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The dependence of physical structure of a coal heated in a coking chamber on non-uniform distribution of a temperature

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ABSTRACT

Temperature conditions in a coal charge during coking depend on the location towards heating walls of a coke oven. Heating rate as well as residence time in a final temperature distinctly increases from a central axis to heating walls of coking chamber. Differentiated temperature conditions affect physical structure of a coal heated. This influence has been studied using molecular acoustics and densitometric methods, EPR spectroscopy and optical microscopy. Distinct correlations between the position of the coal charge in coking chamber and physical properties of resultant coke have been found. Three zones with the coke of various physical structures have been distinguished in relation to their position toward heating walls of coking chamber: zone I — close to the heating wall, zone II — the middle area and zone III — close to the central axis. Coke produced close to the heating walls of the coke oven has better ordered texture of carbon matrix but more free radicals and worse elasticity than the coke from the middle area. Coke obtained in the central part of coking chamber has the lowest degree of textural order, the lowest porosity but, in a consequence, the best elasticity.
The best quality seems to have the coke from the middle area.

1. Introduction

Metallurgical coke serves a very important function in a maintaining of a blast furnace process of iron production. Requirements for a coke quality ever increase, thus investigations of coke properties still remain very important (Couch, 2001; Diez et al., 2002). Coke characteristics directly depends on a coke structure, which is composed of a solid matrix (carbon forms varying in size and shape), a porous system and micro-cracks (Marsh and Clarke, 1986; Moreland et al., 1989; Barriocanal et al., 1994; Sato et al., 1998; Strugała, 2002). An ultimate character of a coke structure is a result of many parameters regarding, from the one hand, quality of a coal charge (rank, plastic properties, petrographic composition, ash content, chemical composition of ash, etc.) and, from the other hand, technical conditions of coking process (final temperature, heating rate, coking time, swelling pressure, etc.). Thus, many studies have been devoted to relations between a quality of initial coal or coal blend and properties of resultant coke (Goscinski et al., 1985; Košina and Heppner, 1985; Valia, 1989; Pusz et al., 2003; Zhang et al., 2004; Krzesińska et al., 2005; Barranco et al., 2007; Koszorek et al., 2009). An effect of technical conditions of coking process on a coke quality has been also investigated frequently in laboratory as well as in industrial scale (Murchison, 1978; Chaudhuri et al., 1997; Sato et al., 1997; Nomura and Arima, 2000; Zubkova, 2004). Nevertheless, some aspects of coking process and its influence on a coke quality are still unclear, so it seems that detailed studies of physical properties of industrial cokes may provide better insight into this field.

According to the author's knowledge, the study of fundamental physical properties of a coke as a result of diversification of thermal conditions in a coking chamber has not been undertaken as yet.

It is obvious, that the temperature is one of the most important parameters of coking process. The temperature field in a coal charge during coking in a coke oven has been intensively studied, which was well presented by Elliot (1981). In general, temperature distribution in a coal charge during coking process is mainly connected with the location towards heating walls and with the time of coking. As one can see in Fig. 1, the coal charge close to the chamber wall is heated quickly and achieves the final temperature of coking after about 6–8 h, whereas in the central part of an oven the heating rate is much lower and the final temperature is reached after about 13–14 h. This means that the coke close to heating walls is kept in the high temperature almost two times longer than that in the central part of coking chamber. In a consequence, there are several parts of coal charge at various coking stage coexisting together in coking chamber for a long time. Such different temperature conditions of coking process have to affect properties of resultant coke.

The aim of this work was to investigate the variability of some physical parameters of the coke along the cross-section of coking

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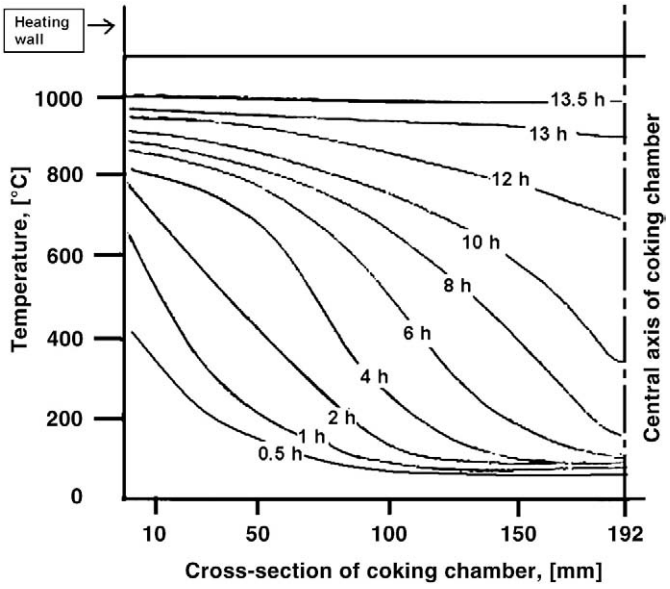

Fig. 1. Temperature distribution in a coal charge during coking process: 0.5 h; 1…13.5 h — time of heating to the final temperature of coking (1000 °C).
Elliot, 1981.

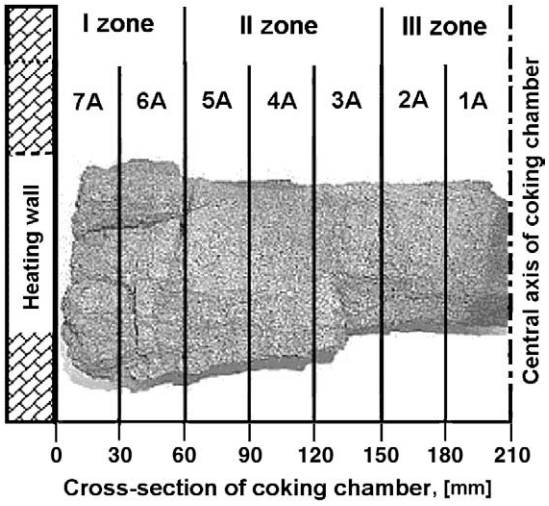

Fig. 2. Location of the samples studied (1A–7A) towards heating wall and central axis of the coking chamber. I–III — zones with different coke structure as the result of various temperature conditions.

chamber, to show the influence of different temperature conditions of coking process on the coke structure. The following physical methods: molecular acoustics, helium densitometry, electron paramagnetic resonance spectroscopy (EPR) and optical microscopy were used to characterize coke samples.

2. Experimental

2.1. Samples

The coke from the standard coke oven battery (PWR 63, gravity charging system) in Zdzieszowice Coking Plant (Poland) was selected to the study. The coke was made from the typical blended coal charge and its CRI and CSR values were equal to 29 and 61, respectively. Proximate, ultimate and petrographic analyses representative for initial coal blend was shown in Table 1. Proximate analyses were performed following the ISO standard procedures for moisture (W^a), ISO 589:2003, for ash content (A^d), ISO 1171:1997a,b and for volatile matter content (VM^{daf}), ISO 562:1998. Ultimate analyses were determined using Perkin Elmer 2400 Series II CHNS/O analyzer. Petrographic analysis and the mean random reflectance of vitrinite were measured according to ISO 7404-5 (1994) standard.

Several lumps of coke taken from the coke wharf after wet quenching were cut along the cross-section of coking chamber from the central part to the heating wall. These blocks were divided into 7 transverse pieces, each of the thickness about 30 mm (samples 1A–7A), where sample 1A was placed in the central part of coking chamber and sample 7A was placed close to the heating wall (Fig. 2).

Table 1
Proximate, ultimate and petrographic analyses of coal blend.

Proximate analysis [wt.%]			Ultimate analysis [wt.%]			Petrographic analysis [vol.%]				R^o_m [%]
M^a	A^d	VM^{daf}	C^{daf}	H^{daf}	N^{daf}	Vt	L	I	MM	
1.07	7.00	25.82	87.13	5.37	1.79	60.28	5.22	23.58	10.92	1.15

Notation: M^a — moisture content, analytical basis; A^d — ash content, dry basis; VM^{daf} — volatile matter content; C^{daf} — carbon content; H^{daf} — hydrogen content; N^{daf} — nitrogen content; daf — dry, ash-free basis; R^o_m — mean vitrinite reflectance.

The samples were prepared in the cuboids form for the ultrasonic and densitometric measurements and in granular form for the EPR and microscopic studies, and for ash yield analysis.

Apparent and helium densities, dynamic elastic moduli and optical reflectance values were measured for each piece of coke separately. Optical texture, porosity and concentration of paramagnetic centers as well as mineral matter content and ash yield of all coke samples were determined.

The values of physical parameters considered in the discussion of the results are the mean values of every sample studied situated in similar distance from the heating walls and the central axis of the coking chamber. Table 2 presents the extreme maximum and minimum values of the sets of average physical parameters using to the calculation of these mean (final) values.

2.2. Ash yield

Ash yield of coke samples studied were performed following the ISO standard procedure — ISO 1171:1997 (dry basis, A^d).

2.3. Physical parameters

2.3.1. Optical reflectance and microtexture

Microscopic characteristics of coke samples were determined with reflected light optical microscope Axioskop MPM 200 (Opton-Zeiss, Germany) using monochromatic plane polarized light of = 546 nm. Coke grains of ≤3.0 mm diameter were embedded in epoxy resin and polished according to the procedure recommended by the ICCP (1963). Apparent maximum (R_{max}) and minimum (R_{min}) reflectance

Table 2
Extreme (minimum/maximum) average values of physical parameters of coke samples situated in adequate position in coking chamber, used for calculation of final results.

Sample	Distance from heating wall [mm]	True density [kg/m^3]	Porosity [vol.%]	Velocity of ultrasonic wave [m/s]	Amplitude of EPR line [a.u.]
1A	195	1945–1982	41–43	1890.83–2050.00	113–153
2A	165	1923–1939	43–46	1844.14–1959.50	119–155
3A	135	1903–1936	47–52	1766.96–1924.15	112–119
4A	105	1867–1881	46–48	1690.00–1860.63	127–169
5A	75	1858–1869	45–48	2014.00–1726.24	144–151
6A	45	1850–1885	43–48	1682.95–1855.42	162–184
7A	15	1828–1875	43–47	1467.63–1754.20	160–178