E3S Web of Conferences **41**, 01035 (2018) https://doi.org/10.1051/e3sconf/20184101035
IIIrd International Innovative Mining Symposium

Research of Concentrations of Ultrafine and Finely Dispersed Aerosols in the Atmosphere of a Southern Urals Mining Region

Dmitry Radchenko[1,2], *Luisa* Gadzhieva[1,*], *Vjacheslav* Gavrilenko[1]

[1]Institute of Complex Exploitation of Mineral Resources of the Russian Academy of Sciences (IPKON RAS), 111020, Kryukovsky tupik, 4, Moscow, Russia
[2]Peoples' Friendship University of Russia, 117198, 6 Miklukho-Maklaya street, Moscow, Russia

Abstract. Until now the world has not had a consistent standard establishing the maximum permissible concentrations of aerosols, that is, of nanosize particles in the air. At the same time, in the foreign literature it is proved that nanoparticles upon deposition in the human lungs may stay there for longer time than larger-size particles because of a more complicated process of a human body self-cleansing and stronger interaction of such particles with human body tissues and organs. Some types of nanosize particles (for instance, titanium or carbon dioxides) more easily penetrate the barrier layer of an epithelial cell and enter interstitial tissue or blood flow. The article presents the results of a pioneering research into concentrations of ultrafine and finely dispersed aerosols in the atmosphere of a mining region. The available literature data on concentrations of submicron-size particles (0.5-5 μm) in the atmosphere of mining regions and operating areas of underground mines and open pits cannot be referred to as nanoparticles. They must be classified as medium and coarse aerosols having a radically different effect on a human body. The studies are performed with the support of the Russian Science Foundation (Project No14-37-00050)

1 Introduction

As it is known, mining has a broad environmental effect covering nearly all environment elements: air and water basins, land surface, earth's depth, flora and fauna [1]. From the comparative qualitative characteristics of the mining effect on the biosphere it follows [1] that the effect of mining industry on the air basin is of medium force causing air pollution with harmful substances, inclusive of industry-related aerosols. Numerous toxicological studies point to the fact that some respirable ultrafine insoluble particles of less than 100 nm may be more toxic than larger-size particles of similar composition [2-9].

According to the classification proposed in [10], in terms of dispersity aerosols can be categorized as follows:

- ultrafine aerosols or nanoparticles of 0.001 – 0.01 μm size;
- finely dispersed aerosols (FDA) of 0.01 – 0.1 μm particle size;
- medium aerosols (in some cases referred to as fine aerosols) of 0.1 – 10 μm particle size;

---

[*] Corresponding author: gadzhilu@gmail.com

- coarse aerosols of 10 – 100 µm particle size.

Dealing with the problem of the human habitat pollution and considering a nanosize particle range it is feasible to focus on the research into ultrafine and finely dispersed particles of 1-100 nm size. It is proved by the studies [11], in which particles with a diameter of less than 100 nm size are referred to as ultrafine aerosols. This article deals with the research into concentrations of this particular size particles – ultra fine and finely dispersed aerosols in the atmosphere of a mining region.

2 Theory

Nanoparticles are numerous by their nature, as they are formed in numerous natural processes, including photochemical reactions, volcano eruption, forest fires and land surface erosion. According to the estimates provided in [12], aerosols generated as a result of human activities account for only about 10% of the total, while the rest 90% are of natural origin. Nanoparticles pollution has a great importance for the global climatic balance, as they play a central role in the ozone layer depletion [13], therefore, in addition to greenhouse gases they have an effect on the global warming.

Nearly all natural aerodispersion systems (aerosols) belong to medium or coarse aerosols [10]. Industrial aerosols generated in the course of various production processes are by far more environmentally harmful. To our opinion, it is precisely these 10% of industrial aerosols that are the main factors contributing to the deterioration of the human habitat, as the majority of the planet population lives in regions with operating industrial facilities rather than in the regions of large-scale forest fires and volcano eruption.

Overall majority of industrial facilities in resource-based economies are those of the mining sector. In mining regions, along with mineral ultrafine aerosols generated in the course of ore mining and processing [14] of great effect in terms of aerosol ingress in the atmosphere is the contribution of motor exhaust of mine heavy haul vehicles, and products of large-scale blasts in open pits and underground mines.

The occurrence of industrial ultrafine and finely dispersed aerosols has given birth to a new research field – nanotoxicology [15]. Indicated in 2005 for the first time, it developed into one of the most important and rapidly-growing subject areas in the subsequent years.

The assessment of possible risks of human body exposure to the effect of nanoparticles makes it clear that human skin, lungs and gastrointestinal tract are in continuous contact with the environment. At the same time, skin is usually viewed as an efficient barrier for foreign agents, while lungs and gastrointestinal tract are more vulnerable. These three ways are the most probable points of exposure to natural or industry-related nanoparticles, as the latter are characterized by their great ability to penetrate through cell membranes [16]. It is assumed that nanoparticles entering a human body through a respiratory tract cause such diseases as asthma, bronchitis, emphysema, carcinoma of lungs, and neurodegenerative diseases, namely, Parkinson's and Alzheimer's diseases. Nanoparticles in gastrointestinal tract may cause Crohn's disease and colon cancer. Nanoparticles in blood circulatory system may become a cause of arteriosclerosis, clots of blood, arrhythmia and cardiac diseases. Their translocation to other organs, such as, liver, spleen, etc., may also result in diseases of these organs. The exposure to some nanoparticles causes autoimmune diseases [13].

The results of studies [17] have shown an opportunity of ultrafine particle transportation to the central nervous system by means of olfactory nerve.

All these factors have lead to the substantiation of a new toxicological parameter characterizing the severity of human body exposure to nanoparticles [18, 19].

As a result of mining activities, particles of the nanosize range are formed as a part of the total bulk of dust emissions generated by a mine [14].

Moreover, main objective laws governing the formation of ultrafine aerosols have been discovered either theoretically, by the analysis of geomaterial decomposition mechanisms, or in laboratory conditions. In [11, 19] a case study is described, when with a help of unique mobile equipment belonging to the IPKON RAS EKON Laboratory (Laboratory for Ecologically Balanced Development of Mineral Resources) for the first time the assessment was made of the mining sector contribution to air pollution with ultrafine aerosols in the regions with operating mining facilities, namely, in the Central Black Earth economic region (KMA mining area). For the subsequent stages of the research the objective of studying the concentrations of ultrafine and finely dispersed aerosols in the mining region atmosphere was set and successfully attained.

3 Methods

The proprietary know-how of the research for the assessment of ultrafine and finely dispersed aerosol concentrations in the atmosphere of a mining region was elaborated in 2017 and described in [11].

For studies in the South Ural region the know-how envisaged the arrangement of gauging stations furnished with the equipment belonging to the IPKON RAS ECON Laboratory [20]:

1) DISCmini miniature diffusion size classifier (fig.1) intended for the measurement of nanoparticle number concentration in the air, mean diameter and lung-deposited surface area (fig. 1). The measuring principle is based on electrical charging of the aerosols in the process of charged particle detection in two separate stages: diffusion stage (iD) and filter stage (iF). Based on the conversion of these values the particle size (it is in direct proportion to iF/iD ratio) and number concentration (which is in direct proportion to iF+iD) are assessed;

2) DT-9881M ecological monitoring device, which was used as a dust particle counter for measurements of 0.3-10 μm dust particle concentration to compare the results with those obtained with DISCmini classifier, and for ambient temperature and humidity measurements.

Location of gauging stations was chosen from the condition of the geographical coverage of ore underground mine (fig. 2, a) and open pit (fig.2, b) sites. Moreover, at the underground mine site the gauging stations were located near intake and return air shafts, processing plant, as well as at the mine take boundaries, including the urban area located on the surface above underground workings of the ore mine.

According to the selected criteria the gauging stations hereinafter referred to as “g.s.” in fig. 2-a are located as follows:

- g.s. No.1 – in the central park of an industrial town coinciding with the southern boundary of the mine take;
- g.s. No.2 and g.s. No.3 – along conventional boundaries of the mine site, including the main shaft and processing plant;
- g.s. No.4 – at the northern boundary of the mine take near the air shaft.

The location of gauging stations in the area of the open pit was determined by condition of the geographical coverage around the perimeter (fig. 2-b): from the northern (g.s. No.5), eastern (g.s. No.6), southern (g.s. No.7), and western (g.s. No.8) pit walls. Gauging stations No.5 and No.6 were located in such a way as to provide an opportunity of studying the parameters of the atmosphere of the main open pit transportation roads to its waste dumps and processing plant.

Fig.1. DISCmini handheld diffusion classifier belonging to IPKON RAS EKON Laboratory

According to the applicable methods and procedures, measurements were taken in warm seasons of the year, when the mean temperature in the South Ural region ranges from +10 to +22°C, average wind velocity does not exceed 4 m/s and relative humidity is at most 50%. At all stations, measurements were taken in the periods free from bulk blasting processes in the open pit and underground mine.

Fig. 2. Location of gauging stations within the boundaries of the underground mine take (left) and open pit shell (right)

4 Results

It was found that the highest dust concentration in the air was predictably characteristic of the open pit site, moreover, the maximum value of the average concentration of 10 µm size dust particles during the period of measurements was registered along the main transportation roads of the open pit, and it exceeded 200 µg/m^3 (g.s. No.5 - g.s. No.6 road profile). Besides, at the non-mining flank (spoil bank) of the open pit (g.s. No.7) the concentration of particles of the above mentioned size was minimal (Table 1). At the sites of the underground mine and processing plant this index was 4-fold lower as an average, and at g.s. No.2 and g.s. No4 it was 48 μg/m^3.

Research into nanosize particle concentration at the open pit and underground mine sites showed the lack of explicit correlation between concentrations of dust and finely dispersed aerosols. For instance, despite the meaningful excess of dust concentration at the open pit site, the average concentration of ultrafine aerosols in the open pit area was 14,700 particles per cm^3, and at the site of the underground mine and processing plant it was 14,101 particles per cm^3, that was about the same.

The maximum concentration of nanosize particles in the air of the region was 26,898.4 см$^{-3}$ at the eastern wall of the open pit (g.s. No.6, fig. 2-b).

It was found that despite the lowest concentration of dust amounting to 20 μg/m^3, the concentrations of ultrafine aerosols in the air near the return air shaft was approximately 1.35-fold higher than near the main shaft and processing plant.

Thus, zones of dispersion and accumulation of ultrafine particles in the atmosphere, time of their existence do not coincide with zones of dust cloud distribution.

The lowest concentration of aerosols was registered at the territory of the industrial town, and it did not exceed 5,000 particles per cm^3 that was 4-fold less than at the underground mine site and nearly 5.5-fold less than the maximum value for the open pit site. Accordingly, the same distribution was typical of the LDSA (lung-deposited surface area [18]). (See Table 1)

Urban territories characterized by the absence of mining operations were chosen as reference regions for the comparative assessment. In 2017, gauging stations were arranged in a small town (Dolgoprudny, Moscow Oblast) and in a metropolis (Moscow). By results of measurements it was found that the average concentration of ultrafine particles in Moscow was 2.3-fold lower than that in the mining region. In Dolgoprudny the average concentration of such particles was 2.2-fold less than that directly in the zone of mine operation. However, the data obtained in the territory of the industrial town did not exceed the concentrations in Moscow and Dolgoprudny. While comparing the data of the reference regions with the values obtained in the central park of a mining town it seems reasonable to pay attention to the fact that despite relatively low concentration of ultrafine particles in the latter, the LDSA was by far greater than a similar parameter in the reference regions.

The obtained results of the monitoring are indicative of the negative effect of mining regions on the environment in terms of ultrafine aerosol ingress to the atmosphere. At the same time, nanoparticles spread area is highly localized and characterized by the formation of high concentration zones directly in the areas of mining operations.

A fair assessment of the effect of mining operations on the air quality can be made only by way of similar studies in the areas of operation of industrial facilities of some other sectors. Such comparative studies were carried out in the area of Ural smelter operation. The maximum concentration of ultrafine aerosols in the air of this region was 121,453.485 cm^{-3} that exceeded the maximum values of KMA and South Ural regions 4.4- and 6-fold accordingly.

5 Discussion

The objective of the human habitat monitoring is not merely the statement of the fact of its pollution. Similar studies in some other mining centers of Russia, as well as a the follow-up research into mechanisms of nanoparticle formation will spur the development of novel technologies of ecologically balanced development of ore deposits [21-24] to minimize the negative effect of geotechnologies on people. The efforts of the IPKON RAS EKON Laboratory are aimed at the development of such technologies [20].

Table 1 Comparative assessment of the results of monitoring of ultrafine aerosol concentrations in the air of mining and Moscow regions.

№	**Index, UM**	**Studied regions**									
		Mining town	**Underground mine take and open pit shell**							**Moscow**	**Dolgoprudny**
		G.s. No.1	**G.s. No.2**	**G.s. No.3**	**G.s. No.4**	**G.s. No.5**	**G.s. No.6**	**G.s. No.7**	**G.s. No.8**		
1	Nanoparticle average concentration, cm^{-3}	4.967	7.587	14.798	19.920	14.771	26.898	5.237	12.179	11.993	12.465
2	LDSA, $\mu m^2/m^3$	62	19	35	77	34	85	15	32	30	24
3	Dust particle average concentration $d=10$ µm, $\mu g/m^3$	10.17	24.58	107.95	20.42	362.37	50.00	6.85	30.16	8.5	8.5

Novel geotechnologies are developed in the course of studies providing for non-presence of man in the zones of mining processes, which are characterized by potential industrial and environmental hazards. In the future, the location of objects requiring the attendance of the personnel will be chosen with due account for the factors, which have never been estimated at all until now, and which are still not monitored in the mining sector.

6 Conclusions

Unlike natural aerosols formed in the environment, industrial aerosols are the main factors of the human habitat deterioration, as the majority of the planet population lives in regions with operating industrial facilities. Zones of dispersion and accumulation of ultrafine particles in the atmosphere, time of their existence do not coincide with zones of dust cloud distribution. Knowledge about objective laws governing the spread of such harmful factors will make possible the right choices for the location of industrial production shops, offices and amenity buildings, some other items of the surface industrial infrastructure, and residential areas, as well as the development of recommendations regarding the minimization of the human body exposure to the effect of ultrafine aerosols. In the future, the location of objects requiring the attendance of the personnel will be chosen with due account for the factors, which have never been estimated at all until now, and which are still not monitored in the mining sector.

References

1. M. E. Pevzner, *Gornaya ecology*, 395 (2003)
2. G. Gelein, R.M. Ferin, Inhal. Toxicol, **7**, 111 (1995)
3. G. Cox, Phil. Trans. Roy. Soc. Lond. Series, **1775,** 2719 (2000)
4. K. Donaldson, X.Y. LI, W. U. MacNee, Journal of Aerosol Science, **29**, 553 (1998)

5. K. Donaldson, V. Stone, P. S. Gilmore, D. M. Brown, and W. MacNee, Phil. Trans. Roy. Soc. Lond., **358**, 2741 (2000)
6. D. M. Brown, M. R. Wilson, W. MacNee, V. Stone, K. Donaldson, Toxicology and Applied Pharmacology, **175(3)**, 191 (2001)
7. C. L. Tran, D. Buchanan, R.T. Cullen, A. Searl, A. D. Jones, K. Donaldson, Inhal. Toxicol., **12(12)**, 1113 (2000)
8. C. A. J. Dick, D. M. Brown, K. Donaldson, V. Stone, Inhal. Toxicol., **15(1)**, 39 (2003)
9. W. MacNee, K. Donaldson, Eur. Resp. J., **21**, 47S (2003)
10. D. A. Taylor, Environ. Health Perspect. **110**, 80 (2002)
11. C. Buzea, I.I. Pacheco, K. Robbie, Biointerphases, **2**, 878 (2007)
12. G. Oberdörster, E. Oberdörster, J. Oberdörster, Environmental health perspectives, **113(7)**, 823 (2005)
13. N. Yu. Kovaleva, Journal of Chemical Safety, **2**, 44 (2017)
14. G. Oberdorster, Z. Sharp, V. Atudorei, A. Elder, R. Gelein, W. Kreyling, C. Cox, Inhalation toxicology, **16**, 437 (2004)
15. D.N. Radchenko, L.A. Gadjieva, V.V. Gavrilenko, RUDN Journal Of Ecology And Life Safety, **4**, 5432 (2017)
16. M. V. Rylnikova, D. N. Radchenko, Gornyi Zhurnal, **12**, 4 (2014)
17. D. R. Kaplunov, D. N. Radchenko, Gornyi Zhurnal, **11**, 52 (2017)
18. D. R. Kaplunov, M. V. Rylnikova, D. N. Radchenko, Sustainable Development of Mountain Territories, **3(25)**, 46 (2015)
19. Z. M. Khasheva, V. I. Golik International Business Management, **9(6)**, 1210 (2015)
20. V. I. Golik, Yu. I. Razorenov, A. B. Efremenkov, Applied Mechanics and Materials, **682**, 363 (2014)