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Physicochemical Characteristics of Hospital Dust Samples in the Kemerovo Region

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Abstract

Because of the high level of cardiovascular diseases in the Kemerovo Region, it is extremely important to reveal a relation between exposition to dust from the coal industry and human health. One of the first steps for this disclosure is investigation into the physical and chemical properties of dust in the hospitals of Kemerovo (Kemerovo Region – Kuzbass), which is reported in this paper. It is found that the object analysed is a mixed type, not uniform, and contains organic and inorganic parts. The major mineral part is silica, which agrees with its content in fly ashes characteristic of the region. Constant concentration ratios of aluminium, silicon and manganese allow an assumption that the dust is built up by similar types of aluminosilicates containing manganese within the structure. Low amounts of sulphur and high amounts of calcium simultaneously indicate the presence of calcite and/or feldspar in the dust. High contents of sodium and calcium can be caused by the application of detergents. The dust is classified as $PM_{0.1}$–PM_1 according to particle sizes. The relationship of the properties of dust with the characteristics of the industrial orientation of the region is outlined.

Keywords: medical dust, ventilation dust, dynamic light scattering, IR spectroscopy, optical emission spectroscopy with inductively coupled plasma

INTRODUCTION

Particulate matter (PM) is a widespread atmospheric air pollutant, represented by a mixture of solid and liquid particles suspended state that poses a serious threat to human health and ecosystems [1]. The most common chemical components of PM are sulphate, nitrate, chloride anions, sodium, potassium, calcium, magnesium cations, ammonia, organic and elementary carbon, minerals of the earth's crust, particle-associated water, metals, and polycyclic aromatic hydrocarbons [2]. The PM also contains biological objects, for example, viruses, bacteria, pollen, protein fragments, *etc*. [3, 4].

In the atmospheric air of coal mining regions like the Kemerovo region, there is a large amount of coal dust, which is formed at all stages of coal production and processing. This is one of the important factors that determine the development of genotoxic effects, with finely dispersed dust and nanosized particles presenting the greatest danger [5–7]. High-dispersed particles are a risk factor for the development of diseases of the respiratory and cardiovascular systems. The pathogenesis of the damaging effects of cells by nanoparticles with the subsequent development of systemic reactions is described in [8]. In the study of the influence of dust pollution of various natures on the environment and human health, it is important to examine the features of such pollution, depending on its source [9]. For example, the formation and properties of dust in a medical organization depend on both atmospheric air pollution, and on the nature of the medical technologies and materials used [10].

The purpose of this work is to determine the physicochemical characteristics of the dust of a medical organization for subsequent establishment of the patterns of its effect on the health of patients.

EXPERIMENTAL

Dust samples were taken into sterile containers with sterile gloves from the inner surface of the ventilation grilles and adjacent-to-them ducts of exhaust ventilation systems in a medical institution of Kemerovo-city (Kemerovo region – Kuzbass). The studied objects include samples from an adult (sample 1) and children's departments (sample 2).

The chemical composition of the inorganic part of dust samples was determined by optical-emission spectrometry with inductively coupled plasma and laser sampling in by means of an iCAP 6500 Duo spectrometer (Thermo Scientific, USA) and a laser ablation system UP-266 (Thermo Scientific, USA). To determine the elemental composition, a method based on GOST R 54237-2010 "Determining the chemical composition of ash by the atomic-emission spectrometry with inductively coupled plasma" [11] modified for laser sampling was used. Weighted samples were mixed in equal quantities with a binder – microcrystalline cellulose. Further, the samples were subjected to one-axis pressing at a pressure of 160 MPa. The resulting compacts were used to conduct laser sampling. All the stages of sampling for the studied and standard samples are identical. The SGD-2A (GSO 8670-2005), ZUK-1 (GSO 7125-94), SG-1A (GSO 520-84P), and SG-3 (GSO 3333-85) produced at Vinogradov Institute of Geochemistry (Irkutsk) were used as reference materials.

The chemical composition of the organic component of in the samples (determination of the content of carbon, hydrogen, nitrogen and sulphur) was determined by high-temperature catalytic oxidation using a Flash 2000 elemental analyzer (Thermo Scientific, USA) with a catalytic reactor filled with CuO/Cu. The oxygen content was determined on the same analyzer using the a reactor filled with Ni/C according to the method described in [12, 13]. The results of the elemental analysis were calculated by three parallel measurements.

IR spectra were recorded by an Infralyum FT-08 IR Fourier-Transform spectrometer (Lumex, Russia) in the range of 370–4000 cm^{-1} with a resolution of 4 cm^{-1}. The correction of the base line was carried out using the software "Spectralyum", and the processing of spectra in the Origin 8.0 program. Dust samples were prepared in a KBr pellet (1 : 50 ratio) by pressing at a pressure of 8 MP.

The analysis of the size composition of medical dust in the nanometre range was carried out by the method of dynamic light scattering using a Zetasizer Nano ZS laser analyzer (Malvern Instruments, Great Britain). Before the acquisition, the studied particles were suspended in deionised water and processed with ultrasound for 20 min until stable colloidal solutions were obtained; then large particles were removed through the syringe membrane nozzles with a diameter of pores of 450 nm. For each sample, from 10 to 50 measurements were made until at least 5 converging results at 25 °C; the sample thermostating time was 20 min as practiced in the method of study of dust nanoparticles in snow water [14, 15].

RESULTS AND DISCUSSION

Chemical composition

The chemical composition of dust samples is rather complicated and is represented by the mineral and organic parts: in sample 1 – 28.9 wt % of mineral part and 71.1 wt % of organic part, in sample 2 these parts were 22.5 and 77.5 %, respectively.

The inorganic part of the dust consists mainly of compounds of silicon, sodium, calcium, aluminium, potassium and iron (Table 1), which is consistent with [12].

Most of the mineral mass is represented by silicon oxide, which is 30–41 wt %, being at the level of its content in the fly ash [16]. In the samples, high concentrations of sodium compounds (12–24 wt %) and potassium (8–10 wt %) were found, which may be due to the intensive use of detergents and disinfectants in medical premises.

Calcium oxide is represented in both the samples in similar amounts of about 15 wt %. With such high calcium content and low sulphur concentrations (1.3–1.4 wt %), calcium can be in the form of calcite or field spar [17]. In addition, a comparable aluminium/silicon ratio was found in the studies (see Table 1), which indicates the possible presence of aluminosilicates of approximately the same composition in both samples. There was no such trend for the ratio of calcium/silicon.

TABLE 1

Chemical composition of the inorganic part of dust samples and standard samples

Compound	Content, wt %			
	Sample 1	Sample 2	GSO 7125-94	GSO 3483-86
SiO_2	30.7±1.3	40.1±0.3	35.8	45.59
Na_2O	24.0±1.0	12.0±0.3	0.22	0.87
CaO	15.8±0.3	15.02±0.27	20.91	7.05
Al_2O_3	10.6±0.4	15.03±0.09	6.79	11.60
K_2O	8.8±0.6	10.0±0.3	0.51	2.96
$Fe_2O_3^{total}$	3.86±0.16	3.43±0.07	6.28	4.62
MgO	3.57±0.12	2.11±0.02	6.70	5.82
P_2O_5	0.209±0.016	0.026±0.003	0.059	0.15
S^{total}	1.31±0.21	1.41±0.17	1.70	0.05
TiO_2	1.05±0.05	0.70±0.02	0.35	0.63
MnO	0.074±0.003	0.083±0.005	0.09	0.07

This suggests that most of calcium in the samples is in the form of calcite. The only element preserving the constant ratio with aluminium and silicon is manganese, which may be a sign of its complete introduction into the structure of aluminosilicates.

In sample 1, a larger amount of sulphur was found in relation to the main components – aluminium and silicon, as well as more phosphorus, calcium and sodium (see Table 1). Obviously, sample 1 contains smaller amounts of aluminosilicates due to the presence of high concentrations of pollutants [12, 14]. All the elements that are present in greater quantities in sample 1 compared to sample 2 can partially have an organic nature, that is, belong to human life, namely, represent the remains of hair, skin, *etc*.

When comparing the results with the indicators of standard samples [16], it was established that the elemental composition of sample 2 is close to the composition of the carbonate-silicate standard (GSO 3483-86) and the fly ash of Kansk-Achinsk Fuel-Energy Complex (GSO 7125-94) (see Table 1). The first sample is a sedimentary rock, and the second one is the finely-dispersed residue of the fuel combustion contained in the flue gas in a suspended state and capable of moving through the air for significant distances, as well as to enter ventilation systems of institutions. Since the Kemerovo region is an industrial and coal mining territory, it seems logical that the mineral part of the prevailing dust consists of a combination of sedimentary rocks and the fly ash formed from the burning of coal.

TABLE 2

Chemical composition of the organic part of dust samples

Element	Content, wt %		
	Sample 1	Sample 2	Proteins [18]
C	48.8±0.9	49.7±1.3	50.0–54.4
O	35.4±1.2	38.3±1.1	21.5–23.5
N	7.9±0.3	4.4±0.2	15–17
H	6.8±0.3	6.7±0.3	6.5–7.3
S	1.1±0.1	0.9±0.1	0.3–2.5

The organic part of the samples is represented mainly by carbon (48.8–49.7 wt %) and oxygen (35.4–38.3 wt %), as well as hydrogen, nitrogen and sulphur (Table 2). The samples are characterized by a similar composition; however, in comparison to sample 1, in sample 2, the oxygen content is somewhat greater (38.3 versus 35.4 wt %) and the nitrogen content is practically two times lower (4.4 versus 7.9 wt %). The qualitative and quantitative characteristics of the organic part of the samples are similar to the characteristics of the protein, which is consistent with the data of the FT IR spectroscopy.

Carbon, determined by the method of high-temperature oxidation, includes organic and elementary carbon, which is in the atmosphere in the form of suspended particles, as well as a “living” carbon that gets into the dust of medical institutions in the form of microorganisms and human life objects [3, 19].

IR spectroscopy

IR spectra of the studied dust samples have a similar appearance, but differ in the intensity of some bands (Fig. 1).

In spectra, there are bands characteristic of vibrations of silicon and aluminium bonds in mineral compounds are observed: Si–O in silica, Si–O–Si in silicates, Al–O in alumina; as well as the bands characteristic of organic compounds (in particular, proteins and polynucleotides): N–H, S–H and S–S in proteins, CH_2 and CH_3 in aliphatic compounds, C=O in the carboxyl group, etc. (Table 3).

Dynamic light scattering

The studied fractions of the medical dust in the nanometre range are polydisperse systems characterized by a wide distribution of particles by size in two areas: in the range 60–150 and 150–500 nm. In the case of sample 1 these areas have a narrower look and are isolated from each other, for sample 2 these areas border each other (Fig. 2).

In sample 1, the area of small sizes is in the range of 60–100 nm with a maximum at 80.7 nm and it is placed amounts to 7.1 % of the total area peaks (Table 4). The area of larger particles lies in the interval of 200–500 nm with a maximum at 302.1 nm.

In sample 2, the area of small sizes is slightly shifted, starting after 70 nm and ending at ca. 150 nm, has a maximum at 102.4 nm and is 10.7 % of the total area of peaks, which is slightly larger than for sample 1. The area of larger particles begins immediately after 150 nm and also ends with particles of 500 nm with a maximum of size at 267.9 nm.

Thus, sample 1 is characterized by the presence of smaller particles (80.7 nm versus 102.4 nm in the case of sample 2) and a narrower distribution in the area of small sizes. Moreover, both samples are characterized by the presence of particles with dimensions of less than 1 μm (PM_1) and even less than 100 nm ($PM_{0.1}$) [1, 22].

CONCLUSION

Studies by a complex of physicochemical methods established that the dust of a medical organization in Kemerovo belongs to the mixed type; it is heterogeneous, contains organic and in-

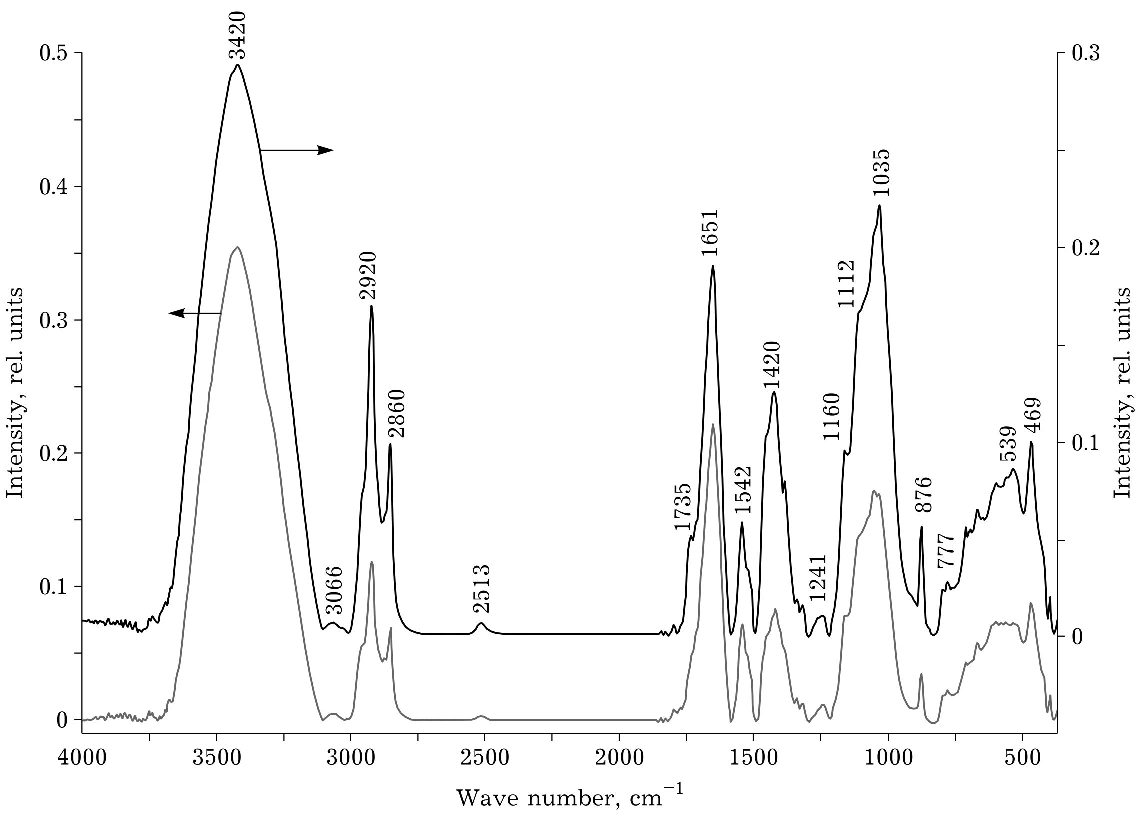

Fig. 1. FTIR spectra of dust samples 1 and 2.

TABLE 3

Assignment of bands of characteristic vibrations of the studied samples in accordance with [20, 21]

Wavenumber, cm^{-1}	Vibration type	Band intensity
3420	Stretching vibration of O–H group bound with hydrogen bond	Strong
3066	Stretching vibration of N–H-group in protein molecules	Weak
2920	Stretching asymmetric vibration of CH_2-group in aliphatic compounds	Strong
2860	Stretching symmetric vibration of CH_3-group in aliphatic compounds	Strong
2513	Stretching vibration of S–H group in proteins	Weak
1735	Stretching vibration of C=O in carboxyl group	Shoulder
1651	Stretching vibrations C=O and C–N in amides	Strong
1542	Bending vibration of N–H amide group	Medium
1420	Bending vibration of CH_2 group in aliphatic compounds	Medium
1241	Stretching asymmetric vibration of P–O–R bond in polynucleotide	Weak
1160	Stretching vibration of C–O–C group	Shoulder
1112	Stretching vibration of Si–O bond in oxide	Shoulder
1035	Stretching asymmetric vibration of Si–O–Si group in silicates	Strong
876	Stretching vibration of Al–O bond	Medium
777	Stretching vibration P–O bond in PO_4-group in polynucleotide	Weak
539	Валентное колебание связи S–S в белковых структурах	Medium
469	Stretching vibration of S–S bond in protein structures	Medium

organic components, and also can be different in the chemical composition.

The mineral part is represented mainly by compounds of silicon, sodium, calcium, aluminium, potassium and iron. An increased amount of sodium and potassium compounds compared to sedimentary rocks and fly may be caused by the intensive use of detergents and disinfectants in medical premises. Otherwise, the chemical composition of the inorganic part of medical dust

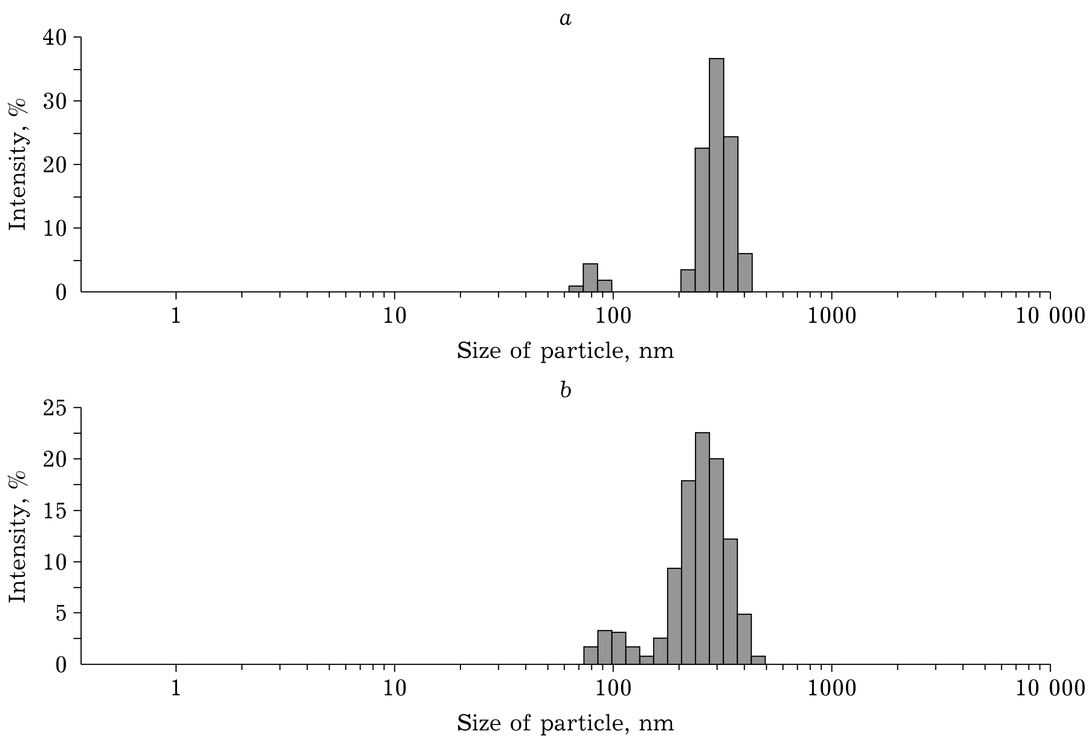

Fig. 2. Histograms of the distribution of dust particles by size: samples 1 (*a*) and 2 (*b*).

TABLE 4

Characteristics of the dust particle sizes determined by the method of dynamic light dispersion

Sample	Particle size, nm	Relative peak area, %
1	80.7±7.1	7.1
	302.1±42.9	92.9
2	102.4±17.5	10.7
	267.9±60.1	89.3

is close to the composition of ashes and sedimentary rocks.

The method of dynamic light scattering detected along with toxic particles PM_{10} и $PM_{2.5}$ the smallest and the most toxic dust fraction PM_{10} и $PM_{2.5}$ (ultrafine particles).

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