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3D MODEL STUDY OF RADIAL DISTRIBUTION OF POWDER HOLDUP IN THE DESCENDING PACKED BED OF METALLURGICAL SHAFT FURNACES

The principle of work of many metallurgical shaft furnaces is based on the flow of reaction gas through the descending packed bed composed of metallurgical materials. Hot gases flow up the shaft furnace through the column of materials, give their heat to the descending charge materials. At the same time due to their reducing nature they interact chemically, causing the reduction of oxides inside the charge. In real conditions, during the course of the process, the powder is generated, the source of which is the batch materials or it is introduced into the as part of the process procedure. The powder in the form of thin slurry is carried by the stream of flowing gas. Such multiphase flow might considerably affect the permeability of the charge due to the local holdup of powder. The holdup of solid phase in packed beds of metallurgical shaft furnaces leads to radial changes in bed porosity. Radial changes in bed porosity uneven gas flow along the radius of the reactor and negatively affect the course and efficiency of the process. The article describes the model studies on radial distribution of carbon powder holdup in the packed bed composed of metallurgical materials. The powder was divided into fractions – "static" and "dynamic". Large diversity of carbon powder distribution was observed in the function of the radius of reactor in relation to the bed type, apparent velocity of gas carrying powder and the level of bed height.

Keywords: blast furnace, system: descending packed bed – gas-powder, radial distribution of powder

1. Introduction

The gas flow which is carrying the powder through the porous layers is observed during various chemical processes. In metallurgical shaft furnaces it occurs in a countercurrent way to the descending charge. A special example of such flow is observed in a blast furnace, where the process of obtaining iron from iron ores is multiphase (gas, packed bed and powder particles, liquids). In this multiphase system the movement of solid phase is dominant and affects not only the flow of other phases, but also the efficiency and effectiveness of the processes inside the shaft furnaces. Therefore, it is essential to learn and understand the phenomena which develop in the course of multiphase flow. Then it is possible to issue more detailed description of chemical reactions and mechanisms of heat and mass transfer between different phases.

Injecting the carbon powder as a substitute fuel for coke generates numerous problems in the way of applying blast furnace technology [1-5]. Large amount of unburned coal and ash may result [5-7]. Powders and ash can additionally feed the amount of powder carried with gas. The increase of powder amount in gas can result in lower permeability of bed (powder holdup in void spaces) and contribute to the increase of gas flow resistance. Such distortions are common for units operating at unequal gas flow when powder holdup in a bed occurs. Unequal powder holdup in a bed needs deeper studies. Different shape or surface properties of packed bed can affect the radial distribution of powder particles.

The aim of the research described in the paper was to evaluate the impact of gas velocity and type of metallurgical bed upon radial distribution of carbon powder (in the function of radius of measuring column).

2. Experimental installation and procedure

Investigations which aimed to evaluation of the effect of gas velocity and type of metallurgical bed upon coal powder hold up radial distribution were conducted using a physical modelling, which commonly is used for modelling ferrous and nonferrous metallurgical processes [8-12]. The research were carried out with use of the procedure described earlier and the physical model 3D of two-phase flow (gas+powder) through the descending bed [13].

Previously, 3D tests of radial distribution of powder hold up were carried out in model systems glass bed-glass powder (A system) as well as blast furnace pellets-iron powder (B system). Their results are described in [14]. The research presented here, blast furnace sinter bed-coal powder (C system) as well as blast furnace pellets bed-coal powder (D system) was realized with the application of previously described procedure [13-15].

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TABLE 1

Research conditions

			Measuring system	Blast furnace (shaft)
Diameter of bed pieces	d_z	m	0.014-0.016	0.01-0.03
Gas density	ρ_g	kg/m^3	1.205	0.67-0.85
Gas viscosity	μ_g	Pa×s	1.86×10^{-5}	$(3.98\text{-}4.25)\times10^{-5}$
Gas apparent velocity	U_g	m/s	0.4-1.2	1-2
Bed velocity	U_z	m/s	0.45×10^{-3}	$(0.6\text{-}1.0)\times10^{-3}$
Reynolds' Number	$Re = \rho_g U_g d_z/\mu_g$	—	362-1243	157-1281
Froude's Number	$Fr = U_z/(d_z\times g)^{1/2}$	—	$(1.1\text{-}1.2)\times10^{-3}$	$(1.1\text{-}3.2)\times10^{-3}$

where: g – gravitational acceleration, m/s^2.

Table 1 presents information about the similarity of studies conditions with the operational conditions of blast furnace shaft.

3. Computation results of radial distribution of powder holdup in the descending packed bed

Investigations into radial distribution of powder hold up have been performed at maximum and minimum superficial velocity of gas, at 4 levels of bed height. Minimum superficial velocity of gas was the velocity value in the point where powder transport into the test column was observed. Maximum superficial velocity of gas, on the other hand, was the velocity determined by the volume of powder hold up in the bed which tends to zero.

Total mass of powder holdup in the packed bed (index ε_p) was divided into two fractions : "static" powder (powder deposited on packed bed – index ε_{ps}.) and "dynamic" powder (powder moving between void spaces – index ε_{pd}).

Investigation results into radial distribution of powder hold up (C and D systems) are shown in figures 1-4. Frequently used marks and their meanings are listed in Table 2.

TABLE 2

List of frequently used marks

Marks ε_p	Marks ε_{ps}	Marks ε_{pd}	d_z m	ε_0 -	d_p, m	Φ_p -	G kg/m^{2}s	Notes
●	▲	■	0.014	0.49	$(100\text{-}140)\cdot10^{-3}$	0.78	0.45	system C
○	△	□	0.016	0.48	$(100\text{-}140)\cdot10^{-3}$	0.78	0.45	system D
			0.016	0.48	$(90\text{-}130)\cdot10^{-3}$	0.76	0.45	system B

where: d_z – diameter of bed pieces, ε_0 – void fraction in packed bed, e_p – volume fraction of the total hold up of powders ($\varepsilon_p = \varepsilon_{pd} + \varepsilon_{ps}$), -, ε_{pd} – volume fraction of the dynamic hold up of powders, -, ε_{ps} – volume fraction of the static hold up of powders, -, d_p – diameter of powder particles, φ_p – shape factor of the powder, G – mass apparent velocity of the powder stream, black marks – max. gas apparent velocity, white marks – min. gas apparent velocity

As the result of the performed investigations it was proved that a lower part of the bed (tuyere region) was the area of intensive powder holdup. At the minimum gas velocity as well as independently of the applied system and the height of the bed no radial diversities between indices of powder holdup were observed. Additionally "static" powder fraction determined the value of index ε_p.

As shown in Fig. 1 the increase of apparent gas velocity from minimum to maximum causes the increase of diversity in radial distribution of carbon powder between the analyzed systems. When the model system is used together with system C and the gas velocity reaches maximum, then at a lower section of bed height the maximum mass of "static" powder holdup in the bed concentrates at the walls. On the other hand the mass of "dynamic" powder grows from the walls towards the bed axis. Along the radius of the reactor the dominant role of the carbon powder fractions in the value of index ε_p. changes.

With the same conditions but with the application of the model system and system D, the radial distribution of the analyzed indices is constant or quasi constant. Here it is "static"

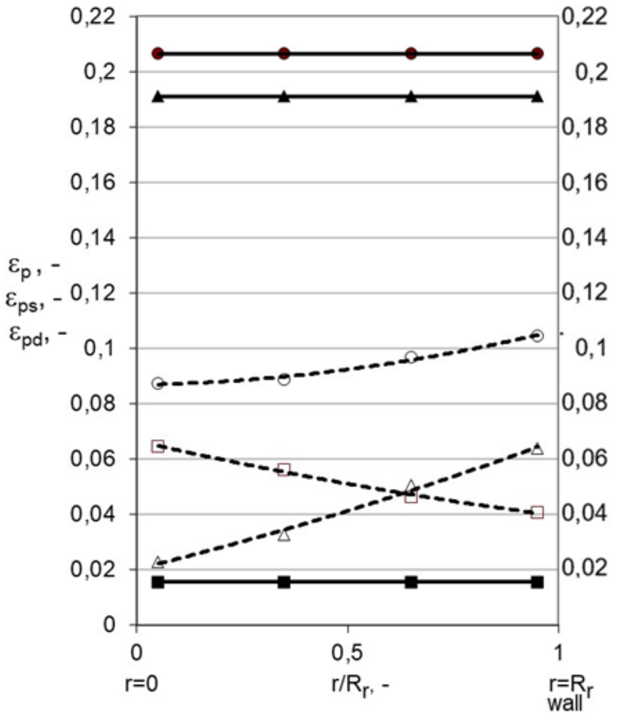

Fig. 1. Radial distribution of ε_p, ε_{ps} and ε_{pd} coefficients at the lower section (0-100 mm) of a bed height in C system

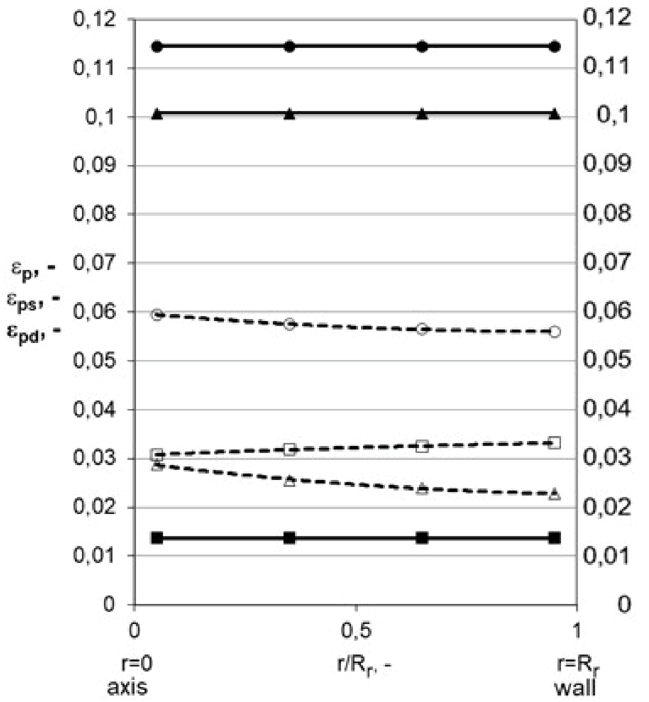

Fig. 2. Radial distribution of ε_p, ε_{ps} and ε_{pd} coefficients at the lower section (100-400 mm) of a bed height in C system

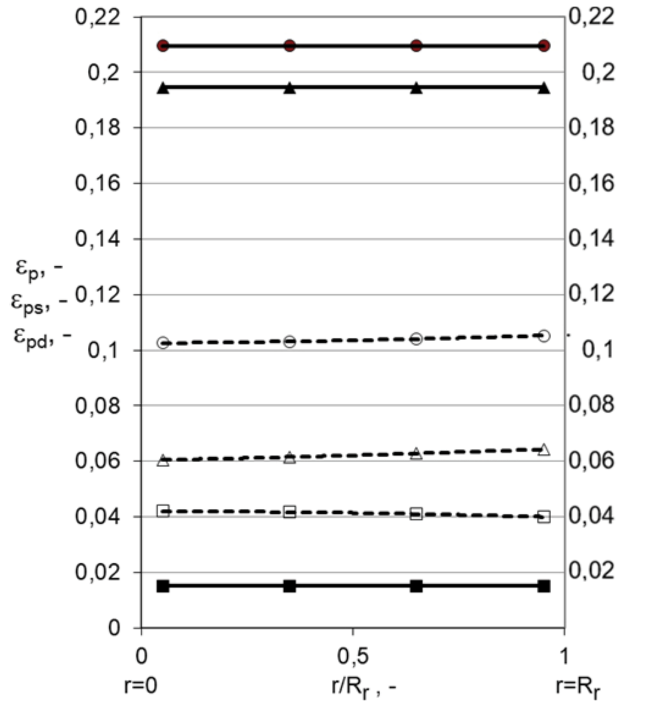

Fig. 3. Radial distribution of ε_p, ε_{ps} and ε_{pd} coefficients at the lower section (0-100 mm) of a bed height in D system

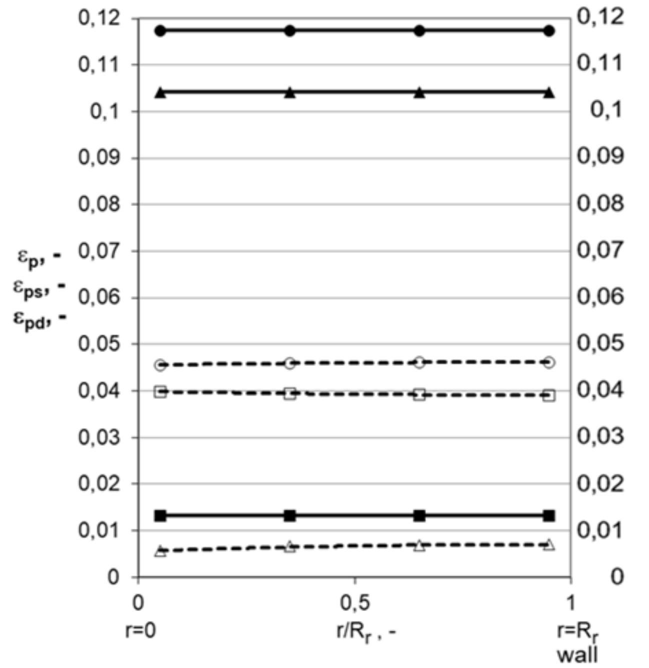

Fig. 4. Radial distribution of ε_p, ε_{ps} and ε_{pd} coefficients at the lower section (100-400 mm) of a bed height in D system

powder which dominates in the total mass of the powder holdup, Fig. 3.

In the upper section of the bed the radial diversity of index ε_{ps} decreases and so does index ε_p. At the minimum gas velocity "static" powder fraction significantly affects the values of index ε_p, but at maximum velocity it is "dynamic" powder which determines the total amount of powder holdup in the bed. See Figures 2 and 4.

4. Discussion and summary

The model research on radial distribution of carbon powder in the packed bed was performed during multiphase flow (gas-powder-moving bed). Two standard metallurgical systems were tested: blast furnace sinter bed-carbon powder (system C) and blast furnace pellets bed-carbon powder (system D).

No radial diversity in powder fractions of both analyzed bed types was found at the minimum gas velocity. Considerable differences, though, occured at maximum gas velocity.

In order to explain the reasons of the detected differences mathematical model described in [15] was applied. Radial distribution of resistances which was present at maximum gas velocity and generated by: forces between gas and packed bed with deposited "static" powder ($F_{g\text{-}z}$) and forces between gas and "dynamic" powder particles ($F_{g\text{-}p}$). was computed. The results are presented in figures 5 and 6. Frequently used marks and their meanings are listed in Table 3.

TABLE 3

List of frequently used marks

Marks		Notes
$F_{g\text{-}z}$	$F_{g\text{-}p}$	
△	○	bed: blast furnace sinter; powder: coal powder – C
×	◇	bed: blast furnace pellets; powder: coal powder – D

In case of the bed composed of blast furnace sinter (system C), resistance $F_{g\text{-}z}$ are the highest in the lower section of the bed height close to the gas inlet (at the wall), whereas resistance

(F_{g-p}) grows from the walls towards the column axis, unlike in the upper section of the bed. When the bed is composed of blast furnace pellets (system D), then only slight differences between the analyzed resistances along the radius of the reactor appear at both levels of the bed height.

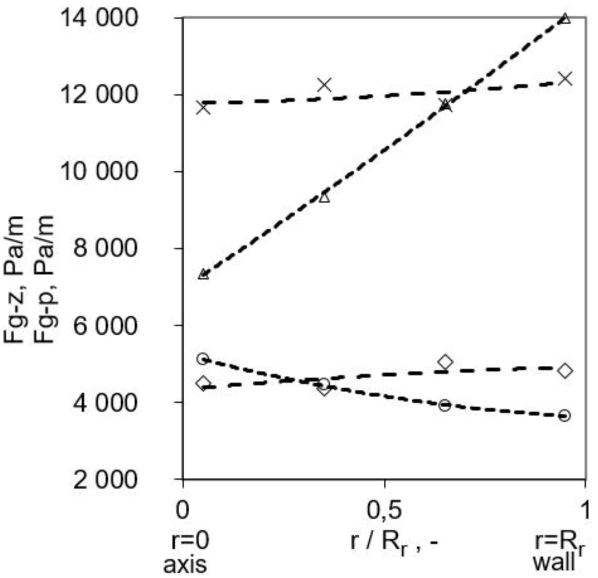

Fig. 5. Radial distribution of resistances F_{g-z} and F_{g-p} at the lower section (0-100 mm) of a bed height in C and D systems

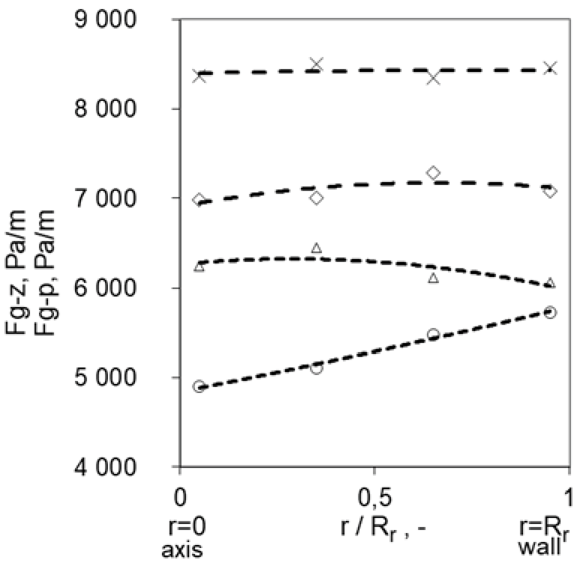

Fig. 6. Radial distribution of resistances F_{g-z} and F_{g-p} at the lower section (100-400 mm) of a bed height in C and D systems

The reason of radial diversities of carbon powder distribution in the analyzed packed beds is the change of impact resistance resulting from differences between the shape factors and surface properties of the packed beds tested for the research.

More porous blast furnace sinter, less regular in its shape (lower shape factor) provides more favorable conditions for holdup of "static" powder close to the column wall and near the tuyeres. This favors the increase of resistances F_{g-z} by the forces between gas and packed bed with deposited 'static' powder. Low resistance (F_{g-p}) in this region foster "dynamic" powder transport (powder carried with gas) to the bed section which are more distant from the column walls. This leads to radial mass diversity of powder holdup fractions in the bed.

When the bed was composed of 0.016 m diameter pellets only insignificant radial diversities in the analyzed resistances were detected. Therefore in such case "static" powder concentration at the wall and in the middle of the bed is almost regular.

Thus the change of bed material used changed the mechanism of powder holdup in the bed. The results obtained contribute to better understanding the reasons of radial diversity of powder mass in the bed as well as the value of static pressure which can occur in shaft furnaces together with the change of bed material and powder.

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REFERENCES

[1] Sh. Raygan, H. Abdizadeh, A. Eskandari-Rizi, Journal of Iron and Steel Research International **17**, 8-12 (2010).
[2] Sh.-W. Du, W.-H. Chen, J.A. Lucas, Energy **35**, 576-581 (2010).
[3] Sh.-fu. Zhang, Ch.-gu. Bai, Li.-yi. Wen, Gu.-b. Qiu, Xu.-w. Lu, Journal of Iron and Steel Research International **17**, 8-12 (2010).
[4] Y.S. Shen, A.B. Yu, P.R. Austin P. Zulli, Powder Technology **223**, 27-38 (2012).
[5] Ch. Zou, Li-yi. Wen, J-x. Zhao, R-m. Shi, Journal of Iron and Steel Research International **24**, 8-17 (2017).
[6] S.G. Sahu, A. Mukherjee, M. Kumar, A.K. Adak, P. Sarkar, S. Biswas, H.P. Tiwari, A. Das, P.K. Banerje, Applied Thermal Engineering **73**, 1014-1021 (2014).
[7] Sh.-W. Du, Ch.-P. Yeh, W.-H. Chen, Ch.-H. Tsai, J. A. Lucas, Fuel **143**, 98-106 (2015).
[8] M. Saternus, Metalurgija **50**, 257-260 (2011).
[9] T. Merder, J. Pieprzyca, M. Saternus, Metalurgija **53**, 155-158 (2014).
[10] M. Saternus, J. Botor, Archives of Metallurgy and Materials **55**, 463-475 (2010).
[11] S. Gil, J. Góral, J. Ochman, M. Saternus, W. Bialik, Metalurgija **53**, 447-450 (2014).
[12] M. Warzecha, T. Merder, H. Pfeifer, J. Pieprzyca, Steel Research International **81**, 987-993 (2010).
[13] B. Panic, Archives of Metallurgy and Materials **59** (2), 795-800 (2014).
[14] B. Panic, K. Janiszewski, Metalurgija **53** (3), 331-334 (2014).
[14] B. Panic, Modelowanie zjawisk zachodzących przy dwufazowym – gaz+pył – przepływie przez ruchome złoża kawałkowe, Wydawnictwo Politechniki Śląskiej, Gliwice (2013).