UDC 621.9

Part 3

ASH AND SLAG HANDLING

3.3. Ash and slag properties

3.3.6. The use of Kamika equipment for examination of distributions of particles in coal dust and ash, as well as for measurements of dust content in flue gases

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Each process engineer in his struggle with precise definition of the grain-size distribution of the coal dust, ash, lime powder and synthetic gypsum, has to give some thought to the question, how much time need such measurements and how frequently he/she is able to repeat these measurements in order to control the process he/she operates e.g. coal combustion or flue gas desulfurization. Usually such measurements are made sporadically in relation to the bulk of material used in the process, trusting that the coal dust or lime powder have stable grain-size distribution, which assumption does not always agree with reality. Moreover the currently made measurements are always made too late. Examination results are obtained after the raw material has been applied and there is no possibility to make any grain-size corrections.

The situation mentioned above can be changed with use of modern measuring methods, which are able to control in laboratory conditions the current raw material in real time and to assist the process of making decisions whether the given raw material is suitable for the production to be continued or whether the coal mills can continue the milling.

The opto-electronic equipment is that one which can do the task and which with use of the Elsieve method is able to simulate measurements in accordance with sieve and/or aerometric analyses with higher precision than in case of classical manual methods, and moreover with many times greater speed. Why it is possible? Because these instruments make measurements automatically and register and recalculate the results without a need of human intervention, while the original measurement is registered on 4096 virtual sieves and in accordance with these sieves is summarized on the several control sieves. The measurement results can be sent from the laboratory to every place through the internet or the company's network in form of electronic document.

It should be underlined that single analyser is able to cooperate, according to the software used, with the classic measuring methods by means of mechanical sieves, supplementing the results from these sieves and "spreading" the measuring range onto the areas where sieve measurements are impossible.

Some analysers are constructed in such a way that except sieve analyses they are able to perform two- and/or three-dimensional scanning of each grain and, owing to this, to determine the grain's shape, which affects the reactivity of the given powdered substance in the process.

In Poland the production of cellular concrete is popular with the use of power plant ashes. Control over the specific surface of the milled ashes used in the production process, is performed with opto-electronic measuring equipment.

REVIEW OF OPTICAL MEASURING METHODS

The optical methods of measuring of the particle size can be divided to methods, which make use of:

1) Fraunhofer diffraction [1];
2) Measurements in the optical focus [2];
3) Measurements in the parallel beam of radiation in the passing light [3].

Ad 1) The Fraunhofer diffraction measuring principle consists of the use of laser radiation refraction on particles and registering of the refraction angles of this radiation on the screen equipped with detectors. The luminance observed at different refraction angles attests to the particle size distribution. This is quite primitive analogue measuring method with narrow range of measuring dynamics. These measurements can only be used correctly for measurements of ball-shaped particles.

Ad 2) The principle of measurement in the optical focus consists in measuring intensity of light reflected by particles mowing across the place, in each the focus is situated of the light emitting and light receiving systems. In this case a measurement is performed within small area of the measurement space due to the known dimensions of the optical focus. When not whole particle gets this small area then the measurement is wrong. The total result over the whole cross-section of the mass stream is a multiple of the optical focus area divided by the cross-section of the measurement gas delivery and is multiplied by 200 to 500, what can cause additional high errors.

Ad 3) The principle of measurement in the parallel beam of radiation consists in formation of large measurement planes of the same sensitivity in each point, limited only by the span and diameter of optical systems. A particle passing through the measurement plane causes the light beam to be diffused in proportion to the particle size.

The method of measurement in the parallel beam of light is free of weaknesses of the previous methods and is used in the IPS analyser.

Laser and infrared light can be used with these methods. The wave length of the laser diode and the near infrared source radiation are approximately the same and are equal from 600 to 900 nm. The 900 nm wavelength is close to the maximum photodiode sensitivity.

Homogeneity of the radiation beam intensity is required for the measurement systems based on the geometric optics due to the fact that it assures homogeneous sensitivity in the given measurement area.

It can be stated as a result of the described review that the light source is the important component of the grain-size distribution measuring equipment. Many different types of laser diode exist nowadays, that generate coherent and concentrated beam of radiation, but these diodes are not suitable for the purposes of the geometric optics. It is difficult to obtain the laser beam radiation of the homogeneous intensity in its each point. The laser beam of the same radiation intensity is difficult to be made.

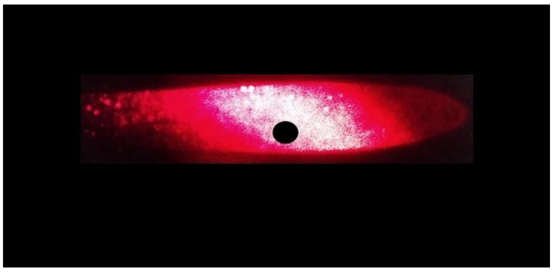

Fig. 1. Irregular distribution of the laser light

Illustration of such light intensity is presented in Fig. 1, where a 40 μm particle is drawn on the background of a 150 μm slit with laser light. Measuring the above mentioned particle with use of the diffused light method in different places of this slit will give different measurement results. With use of “the laser diffraction” the results will also be different. It is a result of the radiation geometry of the laser diode and of positioning of the diode against the slit.

The infrared (IR) diode is a much more proper light source for the geometric optics. The IR diode radiation is much more uniform than that of the laser diode.

THE PRINCIPLE OF OPERATION OF THE IPS SENSOR

Infrared Particle Sizer’s (IPS) operation is based on the particle sensor presented in Fig. 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.

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.

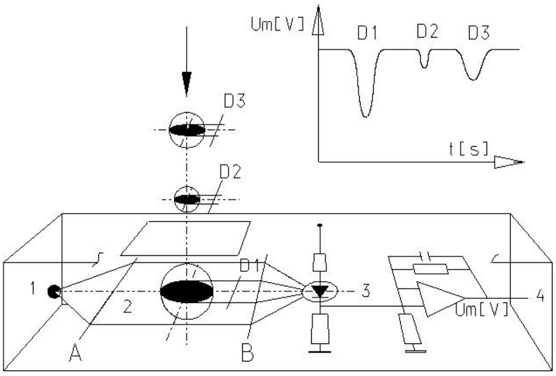

Fig. 2. Particle measurement method

An equation is known, 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.

METHODS OF MEASUREMENT RESULTS PROCESSING

Measurements according to spherical calibration

There is a strong dependence between the maximum grain size and the amplitude of the electric pulse at the measurement sensor output. The measured and counted pulses allow to give a univocal and precise definition of the set of grains and in a repeatable manner, with use of electric units, i.e. in the converter channels, which can be stored in the computer memory. The particle size in electric units is at the same time a channel’s number. The results obtained are then calibrated with use of spherical standards. After such calibration the actual particle dimensions are obtained. In order to pass from number distributions to the volume ones the particle of a given size is inscribed into a sphere. The sphere volume is always greater than the volume of the real particle, so the weight distributions of the spherical particles circumscribed upon the sizes of real particles will always be univocally greater than the sieve distributions of the same particles.

ELSIEVE Method [4]

When developing new methods of measurement, which can be more precise, more rapid and offering a wider size range, one should turn his/her attention to the result compatibility between the new methods and the old ones. The new measuring method should always be comparable with the old method if the measurement performed with this method is correct. The results of measurement of a set of particles, obtained with use of the opto-electronic method should simulate the measurements performed nowadays according to mechanical sieves.

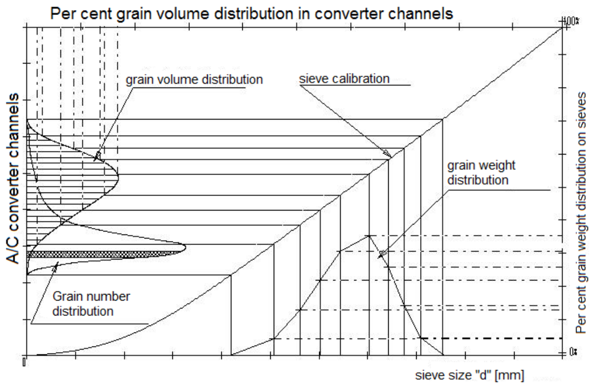

Fig. 3. Sieve calibration of the optical instrument. A transition from virtual electronic sieves to mechanical sieve

In all Kamika's opto-electronic instruments such simulations are used in accordance with the Elsieve method, which employ digital methods of measurement of only one particle dimension stored in the computer memory with use of the A/C converter channels.

The converter channels correspond to 4096 virtual sieves. The set of grains stored in a computer memory in form of statistical distributions of grain numbers and sizes can be compared, after recalculation to the volume distribution, with the actual measurements according th mechanical sieves.

As can be seen in Fig. 3, from the above mentioned comparison one can obtain the characteristics, which will be a sieve calibration of the opto-electronic measuring instrument.

The calibration is assigned to the particular material consisting of grains of typical form, but differing in size.

In case of grains of other type of form one should develop another calibration and create a library of sieve calibrations.

From the library of such calibrations stored in a computer memory one can select the appropriate one and use it for recalculation of the set of particles stored in form of electric units, into the actual dimensions and obtain a precise simulation of the sieve measurements.

2DiSA Method of definition of the particle form [5]

Continuing the previous considerations and assuming that the strong dependence exists between a minimum particle dimension and a width of an electric pulse, knowing furthermore the two mutually perpendicular dimensions, calculated in accordance with the spherical calibration, one can define the additional particle form coefficient equal to the quotient of the maximum dimension by the minimum one.

In order to obtain the particle form coefficient one should fulfil the following basic conditions:

1) The frequency of measurements, i.e. the frequency of the particle scanning, should be increased from 500 kHZ to 12 MHz. Such an increase in frequency by 24 times makes possible the precision of the pulse width measurement to be raised

2) The speed of particle movement in the measurement space should be measured in order to obtain independence of the measurements in the transient state of the instrument (e.g. the compressor accelerations or other adjustments)

3) The specific weight of particles used for the instrument standardization and in the actual measurements, should be taken into account in the recalculations

4) The influence of the calibration of the Elsieve method onto the variation of particle actual dimensions should be taken into account.

The pulse width univocally defines the minimum particle dimension, i.e. its thickness, as in Fig. 4

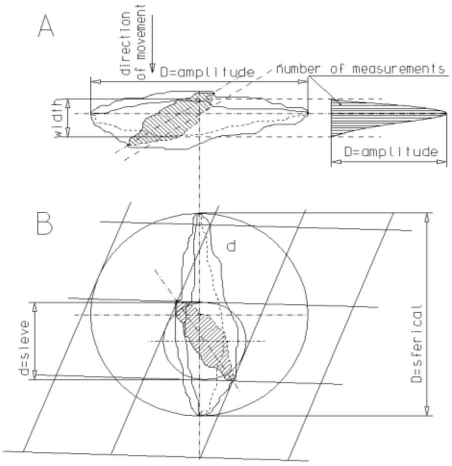

Fig. 4. Comparison of measurement methods

A. Optic-electronic measurement

B. Sieve measurement

The form coefficient

Wk = (Pulse amplitude / pulse width) particle dosing in the ips equipment

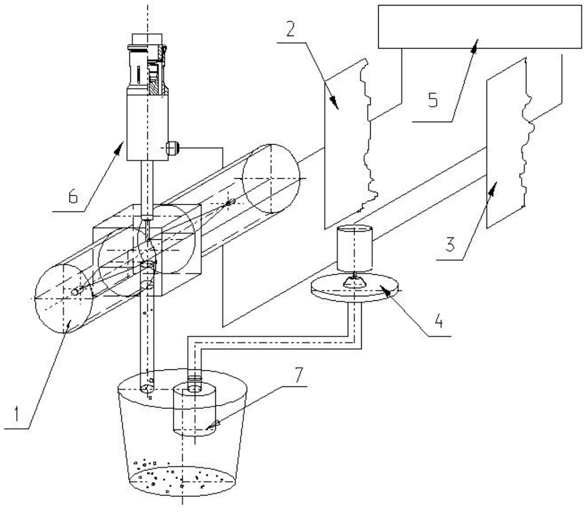

Fig. 5. Measurement and control in the IPS system

Particle dosing, especially in the air medium, is a resultant of many factors comprising the dosing process itself, as well as physical and chemical properties of the material being dosed. The solution adopted in the IPS system assumes the continuous control over the process of dosing during measurement, by keeping nearly constant feed rate of particles in the measurement space.

Fig. 5 illustrates in a schematic manner the dosing method of the IPS system. The particles of material being the subject to the examination, are poured by means of special sampler in the feeder container (6), which is forced to vibrations by the mutually dependent ultrasonic vibrating system, working with 16000000 resolution. The aerodynamic feeders (6) are also used (presented in Fig. 6) for dosing of the larger particles up to 2 mm. Both types of feeders employ the same control system, presented in Fig. 5. The measurement and control system consists of the particle sensor (1) connected to the computer (5) by means of the measuring circuit (2). From the computer (5) the signals enter the feeder (6) and the compressor (4) through the control circuit (3). The whole IPS system works in a closed loop with a feedback. The control parameters can be varied up to 50 times per second. The feeder container is also connected into the cycle of suction system, the inlet height h of which is automatically controlled during the feeding. Particles from the container are sucked out into the inlet opening and further in the air stream pass through the probe measurement space, and then fall onto the bottom of the container or are stopped in the compressor’s filter.

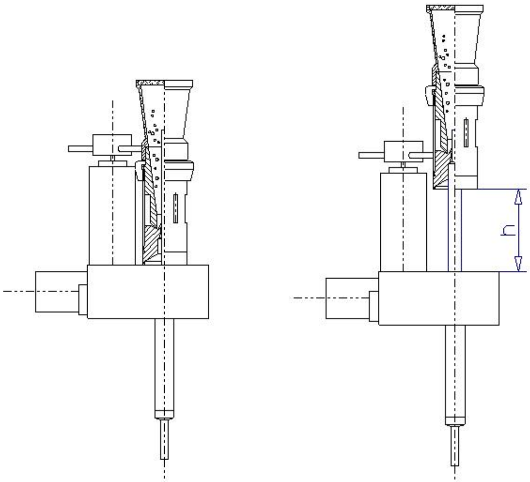

Fig. 6. Operation principle of an aerodynamic feeder.

The compressor is controlled by means of a special electronic circuit with a measuring channel. The both feeders are used alternatively.

A number of particles passing through the measurement space in the unit of time, defined as “the particle concentration”, is maintained automatically at a level assuring effective measurements and at the same time the minimum level of coincidence errors. The solution employed in the IPS is characterized in that there exists a possibility to control the feeding process in a wide range.

IPS K DUST METER

In connexion with constantly decreasing levels of dust concentrations in flue gases, the typical gravimetric dust meters become less and less suitable than the opto-electronic equipment, which can measure and summarize masses of single particles. With use of some proven components of the hitherto used gravimetric dust meters the electronic IPS K analyser has been developed, which is able to fully simulate the operation of gravimetric dust meter at low concentrations.

The IPS K analyser strongly fulfils, in respect to the particle sampling and comparatively to mass calculations, the requirements of the PN-Z04030-7 and ISO 9096 standards concerning the measurements of low concentrations. Furthermore the analyser is provided with the CE certificate. Using the analyser one can determine the suspended dust concentrations PM 10, PM 2.5 in accordance with the EN 481 standard.

The manufacture of the analyser is based on the requirements of the ISO 10012-1 standard concerning ensuring of the measurement equipment quality.

The analyser is calibrated with spherical particles in accordance to the standards and attests of the company of Thermo Scientific, USA.

The IPS analyser in K version [7] is an on-line equipment intended for the dust PM 10 and PM 2.5 measurements for flue gases or in air channels, independently of the gas physical and chemical properties.

IPS analyser’s principle of operation consists in sampling of the particles in the gas stream and in measuring in an optical manner, identically as in the previous instrument. After termination of measurements of the given sample the results are presented by means of statistical parameters of the particle set, as well as with distributions of different properties of the particles.

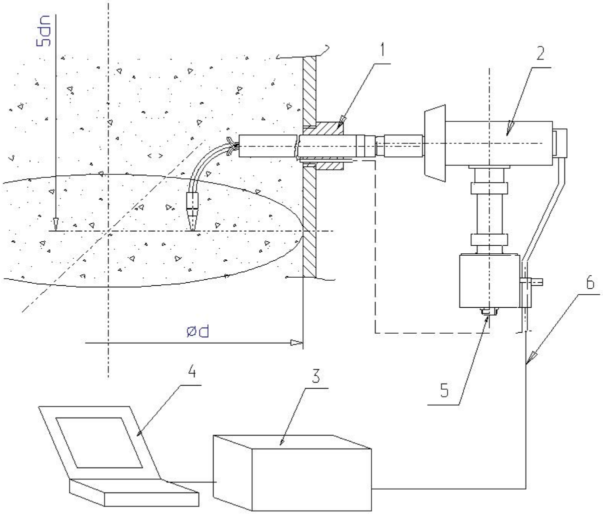

Fig. 7. Examination of dust concentrations with use of IPS K.

The analyser consists of a measuring detector with built-in system of automatic control over the isokinetic sampling.

As a servo-mechanism in the feeding system a miniature compressor is employed.

There is a circuit for the air feed rate measurements in front of the measuring sensor, which circuit makes possible to determine particle concentrations in the sucked air.

Measurements of air volumes are performed by summing of the current outputs, with 0.4% precision. The influence of gas temperature is taken into account in calculation of the gas outputs.

The IPS K measuring system is composed in Fig. 7. A measuring probe [2] is provided with the ring [1], which fasten the probe in the channel being examined. The probe [2] is connected with the electronic control circuit [3] by means of the 25-wire cable [6] 10 m in length.

The processed digitally measurement signals are transmitted to the computer [4] through its USB interface.

When pressure in the channel differs from the atmospheric pressure then it is recommended to have a connection between the compressor [5] outlet and the channel inlet, which is situated in the ring [1].

There are the inlets of two tubes, set one against another at the particle inlet, which are used for measuring of speed of the particle carrying gas. Owing to that, through the suitable suction, the isokinetic particle sampling is ensured.

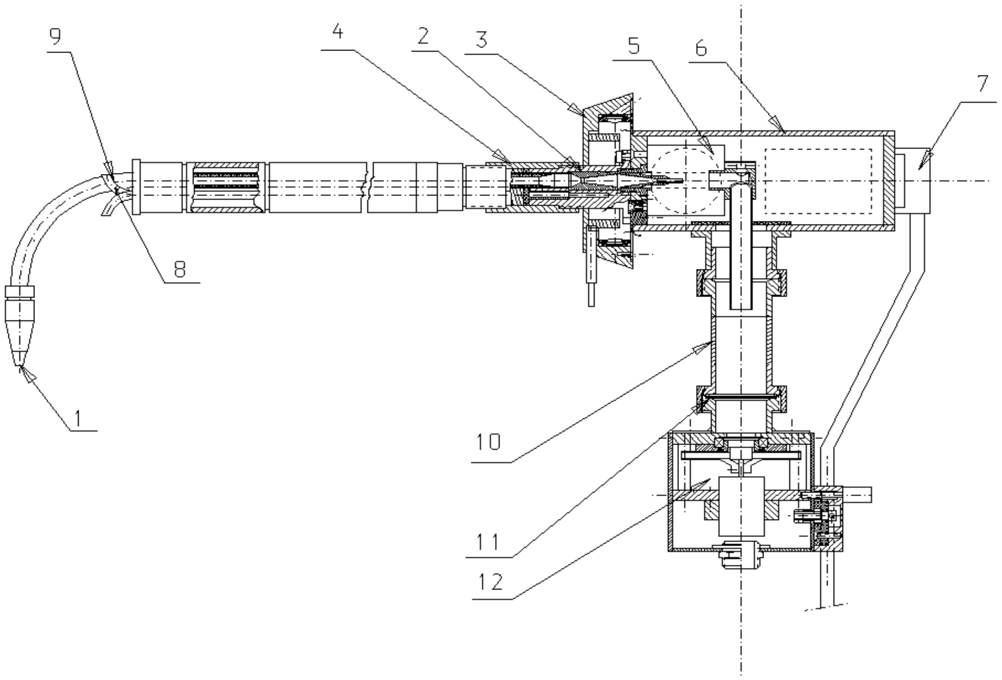

Fig. 8. Construction diagram of the IPS K measuring probe

Measuring method

A diagram of the measuring probe is presented in Fig. 8.

In order to obtain isokinetic intake of flue-gase through the inlet [1], the flue gas speed is measured with the Pitot tube [8]. The isokinetic speed at the inlet [1] is determined from the continuity equation after the output measurement at the Venturi tube [2] and compared with measurement made with Pitot tube [8].

The particles being measured are transported through the inlet [1] in the stream of sucked flue gases. After passage through the Venturi tube [2] and the sensor's [5] measurement area the particles are disposed along the channel [10] through the filter [11] and compressor [12] into the space out of the measuring system. The sensors for humidity and temperature measurements, as well as the filter of air sucked from the external space and used for optics protection, are situated in the casing [3]. The elongated probe part is coupled with the head [6] by means of the threaded coupler [4]. There are electronic circuits in the head [6], intended for measurements of the flue gas speed, made with use of tubes [8], and sensors for flue gas output measurements made with the Venturi tube [2]. The electric conductors are connected to the head [6] with the connector [7], Furthermore the analyser is provided with the thermocouple [9] for temperature measurements in the examined channel. The electronic measurement signals from sensors and the compressor [12] control signal are transmitted through the connector [7]

The analyser is equipped with three optional inlet nozzles, which can be changed at will after removing the inlet cone [1], with five clear air diaphragms, which can be changed after removing the filter casing [3].

Combining the inlet nozzles and diaphragms one can make possible the dust meter operation within wide limits of values of the parameters being measured.

Mounting the standard filter (11), 50 mm in diameter, makes possible additional gravimetric measurements in accordance with the PN EN 13284-1 standard.

MEASURING RANGE OF THE IPS K SYSTEM

- Particle size measuring range from 0.5 to 300 μm
- Sensitivity unevenness of the measurement area 2.5%
- Counting speed up to 10000 particle per second
- Number of dimensional classes – 256 with automatic division to PM 10 and PM 2.5
- Probe length 1000 mm
- Measurements of the flue gas speed from 1 to 30 m/s
- Measurements of the volume of flue gases being sucked

- Measurements of concentration of the solid pollutions in the range from single particles to 5 mg/ m³,
- Measurements of the flue gas humidity and temperature and the instrument temperature
- The measurement duration controlled from the keyboard

Measurements of the above mentioned parameters can be observed in real time on the computer display.

After having performed some single measurements and determination of the average representative point of dust concentration, one can start the monitoring measurements.

A monitoring measurement is performed during predefined period of time, e.g. 15 minutes, its result is stored in the computer and the system is passed to the subsequent measurement with the result number increased by one. After the predefined period of time, e.g 1 week or month, the results of monitoring can be analysed in a summary confrontation.

REFERENCES

1. **ISO 13320** Particle Size Analysis – Laser diffraction method. ISO 2009.
2. **Model 3321** Aerodynamic Particle Sizer Spectrometer, TSI Instruction Manual, 2004.
3. **Kamiński, S., Kamińska, D.,** The comparison of opto-electronic methods of grain-size distribution measurements // Journal “Aparatura Badawcza i Dydaktyczna” (Research and Education Intended Equipment), 2007, Vol. XII, no. 2, p.85
4. **Patent** no. 205738 of the Republic of Poland, A Method of Determination of Grain-Size Fraction Content in Loose Materials, Especially in Minerals, 2006
5. **Kamiński, S.,** The Two-Dimensional Analysis of Grain-Size Distributions in Ashes // Zakopane, Poland, 2011 Conference Publications “Popioły z energetyki” (The Power Plant Ashes)
6. **Patent** no. 169704 of the Republic of Poland, A Feeder for Loose Materials, 1996
7. **Rajczyk, R.,** Emission of Micro Particles in the Process of Combustion of Biomass in the Circulating Fluid Layer // Doctor’s thesis promoted by Ph.D in environment engineering, professor Nowak, W., Technical University in Częstochowa, Poland, 2006.

D. Kamińska, S. Kamiński. The use of Kamika equipment for examination of distributions of particles in coal dust and ash, as well as for measurements of dust content in flue gases // Proceedings of the IV scientific and practical worksop “Ashes from TPPs: removal, transport, processing, landfilling”, Moscow, April 19–20, 2012 — M.: MPEI-Publishers, 2012. P. 173 – 178.