Short Communication

Results of Briquetting and Combustion Process on Binder-Free Coking Coal

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Abstract

Much research has assessed the validity of using partially briquetted coal in the coking process. However, the results are not being published. According to the producers, the use of lump coal in a mixture of coal with a low degree of metamorphism improves coke quality and provides consistency to its parameters. The Polish Department of Manufacturing Systems has undertaken a study to determine the possibility of briquetting fine coke in roll presses without a binding component. Mentioned studies were conducted on a laboratory roll press type LPW 450 equipped with the original asymmetrical layout compacting system. In order to identify merged coal, basic physical and chemical properties were determined. Keeping in mind the value of environmental hazards, the possibility of applying electrostatic precipitators to capture ash from combustion of coal chip, based on past experience in this field, was evaluated [1-7]. This paper presents some of the results of mentioned considerations.

Keywords: briquetting, elektrofilters, coal, roll presses, environmental protection

Introduction

Coking coal is mainly used in the production of coke – apart from iron ore, the primary feed ingredient for the production of steel. According to some producers, preferred coal preparation for the coking process is the concentration that can be implemented, for example, by briquetting. The process itself ensures improved quality of coke for a specific mixture of carbon and fixes its quality for increased participation in the mix of coal with a low metamorphism level, also allowing thermal disposal of certain waste in the process of coking. The Department of Manufacturing Systems in AGH completed an initial research program for the assessment of vulnerability of coking coal briquetting roll presses. In the study, a gravity feed press had its original asymmetrical compaction layout. Given the environmental and economic considerations, a briquetting test was performed without using a binder. Thus in order to evaluate the characteristics of fuel, a thermogravimetric analysis was performed. In the final stage of research special attention was paid to some aspects of the emission and reduction of ash pollution for use of electrostatic aftertreatment generated in the process.

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Research Methodology

Coal was analyzed to determine the main properties affecting thermal conversion. The proximate and ultimate analyses, as well as the calorific values of the studied sample, were determined (Table 1). The properties include volatile matter, ash, moisture content, heating value, and

Table 1. Ultimate and proximate analysis of coal.

Sample	Ash (wt%)	Carbon (wt%)	Hydrogen (wt%)	Nitrogen (wt%)	Sulphur (wt%)	Oxygen[a] (wt%)	HHV[b] MJ/kg
Coal	7.8	80.6	5.0	1.4	0.46	4.7	31.37

[a] calculated by difference
[b] high heat value

chemical composition were made according to European standard procedures: DIN 51718A/CEN/TS 1514-1/-2, DIN EN 15403, DIN EN 14582/CEN/TS 15408, and DIN 51732/CEN/TS 15407. A Truespec CHN Leco elemental analyzer was used to determine carbon, hydrogen, and nitrogen contents. Sulphur content was analyzed using ICP-OES Vista Varian apparatus. Presented coal is typical Polish coal, with high content of carbon and very high heating value. Coal ash yield is low (7.8 wt. %).

To study the briquetting process in a roll press carbon 34 was used, with a moisture content of 11.8%, which was averaged in a laboratory zeta agitator. Some of the material was dried to a moisture content of less than 0.1%. Determination of moisture was carried by gravimetric method. The sample of coal prepared for briquetting was weighed in order to determine its mass. Then it was died at 105ºC to obtain a constant weight. Moisture of material prepared for briquetting was calculated by using the following formula:

$$w = \frac{m_{\mathrm{w}} - m_{\mathrm{s}}}{m_{\mathrm{w}}} \cdot 100\% \ \left[\%\right] \qquad (1)$$

...where:
w – mixture moisture [%]
m_w – mass of the sample before drying [g]
m_s – mass of the sample after drying [g]

An average of 3 moisture determinations was considered representative. Material prepared for briquetting was fed into a compaction zone of LPW 450 roll press equipped with a gravity feed. The formed rings used for briquetting without a parting plane had a volume of 6.5 [cm^3]. Properly prepared coal was briquetted with a peripheral speed of v_w = 0.05÷0.3 m/s, which is equal to the rotational speed n_w = 2.12÷12.73 rpm. The initial value of the gap between the rolls during briquetting was δ_{nom}~1.0 mm. After leaving the pits, briquettes accumulated in the container, from which the sample was collected randomly (in series of 10) in order to determine the parameters characterizing their properties. Given the nature of the strain faced by briquettes during their handling, transport, and management, the scientists decided that the indicators that best reflect their degree of destruction resistance will be compressive strength (K_0) and discharge resistance (D_0), determined directly after the test. Briquette strength tests were performed on a compression bench equipped with a ZWICK 1120 press with pressure of 0÷2000 N. Briquettes were pressed between two parallel planes at a speed of v=0.001 m/s, while the force direction was perpendicular to these planes.

Briquettes were dropped in a series of 10 pieces from a height of 2 m onto a steel plate 60 mm thick. The tests were repeated three times, each time the mass of crushed samples was sieved through a sieve with mesh size of 18×18 mm. Sieve size was determined as 2/3 of the average calculated from the two largest dimensions of the briquette, measured in perpendicular directions.

Strength of briquettes for the drop was calculated by using the following formula:

$$K_0 = \frac{m_{\mathrm{k}}}{m_{\mathrm{p}}} \cdot 100\% \left[\%\right] \qquad (2)$$

...where:
K_0 – resistance of the briquettes dropped right after sampling [%]
m_p – mass of 10 samples before drop [g]
m_k – mass remaining on the oversize sieve [g]

Test Procedure and Results

Two series of coking coal were tested, the first provided by the producer, with a moisture content w = 11.8% and bulk density of 0.62 g/cm^3, the second dried to moisture content of less than 0.1%. As a result of this study briquettes without a parting plane with a volume of 6.5 cm^3 were obtained (Fig. 1).

The results of measurements and calculations were presented in a graphical manner as Figs. 2 and 3.

Fig. 1. Saddle-shaped briquettes with a volume of 6.5 cm^3, obtained in a laboratory LPW 450 roll press, made of fine coking coal.

Drop and compressive strength, measured immediately after the test for briquettes were as follows:

- carbon moisture w=11.8%:
  $K_0 \in (15 \div 32)$%, $D_{168} \in (18 \div 38)$ N
- carbon moisture of less than 0.1%:
  $K_0 \in (55 \div 98)$%, $D_{168} \in (158 \div 327)$ N

Briquettes obtained from fine coal with 11.8% moisture content were distinguished by very low mechanical strength, both the drop and compression. After heating the material at 105ºC to a moisture content of less than 0.1% and briquetting it in a roll press, the strength measured immediately after the sampling grew significantly. With the increase of peripheral speed value of the press rollers, the strength parameters of briquettes decreased.

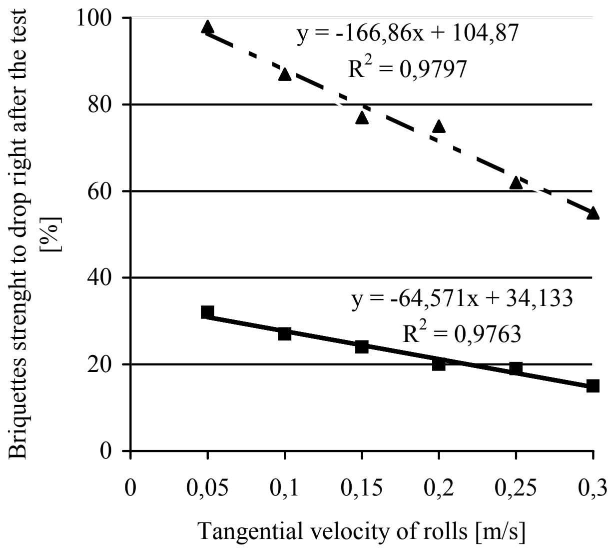

Fig. 2. Graphical expression of dependence of briquette strength to drop right after the test in relation to the tangential velocity of rolls.

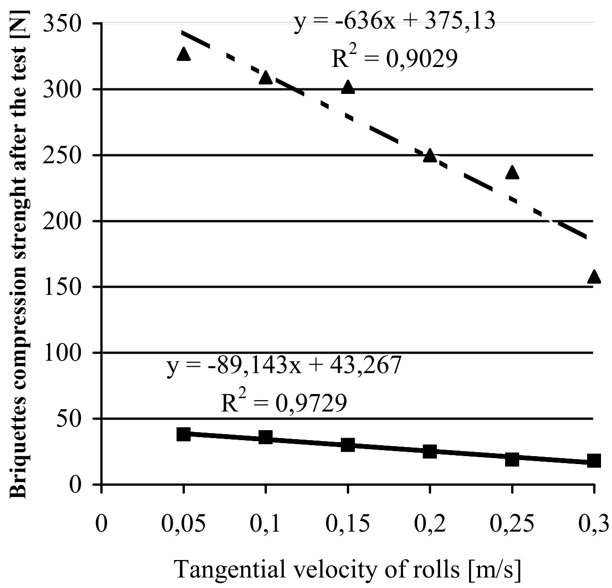

Fig. 3. Graphical expression of dependence of briquette compression strength after the test in relation to the tangential velocity of rolls.

Thermal Analysis Results

Thermal methods such as TG, DTG, and DTA have been used for studying a variety of areas of combustion [8-11]. Combustion characteristics of fuels have been studied widely using thermo-analytical techniques. The advantages of thermal analysis are its rapid assessment of the fuel value, the temperatures at which combustion starts and ends, and other characteristics such as maximum reactivity temperature, ash amount, and total combustion time. Thermal analysis (TA) determines a set of methods for study of the selected physical properties of the substance under the influence of temperature. Sometimes, simultaneously, the environment (pressure, atmosphere chemical composition) can be changed. The thermal analyses were carried out using a Mettler Toledo TGA/SDTA 851 apparatus. The TGA instrument was calibrated with indium, zinc and aluminum. Its accuracy is equal to 10-6 g. For thermal analysis (TG) the samples were placed in an alumina crucible. About 15 mg of sample was heated from an ambient temperature up to 1,000ºC at constant rates of 10ºC/min and 40ºC/min in 40 ml/min flow of air and argon. The measurements for each sample had to be done under exactly the same conditions, including the range of temperature, atmosphere, heating rate, etc. to determine the most repeatable and precise results. The experiments were replicated to determine their reproducibility, which was found to be very good. TG curves for each of the samples were obtained as an output for both combustion and pyrolysis. The TG curves represent the instantaneous weight percentage of the tested samples in contrast to the initial weight. The TG curves were used to assess the thermal characteristics of the studied samples.

Fig. 4 presents TG curves of coal in oxidative (20% oxygen and 80% nitrogen) and inert (argon) atmospheres at 10º/min heating rate. The combustion process in air atmosphere can be divided into three stages: first event to 360º, the

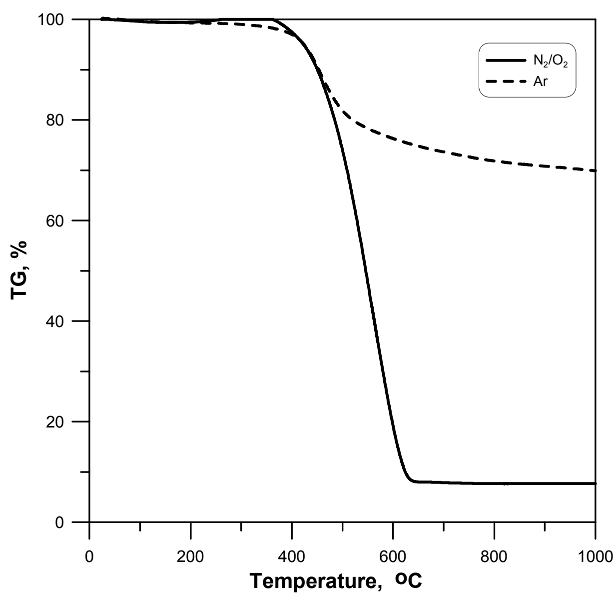

Fig. 4. TG curves for coal at 10ºC/min heating rate under air (N_2/O_2) and argon (Ar) atmospheres.

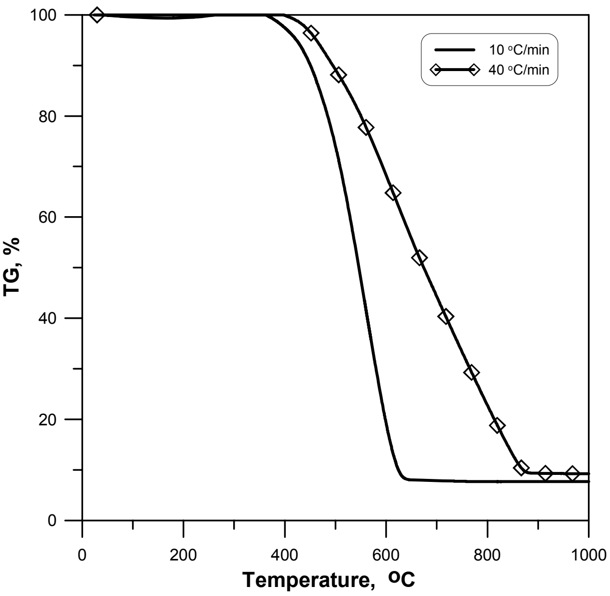

Fig. 5. TG curves for coal at heating rate 10ºC/min and 40ºC/min under air atmosphere.

second in the 360-670ºC range, followed by the modest mass loss above 670ºC. The second stage goes with the highest mass loss, where the combustion process takes place. As may be seen, the thermal conversion under argon atmosphere starts at 340ºC, but mass loss at 1,000ºC is only 30%. Fig. 5 shows the influence of heating rate (10ºC/min and 40ºC/min) on TG profiles of coal in the air atmosphere. As we can observed, the increase of heating rate does not cause the change in profile curves. The increase of heating rate causes the shift of combustion curve toward higher temperature.

Emission and Reduction of Coal Ash Pollution

Adverse image of coal as a fuel does not change the fact that for upcoming years it will remain the most important from all energy sources in the world. Although its combustion is a source of air pollution and produces high amounts of fine solid by-products, coal stands unmatched in relation to other fuels (abundant, available, ease of transport and storage, easy to combust and, above all, is relatively cheap). Poland, with proven reserves of this fuel of 42,000 million tons, is the largest coal producer in the European Union, and its output accounts over 50% of EU production. The government document "Energy Policy of Poland until 2030" ("Polityka Energetyczna Polski do roku 2030") [6], shows that national energy policy involves the use of coal as the main fuel for power generation in order to ensure an adequate level of national energy security. The structure of the installed capacity in the Polish energy system is dominated by coal-fueled power plants (in 2010, solutions based on the use of coal accounted for nearly 60% of all energy production, while over 92% of electricity in Poland is produced by coal combustion).

Also, new investment projects provide for building a new power unit supplied by this type of fuel. Analysis of the investment plans of Polish energy companies shows that in this field one should not expect significant changes in the coming years. Although up to 2018 it is planned to shut down coal-fueled power plants with capacity of close to 3 GW, at the same time it is planned to start new units with a capacity of 6 GW. Polish energy policy until 2030 assumes at the same time reducing the environmental impact of energy production, and the main energy policy in this area includes reduction of CO_2 emissions up to 2020, while maintaining a stable level of energy security, and reduction of SO_2 and NOx and fine ashes (including PM_{10} and $PM_{2.5}$) to levels resulting from existing and planned EU regulations, and change energy production structure toward low-carbon technologies [6, 12, 13].

The basic air pollution resulting from the combustion of coal is ash and gas including sulfur dioxide, carbon monoxide, and dioxide. Total emissions of particulate air pollution in 2010 in Poland was approx 445,000 tons. The ability to operate systems able to reduce dust pollution in 2010 amounted to 4,100 ton, and in 2011, 86,700 Mg/year. Emission of dusts from troublesome plants in 2011 in Poland amounted to 57,500 tons, including 40,000 tons on a field of fuel combustion [7].

Among the 1,777 industrial plants, substantial air pollution 75% (1,338 plants), are plants emitting dust particles. In this group, 90% (1,206 plants) are equipped with systems reducing these pollutants, and the achieved degree of dust particle reduction stands up to 99.7%. Dust pollution retained in filtration systems stood at 19,970 thousand Mg. To remove dust from flue gases, commonly used devices are cyclones (multicyclones), electrostatic precipitators, and fabric filters. In 2011 equipment for the basic devices reducing air pollution was as follows: 3,371 cyclones, 970 multicyclones, 5,608 fabric filters, 586 electrostatic precipitators, and 1,261 damp devices [7]. Among electrostatic precipitators the most common (80%) are devices with high efficiency of pollution reduction. In the vast majority of countries, the energy sector uses mainly electrostatic and/or fabric filters for dust removal efficiency above 99.5%. Also in Poland the vast majority of operating power plants are equipped with electrostatic precipitators. In accordance with EU standards, present dust emission of 30 mg/Nm^3 for existing facilities will be gradually reduced to 20 mg/Nm^3. Modernization and adaptation to these levels will also be required from facilities put into operation earlier. The measures undertaken to improve the performance of electrostatic precipitators, caused by tightening EU standards for particulate pollutant emissions, are mainly realized through new design solutions, and in the case of cleaning flue gases from the combustion of polish coal [14, 15], there was also a tests to reduce high resistivity (above 1,011-1,013 Ωcm) of produced solid particles. Another issue, which also has not found its complete solution, while being a particular challenge for designers and engineers, is the problem of separating in electrostatic precipitators dust particles of size less than 2.5 microns, having a particularly harmful effect on the human respiratory system. Current and planned legal conditions and strategies of the polish energy sector based on coal combustion (or co-firing with biomass – by 2010 the share of renewable energy in the total energy sold to customers should not be less than 7.5%) brings favorable conditions and the need to improve on the development of dust-collecting devices, in particular electrostatic precipitators [14]. The development should be directed to both high-powered power plants such as the electrostatic filter in unit No. 10 in the Kozienice Power Plant – operating on a coal-fueled boiler equipped with currently the biggest electrostatic precipitator in Poland for the purification of exhaust gas of a power unit with a capacity of 500 MV, and boilers with a thermal capacity of 5-50 MV, used, for example, in the municipal district heating system, or the industrial sector.

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