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INVESTIGATIONS OF FINE PARTICLES CONCENTRATIONS IN THE ATMOSPHERIC AIR NEAR HIGHWAYS

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This paper presents the results of the experimental determination of particulate matter $PM_{2,5}$, PM_{10} mass concentration and total suspended particles up to 15 microns (TSP), which are the priority components of air pollutants near the highways. The measurements were made during the year 2016 using a laser analyzer of aerosol DustTrak 8533. The study shows the dependence of the particulate matter concentration from the time of day and the traffic congestion. The sampling (N = 67) was performed due to brief program on the basis of the route monitoring station, which is located on the road junction with heavy traffic – up to1,200 vehicles per hour on the test sites. The single concentrations of the suspended substances reached the levels of the Maximum permissible concentration (MPC) of 1.5. During the study period, the exceeding of the established average daily MPC for fine particles $PM_{2.5}$ and PM_{10} fractions near the highways have not been identified.

The significant linear relationship between the number of diesel vehicles on stops and the concentrations of particulate matter $PM_{2.5}$, PM_{10}, TSP (correlation coefficient from 0.62 to 0.65; Fisher's criterion of 14.2 to 38.0; $p < 0.05$) has been established and parameterized, what allows to predict the level of air pollution by diesel vehicles when braking and accelerating.

It is recommended to fulfill continuous monitoring of the average daily and single MPC of the fine suspended particles near the roads with traffic load of 769 – 1270 or more the diesel vehicles per every 20 minutes. The obtained data may be used in evaluation of the risk to public health induced by the transport emissions as well as in the estimation of the fine particles $PM_{2.5}$, PM_{10} concentrations on the sites close to the highways of the large industrial center.

Key words: *fine particles, $PM_{2,5}$, PM_{10}, transport emissions, atmospheric air, laser nephelometry, correlation coefficient, Fisher's criterion.*

Concentrations follow-up control and decrease in air pollution with fine suspended particles PM2.5 and PM10 in large industrial cities is an urgent task of social-hygienic monitoring and human health risk management.

PM2.5 are suspended particles (solids) contained in the air, of aerodynamic diameter less than 2.5 microns, PM10 – of less than 10 microns in diameter. The fine particles pose threat to human health as they penetrate into lungs, causing a number of diseases or aggravating the existing ones [3.23]. According to scientific literature, the concentration of

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PM2,5 fraction fine particles affects people mortality and cardiovascular disease occurrence [25].

Standards of fine particles content in the air are set in the official documents of the World Health Organization (WHO) and the European Union [12,24,26]. In the Russian Federation, the content of PM2,5 and PM10 fractions fine particles is subject to standardization since 2010. The daily-average maximum permissible concentration (MPC) is 0.035 mg/m3 (PM2,5) and 0.06 mg/m3 (PM10); single maximum 0.16 mg/m3 and 0.3 mg/m3; mean year: 0.025 mg/m3 and 0.04 mg/m3, respectively [7]. Follow-up control over the environment pollution with suspended particles is of high demand, however, until 2016, determining fine dust concentrations was of scientific research nature only [4-6,8, 13,14,18,22], except for the automated monitoring arranged in Moscow, St. Petersburg, Sochi, Kazan [16, 17].

With Ruling document 52.04.830-2015 "Mass concentration of PM10 and PM2.5 suspended particles in the ambient air" and RD1 52.04.840-2015 "Application of the air quality monitoring data obtained using continuous measurement methods" in force since March 2016, the reference gravimetric measurement procedure relating to mass concentration of suspended particles of less than 10 microns and less than 2.5 microns is set, which allows also to determine the correction factor for automatic analyzer.

The peculiarity of the Russian standardization system is a 20-minute data smoothing, including those obtained by means of continuous measurements methods [20]. Direct measurements methods with gas analyzers and dust meters allow for the data-fund on urban air pollution in place. [20]

Under conditions of a large industrial center, fine particles mainly come from anthropogenic sources: vehicle emissions and industry [1]. For example, in Beijing, according to estimates of Beijing Environment protection and monitoring center, PM2.5 particles are generated mainly of coal combustion and exhaust emissions [2].

A large number of fine particles appear in the process of fuel combustion and vehicle diesel-engines operation [9]. Apart from direct emission from engines, fine particles are formed as a result of roadways and tires wear. Soot fine particles, due to their small size, causing a slow natural excretion from the atmosphere, and sorption properties, can increase toxicity by absorption of harmful substances from emissions, being transported to thousands of kilometers, posing threat to human health and environment [9]. The proportion of vehicle emissions in the large cities' air pollution can reach up to 60 - 90% [10]. Vehicle emissions contain dozens of different toxic substances, among which fine particles PM2.5, PM10 are a priority, along with benzo(a)pyrene and carbon black [1.14, 15.18].

The present study was aimed at investigating the content of fine particles PM2.5, PM10 in the atmospheric air at close range of auto-roads.

Materials and methods. To determine fine particles content in the air, we used dust analyzer DustTrak, model 8533, with particles size range detected of 0.1 - 15 microns. Measuring aerosol particles mass concentration ranged within 0.01 - 150 mg/m3. [21]. Instrumental studies of fine particles and TSP content in the ambient air took place during warm season (spring - summer) in 2016. Measurements were held by the reduced monitoring program in accordance with GOST 17.2.3.01-86 on route station site, located in the areas adjacent to asphalt highways of heavy traffic: 1,200 vehicles per hour on the test areas [11]. Measurement duration and averaging period in determining single concentrations were 20 minutes, unit values were recorded per second. The device was placed at a height of 1.5 m. Measurements went along with air temperature and wind speed follow-up.

Measuring air pollution level caused by vehicle emissions [19] was carried out at different weather conditions and traffic rates. According to regulations [19], the monitoring points were selected in heavy traffic localities in the areas of frequent application of brakes, i.e. at highways crossroads and stopping points. The passing vehicles were counted per aerosol concentrations measurements period (20 min). Vehicles were divided into two categories: petrol: cars, motorcycles; diesel: buses and cargo-trucks. In addition, they assessed air pollution with fine particles PM2.5 and PM10 at stops, where people spend a relatively short time, but supposed to be receiving a relatively high dose of fine particles.

The obtained data were compared with the maximum values of single MPC of suspended particles PM2.5 and PM10 in the populated areas atmosphere [7] (Tables 1, 2). Statistical data processing included calculation and estimation of Fisher's criterion, correlation coefficient, taking into account the significance level of <0.05.

Results and discussion. Measuring the level of pollution in the ambient air at stopping points showed that under continuous every-second measurements, including measurements during buses' deceleration, stopping and acceleration, the single concentrations of suspended particles are increasing up to 1.5 MPCSM. However, by smoothing data obtained for 20-minute interval, no MPCSM exceedence was found (Table 1, Figure 1, 2).

Linear relationship equation y=0.0002x+0.0062 is characterized by a correlation coefficient of 0.6452; Fisher's criterion was 38.2, p <0.05, that confirms the hypothesis on a heavy contribution of diesel vehicles emissions into air pollution with fine particles.

In the process of experimental studies for the stopping point №2, far from traffic lights, in a circular movement, we obtained the dependences of suspended particles PM2.5 and PM10 mass concentrations (y), as well as of TSP, on the number of diesel engine vehicles (x) (Fig. 2).

Table 1

Measurements data of PM2.5 and PM10 fine particles single maximum concentrations, as well as total dust of up to 15 microns (TSP) at stops

Point of Measurement	Traffic load, vehicles units/20 min.		$PM_{2,5}$, ±Δ, mg/m³ Single Max Concentration	PM_{10}, ±Δ, mg/m³ Single Max Concentration	TSP, ±Δ, mg/m³ Single Max Concentration
	Diesel engine	Petrol engine	MPC single max value, mg/m³		
			0,160	0,300	–
Bus stop № 1, *n* = 4	95	836	0,025 ± 0,005	0,063 ± 0,013	0,111 ± 0,022
Bus stop № 2, *n* = 11	195	822	0,055 ± 0,011	0,073 ± 0,015	0,091 ± 0,018
Bus stop № 3, *n* = 2	80	520	0,014 ± 0,003	0,041 ± 0,008	0,079 ± 0,016
Bus stop № 4, *n* = 2	160	1400	0,027 ± 0,005	0,038 ± 0,008	0,039 ± 0,008
Bus stop № 5, *n* = 2	120	720	0,014 ± 0,003	0,030 ± 0,006	0,047 ± 0,009
Bus stop № 6, *n* = 2	40	480	0,016 ± 0,003	0,053 ± 0,011	0,095 ± 0,019

Table 2

Measurements data of $PM_{2.5}$ and PM_{10} fine particles single maximum concentrations, as well as total dust of up to 15 microns (TSP) at stops

Point of Measurement	Traffic load, vehicles units /20 min.		Single Max Concentration, $PM_{2,5}$, ±Δ, mg/m³	Single Max Concentration, PM_{10}, ±Δ, mg/m³	Single Max Concentration, TSP, ±Δ, mg/m³
	Diesel engine	Petrol engine	MPC single max value, mg/m³		
			0,160	0,300	–
Crossroad № 1, *n* = 30	120	1039	0,050 ± 0,010	0,063 ± 0,013	0,080 ± 0,016
Crossroad № 2, *n* = 4	450	3185	0,031 ± 0,006	0,040 ± 0,008	0,051 ± 0,010
Crossroad № 3, *n* = 4	277	1250	0,024 ± 0,005	0,028 ± 0,006	0,040 ± 0,008
Crossroad № 4, *n* = 2	160	1000	0,051 ± 0,010	0,093 ± 0,019	0,100 ± 0,020
Crossroad № 5, *n* = 2	100	1080	0,011 ± 0,002	0,020 ± 0,004	0,034 ± 0,007

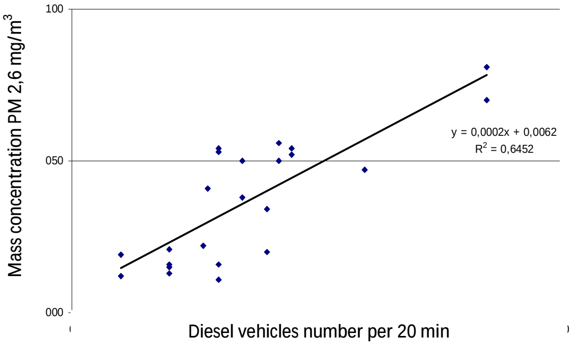

Fig.1. Dependence of single maximum concentration of PM2.5 particles at stopping points on the number of diesel engines vehicles driven along the asphalt road. N = 23, F = 38.2, p <0.05

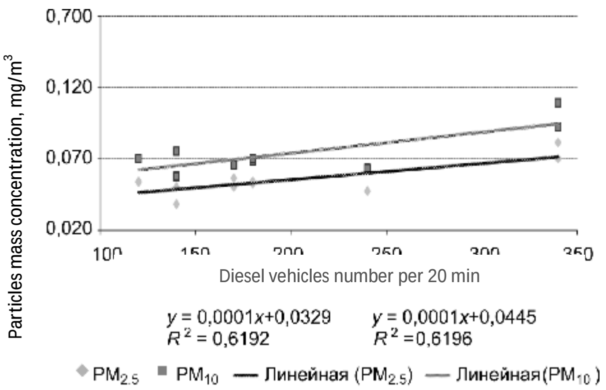

Fig.2. Dependence of single maximum concentration of $PM_{2.5}$ and PM_{10} particles at stopping point № 2 on the number of diesel engines vehicles driven along the asphalt road. N=11, F=14.6, p <0.05

Reliability of approximation and adequacy of linear dependence is confirmed with the calculated values of the correlation coefficient and Fisher's criterion: for PM2.5 y=0.0001x+0.0329 (R2=0.6192, F=14.6, p<0.05), for PM10 y=0.0001x+0.0445 (R2=0.6196, F=14.7, p<0.05), y=0.0002x+0.051, for TSP (R2=0.6203, F=14.7, p<0.05). In this case, increasing the concentration of particles in the atmosphere is linearly related to increasing the proportion of particles in the exhaust gases in conditions of braking and acceleration, and the background level of fine particles concentrations, is likely formed by exhaust gases of vehicles driven at a constant speed, and secondary dust collection from the surface. As for the other stopping points, they were near to traffic lights, so, there were braking factors, vehicles stopping and acceleration, and emissions at idling in the morning and evening traffic jams lined up herewith (Figure 3).

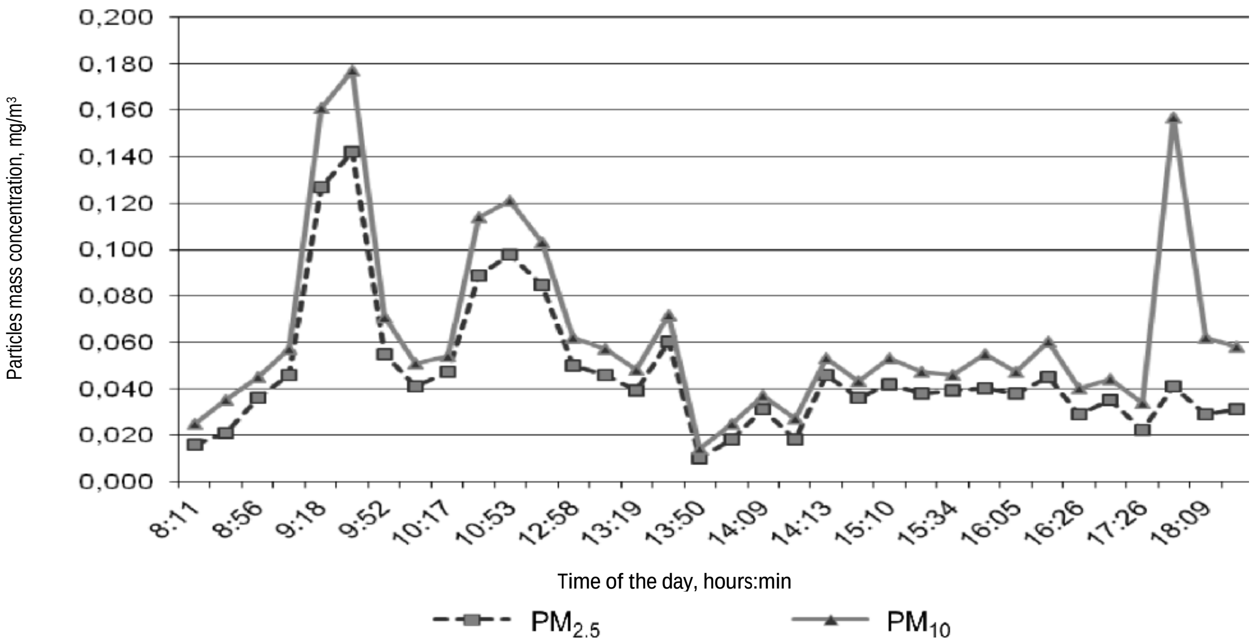

Fig. 3. Dependence of single maximum concentration of $PM_{2.5}$ and PM_{10} particles on time of the day

As per equations obtained, predicting the situation, we can assume that achieving and further exceedence of MACs.max (PM2.5) may occur at a highway stop-point loaded with diesel vehicles, the number of which within 20 minutes must exceed 770 units near the traffic lights or 1271 units far from the traffic lights. In this regard, suspended fine particles single maximum concentrations are rational to be monitored continuously near the roads with traffic close to the reported one.

The measurements results for single maximum concentrations at highways crossroads are given in Table. 2. The measured values of PM2.5 and PM10 fine particles concentrations did not exceed MACs.max. In addition, when determining single maximum concentration of fine particles at crossroads, there was no reliable dependence on the number of vehicles fixed.

Conclusions. When studying fine particles on Perm highways with the traffic intensity of up to 2.5 thousand cars per hour, suspended particles mass concentrations averaged over a 20-minute period at stops and crossroads did not exceed the established hygienic standards.

Linear dependencies between the number of diesel vehicles at stops and PM2.5, PM10, TSP suspended particles concentrations have been established and parameterized, which allows predicting the level of atmospheric pollution by diesel vehicles during their braking and acceleration.

It is recommended to continuously monitor daily average suspended fine particles concentrations near big highways, as well as single maximum concentrations of suspended fine particles near roads with diesel vehicles traffic of 769 – 1270 units or more per 20 minutes.

The studies done can be used for calculation of risks for population health due to vehicles emissions and objective assessment of PM2.5 and PM10 fine particles content near the highways of a large industrial center.

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