Conference Paper

Investigation of the Particle Shape and the Particle Size Distribution of Fine Bulk Solids by the Example of the Shale Cyclone Ash

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Abstract

The article contains brief information on pneumatic conveying of fine-grained polydisperse bulk solids, as well as data on the shape of particles. A method for measuring the particle shape developed by Kamika Instruments is described. The determinations of the particle shape as well as the particle size distribution of the shale ash sample using a two-dimensional IPS UA Kamika particle size distribution analyzer are presented.

Keywords: pneumatic conveying, fine bulk solids, ash, particle shape

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1. Introduction

Pneumatic conveying of fine-grained polydisperse bulk solids is often used in cement, mining, metallurgy, energy, chemical and food industries, as well as in other industries. Air is used as a carrier medium in pneumatic conveying systems. In the practice of industrial production, the share of pneumatic transport accounts for up to 30% of the volume of all transport operations. Unlike mechanical and hydraulic transportation of bulk solids, pneumatic conveying is a safer, more economical and environmentally friendly type of transporting fine-grained polydisperse materials. The materials conveyed can have different physical and chemical properties, mineralogical and fractional composition, as well as the geometric shape of particles - from spherical to lamellar, sharp edged and even shell-like, which also affects the nature of their transportation. Density of the conveyed particles can vary from 16 to 3200 kg/m^3.

In the power industry, pneumatic conveying is used to transport coal dust, ash and slag. Worldwide, thermal power plants (TPPs) burn millions of tons of coal. At the same time, the quality of coal burned is significantly different, depending on the location of coal mining and coal beds. As a result of solid fuel combustion, by-products of coal combustion in the form of ash and slag are formed, the composition of which is also significantly different and depends on the quality of the coal burned and the combustion conditions. Both coal dust and by-products of coal combustion can be efficiently transported by pneumatic (dry) method without using water technologies, thereby causing minimal damage to the environment and at the same time preserving the consumer properties of ash and slag [1]. From the point of view of processing of by-products into commercial products, data on the shape of the particles and the fractional composition of the material are important. This is especially true for high-tech applications of ash and slag, such as their use for cement and concrete production, application in the paints and varnish industry, manufacturing of insulation materials, etc.

The form is a characteristic of particles, which can be easily estimated qualitatively, but it is difficult to quantify. This is due to the fact that the particles have three dimensions that are not uniform. Dusty airflow is polydisperse and contains a large number of particles, which have a variety of shapes - from lamellar and shell-like to complex. Particles of a cenosphere, for example, may have a spherical shape. Particles of irregular shape having a large number of protuberances on the surface have different static and dynamic characteristics as compared to particles of regular shape. Particles of irregular shape will coalesce faster with each other than particles of a cubic or spherical shape, while acquiring the properties of one large particle. As the particle size decreases, the value of their shape decreases. Thus, there is a relationship between the particle size and its shape [2].

2. About the Kamika Measuring Method

The authors of the paper [3] developed the optical-electronic measuring devices which using the Elsieve method can simulate measurements by the sieving or optical-electronic analysis method, having higher accuracy in comparison with the classical manual methods, and being much faster. Some analyzers are constructed in such a way that they can scan each grain in a two-dimensional or three-dimensional space and then determine its shape.

To study the particle size distribution of fine-grained bulk solids with the determination of the particle shape factor from 0.5 μm to 2 mm in size, an automated mobile laboratory complex was used. The analyzer makes it possible to measure two particle sizes – the maximum and the minimum, and determine the shape factor. The appearance of the two-dimensional analyzer is shown in Figure 1.

According to [3] an Infrared Particle Sizer's (IPS) operation is based on the particle sensor presented in Figure 2, which is constructed of a light energy source in 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.

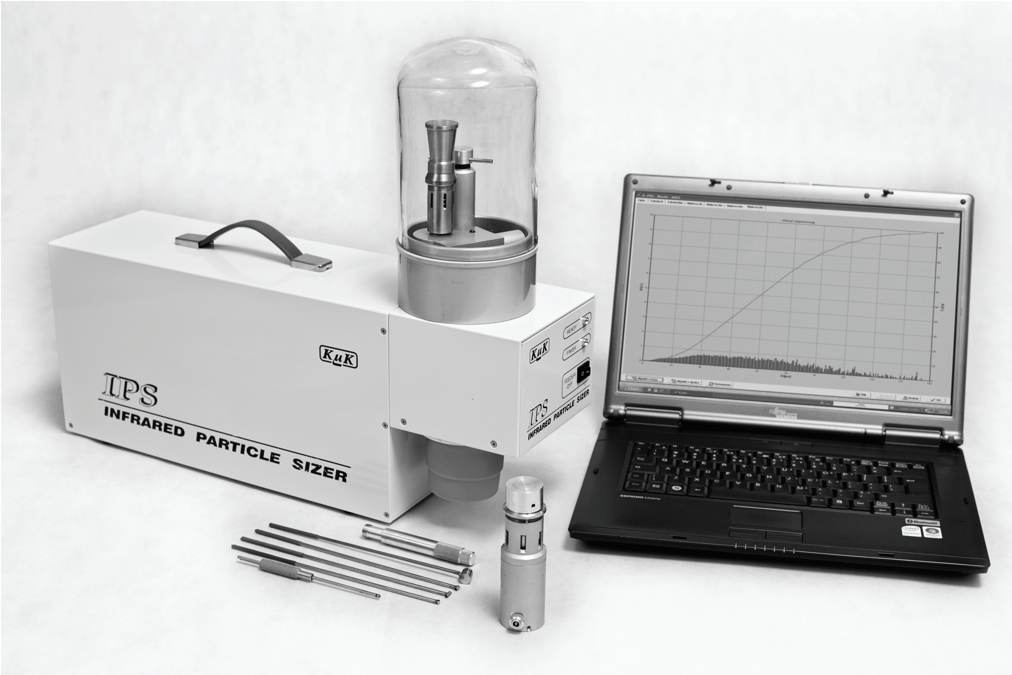

Figure 1: IPS UA analyser.

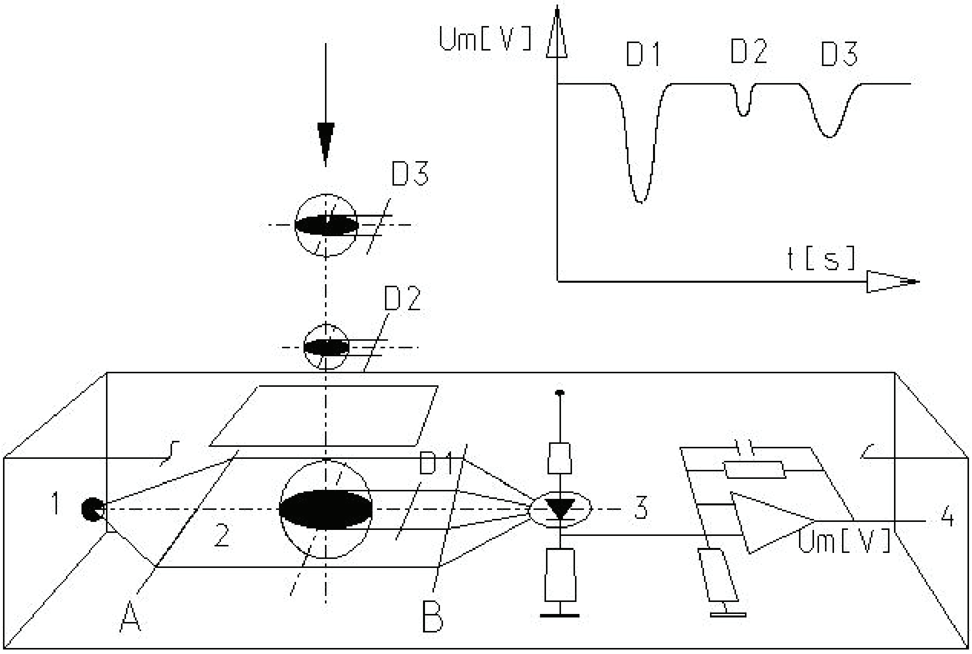

Figure 2: Particle measurement method.

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.

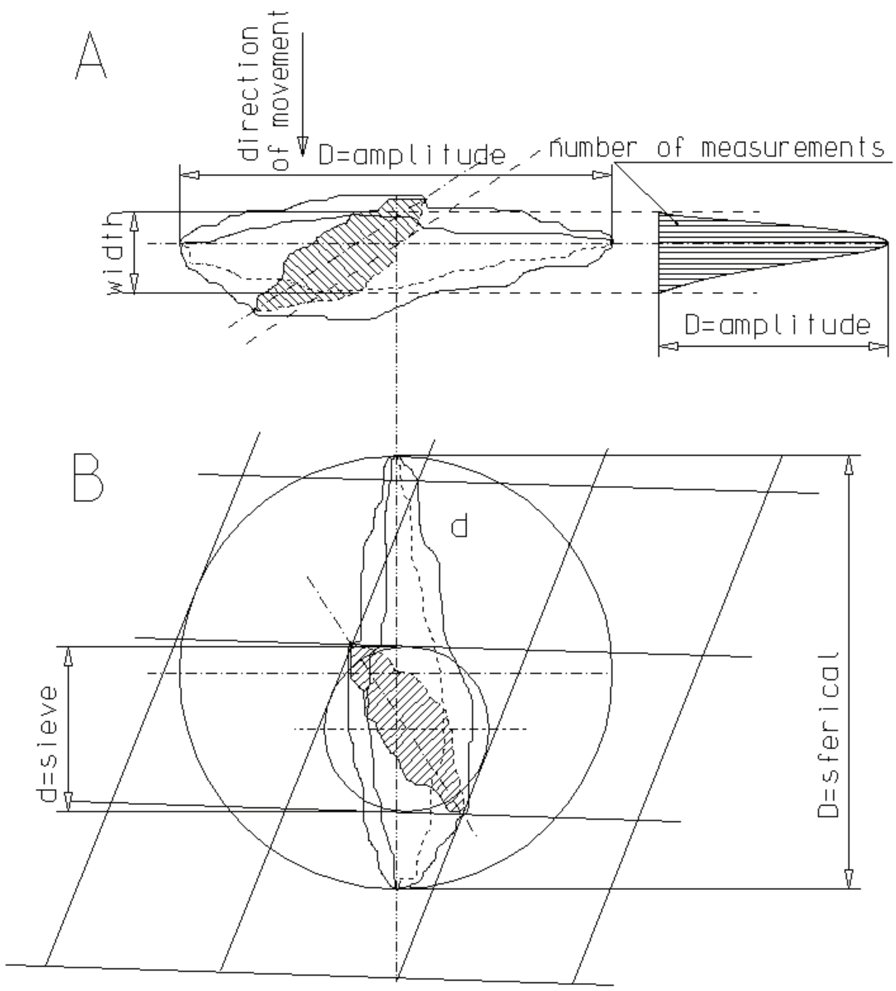

Figure 3: Comparison of the measuring methods: A – optic-electronic measurement; B – sieve measurement. The shape factor k_f = (Pulse amplitude/pulse width) particle dosing in the ips equipment.

There's known an equation, which describes the dependence between the particle diameter and the electric part amplitude. Taking into account the characteristic of conversion of the light beam into the electric signal in the electronic circuit, we can obtain the measuring characteristics in physical units (micro meters) 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 examinations.

There is a strong relationship between the maximum grain size and the width of the electric pulse. Knowing two mutually perpendicular dimensions calculated in accordance with the spherical calibration, it is possible to determine the additional particle shape factor equal to the ratio of the maximum size to the minimum one. The pulse width uniquely determines the minimum particle size, i.e. its thickness (Figure 3).

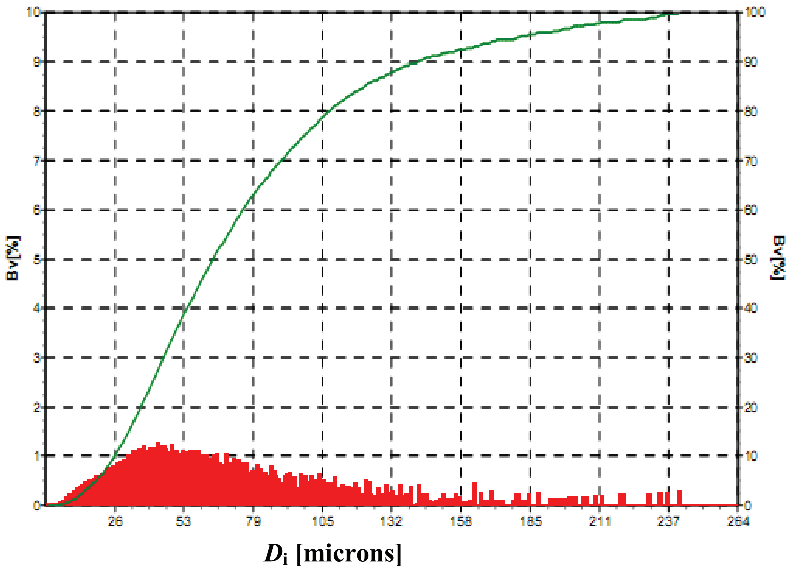

Figure 4: Percentage of particles with the same volume Bv vs the particle size D_i

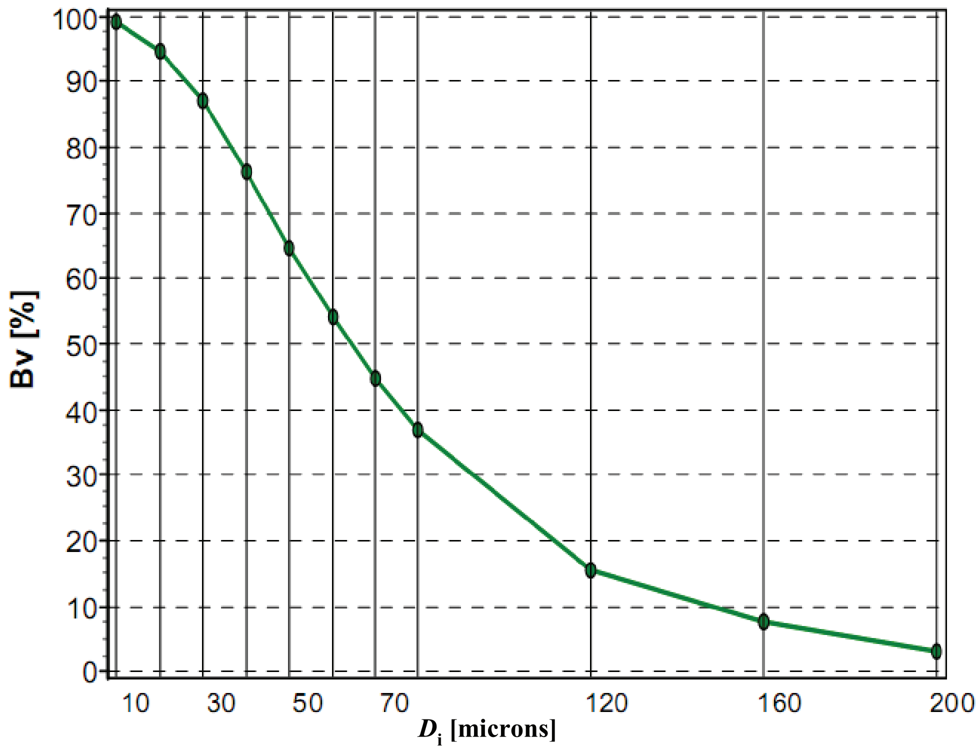

Figure 5: Sieve residue when examining the sample of the shale ash.

In the two-dimensional analyzer of the particle size distribution, the particles are transported by air horizontally to the measurement site, as shown in Figure 3 (A). Thus, $k_f = d_{max}/d_{min}$, where d_{max} and d_{min} are the maximum and the minimum particle sizes, correspondingly.

According to [4] the particle shape factor can be also determined using a three-dimensional AWK 3D analyzer. In the three-dimensional analyzer, the particles fall out

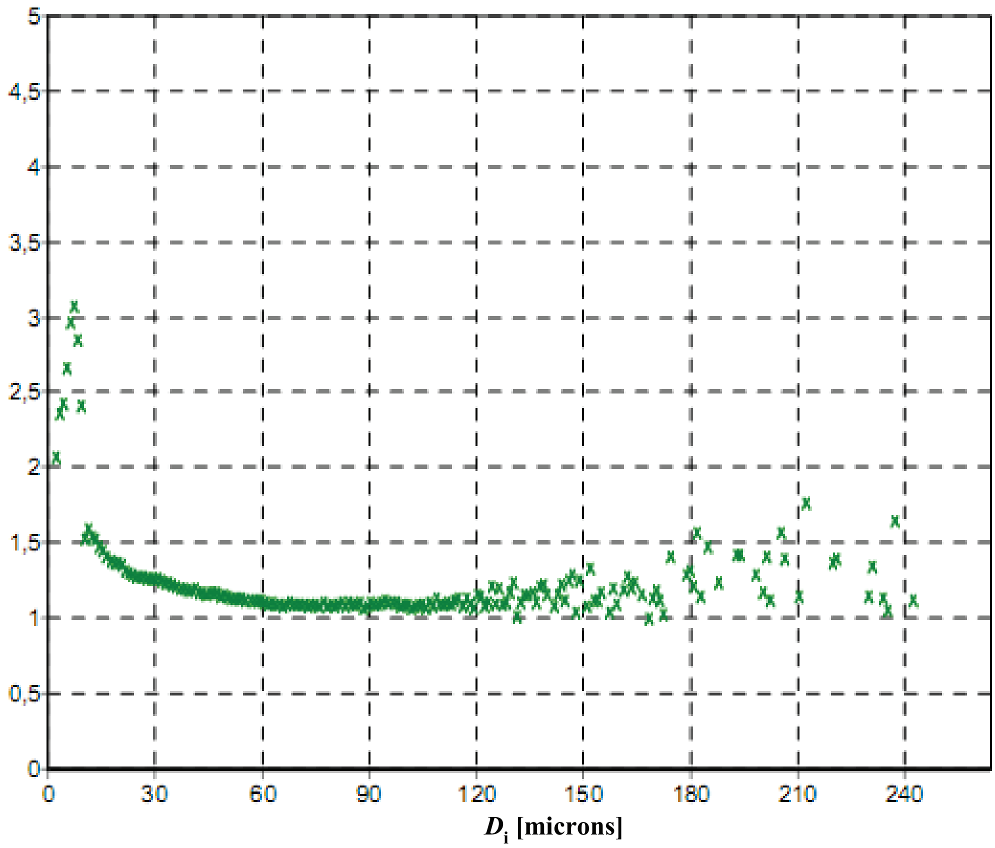

Figure 6: The factor of particles shape vs their diameter.

of the funnel vertically. Their maximum size is in the vertical plane. The two minimum sizes $d_{\min 1}$ and $d_{\min 2}$ are measured simultaneously, and the maximum $d_{\max}$ is measured by the number of particle scans. In this case, to determine the particle shape factor, its maximum size is compared with the average minimum one:

$$k_f = \frac{d_{\max}}{(d_{\min 1} + d_{\min 2})/2} \tag{1}$$

To study the particle shape factor, a sample of the cyclone shale ash of the trade mark "Zolest-oil" was selected. The sample was prepared at the Narva Power Plant (Estonia), manufactured by Eesti Energia Narva Elektrijaamad AS, on November 27, 12, unit 6A, B, lines 1-4.

2.1. The Results of Research of the Cyclone Shale Ash Sample "Zolest-Oil"

The main results of research of the diameters and shape of the particles of the 1st sample of shale ash are given in Table 1 according to [5]. The aggregate density of

Number of particles	222689
Measuring time, s	267,0
Arithmetic average diameter of particles d_{av}, microns	15,0
Average surface diameter of particles $d_{s\ av}$, microns	20,7
Average volumetric diamater, $d_{v\ av}$, microns	27,8
Average surface-volumetric diameter, $d_{vs\ av}$, microns	49,8
Geometrical 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
Volumetric specific surface of particles, cm^2/cm^3	2482
Average width of particles, microns	24,6
Factor of particle shape	1,753

Table 1: Results of research of the diameters and shape of shale ash particles.

Sieve number	12	11	10	9	8	7	6	5	4	3	2	1
Mesh size, 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
k_f	2,755	1,488	1,297	1,230	1,172	1,131	1,098	1,092	1,096	1,151	1,250	1,321
$1/k_f$	0,363	0,672	0,771	0,813	0,853	0,884	0,911	0,916	0,912	0,869	0,800	0,757

Table 2: Particle size distribution of 1st sample of shale ash.

the material was 2.55 kg/m^3. Percentage of particles with the same volume Bv vs the particle size D_i is shown in Figure 4. The particle size distribution of ash is presented in Table 2. Investigations of the particle size distribution were carried out using the sieve analysis at the spherical calibration of sieves.

Sieve residue as a result of the shale ash research is shown in Figure 5. The factor of particles shape vs their diameter is presented in Figure 6.

2.2. Analysis of the Results of Research of the Size, Specific Surface, Particle Size Distribution and Shape of Particles

The particle size of the cyclone ash varies from 6 to 241 μm, however, the majority of the particles have sizes from 10 to 130 μm. The microporosity of the material was 2.06. At the same time, the specific surface area of the particles is 973 cm^2/g. The average factor of the shape of ash particles is 1.753. Analyzing the results of study of particle sphericity, it follows that particles ranging in size from 60 to 120 μm have their shape close to spherical. As the size of particles decreases from 60 to 15 μm, their shape becomes more and more irregular and a stable tendency to the loss of their sphericity is observed. With an increase in the particle size from 120 microns or more, this trend is not stable and the shape factor is scattered from 1.0 to 1.7. About 21% of the particles have the particle size between 80 and 120 μm.

3. Conclusions

For the coal ash processing in order to maximize their use in various applications, in addition to the information on the chemical and mineralogical composition, data on the particle size distribution, the specific surface of particles as well as their shape on fractions should also be available. This is especially true of high-tech applications, such as the use of coal ash in the production of high-quality and special cements and concretes, in the paint and varnish industry, for the manufacture of insulating and other materials. However, there is a general pattern, which indicates that the smaller the filler, the better the strength and other characteristics of the materials and products produced. For example, we can see the reduced water consumption and setting time for concrete.

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