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MODEL INVESTIGATIONS 3D OF GAS-POWDER TWO PHASE FLOW IN DESCENDING BED WITH CONSIDERATION RADIAL DISTRIBUTION OF FLOW

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The results of experimental investigations concerning radial distribution of powder accumulation in bed and static pressure were presented in this paper. To realize this research physical model of gas-powder two phase flow with descending bed was projected and constructed. Amounts of "dynamic" and "static" powder accumulated in bed, in dependence on gas velocity and of bed particles were investigated. In 3D model "static" powder (with its radial distribution) at the tuyere level and in the higher part of bed was measured. The influence of bed particles, powder and gas radial distribution on values of interaction forces between flow phases in investigated system was defined.

Key words: metallurgical furnaces, gas-powder flow, moving bed, radial distribution of flow, physical modeling

INTRODUCTION

In real conditions of the work of metallurgical shaft furnaces the processes are conducted with the participation of many phases (gases, packed and powder particles, liquids). In this multiphase system the particle motion plays the dominant role and affects the flow of remaining phases, has an influence on efficiency and effectiveness of processes conducted in the shaft furnaces. Disturbances of the flow appears more frequently in units working at non-uniform gas flow caused by changing of coefficient of bed void along the reactor radius. In the study [1] distinct influence of bed radial distribution on interaction between the flow phases was stated. Non-uniform, radial distribution of powder, held up in the bed, influences considerably on flow of all the phases. The investigations described in literature, concerning gas with powder flow in moving bed, considering radial bed distribution [1-4], are conducted using flat model 2D.

2D models provide exellent visualization of the occurring phenomena. In full 3D visualization is much more difficult but they mirror real conditions in a better way. As it is written in literature[5] the results obtained from both of those models can differ. Model investigations of metallurgical processes have been conducted in Department of Metallurgy Silesian University of Technology[6-8]. The problem of gas-powder two phase flow in bed has been investigated by author. Now, author investigates gas-powder-moving bed system considering radial flow distribution.

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EXPERIMENTAL INSTALLATION AND PROCEDURE

Physical model 3D has been projected and constructed to realize the investigations of two phase gas-powder flow through the descending bed. Figure 1 presents an outline of the research system. Descending bed was placed in the PCV column of an inside diameter of 196mm and hight of 1m. The motion of the packed bed was generated by the continuous removal of the bed through the feeder located in the bottom. Bed particles were extracted at the column perimeter to simulate "dead zone" in the bed. Air was used as a gas that was fed to the system with constant volume flow rate determined by the rotameter. Pressure drops along the column were measured by using of electronic manometer system($\Delta P1$, $\Delta P2$, $\Delta P3$). The radial distribution of static pressure was measured at 4 levels of model column. Powder was dispensed by feeding screw. The powder in the gas stream was injected into the bed through four tuyeres located along the column's perimeter. The powder carried by gas partially settles on the bed particles ("static powder") and partially moves in inter-particles spaces ("dynamic "powder"). At the bottom of the column, between the feeder and collector, there were the valves that allow measurement of "static powder" in the region of tuyeres (0 - 100mm). Gas with the powder leaving the bed by four exhaust stubs was directed to the cyclone dust collector. "Dynamic powder", held up in lower part of the bed was measured by the use of additional, exhaust stubs located at 100mm of bed height. When steady state was reached, powder injection and bed particles extraction were stopped, amount of "dynamic powder" was measured. When the experiment

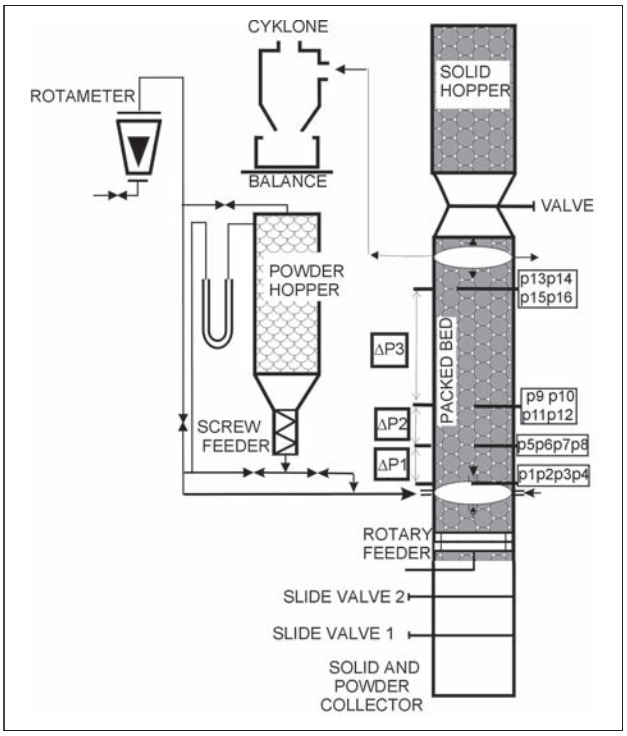

Figure 1 Experimental apparatus

Table 1 **Research conditions**

		Mensuring system	**Blast (furnace shaft)**	**COREX (reduction shaft)**
diameter of bed pieces d_z	/ m	0,010	0,01-0,03	0,015-0,025
diameter of powder particles d_p	/ mm	0,100-0,140	0,075-3,000	0,010-0,040
diameter of column (shaft)	/ m	0,196	12	5
rate of beginning volumes of free spaces in the bed ε_0	-	0,39	0,42	0,42
gas density ρ_g	/ kg/m^3	1,205	0,67-0,85	0,96
gas viscosity μ_g	/ Pa×s	$1,86\times10^{-5}$	$(3,98\text{-}4,25)\times10^{-5}$	$4,49\times10^{-5}$
superficial gas velocity U_g	/ m/s	0,4 - 1,0	1-2	1
bed velocity U_z	/ m/s	$0,45\times10^{-3}$	$(0,6\text{-}1,0)\times10^{-3}$	$0,6\times10^{-3}$
powder mass flux	/ kg/m^{2}s	0,45	0,025-0,10	0,02-0,154
Reynolds' number Re = $\rho_g U_g d_z/\mu_g$	-	267-669	157-1281	320-535
Froude's number Fr = $U_z/(d_z\times g)^{1/2}$	-	$1,27\times10^{-3}$	$(1,1\text{-}3,2)\times10^{-3}$	$(1,1\text{-}1,6)\times10^{-3}$

was finished, the powder settled on the bed particles was measured as a "static powder".

Reynolds and Froude criteria indicated the similarity of study conditions with blast furnace shaft and reduction shaft of Corex installation conditions (Table 1).

DISCUSSION OF EXPERIMENTAL RESULTS

Investigations into distribution of static pressure 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.

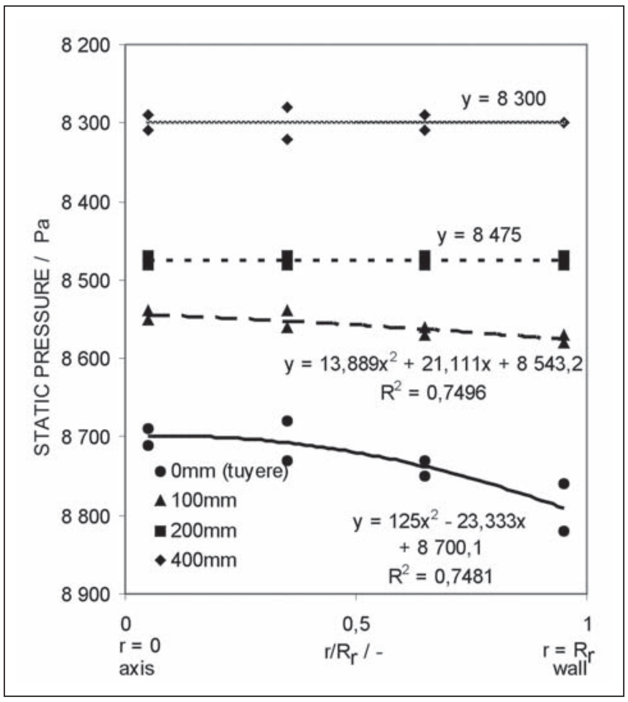

Figure 2 Experimental values of radial distribution of static pressure (U_g = 0,4 m/s)

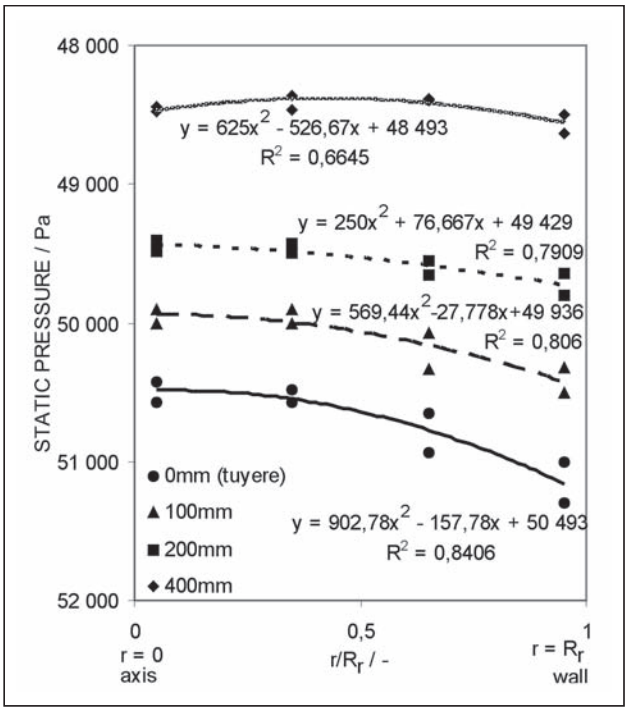

Figure 3 Experimental values of radial distribution of static pressure (U_g = 1 m/s)

It can be noticed (Figure 2 and Figure 3) that pressure is the highest close to the gas inlet (at the wall). Pressure differentiation in relation to radius decreases together with the increase of bed height. At minimum velocity, the pressure in upper parts of the bed takes a constant value.

Making use of experimentally obtained values: radial distribution of static pressure as well as coefficients: volume fraction of total hold up of powder (ε_p), volume fraction of "dynamic" hold up of powders (ε_{pd}), fraction of 'static' hold up of powders (ε_{ps}) – and with the use of mathematical model described in [8], it was possible to determine the correlation between additional drag coefficient induced by gravitation, collisions and friction of powder particles (Fk) and Froude number (Fr) (Figure 4).

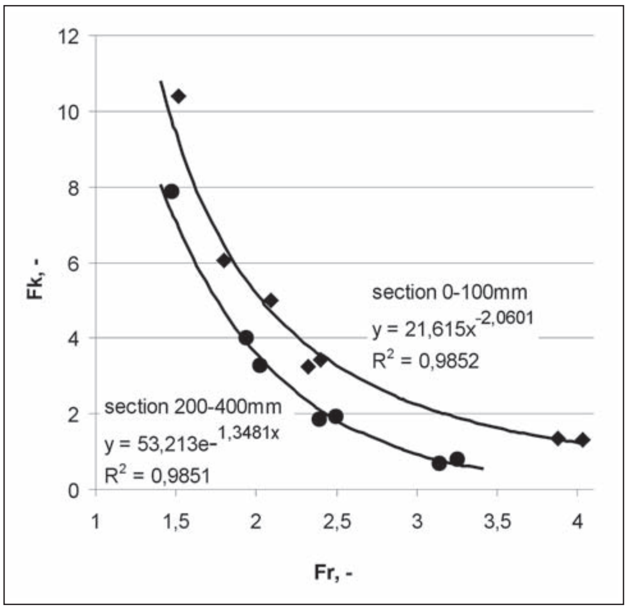

Figure 4 Dependence Fk=f(Fr)

Then radial distribution of the above mentioned values of coefficients (Figure 5 and Figure 6) was calculated. It could be observed that the lower section of the bed (tuyere area) is the area of intensive powder hold up in the bed. It is the area of walls where maximum amount of static powder accumulates. Here this powder fraction determines distribution and ε_p coefficient value.

The influence of dynamic powder upon the value of ε_p coefficient at the velocity of 0,4m/s is insignificant whereas at the velocity of 1,0m/s (maximum velocity) increases from the walls towards bed axis. In the top section of the bed, radial differentiation of ε_{ps} coefficient disappears and as the consequence that of ε_p coefficient.

The fraction of "static" hold up of powder significantly influences the value of ε_p coefficient at minimum velocity of gas , but at maximum velocity it is "dynamic" hold up of powder which determines the total volume of powder in the bed.

Radial distribution of FGZ drags caused by the interaction forces between gas and pieces of bed sur-

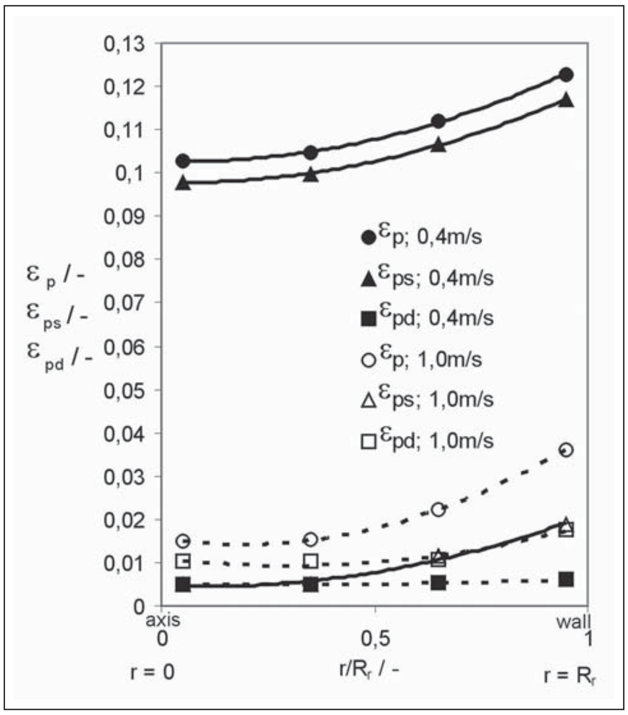

Figure 5 Radial distribution of ε_p, ε_{ps} and ε_{pd} coefficients at the lower section (0-100 mm) of a bed height

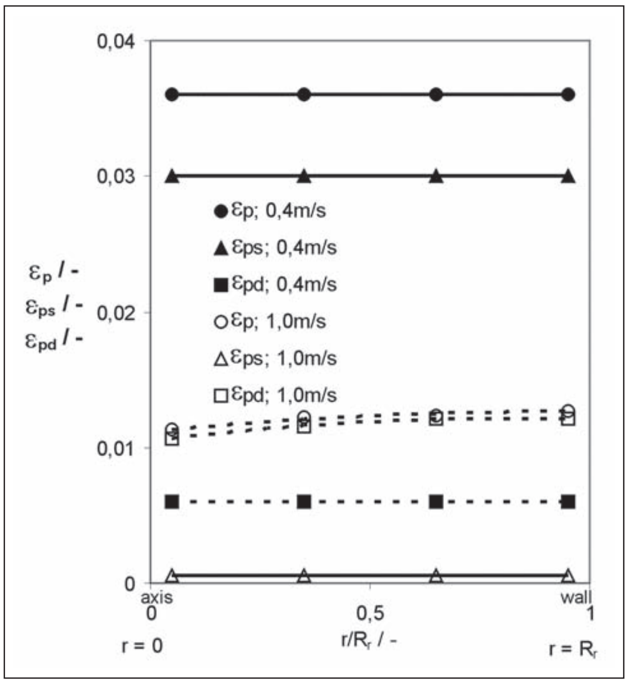

Figure 6 Radial distribution of ε_p, ε_{ps} and ε_{pd} coefficients at upper section (200-400 mm) of a bed height.

rounded by the "static" powder as well as of FGP drags caused by interaction forces between gas and "dynamic" powder particles, has been calculated with the equations described by the authors in [8].

It can be observed (Figure 7 and 8) that at minimum velocity, FGZ interactions greatly influence the drags of gas flows both at lower and upper sections of bed height.

This is the consequence of intensive accumulation of static powder upon pieces of the bed which occur in

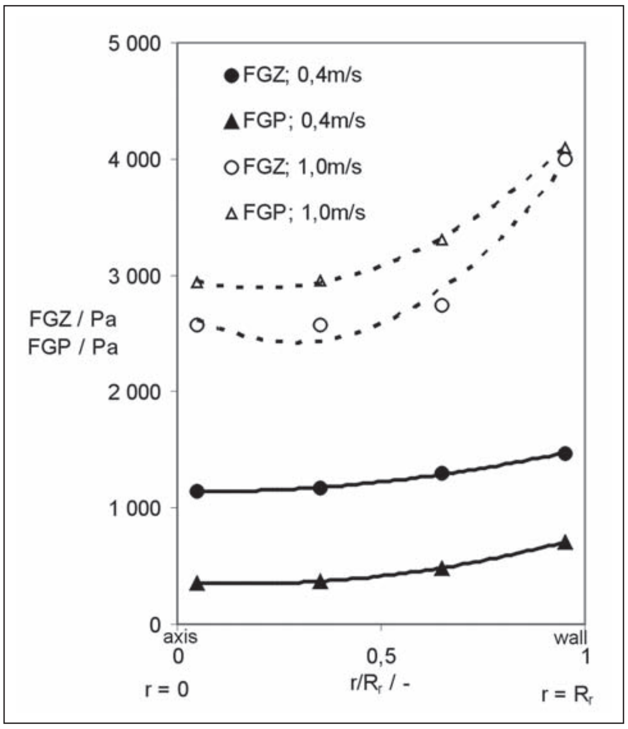

Figure 7 Radial distribution of FGZ and FGP drags (section 0-100 mm).

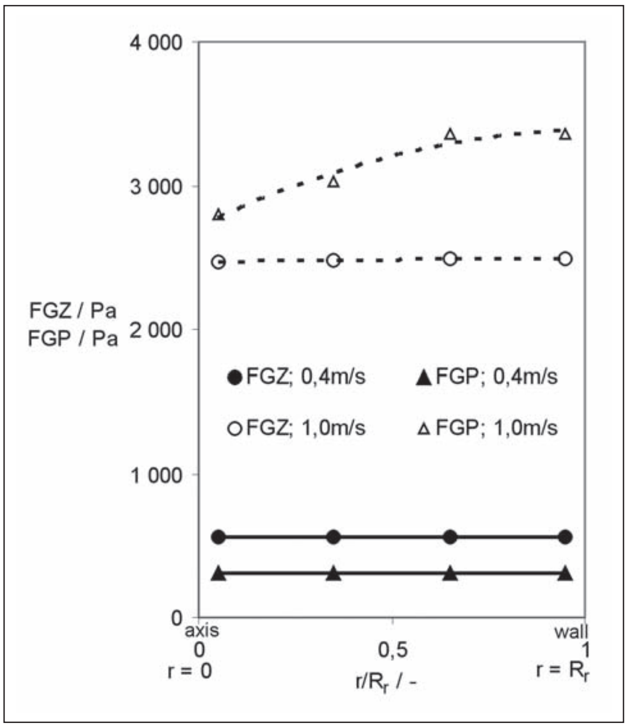

Figure 8 Radial distribution of FGZ and FGP drags (section 200-400 mm).

such conditions. At the maximum velocity of gas more of the dynamic powder hold up causes the increase of FGZ drags which grow from the axis in the direction of bed walls.

SUMMARY

The research upon multiphase flow (gas- powder-moving bed) with the use of full 3D model and with simultaneous analysis of static pressure changes along reactor radius has been carried out. The volume of dynamic and static powder hold ups both in the lower and entire height of the bed was measured. With the application of the described by the author mathematical model[8] and with the use of the above described results of laboratory tests, the calculation method of radial distribution of dynamic and static powder hold ups along the bed height was elaborated (detailed discussion of the method will be presented in a separate article). Significant radial diversity both ε_{ps} and ε_{pd} in the lower section of the bed were observed. It is decreasing together with the height of the bed. As the gas velocity grows the participation of ε_{pd} fraction in the total volume of powder hold up grows as well. The fact affects the value of drags caused by interaction forces between gas and bed as well as between gas and dynamic powder. As the result, it influences the total drags of gas flow.

In future, metallurgical materials will be subjected to laboratory tests and the evaluation of the influence of powder volume in gas together with the size of bed particles upon powder hold up volume in a packed bed and upon flow drags in the function of the radius of test column will be performed. On the basis of the 3D physical model, new calculation procedure will be elaborated. It would be used for evaluation of flow and its disruption in real metallurgical shaft generators.

REFERENCES

[1] H. Takahashi, H. Kawai, M. Kobayashi, T. Fuku: ISIJ International, 45 (2005) 10, 1386–1395.
[2] X.F. Dong, D. Pinson, S.J. Zhang, A.B. Yu, P. Zulli: Applied Mathematical Modelling, 30 (2006) 11, 1293-1309.
[3] K. Yang, S. Choi, J. Chung, J.I. Yagi: ISIJ International, 50 (2010) 7, 972–980.
[4] Z Zhou, H. Zhu, A. Yu, P. Zulli: ISIJ International, 50 (2010) 4, 515-523.
[5] B. Wright, P. Zulli, Z.Y. Zhou, A.B. Yu: Powder Technology, 208 (2011) 1, 86-97.
[6] T. Merder: Materials Science Forum, 654 (2010) 1-3, 1557-1560.
[7] M. Saternus: Metalurgija, 50 (2011) 4, 257-260.
[8] B. Panic: Metalurgija, 50 (2011) 3, 183-187.

Note: The responsible person for English language is A. Aleksander, Zabrze, Poland