UDC 621.9

Part 3

ASH AND SLAG HANDLING

3.3. Ash and slag properties

3.3.11. Refinement of dependence for estimating critical velocities of dust and air flow considering the factors of shape and polydispersity of particles

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ABSTRACT

The paper presents the results of experimental studies of the shape and polydispersity of particles of cyclonic oil shale, unclassified and classified ESP ash and classified cenospheres obtained from combustion of Kuznetsk coals at Belovskaya SDPP. The shape and polydispersity factors of particles of the studied bulk solids are developed.

The dependence for estimating critical velocity of dust and air flow at pneumatic conveying of fine polydisperse materials with regard to particle shape and polydispersity is verified*.

1. INTRODUCTION

As a result of reviewing the Russian and foreign scientific and technical information sources on critical velocity of dust and air flow in pipelines under different modes of pneumatic conveying fine polydisperse raw materials it was revealed that studies, conducted in different countries, contain the results for specific conditions of materials conveying, at which the effect of particle shape and polydispersity on the critical velocities of dust and air flow is not taken into account. Thus, there have been conducted our own research of particles shape and polydispersity for various fine polydisperse materials:

- cyclonic shale ash of Baltic power companies of the brand "Zolest-oil";
- unclassified and classified fly ash from Lethabo power plant (South Africa);
- hollow aluminosilicate ash cenospheres from Belovskaya SDPP.

Formulas for determining the average shape and polydispersity factors of bulk materials have been developed. Ultimately dependence for calculating critical velocities of dust and air flow while conveying fine polydisperse materials in pneumatic conveying pipelines including shape and polydispersity factors of particles has been refined.

2. PREPARATION FOR THE STUDY OF THE PARTICLE SHAPE FACTOR USING IPS UA ANALYZER

2.1. General information

For conducting research on development of the shape factor for particles of various fine polydisperse bulk solids the IPS measurement system and Elsieve method were used. Automated mobile laboratory complex is designed to study the particle size distribution for fine dry bulk solids with the definition of the shape factor for particles ranging in size from 0.5 mm to 2 mm.

Two-dimensional analyzer of particle size distribution. According to [1] IPS measuring system (Infrared Particle Sizer) operates on a basis of the particle sensor presented in Fig. 2, which is constructed of a light energy source in a form of photodiode, emitting light in the Near Infrared range (1), a system of lenses and screens (A) and (B), forming the measurement surface (2), as well as a photodiode detector (3) with an electronic circuit (4) for the preparatory conversion of the signal.

The measurement space is formed by the optical system in such a way, that its surface is of significant size in comparison to the sizes of the measured particles. Such the formation and the uniform sensitivity in the area of the whole surface assure complete elimination of the edge errors and identical detection of each particle.

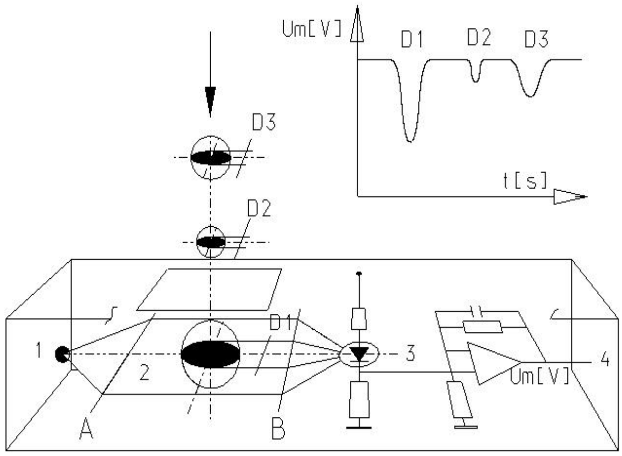

Fig. 1. Particle measurement method

It's known the equation, describing the relationship between the particle diameter and the amplitude of the electric impulse. Taking into account the characteristic of conversion of the light beam into the electric signal in the electronic circuit, it's possible to obtain the measuring characteristics in physical units (microns) with nonlinearities in the area of small values of particle diameters. Any light source of stable and uniform characteristics is needed in order to create such a system. It has become apparent that laser diode is not suitable for such precise studies [1].

There exists a strict relationship between the minimum grain size and the width of the electrical pulse, knowing two mutually perpendicular sizes, calculated in accordance with the spherical calibration. This way an additional factor of the particle shape, that is the maximum to the minimum size, can be defined.

Pulse width uniquely determines the smallest particle size, i.e. its thickness (Fig. 2).

* The paper has been prepared under results of studies according to RFBR grant № 12-08-31145 "Study of the critical velocities of dust-air flows at pneumatic conveying of fine polydisperse materials in pipelines".

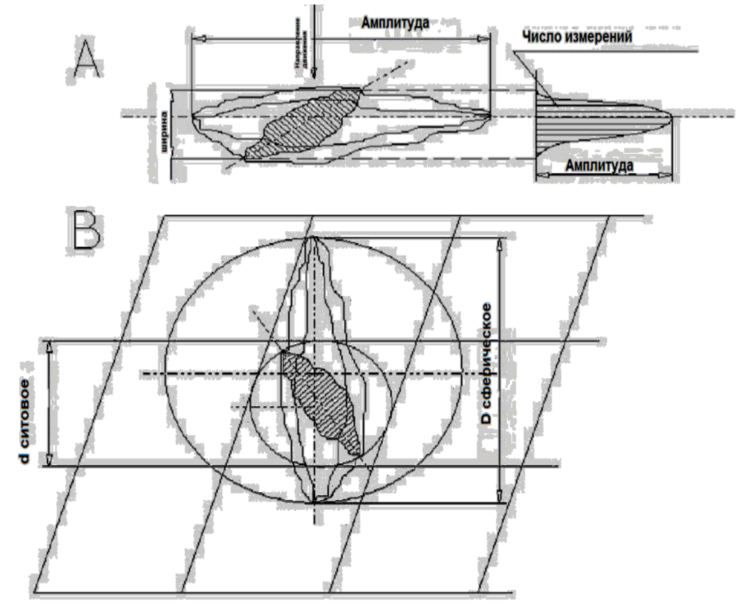

Fig. 2. Comparison of measurement methods: A. Optic-electronic measurement. B. Sieve measurement. The shape factor k_f = (Pulse amplitude / pulse width)

In two-dimensional analyzer of particle size distribution the particles are horizontally transported by air to the place of measurement, as shown in Fig.2 (A). Thus, $k_f = \dfrac{d_{max}}{d_{min}}$, where d_{max} and d_{min} are maximum and minimum dimensions of the particle, respectively.

Fig. 3 shows the appearance of IPS UP analyzer, used in this study.

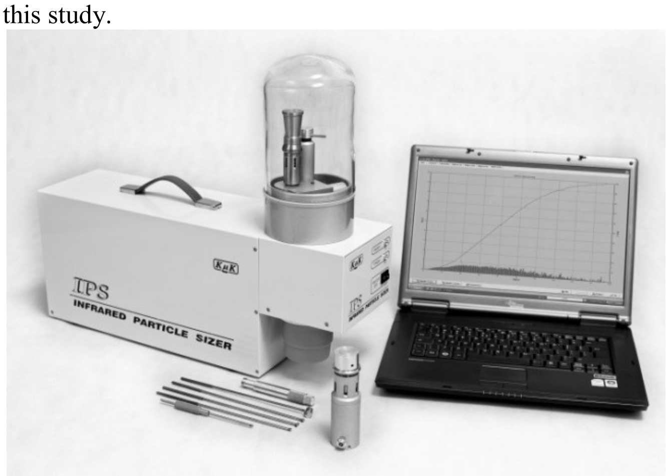

Fig. 3. IPS UA analyzer

To study the particle shape factor the following representative samples have been selected:

1. Two samples of cyclonic oil shale ash of "Zolest-oil" brand. The sample was manufactured at Narva Power Plant (Estonia), the manufacturer – "Eesti Energia Narva Elektrijaamad AS", 27.11.12, unit 6 A, B, lines 1-4;
2. Fly ash sample from the silo of Lethabo TPP (South Africa), not classified named PozzFill®.
3. Fly ash sample from the silo of Lethabo TPP (South Africa), pneumatically classified to separate the fraction less than 90 microns named DuraPozz®. The ash meets EN 450 requirements as Fly Ash of S Class. The larger fraction or a fraction, not corresponding the standard requirements, is transported to the ash disposal area.
4. Fly ash sample from the silo of Lethabo TPP (South Africa) SuperPozz ® was obtained after pneumatic classification of DuraPozz®. SuperPozz® is for sale in very small quantities compared with other products and is manufactured according to customer requirements.
5. The sample of hollow aluminosilicate cenospheres of fly ash from Belovslaya SDPP.

2.2. Sample characteristics

2.2.1. Properties of cyclonic oil shale ash "Zolest-bet"

Extracts from the Protocol of studying the physical properties, performed by the St. Petersburg State Technological Institute (Technical University)

Table 1. **Physical characteristics of cyclonic oil shale ash "Zolest-bet".**

Parameter	Value
Sieve residue, by mass %: 008 005	35,8 21,8
Grain density, g/cm^3	2,55
Specific Blain surface, cm^2/g	850÷1100 under two etalons

Protocol of studying the quantitative chemical composition #1873-12, performed by the Regional analytic centre of the CJSC "MEKHANOBR ENGINEERING ANALYTE» dated 05.12.2012.

The object: gray powder (sample weight ~ 300g.).

Sample name: cyclonic shale ash "ZOLEST-oil" under TU 5743-003-87367999-2012 batch #527 of 31/10/12.

Delivery date: 05.12.2012.

The analysis is performed under GOST 5382-91-definition of K_2O, Na_2O, LOI, SO_3. For other indicators the analyses under GOST 5382-91 were performed, the atomic and emission method with inductively coupled plasma was used.

The results of chemical analysis are presented in Table 2.

Table 2. **Chemical composition of cyclonic oil shale ash "Zolest-bet"**

№	Parameter	Content, % by mass
	Registration number	7273
1	SiO_2	24,1
2	CaO	50,0
3	CaO_{free}	20,0
4	MgO	6,78
5	Fe_2O_3	3,70
6	Al_2O_3	5,49
7	SO_3	3,37
8	K_2O	1,60
9	Na_2O	0,066
10	LOI	4,77
11	chlorides	0,56

Extracts from the Protocol of studying the phase and mineralogical composition, performed by the St. Petersburg State Technological Institute (Technical University)

The sample is of rather complex mineralogical composition and consists of the following components:

1.a. Spherical glassy particles – from colorless to brown and black; transparent with inclusions of other phases, with varying refractive indices - from 1.500 to 1.720; size - 10 ÷ 15 to 70, rarely - to 100 ÷ 200 microns.

b. Angular colorless plates and irregular grains with N from 1.510 to 1.530 (probably alkaline glass).

c. Irregularly shaped fragments with N to 1.630 ÷ 1.650, often with dendritic crystalline phases ingrowths - presumably gehlenite composition glass with ingrowths of melilite group minerals (size from 40 to 80 microns).

2. CaO and $Ca(OH)_2$

CaO_{free} does not occur in practice.

a. They are usually former $CaCO_3$ crystals with point (1 ÷ 3 microns) CaO_{free} ingrowths, locked by glass.

b. Oval glass grains with point CaO_{free} ingrowths as well.

$Ca(OH)_2$, partially carbonized, is formed around the larger aggregates which contain residues not fully decomposed raw minerals and formed during firing.

3. $CaCO_3$ are fine secondary grains and single large $CaCO_3$crystals.

4. Mineral remains - quartz, mica, feldspar, pyroxene. Feldspar and pyroxene are coated with grained calcine - CaO, iron oxides, glass.

5. Those large (up to 70 microns) are colorless and brownish aggregates with N to 1.720 and above, with non-uniform-composition. The calcine formed at their surface with the sizes from 3 to 7 microns makes it impossible to identify their composition. Presumably, they contain CaO_{free}, calcium silicates, iron oxides.

6. Oval brown aggregates composed of β-C2S, iron oxides and calcium aluminaferrites (presumably) ~ 50 ÷ 70 microns.

7. MgO - rare oval brown grains with N ~ 1.735.

8. Individual plates $\beta\text{-}CaSO_4 \cdot 0.5H_2O$ and $CaSO_4$ crystals.

9. Carbonaceous formations.

The approximate mineralogical composition is presented in Table 3.

Table 3. **Mineralogical composition cyclonic oil shale ash "Zolest-bet"**

№	Parameter	Value
1	Spherical glassy particles	~15÷18%
2	Colorless (пpresumably) alkali glass	~3÷4%
3	Glass and minerals of a melilite group	~18÷20%
4	CaO	~18÷20%
5	$Ca(OH)_2$	~4÷5%
6	$CaCO_3$	~5÷6%
7	Remains of raw minerals	~4÷5%
8	Large colorless and brown fragments with N to 1,720, sometimes a little higher	~5÷18%
9	Aggregates containing β-C_2S, Fe_2O_3 and calcium alyumoferrity MgO	~5÷6%
10	MgO	~1÷2%
11	Gypsum and anhydrite	~1%
12	Carbonaceous particles	~2÷3%

2.2.2. Properties of PozzFill® fly ash

According to [2] PozzFill® particles have a spherical shape with sizes ranging from 120 to less than 1 micron. Product color is gray. The material bulk density makes 1100 kg/m^3. Fig. 4 shows a micrograph of PozzFill® particles.

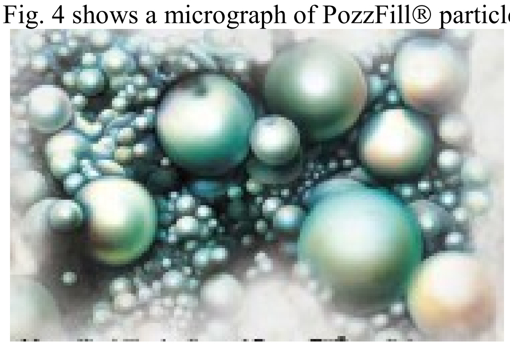

Fig.4. Micrograph of PozzFill® particles.

Typical chemical composition of ash supplied by Ash Resources is presented in Table 4, particle grading analysis of PozzFill® is shown in Fig. 5. [2].

Table 4. **Typical chemical composition of PozzFill® ash supplied by Ash Resources company**

№	Parameter	Content, % by mass
1.	SiO_2	51,0 ÷ 65,0
2.	Al_2O_3	25,0 ÷ 35,0
3.	Fe_2O_3	3,0 ÷ 5,0
4.	Mn_2O_3	0,1 ÷ 0,15
5.	MgO	0,5 ÷ 2,0
6.	CaO	1,0 ÷ 6,0
7.	P_2O_5	0,3 ÷ 0,7
8.	K_2O	0,5 ÷ 1,0
9.	N_2O	0,1 ÷ 0,6
10.	TiO_2	1,6 ÷ 2,0
11.	SO_3	0,1 ÷ 0,3
12.	LOI	0,8 ÷ 2,5

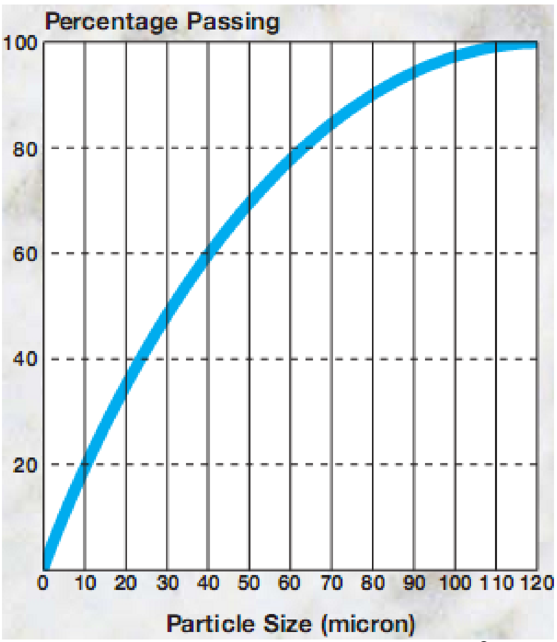

Fig. 5. Typical grading analysis of PozzFill®

2.2.3. Properties of fly ash DuraPozz®

DuraPozz® particles preferably have a spherical shape. [3] The average particle diameter of DuraPozz® is 25 microns. About 90 % of DuraPozz® particles are less than 45 microns. [4] Table 5 shows the chemical composition of the material [5].

Fig. 6 and Fig. 7 show the micrograph of DuraPozz® particles and particle size distribution [5].

Table 5. **Chemical composition of DuraPozz® ash.**

№	Parameter	Value
1.	SiO_2	47,0…55,0
2.	Al_2O_3	25,0…35,0
3.	Fe_2O_3	3,0…4,0
4.	Mn_2O_3	0,1…0,2
5.	CaO	4,0…10,0
6.	MgO	1,0…2,5
7.	P_2O_5	0,5…1,0
8.	K_2O	0,5…1,0
9.	Na_2O	0,2…0,8
10.	TiO_2	1,0…2,0
11.	SO_2	0,1…0,5
12.	LOI	0,5…2,0

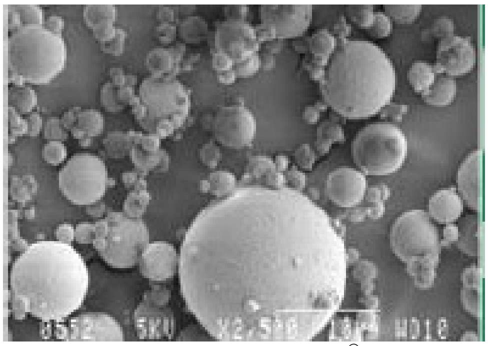
Fig.6. Micrograph of DuraPozz® particles

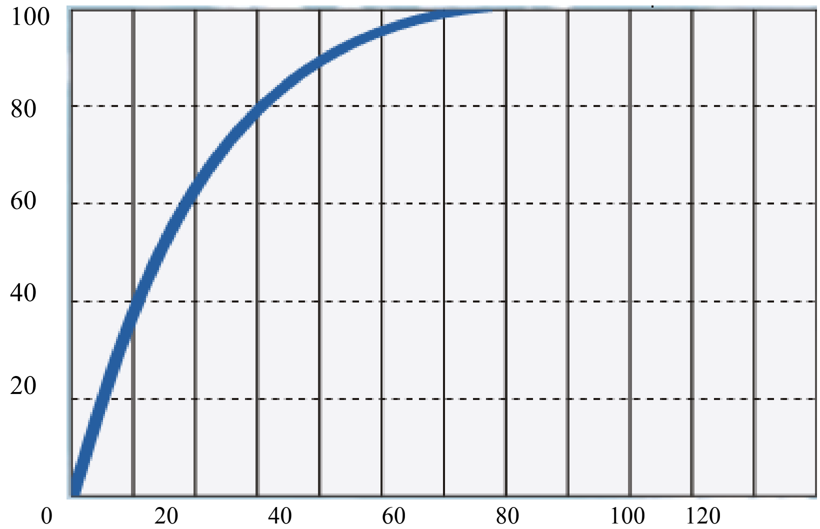

Рис.7. Typical particle size distribution of DuraPozz®

2.2.4. Properties of fly ash SuperPozz®

SuperPozz® represents a fine fraction with the mean particle diameter ranging between 3.9 and 5.0 microns with over 90 % of the material having diameter of particles below 11 microns.

Fig. 8 shows a micrographs of SuperPozz® particles.

Fig. 9 shows the particle size distribution of SuperPozz ® in comparison with the classified ash that meets the requirements of BS 3892, and silica fume. In Tables 6 and 7 physical and chemical characteristics of SuperPozz® are presented.

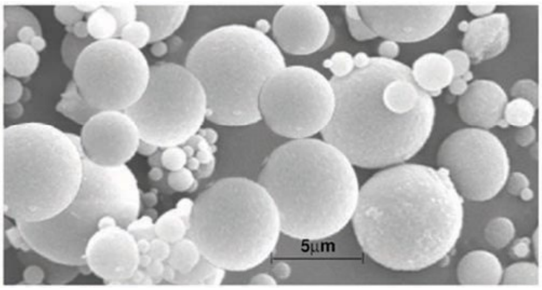

Fig.8. Micrograph of SuperPozz® particles

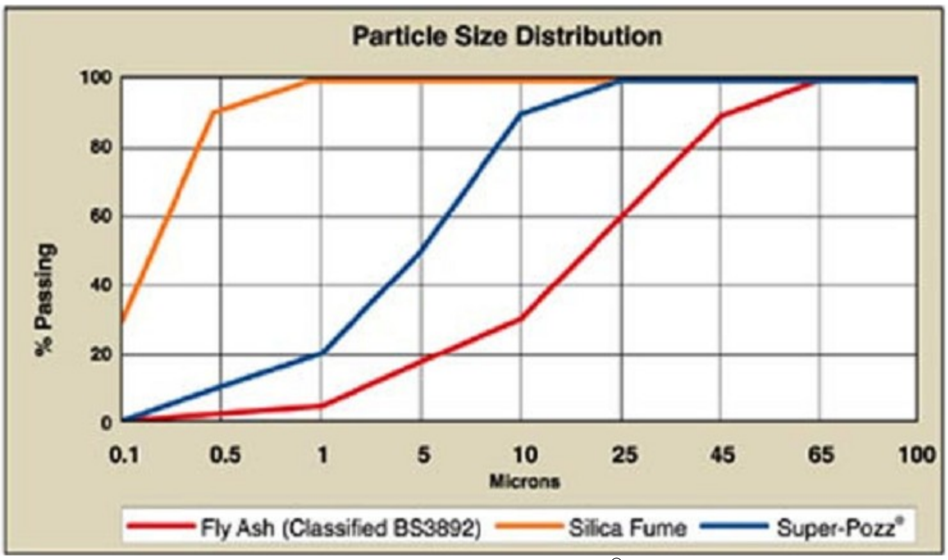

Рис.9. Particle size distribution of SuperPozz® and some other materials

Table 6. **Physical characteristics of SuperPozz®**

№	Index	Value
1.	Relative density	2,2
2.	Theoretical specific surface, cm^2/g	13000
3.	pH-factor in water	11÷12
4.	Humidity, %	<0,2
5.	Color	Pale grey
6.	Los on ignition (L.O.I.), %	0,4
7.	Carbon content, %	<0,2

Table 7. **Chemical composition of SuperPozz®**

№	Parameters	Content, % by mass
1.	SiO_2	53,5
2.	Al_2O_3	34,3
3.	Fe_2O_3	3,6
4.	CaO	4,4

2.2.5. Properties of hollow alumocilicate cenospheres of fly ash from Belovskaya SDPP

Extracts from the Protocol of studying the chemical composition of hollow alumocilicate cenospheres, performed by EC SMIK "Kuzbass" ltd

Date of investigation: March 17, 2011

№	Parameters	Content, % by mass	Value according to TU-5760-001-64538978-2011
1.	SiO_2	60,62	55÷69
2.	Al_2O_3	23,68	15÷40
3.	Fe_2O_3	4,82	1,5÷8,5
4.	CaO	1,72	–
5.	MgO	0,61	–
6.	MnO	0,91	–
7.	TiO_2	1,08	0,5÷2,5
8.	P_2O_5	0,25	–
9.	LOI	3,96	–

Extracts from the Protocol of studying the chemical composition of fly ash from Belovskaya SDPP, performed by ASIC VIMS

Date of investigation: May 16, 2011

Test object	Light fraction of fly ash from Belovskaya SDPP. TU 5712-001 52562003 2005 HS Code 2621 900000. Bulk material of a light gray color. Gross weight 829 g. in a plastic bag attached to an external paper bag outer paper bag sealed with LLC "LITEST" stamp and tagged
Marking	tag labeled on the outer paper bag *Light fraction of fly ash from Belovskaya SDPP*
Sampling	is performed by Commission including the section chief, director of LLC "LITEST" branch Sampling act w/n of 05.05.2011
Methods of analysis	X-ray fluorescence analysis (XFA), atomic emissive with inductive coupled plasma
Equipment	X-ray spectrometer ("Philips", Holland), atomic emissive spectrometer 4300DV (AES) with inductive coupled plasma (ICP) ("Perkin-Elmer", USA)

Results of tests

№	Element	Content, % by mass		Method of analyses
		under TU 5712-001-52562003-2005	in the sample	
1.	SiO_2	57,0 – 65,0	63,4	XFA
2.	Al_2O_3	15,0 - 40,0	30,8	XFA
3.	Fe_2O_3	2,0 - 13,0	2,71	ICP - AES
4.	CaO	0,3 – 6,0	0,91	ICP - AES
5.	MgO	0,1 - 3,5	0,17	ICP – AES
6.	Na_2O		0,26	ICP –AES
7.	K_2O		0,41	ICP – AES
8.	TiO_2		1,13	ICP – AES
9.	MnO		0,030	ICP – AES

3. TEST RESULTS OF PARTICLE SIZE DISTRIBUTION, SPECIFIC SURFACE AND SHAPE OF PARTICLES

Analyzer used in the study allows to measure two particle sizes - the maximum and minimum, and to determine the shape factor of particles by fractions groups, as well as the average shape factor of the entire sample. Initially, the analyzer developers were based on the principle of determining the shape factor of particles through the ratio of the maximum size of the particle to the minimum one, however, the authors believe that it's more correct to define the shape factor of particles through the minimum to maximum size of particles. In this connection the appropriate software has been modified in accordance with our feedback.

The following materials have been tested:

- cyclonic shale ash branded "Zolest-oil" (samples 1 and 2);
- unclassified ash PozzFill® (sample 3);
- classified ash DuraPozz® (sample 4);
- double-classified ash SuperPozz® (sample 5);
- hollow aluminosilicate ash cenospheres from Belovskaya SDPP (sample 6).

The main test results of diameter and shape of particles of the sample №1 (shale ash) are given in Table 8. In this case, the material aggregate density made 2.55 kg/m^3.

Percentage of particles of equal volume B_v vs particle size D_i is shown in Fig. 10. Fig. 11 shows the sphericity of the particles depending on their size.

Table 8. **Test results of diameters and shape of shale ash particles**

Number of particles	222689
Testing time, sec	267,0
Arithmetic average particle diameter d_{av}, microns	15,0
Mean surface diameter $d_{s\ mean}$, microns	20,7
Mean volumetric diameter, $d_{v\ mean}$, microns	27,8
Mean surface-volumetric diameter, $d_{vs\ mean}$, microns	49,8
Geometric diameter, d_{geo}, microns	10,8
Median diameter d_{med}, microns	64,4
Modal diameter d_{mod}, microns	43,3
Minimum particle size, microns	5,6
Maximum particle size, microns	242,2
Specific surface of particles, cm^2/g	973
Specific surface of particles by volume, cm^2/cm^3	2482
Average width of particles	24,6
Shape factor W_k	1,753

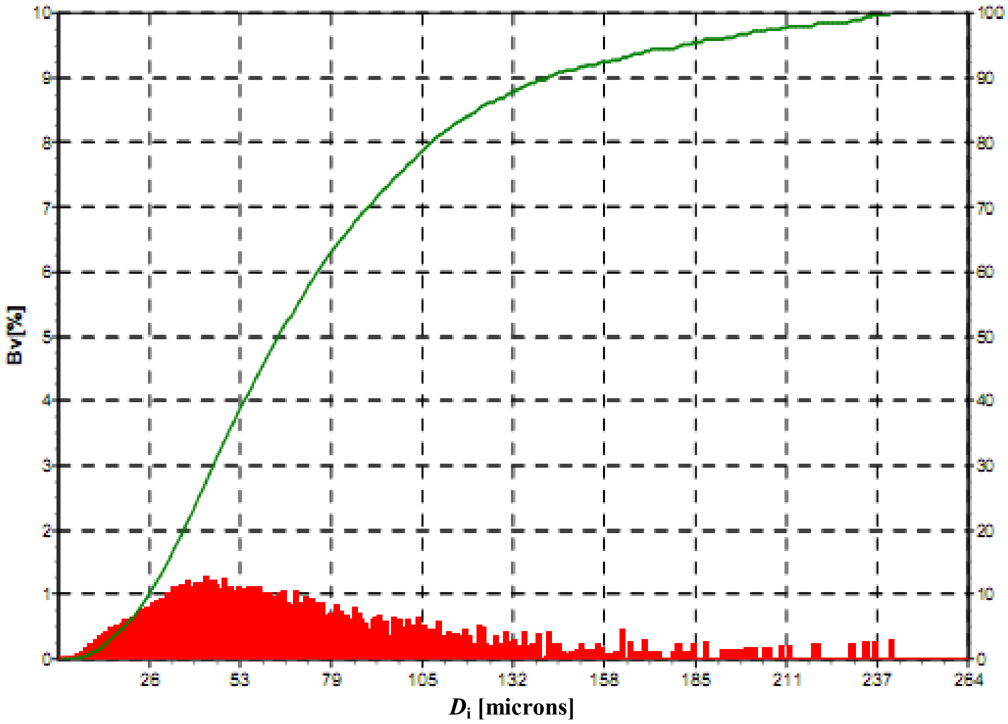

Fig.10. Percentage of particles of the equal volume versus particle size

Particle size distribution of the ash is presented in Table 9. The studies were conducted using sieve analysis at the sieve spherical calibration.

Sieve residues while studying the shale ash samples is shown in Fig. 12. Particle shape versus particle diameter characteristic is shown in Fig. 13.

Table 9. **Particle size distribution of the sample1 (shale ash).**

Sieve number	12	11	10	9	8	7	6	5	4	3	2	1
Size of mesh, microns	Bottom	10,00	20,00	30,00	40,00	50,00	60,00	70,00	80,00	120,00	160,00	200,00
B_v, %	100,00	99,14	94,70	87,06	76,31	64,77	54,27	44,87	36,72	15,63	7,50	3,21
W_k	2,755	1,488	1,297	1,230	1,172	1,131	1,098	1,092	1,096	1,151	1,250	1,321
$1/W_k$	0,363	0,672	0,771	0,813	0,853	0,884	0,911	0,916	0,912	0,869	0,800	0,757

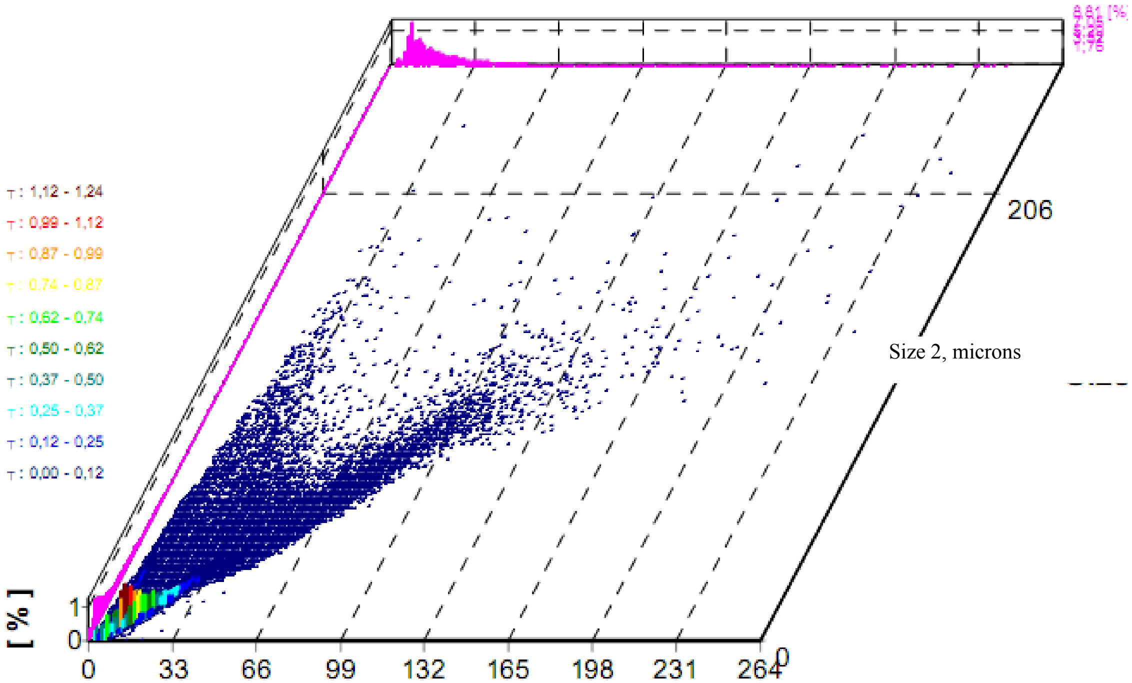

Fig. 11. Sphericity of particles depending on their sizes

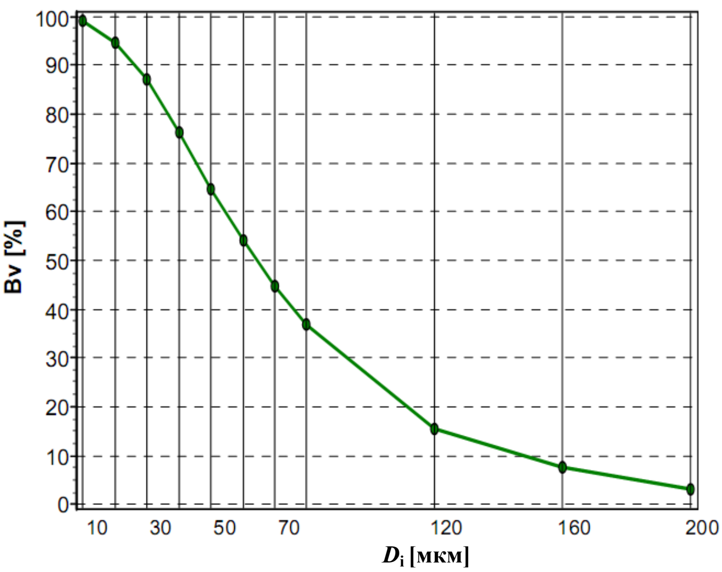

Fig. 12. Sieve residues of the shale ash, sample №1

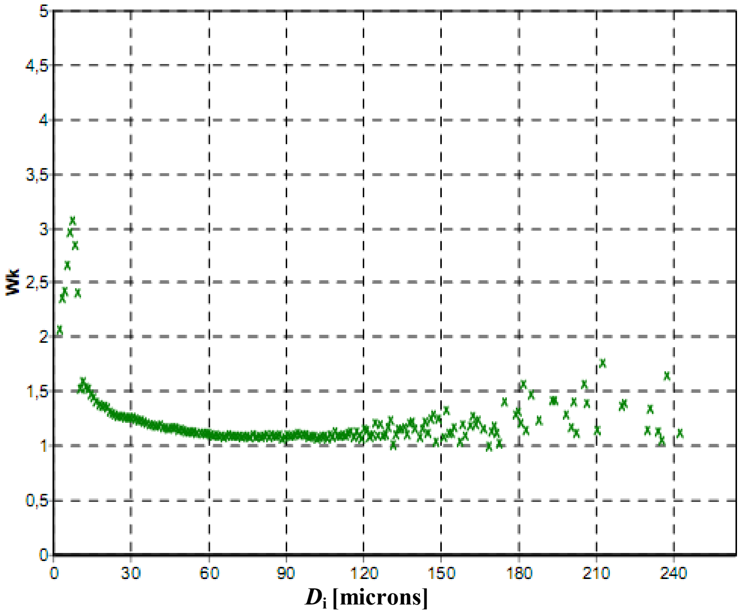

Fig. 13. Shape factor of particles versus diameter of particles

Analysis of results of studying the size, specific surface of particles, particle size distribution and shape of the sample №1. Particle sizes of cyclonic ash vary from 6 to 241 microns, however, the bulk of the particles are from 10 to 130 microns. Microporosity factor of the material was 2.06. At the same time, specific surface area of particles is equal to 973 cm^2/g, which corresponds to the results of studies of the specific surface, conducted by St. Petersburg State Institute of Technology (Table 1). The average shape factor of ash particles is 1.753. Analyzing the results of studies of particle sphericity testifies that spherical particles are located on the diagonal (Fig. 11). Moreover, the different colors denote groups of particles with different parameters (maximum and minimum size, specific surface of particles, etc.). For example, 1.12 ... 1.24% of the particles have diameters of 10.5 ... 12.5 microns, 0.99 ... 1.12% of particles are of 12.5 ... 13.5 microns, 0.87 ... 0.99% particles are of 10.5 and 14.6 microns, etc. Thus, the smaller the particles are, the more their shape is close to a sphere, and the larger they are means more irregular becomes their shape. Particles with sizes from 60 to 120 microns have their shape close to the spherical, and the shape factor of those particles is close to 1.1. Approximately 21% of the particles are from 80 to 120 microns.

Likewise, the samples №№2-6 have been investigated and analyzed.

4.DEVELOPMENT OF THE SHAPE FACTOR OF PARTICLES OF FINE POLYDISPERSE MATERIALS

Authors believe that the shape factor of a single particle is to be determined as the ratio of the minimum particle size d_{min} to the maximum one d_{max}, and not vice versa in the case of two-dimensional measurement, i.e.:,

$$k_{f1} = \frac{d_{\min}}{d_{\max}} \qquad (1)$$

In case of three-dimensional measurement of a particle, the shape factor is a ratio of the minimum particle size d_{min} to half the sum of the remaining two dimensions d_1 и d_2, i.e.

$$k_{f1} = \frac{d_{\min}}{d_1 + d_2} \qquad (2)$$

Formula (1) has been selected as while testing two-dimensional analyzer of particle size distribution of particles was used.

Thus, $0 < k_f \leq 1$. For spherical particles the shape factor is equal to 1 and for non-spherical particles it is less than 1.

To determine the shape factor of the representative sample of particles it is necessary to have particle size distribution of the testing sample, considering the shape of particles by groups of fractions $k_{f^o 1 \ldots}$ $k_{f^o n}$. Then the average shape factor k_f is determined as follows:

$$k_f = \frac{k_{f1} \cdot m_1 + k_{f2} \cdot m_2 + \ldots + k_{fi} \cdot m_i}{100\%}, \qquad (3)$$

where $m_1 \ldots m_i$ is the content of *1* ... *i* particle fractions, % by mass.

On the basis of data obtained while studying particle size distribution of the samples №№1-6 the averaged shape factors of materials have been determined using the dependence (3).

Table 10 shows shape factors of the samples №№1-6 based on research, conducted by Kamika and MPEI.

Table 10. **Shape factors for the samples №№1-6.**

№ of the sample	Material	$W_{k\ mean\ kamika}$ [1)], Kamika calculation	$W_{k\ mean\ mpei}$ [2)], MPEI calculation	k_f [3)], MPEI calculation
1	Cyclonic Estonian shale ash “Zolest-oil”	1,753	1,188	0,852
2	Cyclonic Estonian shale ash “Zolest-oil”	1,377	1,117	0,904
3	Unclassified ash PozzFill®	1,915	1,283	0,807
4	Classified ash DuraPozz®	2,141	1,470	0,732
5	Double-classified ash SuperPozz®	2,283	1,929	0,564
6	Hollow aluminosilicate ash cenospheres from Belovskaya SDPP	1,218	1,134	0,882

Notes:

1) $W_{k\ mean\ kamika}$ was obtained as a result of analyzing the samples №№1-6 using the sizer of Kamika company. It was assumed that the shape factor $W_k = d_{max}/d_{min}$.

2) $W_{k\ mean\ mpei}$ is defined on the basis of the dependence (3), substituting $W_{k1} \dots W_{kn}$ instead $k_{f^\circ 1} \dots k_{f^\circ n}$. Percentage of the particle fractions and $W_{k1} \dots W_{kn}$ were taken from the results of studies of particle size distribution of the samples №№1-6 using the Kamika sizer.

3) $k_{f\ mean}$ was determined by the relation (3). In this case, it was considered that the shape factor of the particles $k_f = d_{min}/d_{max}$.

5. DEVELOPMENT OF THE POLYDISPERSITY FACTOR FOR BULK SOLIDS

Based on the fact that polydispersity of material is heterogeneity of size of particles, the polydispersity factor k_d depends on the average grain size of the material, which is determined by the formula:

$$d_{av.weighed} = \frac{\sum_{i=1}^{n} d_i \cdot m_i}{100} \quad (4)$$

Polydispersity of material also depends on the median particle diameter in the distribution. Therefore, determining the polydispersity factor of material it is necessary to take into account the average weighted particle size $d_{av\ weighted}$, as well as the median particle diameter d_{med}:

$$k_d = \frac{d_{avweighted}}{d_{med}} \quad (5)$$

The authors suggest that $k_d > 1$. For monodisperse media $k_d = 1$, for polydisperse media $k_d > 1$.

Table 11 shows polydispersity factors of the samples №№1-6, calculated using the developed dependence (5). The average weighted particle size is determined by the formula (4) on the basis of measurements of the particle size distribution of materials. Median diameters of particles were obtained when testing the samples with the Kamika analyzer.

Table 11. **Polydispersity factors of the samples №№1-6.**

№ of the sample	Material	$d_{av\ weighted}$ microns	d_{med}, microns	k_d
1	Cyclonic Estonian shale ash “Zolest-oil”	76,83	64,4	1,19
2	Cyclonic Estonian shale ash “Zolest-oil”	75,33	64,3	1,17
3	Unclassified ash PozzFill®	73,44	60,0	1,22
4	Classified ash DuraPozz®	42,99	31,4	1,37
5	Double-classified ash SuperPozz®	15,59	12,6	1,24
6	Hollow aluminosilicate ash cenospheres from Belovskaya SDPP	48,89	48,3	1,01

Thus, the most homogeneous materials are those the average weighted diameters of which are close to median diameters. The most homogeneous of all the investigated materials are cenospheres from Belovskaya SDPP as confirmed by the results of the estimating the polydispersity factor.

6. REFINEMENT OF DEPENDENCE FOR ESTIMATING CRITICAL VELOCITIES OF DUST AND AIR FLOW TRANSPORTING FINE POLYDISPERSE MATERIALS IN PNEUMATIC CONVEYING PIPELINES CONSIDERING THE FACTORS OF SHAPE AND POLYDISPERSITY OF PARTICLES

Critical velocity of dust and air flows while transporting fine polydisperse materials in pneumatic conveying pipelines, excluding factors of shape and polydispersity of the material is determined by the relation (6) from [6].

$$U_{cr} = 0{,}481 \left(\frac{\rho_m}{\rho_w}\right)^{0{,}581} \left(\frac{D_{200}}{D}\right)^{0{,}943} \left(\frac{\rho_m d_{av\ weighted}}{6}\right)^{0{,}159} m^{-0{,}258} \quad (6)$$

Originally, this expression was used to calculate the critical velocity meeting the following conditions:

$$m \geq 2;\ D \geq 0{,}08\ \text{m};\ d_{av\ weighted} \geq 20 \cdot 10^{-6}\ \text{m},$$

where m is the solids loading ratio (mass concentration), kg material/kg air; D is the pipeline bore, m; $d_{av\ weighted}$ is the average weighted equivalent diameter of particles of the material (average weighted particle size), m.

While studying the samples №№1-6 it was found out that the mentioned relation can be used for the materials with sizes less than 20 microns, including the double-classified ash SuperPozz®, the average weighted size of which is 16 microns.

Through studies of the influence of particle shape on critical velocities of dust and air flow the dependence considering the shape factor of particles has been developed:

$$U_{cr} = 0{,}381 \left(\frac{\rho_m}{\rho_w}\right)^{0{,}581} \left(\frac{D_{200}}{D}\right)^{0{,}943} \left(\frac{\rho_m d_{av\ weighted}}{6}\right)^{0{,}159} m^{-0{,}258} \cdot k_f \quad (7)$$

The shape factor k_f is defined by the dependence (3).

As a result of experimental and analytical studies the authors developed a dependence to calculate critical velocities of dust and air flows for different conditions of pneumatic transport, taking into account the factors of shape and polydispersity of particles:

$$U_{cr} = 0{,}317 \left(\frac{\rho_m}{\rho_w}\right)^{0{,}581} \left(\frac{D_{200}}{D}\right)^{0{,}943} \left(\frac{\rho_м d_{av\ weighted}}{6}\right)^{0{,}159} m^{-0{,}258} \cdot \frac{k_f}{k_d} \quad (8)$$

Polydispersity factor k_d is determined by the formula (5).

CONCLUSION

The authors conducted their own experimental investigations relating to the shape and polydispersity factors of the following samples: shale ash, unclassified, classified and double-classified fly ash, as well as ash cenospheres.

Dependences for estimating the form and polydispersity factors of particles of fine polydisperse materials have been developed.

Dependence for estimating critical velocities of dust and air flow transporting fine polydisperse materials in pneumatic conveying pipelines considering the factors of shape and polydispersity of particles have been refined.

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