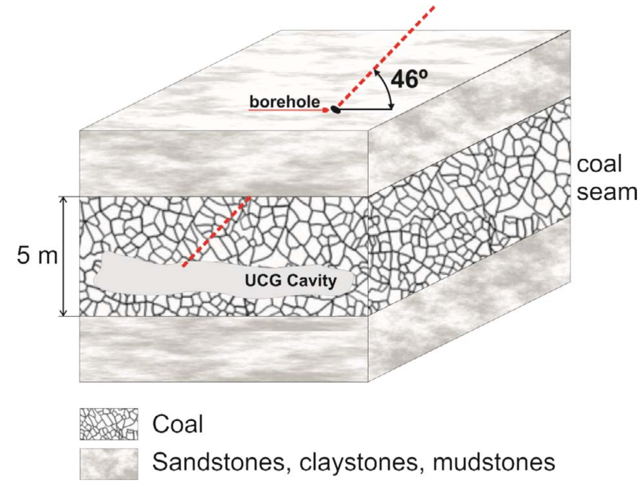

Fig. 1. Schematic of bore run in experimental coal seam.

Coal collected from the seam (PI) was degassed in laboratory conditions. The experiment was conducted in a thermogravimetric analyser at temperatures of: 700, 1000 and 1300 °C, in flowing nitrogen, at steadily increasing temperature at a rate of 25 °C/min. After reaching the chosen temperature, a sample was heated at this temperature for 60 min.

In laboratory scale tests, temperature values were chosen based on available literature [13,32,33]. It is known that the coal gasification process is often conducted in temperatures up to 1300 °C. With this information in mind, temperatures of 700 °C, 1000 °C, 1300 °C were used in laboratory scale tests to obtain the full profile of coal transformation during temperature influence of vitrinite reflectance. For temperature prediction in the UCG process, an analysis of the mean reflectance of vitrinite index (R_o) for borehole samples was conducted. Based on R_o values from borecore samples compared with R_o values received from laboratory tests in 700 °C, 1000 °C, 1300 °C, information about temperature distribution in surroundings of the cavern and in the cavern itself were completed. For the samples collected from a drill core (PII), for remnants of gasification (PIII) and remnants of degassing in laboratory conditions (PI), changes in coal properties, based on the mean reflectance of vitrinite index and the obtained reflectogram, were conducted [30]. To determine R_o, intensity photocurrents induced in a photomultiplier under the influence of light reflected from the polished surface of the vitrinite are measured. Observations of structural changes in the organic substance of coal occurring in samples subjected to temperatures of 700 °C, 1000 °C and 1300 °C in laboratory conditions and in samples collected from drill cores and from the inside of the UCG cavity were performed with a Carl Zeiss microscope Axio Imager.D1m equipped with J&M's photomultiplier PMT. The tests were conducted in oil immersion, objective magnification of 50x and ocular magnification of 10 ×.

3. Results

3.1. Results of laboratory scale tests

Coal from the seam, where the UCG experiment was conducted, shows properties of flame coal (type 31.1 according to Polish coal classification). The observed mean reflectance of the vitrinite index (R_o) is 0.68% and the carbon content is (C^{daf}) 76.79% (Table 1). Macerals of the vitrinite group (Table 2) are dominant in the petrographic structure of coal.