Comparison of sieve analysis and laser diffraction for size distribution of fine ash particles

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Abstract This paper is discussing possible ways of how to determine the size distribution of fine solid particles, focusing on two methods in particular. The first is the sieve analysis which is one of the oldest methods suitable for sorting of groups of particles by size. The second is a modern method utilizing laser diffraction on small particles. For the measurement itself were used the sieve analyzer Analysette 3 PRO and universal laser diffraction device Analysette 22 MicroTec plus, both from the Fritch company. The comparison was made by analyzing fine ash particles from biomass burners. The particles were in the size range of 0.08 μm to 2000 μm.

1 Introduction

Knowing the size of particles is important in many industries and science fields, such as material science, medicine, biology, power industry etc. The size of a particle is considered as the diameter (radius) of perfectly spherical particle. For any other shape of a particle the size parameter is its length that must be defined accordingly to the used method of measurement.

2 Compared methods

Sieve analysis is based on utilization of a set of sieves with the known size of mesh. It is used mainly for separating the coarse particles from the fine ones. One of the advantages of this method is the known size of particles on particular sieves. The main disadvantage is the time demand and a possible destruction of a granularity of tough and fragile particles. In the sieving process, these particles tend to reduce their size dramatically due to abrasion and collisions which leads to inaccurate results that do not reflect the real size distribution of particles in the measured sample.

Laser diffraction is the present most widespread method used for the particle size measurement. The utilized physical principle is known from the begging of the 20th century, but only after the invention of suitable laser devices and computers have this method been developed. In the present day this method due to its flexibility and quickness is superseding other methods of the particle size measurement.

3 Principle of measurement

The sieve analysis uses a set of sieves placed on top of each other, each with a different size of mesh that is decreasing in the direction of the gravitation gradient. For the analysis itself standardized round sieves with a rectangular mesh made of metal fibers are used. These sieves are usually used for analyzing powder samples with particle size in range from 40 μm to 4 mm. In our case the dry method of sieving was used on the particular device ANALYSETTE 3 PRO (fig. 1). It is a typical device of which performance can be recognized by bare eyes. The construction is utilizing a cradle to which the sieves are fixed and that is placed on propulsion on which amplitude of vibrations, sieving intervals and a sieving time can be adjusted.

When the sieving process ends there is a fraction of the original sample on each sieve. Each fraction has particles with the size range that is in match with the mesh size of the current and previous sieve. These fractions are then weighted. The results are weights of particles with particular size ranges which are one of the biggest advantages of this method.

Fig. 1 Sieving analyzer

Fig. 2 Laser analyzer

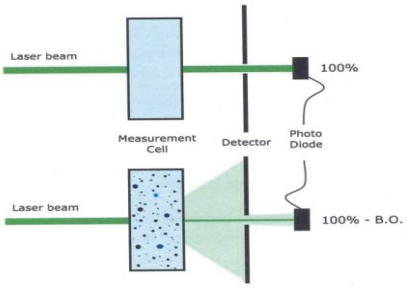


Fig. 3 Concept of the laser beam shielding

The ANALYSETTE 22 MicroTec plus (fig. 2) is a universal analyzing device for particle measurement of suspensions, emulsions and solid matters that is utilizing laser diffraction. The device is composed of central measuring unit and dispersion module. In the central measuring unit two semiconductor lasers, each with the output of 7 mW and wavelength of 532 nm and 940 nm respectively, are present. The measuring range is from 0,008 µm up to 2000 µm. The dispersion unit is an ultrasound water (for a short term organic fluids or saturated inorganic salt solutions can be used) bath with the output of maximum of 50 W and frequency of 40 kHz. Any fluid gets in contact with only chemically stable materials. The entire device is operated via computer with MaScontrol software. Laser diffraction utilizes laser light that after it hits a particle is reflected in a different than the original direction as diffracted light. The amount of how much the laser beam is diffracted and how it is reflected depends on the size and optical attributes of each particle the beam hits. The diffracted light then hits Fourier lens in which by a sensor (photodiode) the distribution of intensity of the diffracted light in the focal plane in dependence of incoming angle is measured. From results of the sensor the size of the particles and their distribution are then calculated. The concentration of particles inserted in the device must be low enough to avoid multiple laser light diffractions. On the contrary, the concentration must be high enough, so the particles are able to diffract enough lasers light for the sensor to detect. The optimum shielding of the laser beam for wet dispersion is 10 – 15 %. After the optimum amount of sample is inserted in the device, the measuring will start automatically. On fig. 3 we can see the principle of laser beam shielding. In the upper section the laser beam is not shielded at all and its full intensity is hitting the photodiode. In the lower section a sample is introduced and the intensity that was hitting the photodiode has decreased due to the aforesaid shielding of laser beam caused by the introduced particles. For an optimal evaluation of the gathered data the device is using the Mie solution to Maxwell's equations for fine particles. For particles many times bigger than the wavelength of laser beam the Fraunhofer approximation is used.

4 Experiments and results

For the experiments fractions of ash from biomass burners were used. The first sample of ash (P1) originated from Dakon Damat Pyro 20G that is burning pieces of wood (spruce, pine tree). The sample has been taken from ash collector. The second sample (P2) originated from Slokov Variant SL 22D that is burning walnut tree chips and was taken from its ash pit.

4.1 Sieving analyzer

First, both samples were sieved in order to remove coarse particles. Multiple sieving courses have been done, each with bigger amplitude of vibrations and longer sieving intervals and a sieving time. The ash sample P1 have been sieved three times (samples 1, 2, and 3) and the ash sample P2 have been sieved two times (samples 4, 5). For the analysis nine sieves with different mesh sizes were used. Meshes with a size of 2 mm and 1mm were used to remove the coarsest particles. After this, the samples ran through the meshes with sizes of (in given order) 500 µm, 200 µm, 160 µm, 125 µm, 90 µm, 63 µm and 45 µm. The fractions that were left on meshes below 500 µm (included) were then weighted and used for thorough analysis in the laser analyzer.

4.2 Laser analyzer

Laser analyzer is showing the results in data sheets where for the corresponding range of particle sizes a frequency of such range to the whole sample is shown. All results are transparently arranged in form of a diagram.

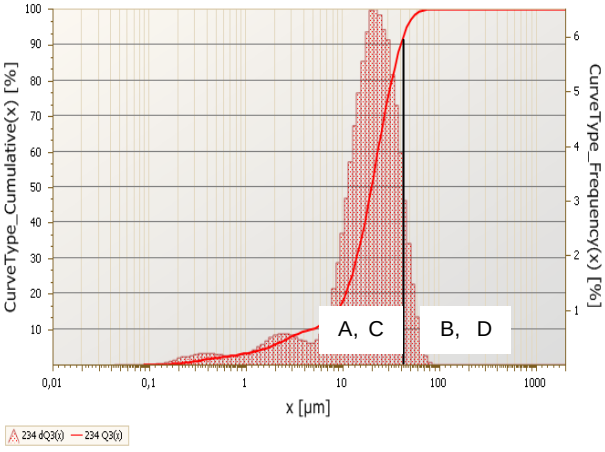


Diagram 1 Ash P1, sample 2, 45 µm

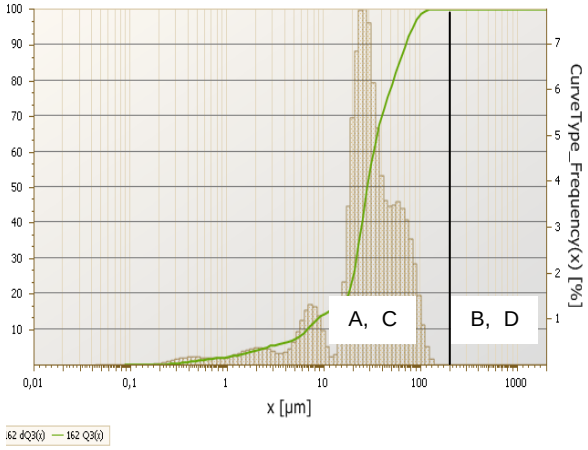


Diagram 2 Ash P1, sample 1, 200 µm

From the diagram 1 that is showing results obtained from the analysis of the P1 residue on 45 µm mesh we can clearly see that there are many particles that are smaller than 45 µm (area A). Logically, there should be only particles of the size of 45 µm and greater. On the diagram 2 we can see a situation when on the 200 µm mesh, according to the laser analysis, there are no particles bigger than 200 µm. All the particles have been identified as smaller than 200 µm (included). Similar results have been obtained from the majority of the measurements.

In table 1 are shown the results of the executed analyses from which by the laser diffraction there were detected particles bigger than the size of the mesh they were taken from (see diagram 1, area B). Evaluation of the obtained results was made with these assumptions: all particles are flawlessly spherical and have a constant density $\rho = 1200\ kg/m^3$.

From the data sheets were obtained the frequencies A [%] (particles smaller than the mesh size of corresponding sieve) and B [%] (particles bigger than the mesh size of corresponding sieve). Values of these frequencies were transformed into weight portions (C, D [%]). Obtained results are lucidly arranged in table 1 and figure 3.4.

Tab. 1 Non-zero frequencies and weight portions of evaluated samples

Sample	Meas. No.	Mesh	Number portion		Weight portion		Sample	Meas. No.	Mesh	Number portion		Weight portion	
		[µm]	A [%]	B [%]	C [%]	D [%]			[µm]	A [%]	B [%]	C [%]	D [%]
2	1/1	45	82	18	54	46	5	1/1	500	78	22	6	94
2	1/2	45	91	9	56	44	5	1/2	500	79	21	37	63
2	1/3	45	88	12	56	44	5	2/2	500	84	16	28	72
2	1/4	45	87	13	53	47	5	1/1	200	85	15	19	81
2	2/4	45	88	12	52	48	5	2/1	200	90	10	16	84
3	1/1	45	87	13	54	46	5	1/2	200	85	15	17	83
3	2/1	45	88	12	54	46	5	2/2	200	89	11	15	85
3	3/1	45	88	12	53	47	5	1/1	45	68	32	42	58
4	1/2	500	87	13	28	72	5	2/1	45	75	25	40	60
4	1/3	500	85	15	36	64	5	1/2	45	80	20	36	64
4	1/1	200	87	13	15	85	5	1/3	45	80	20	60	40

Diagram 3 Frequency of particles bigger than the than the mesh size of corresponding sieve

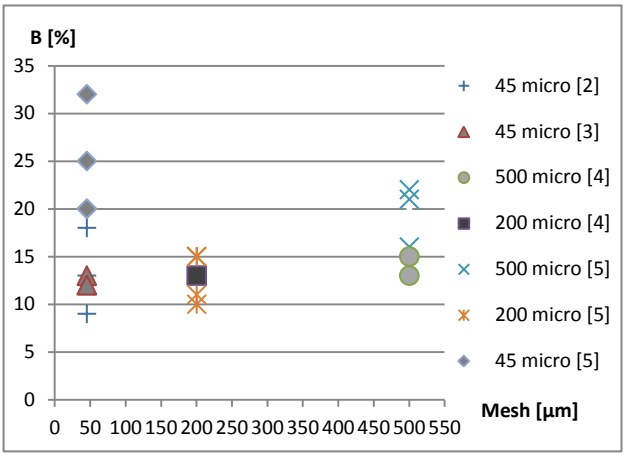
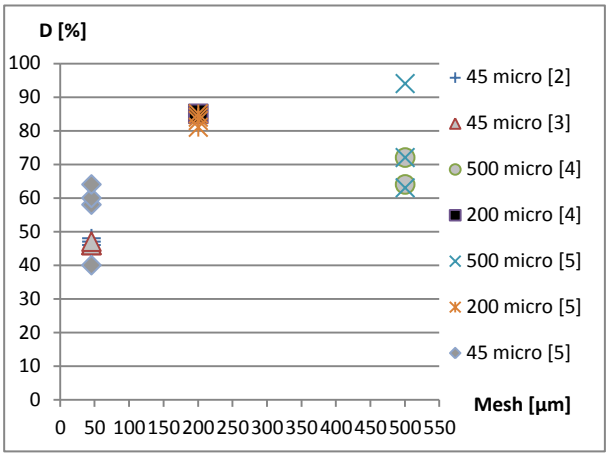


Diagram 4 Weight portions of particles bigger mesh size of corresponding sieve



5 Conclusion

Evaluation of the analyzed ash samples shows a high amount of fine particles in individual samples. Transformation of frequencies into the weight portions shows a significant impact of a relatively minor number of bigger particles on the results obtained from sieving analysis. Evaluated samples shows a significant cohesiveness of ash particles that is causing overvaluation of the results obtained by sieving analysis from the sieves with the used mesh size. Executed trials do not show any improvements in stated overvaluation by using more intense and repeated sieving. With the cohesiveness of the ash particles in consideration, the most significant boon of the laser analysis is the high-quality dispergation of the sample in water bath that prevents the flocculation of the ash particles and leads to more accurate evaluation of samples of ash particulates. The accuracy of laser diffraction instruments alone and was verified by a calibrated particles supplied by Fritsch.

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Sources

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