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INVESTIGATIONS OF GAS PERMEABILITY OF THE CHARGE IN THE REDUCTION PROCESS OF IRON ORES BY HARD COAL

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An increased interest in new methods of pig iron production, which do not require the use of coke, leads to searches for substitutes of coke as the reducing agent. Hard coal is gaining an increasing importance in these searches, as its resources in the world's deposits presently known should be sufficient for the next 300 to 500 years, whereas the resources of petroleum or natural gas are estimated to suffice only for a few dozens of years. This is particularly true for Poland, where the difference in the respective resources indicates even more clearly the need of using hard coal as a reducing agent. The purpose of the study was to investigate the change of the gas permeability of different types of coal as a result of phenomena occurring in the processes of reduction of iron ores, in order to evaluate the suitability of various Polish coals for these processes. The article describes the methodology of examination of the gas permeability of a hard coal bed in a stream of hot reduction gases. Tests were performed in a model testing furnace. As the test material, hard coal types 32, 33 and 34 from selected Polish coal mines were used.

Key words: *coal, smelting reduction, permeability*

Ispitivanja šarži na propusnost plina u procesu redukcije željezne rude krutim ugljenom. Sve veće zanimanje za nove metode proizvodnje sirovog željeza koje ne traže uporabu koksa vodi do traženja redukcijskog sredstva. U tim traženjima kruti ugljen zadobiva sve veću važnost jer su njegova nalazišta u svijetu, za koja trenutno znamo, dovoljna za slijedeći 300 - 400 godina, dok su rezerve nafte ili zemnog plina dovoljne za samo nekoliko decenija. To posebno važi za Poljsku gdje su nalazišta takva da još jasnije ukazuju na potrebu uporabe tvrdog ugljena kao redukcijskog sredstva. Cilj ovog rada je bio da se ispita propusnost različitih vrsta ugljena kao rezultat fenomena koji se pojavljuju u procesu redukcije željeznih ruda. Kao ispitni materijal koristio se kruti ugljen tipa 32, 33 i 34 iz odabranih poljskih rudnika. Članak ispituje metodologiju ispitivanja propusnosti na plin posteljice tvrdog ugljena u struji vrućih redukcijskih plinova.

Ključne riječi: *ugljen, redukcijsko sredstvo, propusnost*

TESTING THE AIR PERMEABILITY OF THE COAL BED DURING CARBONIZATION IN A HOT COMBUSTION GAS STEAM

In a reducing atmosphere, in the temperature range 400 - 500 °C, coal undergoes "transition" to a plastic state. In this condition, coal lumps may deform or even stick to each other to form an impermeable bed. This may be the cause of difficulties in the charge material "descending" within the shaft towards the tuyere zone (the phenomenon known as the "suspension" of the charge), which would make the flow of gases from the tuyeres to the shaft top and the displacement of the metal and slag downwards difficult or (in extreme cases) even impossible. Thus, a question arises of what lumped coals should be used in such a plant so that it could operate, and in addition, whether there are any factors that could hamper this likely lumping of coal [1-2].

Air permeability is normally a conventional quantity, being dependent on the method of measurement. By maintaining the fixed conditions of measurement, air permeability can be made comparable. Changes in the air permeability of the charge column are reflected in a change in the pressure difference.

In order to perform the necessary measurements, a proper testing stand was assembled, whose components are shown in Figures 1. and 2. [3].

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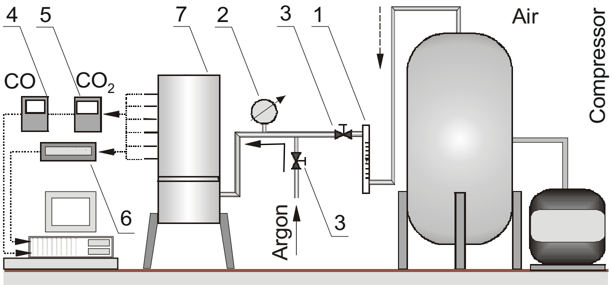

Figure 1. **Schematic diagram of the testing stand [2]**
1. Flowmeter; 2. Pressure gauge; 3. Valves; 4. CO analyzer; 5. CO_2 analyzer; 6. Temperature indicator; 7. Test shaft furnace

Slika 1. **Shematski dijagram ispitnog stola**
1. mjerač protoka, 2. tlakomjer, 3. ventili, 4. CO analizator, 5. CO_2 analizator, 6. termometar, 7. ispitna peć

Investigations comprised the measurement of bed air permeability during the carbonization of three selected coals in a stream of hot reduction gas. Coals derived from different collieries were used for the tests, namely: type 32 (KWK Kleofas colliery), type 32 (KWK Zabrze-Bielszowice colliery) and type 34 (KWK Pokój colliery), all with a grain size of 10 - 20 mm.

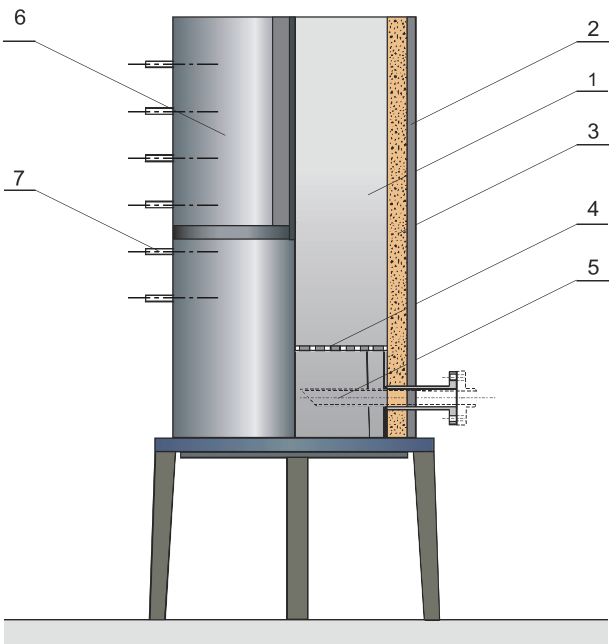

Figure 2. **Schematic diagram of the experimental furnace**
1. combustion chamber, 2. shaft casing; 3. refractory lining; 4. grate; 5. tuyere; 6. removable part of the chamber casing; 7. measurement holes

Slika 2. **Shematski dijagram ispitne peći**
1. komora izgaranja, 2. plašt, 3. teškotopivi plašt, 4. rešetka, 5. uvodna cijev, 6. izmjenjivi dio komore, 7. otvori za mjerenje

The work was focused on searching for coals and the method of their carbonization, which would prevent the formation of an impermeable bed. The investigations in-

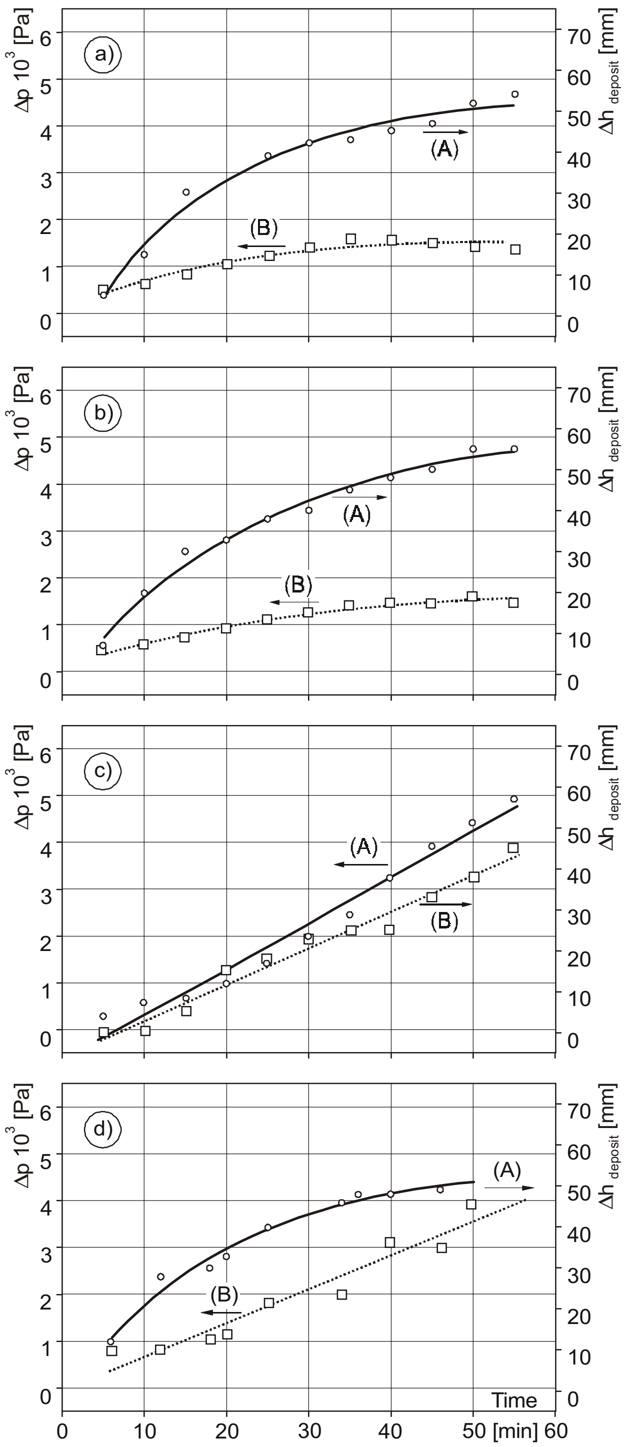

Figure 3. **Diagram of pressure and bed height variation during the carbonization of coal:**
a) type 32 (KWK Kleofas colliery); b) type 32 (KWK Katowice colliery); c) type 33 (KWK Zabrze-Bielszowice colliery); d) type 34 (KWK Pokój colliery)

Slika 3. **Dijagram tlaka i promjenljivosti visine posteljice tijekom naugljičavanje ugljena:**
a) tip 32 (KWK rudnik ugljena Kleofas); b) tip 32 (KWK rudnik ugljena Katowice); c) tip 33 (KWK rudnik ugljena Zabrze-Bielszowice); d) tip 34 (KWK rudnik ugljena Pokój)

cluded the measurement of bed air permeability during the carbonization of three selected coals in a stream of hot reduction gas.

The test involved the carbonization of coal in the stream of hot reduction gases. On the furnace grate, there was an incandescent layer of coke with grain size of 10 - 20 mm, above which a layer of coal was positioned. Air flowing through this layer caused the combustion of the coke and production of hot gas with an optimal CO content. The height of the coal layer assuring a constant CO content of the reduction gas, and the duration of the reduction process were determined by an experimental method.

This layer enabled:

- reaching a CO content of the gas, which did not increase as a result of subsequent thickening of the layer,
- obtaining an almost constant temperature of the "heating" gas and a constant CO content for the entire duration of the coal carbonization process.

After the coke had incandesced, the furnace chamber was filled up with a coal sample. For the entire duration of the test, air was fed to the furnace at a rate of 10 m^3/h. Ten minutes after the completion of loading coal, measurements were started. The test was conducted for 60 minutes. The quantities measured during the test were:

- the temperature of particular bed layers,
- the pressure difference between the pressure under the grate and the atmospheric pressure,
- flow rate,
- bed height,
- gas composition (CO, CO_2), mainly for controlling its fluctuations.

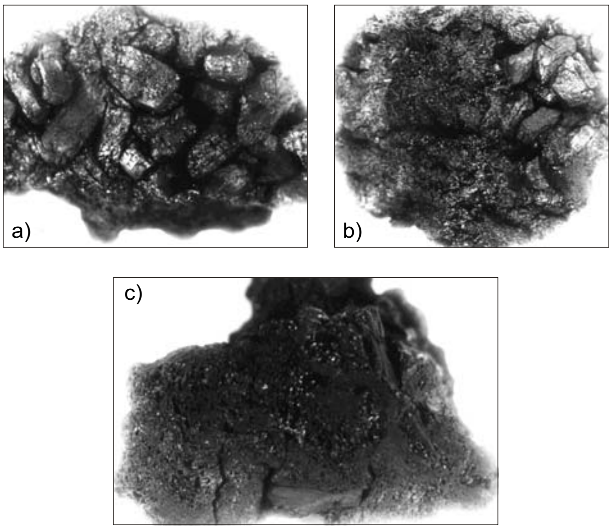

Figure 4. **Photographs of the structures of the product obtained from coal gasification:**
a) type 32, b) type 33, c) type 34

Slika 4. **Fotografije strukture proizvoda dobivenih plinifikacijom ugljena:**
a) tip 32, b) tip 33, c) tip 34

The tests allowed the air permeability variations in time to be monitored and the characteristic, variable parameters to be controlled.

RESULTS OF COAL CARBONIZATION TESTS

Coal of type 33, and particularly type 34, underwent so strong deformation of lumps that the air permeability of the bed decreased during carbonization to a level at which the process was stopped. The gas only flew through the gaps, carbonization cracks (Figure 4.), and mainly between the bed and the wall of the furnace model. Therefore, the degree of advancement of carbonization was diverse in particular bed cross-sections. In the case of coal type 34, the air permeability of the bed decreased to such a degree that there were unprocessed coal lumps left at the top of the bed after carbonization.

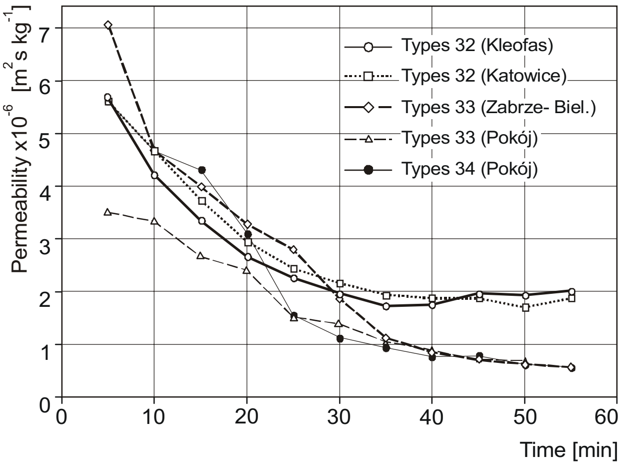

Figure 5. **Variation of the air permeability of the bed for coals tested in the experimental furnace**

Slika 5. **Varijacije u propusnosti zraka u ugljenoj posteljici ispitanoj u eksperimentalnoj peći**

DISCUSSION OF RESULTS

The tests carried out have enabled the calculation of air permeability during the gasification of coals tested, Figure 3.

The preliminary tests of coals, types 32, 33 and 34, showed that only coal type 32 retained its lumpy structure (as before the carbonization). A decrease in air permeability (an increase in pressure) during heating the bed was small, and it will probably be of little importance for the shaft-furnace process, Figure 5.

Although all coals tested are suitable for reduction smelting processes for energy reasons, yet coal type 34 arouses serious reservations.

In summary, it can be concluded that despite the bed-loosing effect of the iron-bearing charge added to reduction smelting reactors together with coal, the use of coal type 34, and even 33, may cause disturbances in the process (charge descending) and non-uniform (mineral silicon) reduction processes and product heating. Of the coals tested, the coal from the KWK Kleofas colliery has proved to be the best, providing the best air permeability of the bed with an average drum resistance of the carbonizate (among the obtained results).

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