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Chemical and Granulometric Composition of Coal Dust of a Mine Degassing Plant

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Abstract

Physicochemical properties of coal dust sampled from the fine filter of the mine degassing plant of the Kuznetsk coal basin were explored. The coal dust sample was thoroughly characterised by scanning electron microscopy and atomic emission spectroscopy; technical analysis was also carried out and granulometric composition was determined. Relationships were found between changing the chemical composition of mineral components of the mineral portion of coal dust and coal particle size relying on the data acquired.

Key words: coal dust, mine dust, coal, granulometric composition, electron microscopy, elemental analysis

INTRODUCTION

Large quantities of coal dust are generated upon coal production and various technological enriching and processing processes. Air-suspended and inhaled coal dust particles are toxic. Herewith, small particles (below 1 μm) are more toxic than larger ones (below 10 μm) with the same composition [1–4]. This is related to a different mechanism of their absorption depending on sizes and properties: large particles settle in the upper respiratory tract and if non-toxic, may cause dust bronchitis. Thin dust particles (below 1 μm) reach alveoles and may cause pneumoconiosis or its varieties depending on dust composition, such as silicosis, anthracosis, *etc*. [5–8].

In order to determine the effect of coal dust particles on human health, in addition to the dust granulometric composition, the detailed investigation of the chemical content using a set of physicochemical methods is also required. Developing such approaches may be used to determine interlinks between physicochemical properties, the size of dust particles, and their effect on human health [9].

EXPERIMENTAL

The paper investigates the coal dust sample taken from the fine filter of the degassing unit in the mine named November 7 of the Kuznetsk coal basin, whereat G coal production is carried out.

Dust collection was performed in ten different points of the filter surface using a brush. The mass of the selected sample was 500 g. It was numbered, packed into the prepared glassware, and delivered to the laboratory for physicochemical research.

The technical analysis of the dust sample was performed using standard techniques according to GOST P 53357–2013. Low-temperature extraction was carried out by an alcohol-benzene mixture (1 : 1) *via* Graefe method for 6 h (an error of 0.2 %). The chemical composition of coal ash was determined by standard techniques according to GOST 10538–87. The granulometric composition of the mineral fraction (ash) was defined by the sieve method according to GOST 2093–82. Ash residues were obtained at 815 °C according to GOST 11022–95. Analytical ash was produced by the slow ashing of samples of dust and its fractions in a muffle furnace at 815 °C for 3 h.

The chemical composition of the mineral fraction (ash) was determined by atomic emission spectroscopy using the atomic emission spectrometer with inductively coupled plasma iCAP 6500 Duo LA (Thermo Scientific). Analytical ash was obtained by the slow ashing of samples of dust and its fractions in a muffle furnace according to GOST 11022–95.

Research on the surface morphology for macrocomponents of the mineral fraction of the sample was performed by scanning electron microscopy (SEM) with JEOL JSM-6390 LA microscope using an analytical system with JED-2300 X-ray microanalyser (EDS) to acquire data regarding the elemental composition of the sample under scrutiny. The registering of the characteristic radiation sample was performed at an accelerating voltage of 30 kW and a sonde current of 1 nA. The resolution power of the energy dispersive detector is 133 eV. Calculating the percentage content of each element was conducted according to the spectra acquired with Analysis Station Software (3.62.07 version) of JEOL Engineering Co. using the standard-free ZAF method.

RESULTS AND DISCUSSION

Elemental and granulometric composition

Table 1 reports the characteristics of the coal dust sample. According to the volatile-matter yield, ash residue amount, and elemental analysis data, the investigated dust sample corresponds to G coal [10–12] and is notable for a significant number of heteroatoms. The alcohol-benzene extract yield of the investigated coal sample corresponds to the quantity of bitumens extracted from humic coal in the medium carbonization grade (see Table 1).

Figure 1 lists granulometric composition data for the coal dust sample. As ascertained, particles in the 0.2–1.0 mm size range are prevailing in the tested sample (64.9 %). Particles with above 1 mm sizes are least presented.

There is an increase in the ash content of coal dust upon reducing coal fraction particle sizes. For example, the dust fraction with a particle size

TABLE 1
Characteristics of the initial coal dust sample

Technical analysis, %			Elemental analysis, % per daf			Atomic ratio		Alcohol-benzene extract yield, %
W^a	A_d	V^{daf}	C	H	(O + N + S)	H/C	O/C	
1.6	14.7	43.3	81.3	5.4	13.3	0.80	0.12	1.2

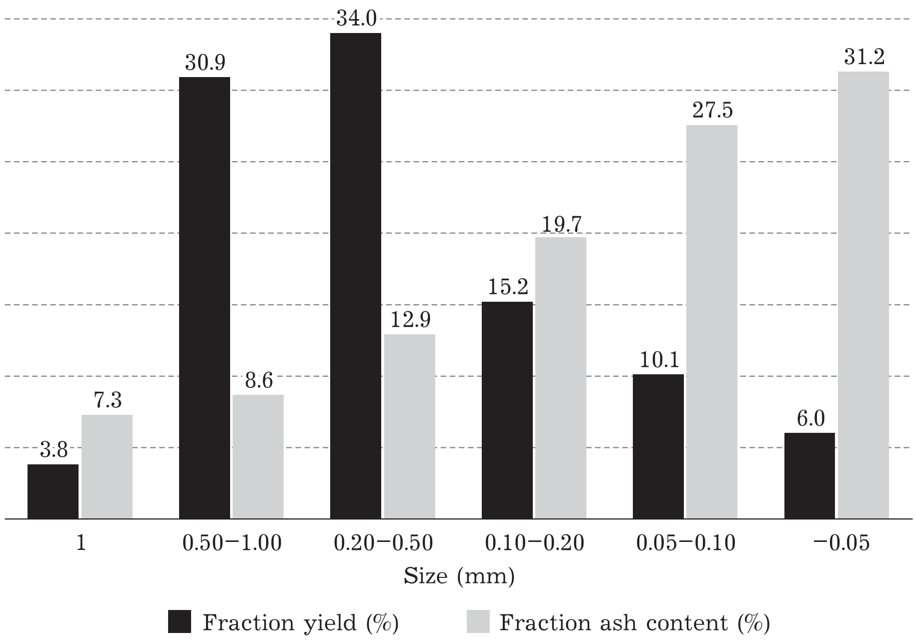

Fig. 1. Granulometric composition of the coal dust sample and ash contents in appropriate fractions.

TABLE 2
Ash chemical composition in the investigated dust samples, mass %

Size grade, mm	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	K_2O	P_2O_5	SO_3^{2-}	I_0*
-0.05	27.0	11.0	28.0	26.0	1.0	0.4	2.0	1.3	0.5	3.0	1.53
0.05–0.10	28.0	13.5	40.0	10.0	0.8	0.5	2.1	1.5	0.4	3.2	1.31
0.10–0.20	27.8	14.0	43.0	7.0	0.8	0.7	2.0	1.4	0.3	3.0	1.30
0.20–0.50	28.0	14.0	42.0	7.0	0.6	0.7	2.0	1.4	0.5	3.0	1.26
0.50–1.00	34.3	19.0	30.0	7.0	1.1	0.8	2.0	1.7	0.4	3.7	0.78
+1.00	35.5	20.0	22.7	9.8	1.5	0.9	2.6	2.0	0.8	4.2	0.70
Initial sample	33.0	17.0	28.0	12.0	1.1	0.7	1.8	1.7	0.7	4.0	0.65

* $I_0 = Fe_2O_3 + CaO + MgO + Na_2O + K_2O/(SiO_2 + Al_2O_3)$.

below 0.05 mm has the highest ash content (31.2 %), whereas particles with sizes above 1 mm are typical for the lowest ash concentration (7.3 %).

The chemical composition of mineral components of coal dust was determined in ash residues obtained according to GOST 11022–95 by atomic emission spectroscopy. As shown, ash residues are comprised of all major compounds of ash-forming elements (Table 2). According to the composition of the main ash components, the ini-

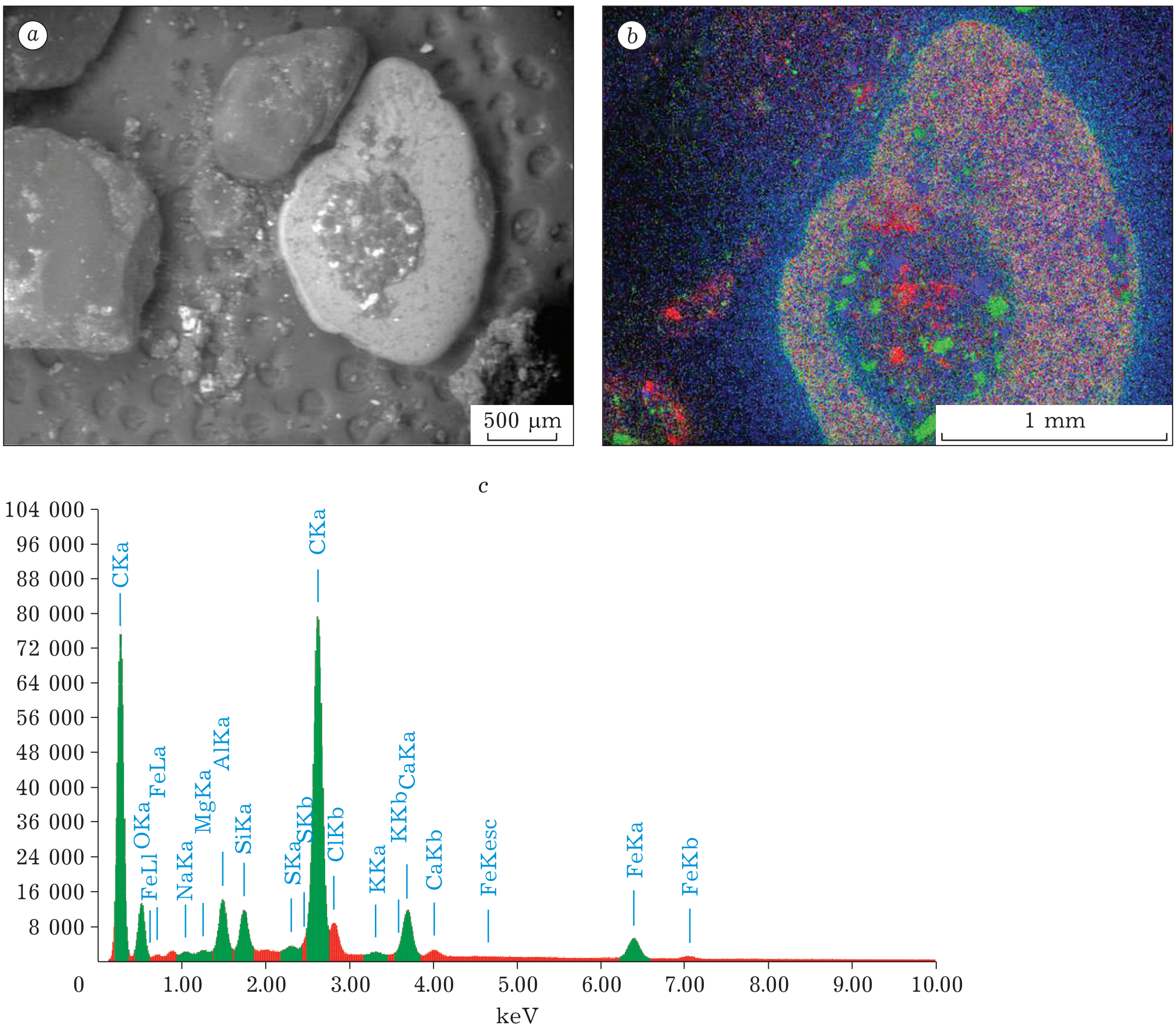

Fig. 2. Micrograph in the backscattered electron mode (*a*), surface map with an overlap in characteristic X-ray radiation of Ca (blue), Fe (green), and Si (red) (*b*) components, characteristic X-ray spectrum for the surface area of coal dust particles (*c*).

TABLE 3

Chemical composition of dust particles with various sizes according to electron microscopy data, mass %

Element	Particle size, mm					
	−0.05	0.05−0.10	0.10−0.20	0.20−0.50	0.50− 1.00	+1.00
C	61.03	60.46	63.47	69.04	66.87	70.71
O	29.00	28.75	26.72	24.69	27.70	24.99
Fe	3.30	5.17	5.20	3.35	3.90	1.38
Ca	2.74	2.10	1.33	0.68	0.86	0.64
Si	2.17	1.83	1.61	1.03	1.20	1.09
Al	0.91	0.86	0.87	0.71	0.78	0.63
Na	0.27	0.27	0.26	0.19	0.28	0.25
Mg	0.15	0.15	0.13	0.10	0.13	0.10

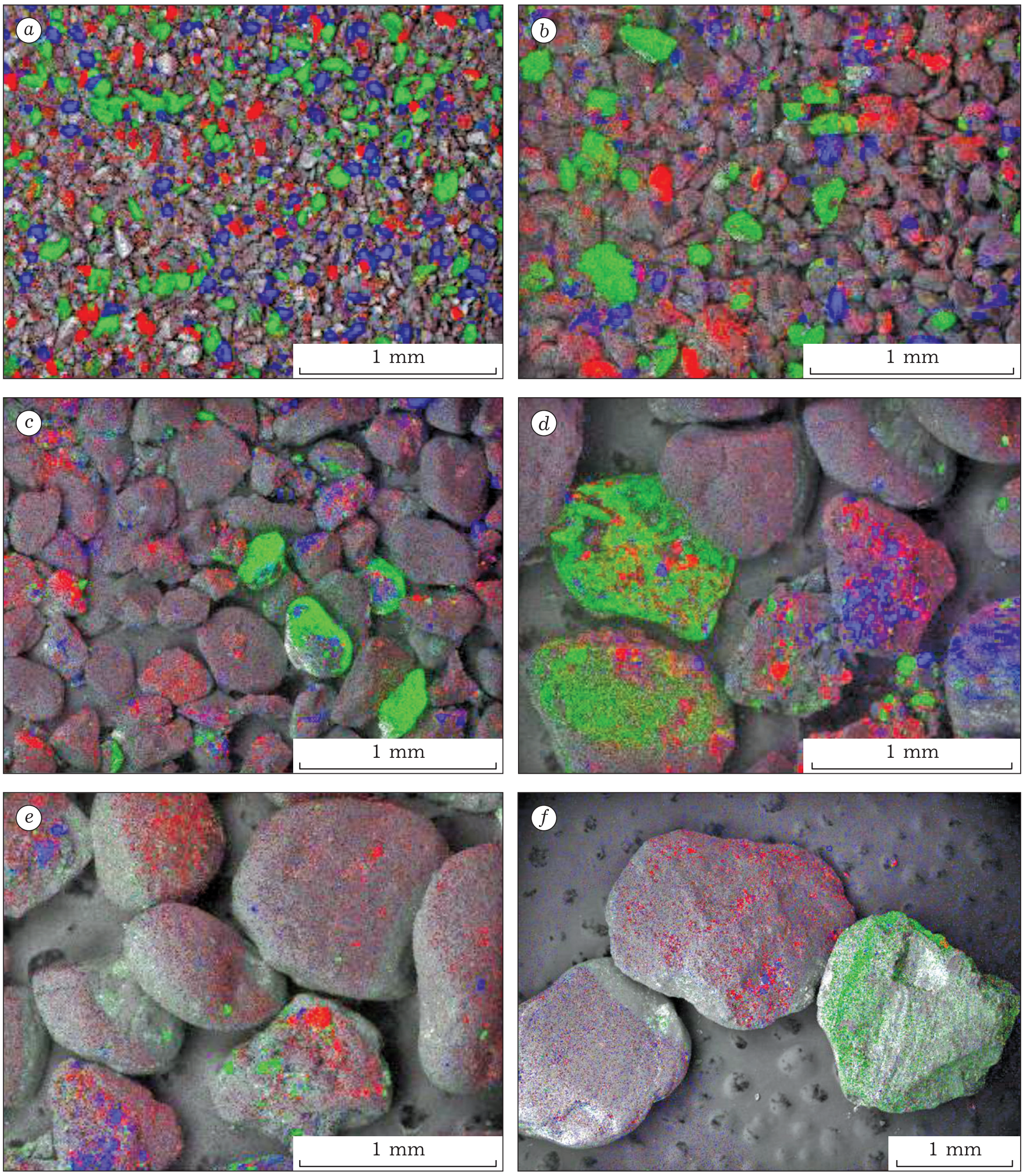

Fig. 3. Micrographs of the surface area of coal dust particles of various coarseness grades with an overlap in characteristic signals of elements Ca (blue), Fe (green), and Si (red).

tial coal dust sample may be referred to medium-aluminous (an Al_2O_3 content of 17.0 %), high-ferrous (Fe_2O_3 concentration of 28.9 %), and high-calc (CaO + MgO – 13.1 %) types of coal waste [13]. As determined, the fraction of silicon and aluminium compounds, as well as less common elements, i.e., titanium and phosphorus, is reduced when dust size grade is decreased and their ash content is increased. There are enhanced iron oxide and calcium amounts in the ash fraction of low grades.

An increase in the ash basicity degree (I_0) has been found when the fraction size is decreased: ash residues of fractions larger than 0.50 mm, and also the initial coal dust sample are referred to acid ashes ($I_0 < 1$) and the rest of fractions – to basic ones (see Table 2).

Scanning electron microscope

According to electron microscopy, the investigated samples are mixtures of mineral and organic compound particles in various dispersion and homogeneity degrees [14 and 15]. In order to visually separate mineral inclusions of coal organic matter, there was performed research in the mode of registering backscattered electrons. In this mode, the mineral inclusions comprised of heavier metals (Fe, Ca, Al, Mg, *etc.*) look lighter compared to lighter atoms (carbon and oxygen) of organic matter in caкbon particles (see Fig. 2, *a*). In order to determine the particle nature, the distribution of chemical elements on the surface of the investigated sample was mapped (see Fig. 2, *b*), With a view of calculating the percentage content for each element in the compound analysed, characteristic X-ray spectra were recorded. Figure 2, *c* reports the typical spectral pattern.

Relying on spectra with the use of Analysis Station Software, elemental contents in coal dust samples were calculated. Table 3 lists the data for the most representative elements.

As can be seen in micrographs of the surface of coal dust particles of various size grades with an overlap in characteristic signals of elements (Fig. 3), mineral particles are mainly found as separate particles and their sizes are varied between dozens and fractions of micrometres upon a decrease in particle size, beginning with the sample with a size of 0.10–0.20 nm. The size of mineral particles is decreased together with a decrease in the coarseness of coal dust particles.

CONCLUSION

Relationships have been found between changing the chemical composition of mineral components of the mineral fraction of coal dust vs the coarseness of coal particles. There is an increase in the degree of basicity of ash when the coarseness of the fraction is decreased: ash residues of fractions larger than 0.50 mm, and also the initial coal dust sample are referred to acid ashes and the rest of fractions – to basic ones.

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REFERENCES

1 Donaldson K., Stone V., Gilmore P. S., Brown D. M. and MacNee, W. Ultrafine particles: mechanisms of Lung Injury. Phil. Trans. Roy. Soc. Lond., Series A 358, 2000, P. 2741–2749.
2 Brown D.M., Wilson M.R., MacNee W., Stone V. and Donaldson, K. *Toxicology and Applied Pharmacology*, 175 (3), 2001, P. 191–199.
3 Tran, C. L., Buchanan D., Cullen R. T., Searl A., Jones A. D. and Donaldson, K. *Inhal. Toxicol.*, 12 (12), 2000, P. 1113–1126.
4 Dick C. A. J., Brown D. M., Donaldson K. and Stone V. *Inhal. Toxicol.*, 15 (1), 2003, P. 39–52.
5 Dockery D. W., Speizer F. E., Stram D. O., Ware J. H., Spengler J. D. and Ferris B. G. *J. Ann. Allergy*, 139, 1989, P. 587–594.
6 Pope C. A. I., Dockery D. W., Spengler J. D. and Raizenne M. E. *Am. Rev. Resp. Dis.*, 144, 1991, P. 668–674.
7 Schwartz J., Spix C., Wichmann H. E. and Malin, E. *Environ. Res.*, 56, 1991, P. 1–4.
8 Dockery D. W., Pope C. A., Xu X., Spengler J. D., Ware J. H., Fay M. E., Ferris B. G. and Speizer F. E. N. *Engl. J. Med.*, 329 (24), 1993, P. 1753–1759.
9 Zhuravleva N. V., Khabibulina E. R., Ismagilov Z. R., Efimova O. S., Osokina A. A. and Potokina A. A. *Khimiya Ust. Razv.*, 24 (2016), P. 509–519.
10 Mironov K. V. Directory of geologist-coal miner. M. : Nedra, 1991. 363 P.
11 Artemyev V. B, Eremin I. V., Gagarin S.G. Petrography of coal and their effective use. M.: Nedra kommunikuysjats LTD., 2000. 334 P.
12 Eremin I. V., Arzer A. S., Bronovets T.M. Petrology and chemical-technological parameters of Kuzbass coal. Kemerovo: Pritomskoe 2001. 399 P .1–3.
13 Shpirt M. Ya., Claire V. R., Pertsikov I. Z. Inorganic components of solid fuels M.: Chemistry, 1990. 240 P.
14 Shpirt M. Ya. Waste-free technology. Recycling of extraction and processing of solid combustible minerals. M.: Nedra. 255 P.
15 Koshina M., Maglicheva A. *Chemistry of Solid Fuels*. 1980. No. 4 P. 12–18.