PT Procesne tehnologije

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Impact of particle size distribution of material on pneumatic conveying operation on example of ground phosphate

Phosphates, in the form of fertilizers, are essential in the agricultural sector. About 95% of the world phosphate rock production is used in fertilizer industry, and most of the balance is processed into elemental phosphorus which is the main raw material for manufacturing various phosphate compounds [1].

1 Introduction

One of the steps in phosphate ore processing is its grinding. After achieving adequate granula-tion, material is required to be transported to further process. Variety of pneumatic conveying systems are effectively being implemented in the wide range of industries utilizing different kinds of bulk materials [2]. Well-designed pneumatic conveying systems are preferred over alternative mechanical systems, primarily due to their usage convenience related to being totally enclosed [3].

There are many phosphate resources all over the world, and considering the fact that different types of phosphate rocks widely differ in their characteristics [1], physical properties of fine grained material must be taken into the consideration [4] in pneumatic conveying system design and operation.

This paper will make a short review on problems with pneumatic conveying of ground phosphate that occurred in fertilizer production plant.

2 Materials and methods

The research presented in this paper was initiated by persistent problems with pneumatic conveying of about 30 t/h ground phosphate to distance of 240 m.

Pneumatic conveying system in considered plant was designed based on all input data on raw material, such as granulometry (average diameter), bulk density, tapped bulk density and physical density, and the built system was working with no problems. After some time, different phenomenon, such as clogging, line chocking, build-ups in pipes and sudden pipe blockage started to occur.

All kinds of pneumatic system inspections were conducted, and possible causes that were leading to stoppage of the flow could not be found. Laboratory for Process and Environmental Engineering (Faculty of Mechanical Engineering, University of Belgrade) proposed simple characterization of problematic material.

In order to conduct necessary laboratory tests, one sample, about 20 kg of ground phosphate was delivered from the plant, together with the input data on material characteristics used for pneumatic conveying system design (Table 1).

Table 1. Input data on grinded phosphate characteristics for pneumatic conveying system design

Ground phosphate										
	Sieve analysis								Bulk density (kg/m^3)	
Sieve (mm)	1	0.63	0.5	0.4	0.25	0.125	0.063	< 0.063	Non-tapped	Tapped
coarsely ground (%)	0.60	1.90	2.20	3.20	33.80	26.70	14.60	17.00	1343	1702
finely ground (%)	0.40	1.30	1.90	2.70	10.60	20.00	41.50	21.60	1207	1582

Laboratory tests included sieve analysis with calculation of average particle diameter, bulk density, tapped bulk density, physical density, minimum fluidization velocity and permeability of material.

Sieve analysis was conducted according to SRPS ISO 2591-1:1992 and SRPS ISO 3310-1:2018, bulk density and tapped bulk density according to SRPS EN ISO 787-11:2010 i ASTM D7481-18, and physical density according to SRPS B.C8.023 [5].

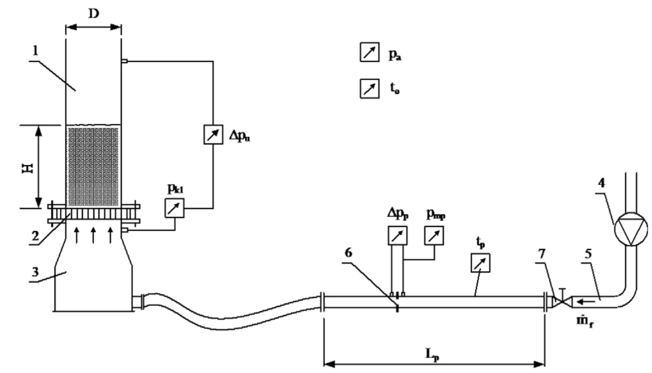

Figure 1: Schematic view of experimental rig [4], [5]:
1. plexiglas fluidizing column, 2. porous membrane, 3. air flow equalization chamber, 4. air mover, 5. pipeline for air supply, 6. orifice plate, 7. regulating valve

Experiments on determining permeability were carried out according to ASTM D7743-12 in a standard type of experimental fluidization rig shown in Figure 1 [4], [5].

The permeability factor of a material may be expressed as the relationship between the superficial air velocity and the pressure drop of a gas passing through a fixed bed [6].

3 Results and Discussion

Results on sieve analysis and average diameter calculation are given in Table 1 and Table 2, and results on calculation of average diameter for input data in Table 3, while results on bulk and physical densities are given in Table 4.

Table 1. Sieve analysis on first sample

Sieve (mm)	0.8	0.63	0.4	0.315	0.2	0.125	0.08	0.063	0.056	<0.056
Sample 1.1	0.59	1.85	9.19	10.29	21.33	34.06	18.38	1.60	0.51	2.19
Sampe 1.2	0.74	1.57	9.48	10.80	52.68	17.64	4.70	1.73	0.16	0.49

Table 2. Average particle diameter for tested sample

Sieve (mm)	Average particle diameter (mm)
Sample 1.1	0.233
Sampe 1.2	0.275

Table 3. Average particle diameter for input data

Sieve (mm)	Average particle diameter (mm)
coarsely ground	0.227
finely ground	0.155

Table 4. Bulk and physical densities

Bulk density (kg/m3)	Bulk tapped density (kg/m^3)	Physical density (kg/m^3)
1320.4	1692.8	2663.3

As given in Table 1, repeated tests showed inconsistency of obtained results with investor data. There was almost no fraction of material < 0.063 mm (less than 3%), while there was about 20% of this fraction in the input data. Also, calculations on average diameter showed noticeable difference in average diameter based on input data 0.155÷0.227 comparing to laboratory tested sample 0.233÷0.275. These results clearly indicate a problem with the quality of grind or some kind of problem with the raw material. Test results on bulk and tapped densities showed almost no differences to investor data, but as given in Table 1, there is no data on physical density in order to compare these values. Nevertheless, difference in granulometry and average particle size is enough to make huge impact on pneumatic conveying systems, especially with high density materials such as phosphates.

Considering input data, test results and the fact that about 60÷80% of input material was fraction < 0.25 mm, this fraction was sieved out for research purposes. Results are given in Table 5 and Table 7.

Table 5. Sieve analysis on sample < 0.25 mm

Sieve (mm)	0.2	0.16	0.125	0.09	0.08	0.071	0.063	0.063	0.056	<0.056
Sample < 0.25 mm	4.20	19.80	34.95	26.28	3.92	5.02	4.93	0.27	0.09	0.55

Table 6. Average particle diameter for sample < 0.25 mm

Sieve (mm)	Average particle diameter (mm)
Sample < 0.25 mm	0.135

Table 7. Bulk and physical densities

Bulk density (kg/m3)	Bulk tapped density (kg/m^3)	Physical density (kg/m^3)
1141.4	1331.2	2500

This fact compelled investor to run multiple inspections and tests on milling plant, which confirmed previous conclusion. After the appropriate working regime of mill plant had been established, another sample of ground phosphate was delivered for laboratory testing.

Minimum fluidization velocity for this material was in range 16÷17 cm/s, and values for permeability factor in range (7.41÷24.09)·10^{-6} m²/(Pa·s).

These two sets of data are presented in various charts Figures 2-6 [7]–[11] recommended for pneumatic conveying flow regime assessment [6], [11]. According to Geldart's and Dixon's classification chart, both sample sets belong to Group B materials that are coarser, sand like and are not likely to convey in dense phase in a conventional system [11], but there is noticeable tendency of finer ground phosphate to boundary between group A and B, what could lead to more convenient regimes of fluidization and pneumatic transport.

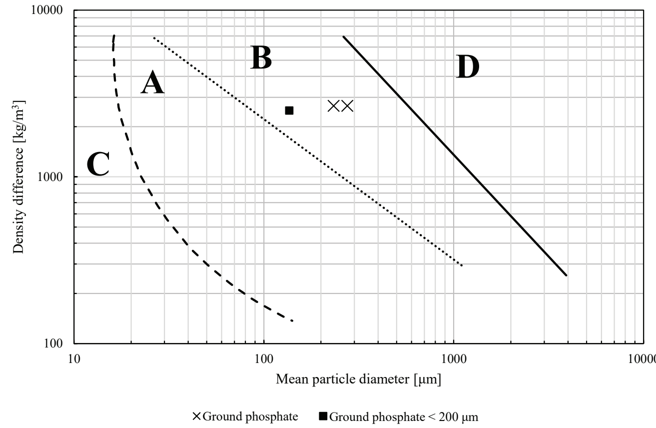

Figure 2: Geldart's classification [7]

Materials that belong to Pan's PC3 group are usually consisted of heavy granular and/or crushed products, with densities over 2000 kg/m³ and bulk densities over 1000 kg/m³ and can be conveyed in dilute phase only, but Pan showed that materials in the group PC1 can be transported smoothly and gently from dilute to fluidized dense phase, usually fine powders [6], [9].

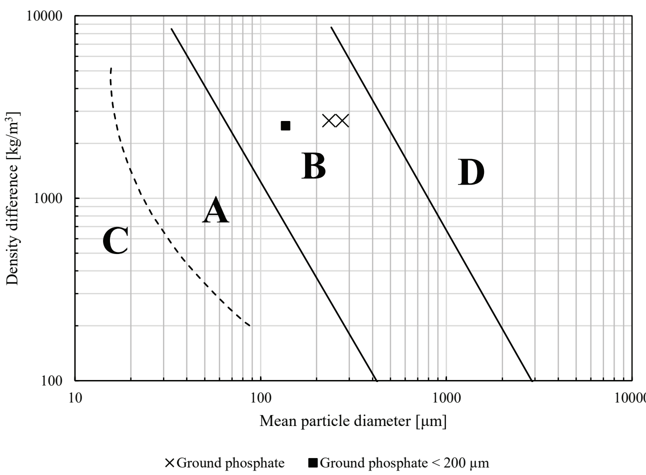

Figure 3: Dixon's slugging diagram [8]

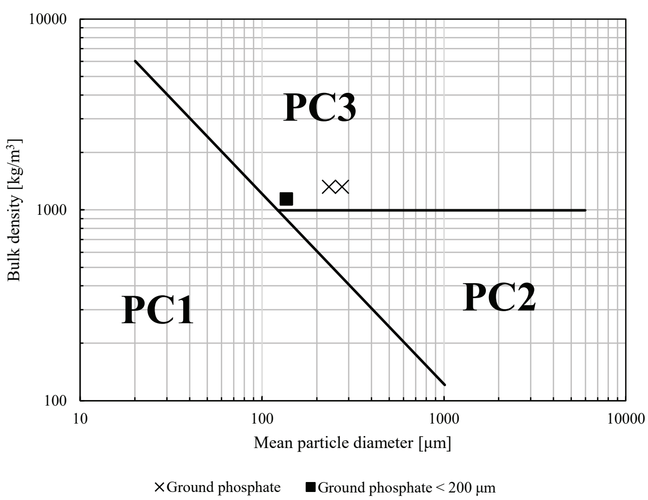

Figure 4: Pan's diagram [9]

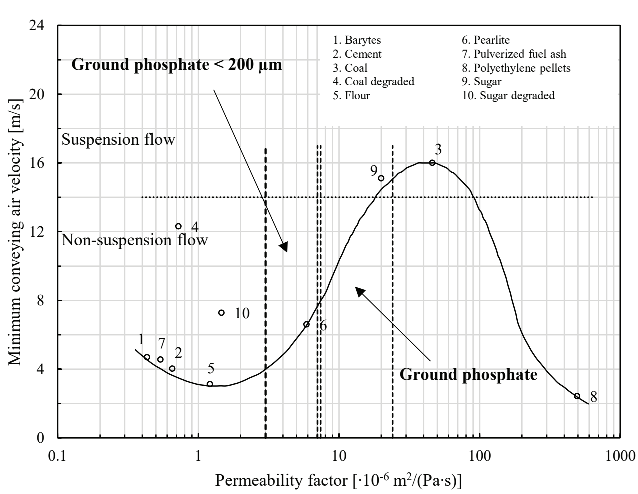

Figure 5: Jones' diagram [10]

According to [9] the materials in the PC1 category are Geldart Types A and C, and some materials in the boundary A/B. Since sample of Grounded phosphate < 200 µm belongs to very border between PC3 with PC1, this fact could explain sudden problems in pneumatic conveying system operation with just when minor deviation in particle size distribution occurs.

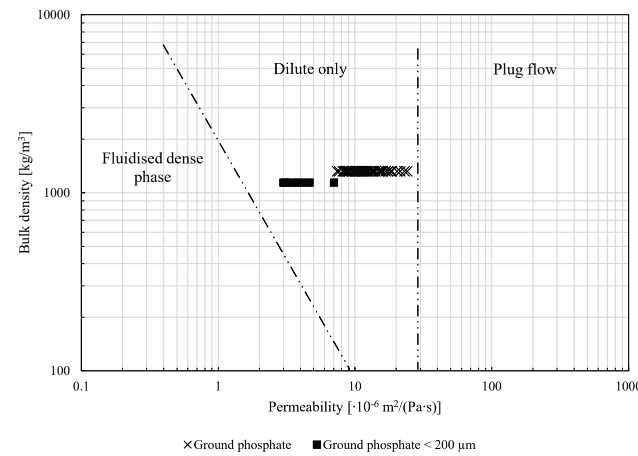

Figure 6: Mills' diagram [11]

Based on Jones' and Mills' diagrams Ground phosphate < 200 µm might be conveyed in fludised dense phase regime/non-suspension flow, because of its closeness to boundaries, compared to coarser ground phosphate that definitely tends only to dilute or non-suspension flow regime.

4 Conclusion

This research showed that a few simple laboratory tests of material to be conveyed might be sufficient to indicate possible roots of problems with pneumatic conveying system operation. It has been confirmed that even minimal deviation of initial particle size distribution of material is very important issue, which could make huge impact on pneumatic system reliability and operation with high density materials such as ground phosphate. Thus, if the plant operates with previous crushing or milling facility, constant and uniform grinding quality must be ensured in order to maintain smooth operation of the pneumatic conveying system.

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