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HYGIENIC ASSESSMENT OF PM_{10} AND $PM_{2.5}$ CONTENTS IN THE ATMOSPHERE AND POPULATION HEALTH RISK IN ZONES INFLEUNCED BY EMISSIONS FROM STATIONARY SOURCES LOCATED AT INDUSTRIAL ENTERPRISES

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Our research focused on air contamination with solid particles which occurred in settlements influenced by stationary sources located at enterprises involved in construction materials production. Our goal was to examine concentrations and fractional structure of solid particles and to assess health risks caused by air contamination with fine-dispersed solid particles for population living on territories adjoining to sanitary-hygienic zones of industrial enterprises. The research was conducted with laboratory control techniques, health risk assessment, sanitary-hygienic and statistic techniques. We measured solid particles concentrations in real-time detecting them incessantly, and it allowed us to obtain data on concentrations of fine-dispersed solid particles (10 and 2.5 microns diameter) averaged over 20-minutes period; we also managed to calculate sums of solid particles (dust/aerosol not differentiated in its compound) in the atmosphere in settlements influenced by stationary sources located at industrial enterprises. We analyzed fractional structure of solid particles, performed a hygienic assessment of atmospheric air contamination, and determined population health risks caused by atmospheric air contamination with fine-dispersed particles. The obtained results gave grounds for working out analytical (laboratory) techniques for control over atmospheric air contamination at a border between a residential area and a sanitary-hygienic zone and for hygienic assessment of solid particles content in the air in settlements, both for overall fraction and for particles with aerodynamic diameter 10 microns and 2.5 microns.

Key words: *atmospheric air, concentration, sanitary-hygienic zone, fine-dispersed solid particles, enterprise, health risk, a residential area.*

In Belarus hygienic standards for fine-dispersed solid particles content in the atmospheric air were fixed in 2004. The maximum permissible concentrations for 3 averaging periods (maximum single, average daily and average annual concentrations) were fixed for PM_{10} solid particles at 150 $\mu g/m^3$, 50 $\mu g/m^3$, and 40 $\mu g/m^3$; and for $PM_{2,5}$ solid particles, at 65 $\mu g/m^3$, 25 $\mu g/m^3$, and 15 $\mu g/m^3$ м^3[1]. They were also fixed at 300 $\mu g/m^3$, 150 $\mu g/m^3$, and 100 $\mu g/m^3$ for dust/aerosols which were not

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Normativy predel'no dopustimykh kontsentratsii zagryaznyayushchikh veshchestv v atmosfernom vozdukhe: gigienicheskii normativ / utv. postanovleniem Ministerstva zdravookhraneniya Respubliki Belarus' № 113 08.11.2016 g. [Standards for maximum permissible concentrations of contaminants in the atmosphere: hygienic standard / approved by the Order of.Belarus Public Healthcare Ministry on November 08, 2016 No. 113]. *Belarus Public Healthcare Ministry: official web-site*. Available at: http://minzdrav.gov.by/upload/dadvfiles/000352_132617_postan113.doc (23.07.2017).

differentiated in their composure (total suspended particles or TSP).

In Belarus solid particles are one of the most widely spread air contaminants which exert negative influence on population health. Contribution made by solid particles into multi-component air contamination accounts for 7-25%. Dusts are among top five contaminants which form 70% of the total technological emissions [1].

A sum of solid particles is a widely used, controllable, and informative parameter of air contamination. System of monitoring over atmospheric air quality in Belarus involves observations over total concentrations of solid particles at 67 stationary observation points belonging to the National Environmental Monitoring System. Laboratory control over total contents of solid particles in the air is performed via weight method, without any allowance for their component and disperse structure.

Monitoring over PM_{10} in the atmosphere is provided by an automated monitoring system which consists of 19 automatic control stations. PM_{10} concentrations are measured round-the-clock continuously. $PM_{2,5}$ concentrations in the air are controlled only at 2 automatic stations located in Minsk and Zhlobin [2, 3].

Results of analytic laboratory control are another source of information on solid particles contents in the atmosphere. This control is performed by laboratories at industrial enterprises and regional bodies of state sanitary surveillance and is based on data collected at borders of enterprises sanitary-hygienic zones and on housing territories influenced by industrial emissions. However, the existing monitoring system in Belarus doesn't envisage industrial control over technological emissions containing fine-dispersed solid particles. As a result, today we don't have sufficient data on solid particles dispersity and how they spread in the atmosphere. The existing practices for setting up borders of sanitary-hygienic zones don't allow for the disperse structure of solid particles. And when such zones are designed, emissions of various solid particles fractions are not taken into account, and it results in considerable decrease in accuracy of detecting a zone on territories adjacent to an industrial source and influenced by its emissions. But at the same time, a lot of researchers state that fine-dispersed dusts exert negative influence on population health (the cardiovascular system [4], and the respiratory organs [5–7]), including mortality caused by respiratory organs and cardiovascular system diseases [8, 9].

We analyzed results of research on background PM_{10} concentrations and solid particles sum in the atmosphere near 450 regional industrial complexes in Belarus (over 2012-2016). It was detected that a contribution made by solid particles into total atmosphere contamination accounted for more than 30%; it was also true for the hazard index which described possibility of negative responses from the respiratory organs caused by background atmosphere contamination with a set of various contaminants. A share of PM_{10} concentrations in solid particles mixture amounted to 55.00±0.02 % (95 % CI 51.20–58.80 %). These data are in line with the results obtained in other research works, including foreign ones, which show that shares of fine-dispersed solid particles in the air vary from 30 to 60% of total suspended particles [10–14].

In Belarus the highest background concentrations were detected in Mogilev, Minsk, and Gomel regions. In terms of regional industrial complexes, the highest background PM_{10} concentrations and solid particles sums were detected near large industrial enterprises dealing with construction materials manufacturing. Background concentrations of solid particles made a 62.58% contribution into the overall air contamination on such territories. Hazard index showing possibility of negative responses from the respiratory organs reached 2.23, solid particles contribution into the danger being equal to 47.48% [2].

Fine-dispersed dusts can be found in emissions from various productions such as ferrous and non-ferrous metallurgy, civil engineering, electrical engineering, and construction materials production [15–19].

A lot of technological processes existing at construction materials production result in solid particles formation. In 2014 research on fine-dispersed solid particles was performed on housing territories in three different functional zones: a) a zone influenced by emissions from motor transport; b) a zone influenced by emissions from stationary sources located at industrial enterprises; and c) a "conditionally clean" housing territory. The research results proved a hypothesis that emissions from construction material productions made a considerable contribution into population exposure to air contamination with fine-dispersed solid particles [3].

Grinding, mixing, storage and transportation of dried breakages and fine-dispersed powders result in formation of poly-dispersed solid particles. Industrial emissions contain solid particles sized from 0.5 to 200 microns. However, particles with their aerodynamic size being less than 10 microns are the most interesting research objects due to the fact that they are practically uncatchable for most dust collectors applied at industrial enterprises, as opposed to larger particles, 90-95% of those being easily caught [16, 20].

Our research goal was to examine fraction structure and concentrations of total suspended particles, $PM_{2,5}$ and PM_{10} in the atmosphere in settlements influenced by emissions from stationary sources located at industrial enterprises and to perform consequent health risk assessment for people living on such territories.

Data and methods. We chose our examined territory basing on the spatial territorial analysis, positional relationship between sources of solid particles emissions and housing territories, as well as on preliminary calculations of contamination dispersion and spreading.

We examined a housing territory located in a zone which was under maximum influence exerted by emissions from stationary sources located at large industrial enterprises dealing with construction materials production. Control points for taking air samples and instrumental measuring of solid particles were located in zones where maximum calculated concentrations caused by technological emissions sources were likely to occur. Overall, we selected 6 points on the housing territory located 500-800 meters away from an emission source. Research was performed from March to June, at weekdays, when an enterprise dealing with construction materials production worked in its standard functioning regime. The points were located on dust-free grounds, beyond aerodynamics shadows cast by buildings and trees.

Concentrations of TSP, $PM_{2,5}$ and PM_{10} were measured real-time (with each second detection) via short-range infra-red radiation dispersion technique with a SKCEPAM-5000 appliance. Registered particles sizes ranged from 0.1 to 100 micron. Range of aerosol particles mass concentration measuring was 0.01–200 mg/m^3. Totally, we performed 144 measurements of single (20 minute) concentrations of TSP, $PM_{2,5}$ and PM_{10}.

Results of atmospheric air research were assessed in conformity with the values of maximum single permissible concentrations of TSP, PM_{10} and $PM_{2,5}$ (300 μg/m^3,150 μg/m^3 and 65 μg/m^3, correspondingly) in the atmosphere [8]. Hygienic assessment of hazard caused by air contamination with fine-dispersed solid particles was performed as per "P" complex parameter value and air quality index on the basis of the upper 95% confidence limits of average single solid particles concentrations obtained during the research. Air quality index was calculated for each fraction and for solid particles sum separately, and the least obtained value was taken as the value of air quality index which characterized complex air contamination with solid particles on the examined territory [9].

When assessing health risks caused by fine-dispersed solid particles concentrations in the air, we calculated risks of an immediate (reflex) impacts and hazard quotients (indexes) under short-term exposure to TSP, PM_{10} and $PM_{2,5}$, taking critical organs (systems) into account [10]. All the obtained data were processed with Microsoft Office Excel 2010 and Statistica 10 software (serial number 1234567890).

Results and discussion. Our research on atmospheric air contamination revealed that single concentrations of both fine-dispersed PM_{10} and $PM_{2,5}$ solid particles and TSP mixture was correspondingly 2.0, 2.7 and 1.7 times higher than the fixed standards on the examined housing territory influenced by emissions from stationary sources located at industrial enterprises. Detected single concentrations of solid particles in the atmosphere are given in Table 1.

Comparative analysis of TSP content and PM_{10} and $PM_{2,5}$ fine-dispersed fractions allowed us to reveal that PM_{10}:$PM_{2,5}$:TSP ratio was 0,58:0,34:1 in zones influenced by emissions from stationary sources located at industrial enterprises. PM_{10} fraction share in TSP mixture was from 56.41 to 60.04%; and $PM_{2,5}$ fraction share, from 21.61 to 46.13%. On average, PM_{10} contribution into TSP concentration amounted to 58.34 ± 0.05 % (95 % CI 58.24–58.44 %); $PM_{2,5}$contribution, 34.38 ± 0.18 % (95 % CI 34.02–34.73 %), Table 2.

Table 1

Atmospheric air contamination with solid particles on the housing territory influenced by emissions from stationary sources located at industrial enterprises

Contaminant	Control point No.	Actual single concentration, μg/m3,M ± m	Minimum - maximum, μg/m3
PM_{10}	1	298,30 ± 0,97	287,00–316,00
	2	299,00 ± 0,88	286,00–308,00
	3	299,35 ± 0,53	291,00–313,00
	4	297,22 ± 0,89	272,00–309,00
	5	298,59 ± 0,89	272,00–309,00
	6	294,46 ± 0,45	274,00–310,00
	On the overall territory	297,94 ± 1,40	272,00–316,00
$PM_{2.5}$	1	167,65 ± 1,72	136,00–213,00
	2	183,63 ± 0,35	113,00–250,00
	3	172,82 ± 0,81	150,00–232,00
	4	170,11 ± 2,70	135,00–206,00
	5	187,25 ± 1,23	174,00–206,00
	6	185,46 ± 0,51	175,00–206,00
	On the overall territory	175,56 ± 3,43	113,00–250,00
TSP	1	515,86 ± 0,81	505,00–536,00
	2	520,25 ± 0,46	507,00–542,00
	3	511,51 ± 1,17	497,00–538,00
	4	502,79 ± 1,66	467,00–525,00
	5	508,70 ± 1,42	467,00–535,00
	6	502,17 ± 0,72	463,00–523,00
	On the overall territory	510,38 ± 2,48	467,00–542,00

Table 2

Fractional structure of solid particles in the atmosphere on housing territories influenced by emissions from stationary sources located at industrial enterprises предприятий

Control point No.	Mass fraction of solid particles, %, M ± m	
	PM_{10}	$PM_{2.5}$
№ 1	57,82 ± 0,13	32,49 ± 0,31
№ 2	57,47 ± 0,12	35,27 ± 0,49
№ 3	58,53 ± 0,07	33,81 ± 0,44
№ 4	59,12 ± 0,08	33,82 ± 0,51
№ 5	58,70 ± 0,01	35,89 ± 0,94
№ 6	58,61 ± 0,01	36,07 ± 0,06

PM_{10} and TSP concentrations were on average correspondingly 4.08 and 4.56 times higher in zones influenced by industrial emissions than the background solid particles concentrations in the atmosphere (background PM_{10} concentration is 73.00 μg/m^3; TSP, 112.00 μg/m^3, and $PM_{2,5}$ background concentration is not fixed [2]), which means that "higher" atmospheric contamination with solid particles is local.

"P" atmospheric air contamination with PM_{10} and $PM_{2,5}$ fractions amounts to 3.35±0.05 (95 % CI 3.26–3,45) and corresponds to "moderate" atmospheric contamination. Air quality index determined by solid particles contents in the atmosphere is equal to 137.33±6.96 (95 % CI 122.49–152.17). "Moderate" atmospheric air contamination causes stress in a body adaptation to impacts exerted by contaminants, considerable health risks, and a growth in background morbidity. Air quality index values obtained on the examined territory prove that background morbidity is likely to grow among the exposed population.

$PM_{2,5}$ and PM_{10} concentrations in the air which are above permitted standards (higher than MPC) are primary factors which cause risk of unfavorable responses from the respiratory organs. And the hazard index for such responses and potential risk of immediate (reflex) impacts exerted by $PM_{2,5}$ is authentically higher than the same parameters related to PM_{10} effects ($t = 13.54$ and $t = 12.66$, at $p < 0.05$).

Thus, potential population health risk caused by the atmospheric air contamination with PM_{10}, amounts to 0.108 ± 0.001 (95 % CI 0.105–0.111) and can be considered satisfactory, the hazard index for unfavorable responses from the respiratory organs is moderate (1.99±0.01, 95 % CI 1.97–2.01). Such risk, as a rule, can result in a growth in background morbidity, and

[2] Germanovich F.A. [et al]. Otsenka riska dlya zdorov'ya naseleniya ot vozdeistviya khimicheskikh veshchestv, zagryaznyayushchikh atmosfernyi vozdukh: instruktsiya 2.1.6.11-9-29-2004. Utv. Postanovleniem glavnogo gosudarstvennogo sanitarnogo vracha Respubliki Belarus' № 63 05.07.2004 g. [Assessment of population health risk related to impacts exerted by chemicals which pollute the atmospheric air: Instruction No. 2.1.6.11-9-29-2004. Approved by the Order signed by the Belarus Chief Sanitary Inspector on July 05, 2004, No. 63]. *Sovremennye metody diagnostiki, lecheniya i profilaktiki zabole-vanii: sb. instruktivno-metodicheskoi dokumentatsii*, Minsk, 2005, vol.6, no. 5, pp. 83–157.

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population are likely to complain about various discomfort related to impacts exerted by the examined factor [2].

At the same time, potential population health risk caused by effects exerted by $PM_{2,5}$ is unsatisfactory (0.230 ± 0.010, 95 % CI 0.209–0.250), the hazard index for unfavorable responses from the respiratory organs and the cardiovascular system is average (2.70 ± 0.05, 95 % CI 2.59–2.81). Unsatisfactory risk results in constant complaints from the population about various discomfort related to impacts exerted by the examined factor and a trend for a growth in overall morbidity [8].

Hazard index for unfavorable responses from the respiratory organs and potential risk of immediate (reflex) impacts exerted by TSP allowing for solid particles dispersity is equal to 4.81±0.05 (95 % CI 4.71–4.91) and 0.338±0.010 (95 % CI 0.316–0.359) and is correspondingly 2.8 and 5.0 times higher than the same parameters without any allowance for dispersity (1.70±0.01, 95 % CI 1.68–1.72 and 0.068±0.001, 95 % CI 0.066–0.071) ($t= 6.39$ and 2.62, at $p < 0.05$). Qualitative assessment of risks obtained with allowance for dispersity of solid particles in TSP composition makes population health risks caused by TSP impacts unsatisfactory. $PM_{2,5}$ contribution into the hazard index for unfavorable responses from the respiratory organs caused by TSP impacts amounts to 56.07±0.57% (95 % CI 54.86–57.29 %); PM_{10} contribution, to 41.34±0.34 % (95 % CI 40.61–42.06%).

These data are extremely significant as they can help to develop relevant monitoring programs for atmospheric air quality which will be aimed, first of all, at control over the greatest population health risk factors [21].

Conclusion. So, maximum single PM_{10}, $PM_{2,5}$ and TSP concentrations are correspondingly 2.0, 2.7 and 1.7 higher than the hygienic standard on the examined housing territory influenced by stationary emission sources located at industrial enterprises. Atmospheric air contamination with fine-dispersed solid particles can be considered moderate.

Maximum single PM_{10} and TSP concentrations are on average correspondingly 4.08 and 4.56 times higher than the background solid particles concentrations in the atmosphere and it proves air contamination with solid particles is local, that is, higher air contamination occurs within zones influenced by stationary emission sources located at industrial enterprises.

A share of $PM_{2,5}$ solid particles in overall TSP amounts to 34.38 %; a share of PM_{10}, about 58.34%. Potential population health risks and hazard indexes for unfavorable responses from the respiratory organs allowing for solid particles dispersity in TSP structure are correspondingly 2.5 and 5.0 times higher than the same parameters without any allowance for particles dispersity.

Potential population health risk can be considered satisfactory in case of PM_{10} effects and unsatisfactory in case of $PM_{2,5}$ effects. Hazard index for unfavorable responses from the respiratory organs and risk of immediate (reflex) impacts is authentically higher under exposure to $PM_{2,5}$ than the same risk parameters related to PM_{10} impacts.

Therefore, all the obtained data prove it is vital to determine disperse structure of solid particles both to assess atmospheric air quality and impacts exerted by fine-dispersed solid particles on population health adequately. When solid particles dispersity is taken into account, it allows to reveal actual population health risk, to develop adequate programs for control over contamination, to give grounds for optimal design decisions related to housing zones placement, and to make other relevant decisions in the sphere of population health risk management.

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