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INFLUENCE OF PARTICLE SHAPE ON BALANCING THE CLASSIFICATION PRODUCTS GIVEN BY HYDROCYCLONES ON THE BASIS OF THE RESULTS OF LASER PARTICLE SIZE ANALYSIS**

1. Introduction

Article is the effect of continuation the investigations concerning the usefulness of laser granulometric analyzes to balancing the classification products of fine-grained materials [1, 2].

Previous investigations guided by authors showed, that there is possibility of balancing the products of classification fine-grained materials in hydrocyclones, despite varying accuracy of laser analyzes of respective material streams which resulted first of all with differences in granulation of classification products.

Investigations proved that there is no essential influence of material density on precision of the laser analyzes of granulation [2]. In addition, the balance of classification products should be based on percentage parts of the finest grain classes which be determined with high accuracy by laser method.

The purpose of the research presented in the paper was to verify the influence of grain's shape on results of laser analyses, and the same on possibility the accurate balancing products of their classification.

As in previous investigations, the accuracy of laser analyses was characterized by the coefficient of variation w for percentages of respective grain classes in classification products.

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2. Experiments and analysis

Two materials differing with grains shapes — shale copper ore and fly ash from burning the coal, was investigated. The shapes of grains was described with the coefficient K_α — elongation rate (in relation to a circle). It was calculated using of computer image analysis of tested materials. The optical microscope connected with digital camera as well as the Aphelion 3.2 — image processing and image analysis program, was used for this stage of research. Figures 1 and 2 present the examples of microscopic photographs of studied materials. Coefficient K_α for shale ore carried out 1.87, and for fly ash 1.12 (for the circle $K_\alpha = 1$). Differences in the ratio confirm different grain geometry of both materials. Shale ore grains are characterized by irregularly shaped, elongated, with sharply outlined edges (Fig. 1).

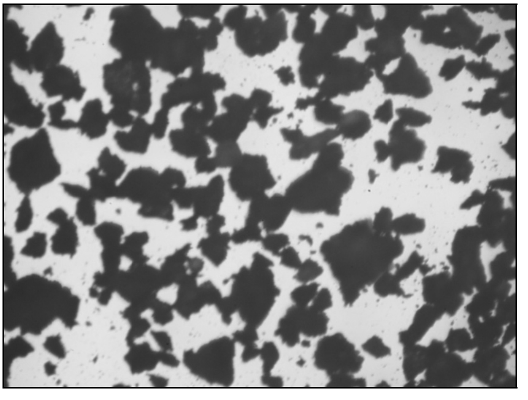

Fig. 1. Microscopic image of the copper shale ore

However the fly ashes have a spherical shape of particles of different size, color and degree of crystallinity (Fig. 2).

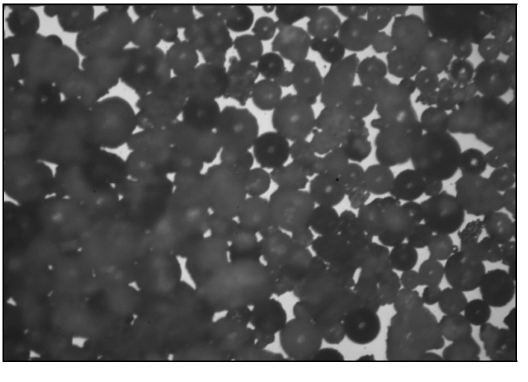

Fig. 2. Microscopic image of fly ash from coal combustion

Some of the grains are microspheres with particle size < 0.4 mm, which contain smaller grains inside. There are also grains in the form of vitreous gas-filled bubbles. The coarser fractions of fly ash can be seen irregularly shaped grains with high porosity.

The tested materials were characterized by a similar range of grain sizes (0–300 μm). Suspensions of this material was subjected to a series of classification in the laboratory hydrocyclones. Diameter of its cylindrical part carried out 30 mm (article did not concern the test of classification process).

For each material was performed the two experiments (1, 2) differ with conditions of classification. For granulometric analysis, for each experiment, we collected representative samples of the three product classification (underflow and overflow) in order to estimate the coefficients of variation w. In Figure 3 are given average grain size composition of tested products.

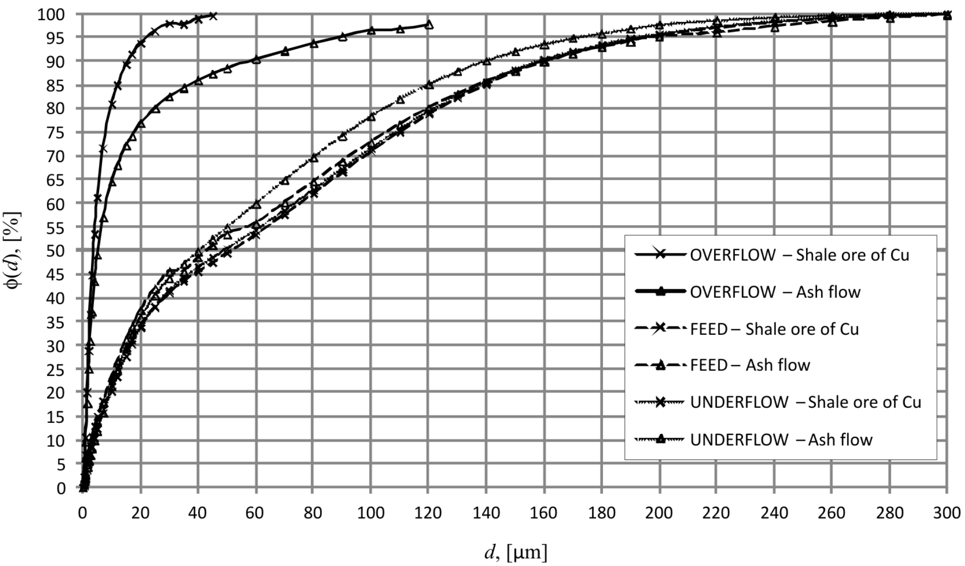

Fig. 3. Grain size composition of products

3. Results and discussion

3.1. Analysis of the coefficients of variation

To demonstrate the influence of particle shape on the accuracy of laser granulometric analysis, basic statistical parameters were calculated: the standard deviation *s* and coefficient of variation for percentages of respective grain classes in classification products. For example, in Figures 4–5 the average values of the coefficients of variation for underflow and overflow of individual materials, was showed.

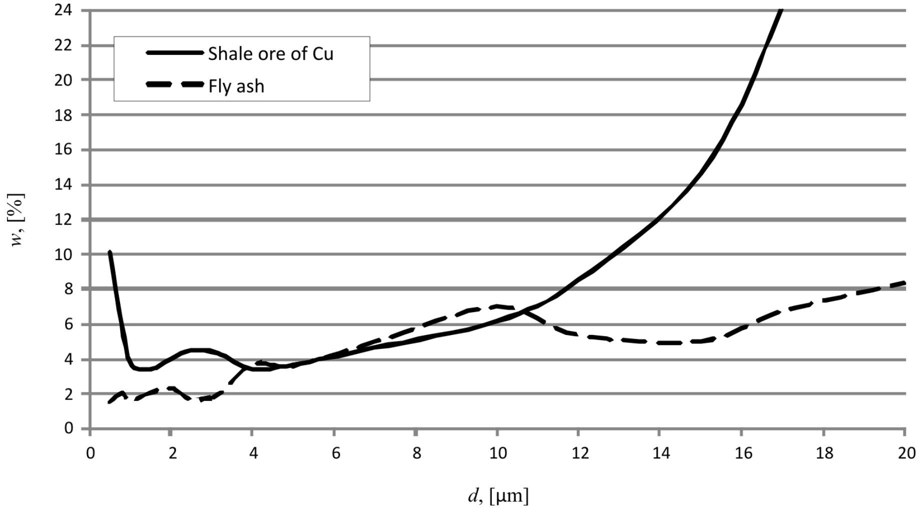

Fig. 4. Distribution of average values of the coefficient of variation in tested overflows

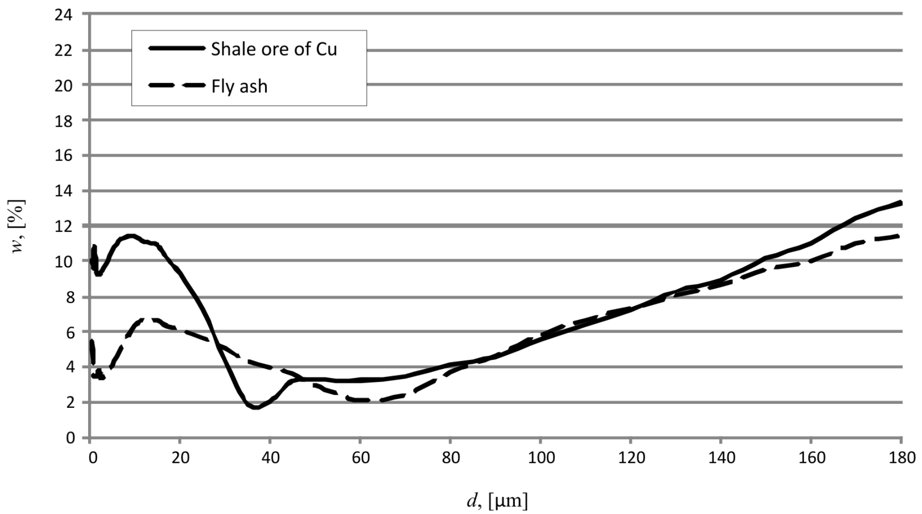

Fig. 5. Distribution of average values of the coefficient of variation in tested underflows

Analysis of these graphs (Figs. 4–5) confirms the former interpretation of the results published in the articles [1, 2]. It indicates that the accuracy of analysis expressed in coefficient of variation is different for respective class of grain in the classification products. Once more underflows were characterized with the highest values of the coefficients of variation and overflows with the lowest one. Particle size range of overflow in relation to underflow was much narrower, hence the accuracy of the overflows granulometric analysis proved to be the highest. This is directly related to measurement method (light diffraction) used in laser analysis. Diffraction patterns emerging during the analysis of derived from the measured particle interfere with each other (overlap), complicating the analysis [1]. The variability coefficients w was not as considerable as has been demonstrated in previous studies [1, 2]. The reason was the lower particle size range of test materials (0–300 μm) than in previous studies [2]: carbon, porphyry, and barite (0–600 μm), and the floatation waste of Zn–Pb ore (0–1000 μ m) [1] , which is also associated with lower sampling errors of underflows for testing.

Coefficients of variation achieve high values for extremely fine and coarse grain classes. Obviously it results from the randomness of measuring a little population of these grains, which is burdened by large measuring errors.

Analyzing the impact of particle shape on the accuracy of the laser granulometric analyzes, it is observed that the fly ash characterizes with more stable results especially in range of extreme grain classes. This may result from a more spherical shape of the grains of ash. Coefficients of variation of the contents grain classes for ashes in the both classification products were lower compared to the coefficients for copper ore. However, it is not very big differences.

3.2. Calculation of balancing

The impact of these differences on the balance of the classification products both materials were verified the calculations below.

Balance of product classification in hydrocyclones is based on commonly used in the separation process law of conservation of mass, expressed with system of balance equations:

$$\begin{cases} \gamma_O + \gamma_U = 1 \\ \gamma_O \cdot a_{Oi} + \gamma_U \cdot a_{Ui} = 100 \cdot a_{Fi} \end{cases} \Rightarrow \gamma_O = \frac{100\left(a_{Fi} - a_{Ui}\right)}{\left(a_{Oi} - a_{Ui}\right)} \qquad (1)$$

where:

γ_O, γ_U — percentage yields, respectively: of overflow and underflow;

a_{Oi}, a_{Ui}, a_{Fi} — the percentages of the *i*-grain classes respectively: in the overflow, underflow and feed.

Below in Table 1 gives the results of calculations for balancing grain classes. Results of balancing calculations for the classification products of the tested materials expressed as overflow yields (γ_0) was calculated as the mean value of selected ultra fine-grained classes (values shown in bold).

Averaged values of product yields for each experiment was compared with experimentally defined yields based on the mass of overflow and underflow samples. Results with standard deviations and errors are shown in Table 2.

TABLE 1

Yields of overflows calculated from granulometric analysis for each material in both experiments (1, 2)

d, [μm]	Shale ore of Cu		Fly ash	
	1	2	1	2
	γ_O, [%]	γ_O, [%]	γ_O, [%]	γ_O, [%]
0,5	**8.47**	**8.66**	**5.90**	**6.91**
0,8	**7.41**	**5.89**	**5.96**	**5.32**
1	**9.81**	**9.12**	**4.51**	**5.25**
1,5	**6.91**	**3.14**	**5.66**	**5.45**
2	**8.02**	**4.39**	**6.56**	**5.41**
2,5	**8.04**	**4.01**	**6.81**	**5.96**
3,15	**7.87**	**3.80**	**6.52**	**5.26**
4	**7.22**	**3.18**	**5.94**	**5.71**
5	**5.89**	**2.48**	**4.39**	**5.89**
7	1.98	1.81	–0.48	5.73
10	–14.09	1.06	–49.71	5.16
12	432.88	1.08	38.17	4.56
15	41.25	1.08	21.59	8.54
17	27.22	1.90	14.86	20.45
20	21.83	3.67	13.30	230.00
25	19.18	2.41	9.42	–118.75
30	17.16	66.67	10.45	–70.00
35	15.99	7.51	14.17	–32.73
40	13.15	4.07	18.50	–5.93
45	8.13	1.15	6.84	–31.06
50	3.05	0.00	14.88	4.12
60	–2.67	1.24	65.26	162.11
70	–7.50	3.19	14.90	25.50
80	–9.61	5.22	10.53	20.07
90	–10.47	6.44	6.28	14.56
100	–10.14	7.30	–0.95	4.13
110	–9.81	7.38	–5.81	–1.08
120	–8.00	7.58	–11.11	–4.19
130	–6.85	6.89	–17.05	–7.73
140	–4.36	6.35	–22.33	–10.35
150	–2.67	5.19	–27.85	–13.43
160	–0.46	3.74	–33.33	–16.21

TABLE 2

Average values yields of overflows calculated on the basis of the percentages grain classes (balance sheet) and quantified empirically

Statistics	Shale ore of Cu		Fly ash	
	1	**2**	**1**	**2**
	γ_O, [%]	**γ_O, [%]**	**γ_O, [%]**	**γ_O, [%]**
The average of the balance	**7,16**	**4,96**	**5,80**	**5,69**
Standard deviation	2,09	2,43	0,85	0,50
The average of the experiment	**9,83**	**1,41**	**9,67**	**1,55**
Standard deviation	0,55	0,61	0,43	0,49
The absolute error	2,67	3,55	3,87	4,14

Results of balance calculation presented in Tables 1 and 2 confirm the ability to accurately determine the yields of products classification in hydrocyclones. However, this balance must be based upon the percentages of grain classes in the range of overflows graining ($d_{5\%}$–$d_{80\%}$), which are determined by laser method with high accuracy. In this range of graining, yields of overflows γ_0 for each material, calculated from the balance formula above, shows a stable value, especially for the more spherical particles of ash (Tab. 1).

There was no significant effect of particle shape on the balancing accuracy products of classification. Yields balancing errors for both materials are similar, the copper ore at 2.67–3.55% and ash 3.87–4.14%.

4. Conclusions

The following general conclusions ensue from the research work performed:

- there was no significant influence of particle shape of the tested materials on accuracy of laser granulometric analysis, although more stability of measurements was for grain shape closer to spherical;
- confirmed the possibility of balancing classification products given by hydrocyclones based on the results of laser particle size analysis for fine-grained materials;
- the balance of the products should be based on the percentages of the finest grain classes, which are determined by laser with high accuracy;
- precision laser granulometric analyzes of the various streams of material, expressed as variation coefficient of contents of grain classes, is different; the most precisely analyzed overflows.

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