Fuel 236 (2019) 82–91

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Assessment of coke quality related to of effective permeability coefficient and anisotropy coefficient

Grzegorz Wałowski

Department of Renewable Energy Resources, Institute of Technology and Life Sciences, 67 Biskupińska Street, 60-463 Poznań, Poland

ARTICLE INFO

Keywords:
Frame-structured porous material
Coke
Carbon reactivity index
Coke strength after reaction
Permeability
Anisotropy

ABSTRACT

The assessment of process phenomena resulting from the hydrodynamics of gas flow through various kinds of coal chars may refer to a vast number of technological aspects pertaining to qualitative features of those materials. Those issues are subject to the assessment of the post-reaction gas movement in the conditions of the thermal processing of coal substances. In the case, an additional aspect of this assessment is also phenomena referring to the determination of the permeability of coal chars in the context of their application in other technological processes, e.g. coke in the metallurgical cycle.

In the context of research upon the hydrodynamics of gas flow through porous materials an attempt was made to correlate the results of that research with the process issues resulting from the technological reasons for applying various kinds of coal chars. This correlation was referred to the assessment of the technological quality of coke referring to its features for the blast furnace technology.

The basis for the assessment was the obtained results referring to the measurement of structural features of the analysed coal chars and the hydrodynamics resulting from their gas permeability.

1. Introduction

In the industrial control of the coke quality great emphasis is placed not only on its mechanical features but also on its process features concerning the use of coke in the blast furnace technology. In the context of this technology, the features of coke resulting from its gas permeability have a fundamental significance as they constitute a direct quality measure of coke for those processes.

The high temperature features of blast furnace coke are determined according to a standard test of Nippon Steel Corporation (NSC) [1–4]. This forms the basis for determining the quantity and quality of chemical products of coking of coals and coal mixtures in conditions resembling the industrial ones [5]. The coking tests are conducted for about 2.5 h at a temperature of 930 ÷ 980 °C and a sample of the coal mixture weighs 4 kg. The coke obtained in those conditions is cooled down for 24 h to around 50 °C [6,7]. Subsequently, those measurements are carried out to determine two coke quality indexes, viz.[8]:

(a) Carbon Reactivity Index (CRI) (1) – an index that shows the loss in weight of the coke sample affected by carbon dioxide for over 2 h at 1100 °C;
(b) Coke Strength after Reaction (CSR) (2) – an index that shows the yield of coke with a granulation of over 10 mm after being machined in the fixed conditions (600 rotations of the drum within 30 min) and after determining its reactivity.

Those indexes are determined with respect to a change to the sample weight on the basis of the following dependency

$$CRI = \frac{m_{1R}-m_{2R}}{m_{1R}}\cdot 100\% \tag{1}$$

$$CSR = \frac{m_{3R}}{m_{2R}}\cdot 100\% \tag{2}$$

where *CRI* – Carbon Reactivity Index, %; *CSR* – Coke Strength after Reaction, %; m_{1R} – weight of the coke sample before determining its reactivity, kg; m_{2R} – weight of the coke sample after determining its reactivity, kg; m_{3R} – weight of the coke sample with a granulation of above 10 mm, kg.

Considering the quality requirements of coke recipients, it is assumed [2] that coke with a maximum process quality has CRI is less than 28%, where the optimal CRI is 24%, and its high durability is when CSR is greater than 60%, where the optimal CSR is 70%.

2. Materials and method

The experimental material was coke processed at the Zdzieszowice

E-mail address: g.walowski@itp.edu.pl.

https://doi.org/10.1016/j.fuel.2018.08.149
Received 30 October 2017; Received in revised form 22 February 2018; Accepted 30 August 2018

Nomenclature

List of major signs

CRI	carbon reactivity index %
CSR	coke strength after reaction %
K	permeability coefficient m^2
P	pressure Pa
Q	stream, volume flow rate m^3/s
V	volume m^3
m	weight kg
ΔP	pressure drop Pa
β	anisotropy coefficient
ε	porosity
ρ	density kg/m^3

Lower indices refer to

P	own model
R	reactivity
X	direction
Y	direction
Z	direction
b	absolute
ef	effective
exp	measured
g	gas
h	horizontal
o	ambient pressure
poz	apparent
pr	sample
st	solid body
swo	free
v	vertical

Coke Plant Arcerol Mittal Poland S.A. This material, as a char was hard coal products acquired from Poland, Czech Republic, Canada, USA and Australia. Since numerous types of coke were applied in our own research, samples of this material were classified according to names of hard coal deposits (see Table 1).

Porous materials (samples) applied in research underwent the assessment of selected parameters. Described features characteristic for porous materials resulting from their porosity and physical structure as basic process quantities affecting the hydrodynamics of the gas flow through porous materials. The quantity-based assessment applied to such parameters as the apparent density and porosity of a specific type (sample) of the porous material.

The apparent density ρ_{poz} (3) of the porous material was determined by measuring the total volume of the sample V_{pr} (by immersing it into water) and its mass, which in this case corresponds to the mass of the solid body $m_{pr} = m_{st}$. Definition:

$$\rho_{poz} = \frac{m_{st}}{V_{pr}} \tag{3}$$

where ρ_{poz} – apparent density, kg/m^3; m_{st} – mass of the solid body, kg; V_{pr} – total volume of the sample, m^3.

Porosity was determined in two ways. The first way by weighing the sample mass. The second way by applying the porous structure image identification method.

The absolute porosity of the porous material ε_b (4) is calculated on the basis of the quotient of the free volume V_{swo} and the total volume of the sample V_{pr}. Following some relevant transformations this definition may be as follows:

$$\varepsilon_b = \frac{V_{swo}}{V_{pr}} = 1 - \frac{V_{st}}{V_{pr}} = 1 - \left(\frac{m_{st}}{\rho_{st}}\right)\left(\frac{\rho_{poz}}{m_{st}}\right) = 1 - \frac{\rho_{poz}}{\rho_{st}} \tag{4}$$

where ε_b – absolute porosity of the porous material; V_{swo} – free volume, m^3; V_{pr} – total volume of the sample, m^3; V_{st} – volume of the solid body, m^3; m_{st} – mass of the solid body, kg; ρ_{st} – density of the solid body, kg/m^3; ρ_{poz} – apparent density, kg/m^3.

By knowing the relative density of the solid porous material, a serious difficulty in assessing the absolute density is to determine the real density of this material. A separate and very essential issue affecting the actual assessment of this kind of porous materials is to determine a share of porosity – for the liquid flow.

The experimental research proves that the degree of this deviation may be the so-called effective porosity ε_{ef} (5) – a share of volume of interconnected pores compared to the total volume. As for solid porous materials (frame-structured ones) Łuszcz [9] defines this degree as:

$$\varepsilon_{ef} = (0.5 \div 0.8)\varepsilon_b \tag{5}$$

where ε_{ef} – effective porosity of the porous material; ε_b – absolute porosity of the porous material.

The permeability research was conducted cokes, the average porosity absolute of 52.2%, the average porosity effective of which ranged from (26.1 ÷ 41.8)%, the average density apparent of 1075 kg/m^3, and the average density skeleton of 2250 kg/m^3.

2.1. Experimental stand

Experimental studies were carried out on a specially measuring setup [10], the general scheme of which is shown in Fig. 1a. An essential element of this bench is a flow module (Fig. 1b), in which a specimen of porous material (1) is placed, the specimens were cube shaped (Fig. 1c). The module flow channel design allowed for the measurements of permeability for each of the three main flow directions X, Y, Z – by rotating the cubic specimen in a selected plane [11].

In this system (Fig. 2a) the gas flow was always directed with

Table 1
Characteristic of cokes.

No.	No. sample	Name	Country of origin of coal
1	II-5	Oaky Creek	Australia
2	II-17	Peak Down	Australia
3	II-23	Saraji	Australia
4	II-22	Elkviev	Canada
5	II-4	CSM	Czech Republic
6	II-8	Darkov	Czech Republic
7	II-19	Paskov	Czech Republic
8	II-6	Knurow	Poland
9	II-7	Zofiowka	Poland
10	II-11	Szczyglowice	Poland
11	II-14	Bielszowice	Poland
12	II-15	Rydultowy Ruch I	Poland
13	II-16	Borynia	Poland
14	II-21	Jas-Mos	Poland
15	II-12	Blue Creek Premium	USA