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ORIGINAL PAPER

EVALUATION OF EXPOSURE TO NANO-SIZED PARTICLES AMONG TRANSPORT AND VEHICLE SERVICE WORKERS

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Abstract

Background: Exposure to fine and ultrafine particles from transport processes is a main consequence of emissions from engines, especially those with self-ignition. The particles released in these processes are a source of occupational and environmental particles exposure. The aim of this study was to assess the fine and nano-sized particles emission degree during work connected with transport and vehicle servicing. **Material and Methods:** The tests were carried out at 3 workplaces of vehicles service and maintenance (a car repair workshop, a truck service hall, and a bus depot) during 1 work day in each of them. Measurements were performed using the following devices: DISCmini meters, GRIMM 1.109 optical counter and the DustTrak monitor. The number, surface area and mass concentration, and the number size distribution were analyzed. **Results:** The mean number concentration (DISCmini) increased during the analyzed processes, ranging from 4×104 p/cm^3 to 8×104 p/cm^3, and the highest concentration was found in the car repair workshop. The particles mean diameters during the processes ranged 31–47 nm, depending on the process. An increase in the surface area concentration value was observed in correlation with the particles number, and its highest concentration (198 m^2/cm^3) was found during work in the car repair workshop. The number size distribution analysis (GRIMM 1.109) showed the maximum value of the number concentration for particles sized 60 nm. The mean mass concentrations increased during the tested processes by approx. 40–70%, as compared to the background. **Conclusions:** According to the measurement results, all the workplaces under study constituted a source of an increase in all analyzed parameters characterizing emissions of nano-sized particles. Such working environment conditions can be harmful to the exposed workers; therefore, at such workplaces solutions for minimizing workers' exposure, such as fume hoods or respiratory protection, should be used. Med Pr. 2021;72(5):489–500

Key words: ultrafine particles, particle number concentration, particle surface area concentration, nanoparticles exposure, diesel engine exhaust, particle number size distribution

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INTRODUCTION

Transport is one of the basic parts of economy, both as it is an independent branch and also because it plays an important role in the functioning and development of the country's financial system. At the same time, apart from non-industrial and industrial combustion processes, transport is one of the largest sources of emissions of gaseous and solid pollutants to the environment [1], and despite the systematically undertaken preventive measures, total emission is still growing. The main components of engine exhausts are gaseous components, including in particular the following: carbon oxides, nitrogen and its compounds, oxygen, sulfur compounds, and numerous hydrocarbons, mainly aromatic ones. Apart from vapors and gaseous compounds, significant components of engine exhausts are fine solid particles.

Exposure to fine and ultrafine particles, i.e., nanoparticles from road traffic, is mainly a consequence of particle emissions resulting from incomplete combustion of fuels in engines, especially those with self-ignition. Diesel engine exhausts and their nanoparticles occur both in atmospheric air where they come mainly from transport means such as buses, railway, cars, and trucks, and in workplaces where vehicles with high-pressure engines are serviced and maintained. The group of workers occupationally exposed to particles emitted from diesel engines includes drivers and operators of various

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machines (excavators, cranes, forklifts, etc.), bus depot workers, car mechanics, railway men, miners, and other workers operating vehicles with diesel engines or working near them. The environmentally exposed social group, in turn, includes mainly inhabitants of big cities, areas with high traffic density, or those who commute mainly by urban or interurban transport [2,3].

The properties of ultrafine particles formed in the diesel engines combustion process differ considerably both in physical properties, such as the dimension or shape, and in chemical composition. The composition of emitted exhaust fumes from high-pressure engines is affected by such parameters as the composition and properties of diesel oil and its combustion conditions, the use of ignition control additives, emission control systems as well as engine conditions. It has been estimated that the amount of incomplete combustion products in diesel engines may reach several thousand compounds occurring in a form of gases or particulate matters [4].

Increased particle emissions occur with poorly heated engines, especially during the so-called cold start. Particles released by diesel engines are mostly fine particles, especially $PM_{2.5}$ – a fraction containing mainly nanoparticles sized <0.1 μm [5,6]. The estimated size of particles emitted by petrol engines ranged 20–60 nm [5,7]. The nano-sized solid particles contained in combustion gases may be formed directly in the engine due to incomplete combustion of fuel, or they may result from the condensation of emitted gas impurities. In environmental conditions, soot produced during incomplete combustion aggregates very fast, creating bigger structures, and particles exist as single and independent only for a short period [8].

Typical diesel engine combustion particles may be characterized as agglomerates consisting of basic particles with diameters ranging from a few to several dozen nm [9,10]. Because of such a small size, these particles are characterized by a highly developed surface, often with high reactivity which enables the adsorption of various compounds. The main chemical component of diesel engine combustion particles is elemental carbon occurring as soot particles. On the surface of the elemental carbon, different organic and inorganic compounds such as hydrocarbons and their derivatives, sulfates, nitrates, metals and trace elements may be adsorbed [11].

The emission of particles from diesel engines, and also, though less significantly, from petrol engines, is not the only source of nanoparticles released by vehicles to the working and urban environments. A considerable part of fine and ultrafine particles may also be emitted in other processes connected with traffic. In literature, they are defined as non-exhaust emissions. Such emissions include the generation of nano-sized particles during frictional use of selected elements of vehicles. The most prevalent is information about particles formed in the abrasion of clutches and brake lining during their use [12,13]. Ultrafine particles may also arise from wear of tyres and road surface by inter-friction during driving, which is significantly increased in city traffic, especially during frequent braking, car maneuvering and rubbing of wheels against kerbs [14–17].

Other processes which generate particles, including those of nanometric sizes, may be those connected with cleaning and maintenance of vehicle elements. The procedure of cleaning of coolers in trucks which cover hundred thousand kilometers annually, so they accumulate some hazardous substances on the heat exchangers surface, including particles of suspended dusts and nanoparticles formed from wear processes and emissions from engines, can be mentioned in this context. Products of the so-called car chemistry group (e.g., preparations for cleaning of air conditioners or cockpits), which contain nanoparticles designed and intentionally used to achieve specific properties of a given product, are increasingly used in vehicle maintenance processes. Such products often occur in the form of aerosols, atomizers or powders which facilitate nanoparticle emissions into the air.

The main route of exposure to particles emitted from diesel engines (and particles from other sources connected with transport) is the respiratory tract. Because of an ultra small size of the particles emitted from vehicles, they may get into the deepest parts of the respiratory system, i.e., the alveoli. They may also accumulate in other, sometimes distant, tissues and organs, including the brain. Toxicological and epidemiological studies indicate that nanoparticles released into the environment by vehicles may cause adverse health effects – mainly diseases of the respiratory tract and the cardiovascular system, including tumors. Acute poisoning with diesel engine exhausts causes the irritation of eye mucosa, the irritation of upper respiratory routes, dizziness and nausea. Chronic poisonings are usually observed among persons occupationally exposed for at least several years. Under chronic poisoning conditions, both severe non-cancerous diseases (obturative disorders of pulmonary ventilation) and cancers were observed [4,18,19].

According to the International Agency for Research on Cancer (IARC), diesel engine exhaust fumes are carcinogenic for people and are classified as group 1 of the IARC classification. Epidemiological findings indicate that chronic exposure to diesel engine exhaust fumes may increase the risk of pulmonary carcinoma (sufficient evidence). There is also an association between exposure to diesel exhausts and bladder carcinoma (limited evidence) [20]. The main cause of lung cancer are nanometric size particles with adsorbed organic compounds, having mutagenic or carcinogenic effects.

The present study assesses the ultrafine particles concentrations at 3 different workplaces connected with the servicing of vehicles during standard work characteristic for a given workplace. The selected workplaces are: a bus depot, a truck service hall, and a repair workshop of passenger cars and delivery trucks. The authors assessed the mass concentration and also such parameters of airborne particles as the number and surface area concentrations, and the number size distribution of particles present at given workplaces.

The measurements concerned mainly particles in the nano-sized range, but due to the measuring ranges of the instruments, some results also include larger particles.

MATERIAL AND METHODS

The measurements were conducted at the following workplaces:

- The daily service hall (DSH) of a bus depot where the technical condition of buses such as the braking system, the steering system, power transmission, and the level of fluids are checked on a daily basis. Then, the buses are washed and cleaned inside. The everyday service hall system consists of 2 parallel inspection lines through which the vehicles are riding continuously, stopping on consecutive stands. The gates to DSH were opened to let in a consecutive bus and closed right away behind it. The depot had a stock of approx. 200 buses, all of which were inspected during the measurement. The area of DSH was approx. 12×80 m and height approx. 10 m. The measurement was carried out in the first part of this hall which constitutes one-third of the building (the entire hall is an open space). No mechanical ventilation or local point extractions were used during the measurement. Air movement in DSH was caused by gates opening and buses driving in and out.
- The truck service hall. The research stand was situated in the hall where the servicing and repairs of trucks were carried out. There were 6–7 vehicles at a time in the hall. Particles were emitted while the vehicles were driving in and out of the hall, and during activities resulting from the servicing of a given vehicle specificity, e.g., the necessary start-up of the engine during the repair process. The entrance gates to the service hall were closed. They were opened only when a vehicle had to drive in or out of the service hall. The floor area of the service hall was 35×30 m, with an approximate height of 10 m. No mechanical ventilation or local exhaust ventilation were used during the measurement. Air movement in the service hall was caused by gates opening and trucks driving in and out.
- The car repair workshop which conducted standard works connected with the repairs of cars and delivery trucks with diesel engines. The repair room had enough space for 3–4 vehicles. Emissions occurred while the cars were driving in and out of the hall, and during the activities resulting from the servicing of a given vehicle, such as an engine start-up during the repair. The entrance gates to the service hall were closed. They were opened only when the vehicle had to drive into or out of the hall. The floor area of this service hall was 13×11 m with an approximate height of 4 m. No mechanical ventilation or local point extractions were used during the measurement. Air movement in the car repair workshop was caused by gates opening and cars driving in and out.

During measurements at all workplaces under study, vehicles with diesel engines only were present. At each workplace, the measurement was performed during 1 work day.

The evaluation of the release of nanoparticles in the above workplaces included the determination of such parameters as the particles number concentration, their surface area concentration, and mass concentration of aerosol. Additionally, the number size distribution of the emitted particles was analyzed. The following devices were used for the measurements to determine the nano-sized particles concentration emitted during the tested processes:

- DISCmini measurers (Matter Aerosol) to determine the particles number concentration, their mean diameter and lung deposited surface area (LDSA) concentration (measuring range: particles sized 10–700 nm with the modal value of 300 nm).

The accuracy of DISCmini is ±30%, typical for the size and number;
- the particles optical counter GRIMM 1.109 with NanoSizer model 1.321 to determine the number concentration of particles with their size distributions (measuring range: 10 nm–32 μm);
- the aerosol concentration monitor DustTrak (TSI, model 8534) used to determine the size-segregated mass concentration (particles ranging 0.1–15 μm). As described in literature, data obtained with the DustTrak can be over- and underestimated and, therefore, they should be handled with care. Here they will be given as proxy values for the purpose of comparison with the background.

The measurements were performed with the above devices which have some inaccuracy and methodological limitations. Therefore, the results should not be treated as those of other, standardized methods. The following results, however, illustrate changes in the concentration values over time and may be an indication of changes in the exposure of workers over the work shift.

The measurement strategy involved the following stages of sampling:
- before starting work at a given workplace – the background (16 min);
- during work, when particles were emitted from vehicles (approx. 3.5 h);
- after work (16 min).

The measuring devices were placed at the level corresponding to the height of the worker's head in the area corresponding to the breathing zone.

The results analysis involved determination of the arithmetic mean values, standard deviation, and minimum and maximum values observed during the measurements. Average time is the period of individual stages, e.g., 16 min for the background and after works, and approx. 3.5 h for the work cycle (for every workplace).

RESULTS

Determination of the number concentration, the mean diameter of particles and the LDSA concentration of particles, using DISCmini meters

The mean values of the parameters determined using DISCmini meters at the workplaces under study are presented in Table 1.

Number concentration

The number concentration of particles released from vehicles mainly due to combustion in engines, measured as the mean number concentration of particles sized within the DISCmini measuring range, i.e., 10–700 nm,

Table 1. The parameters determined using DISCmini during work at the workplaces under study (daily service hall in the bus depot, truck service hall and car repair workshop)

Measurement place and stage*	Concentration [particles/cm^3]		Particles diameter [nm]		LDSA [μm^2/cm^3]	
	M±SD	min.–max	M±SD	min.–max	M±SD	min.–max
Daily service hall in the bus depot						
background	19 271±798	18 138–20 650	47±0	47–47	49±2	46–53
during work	61 370±37 621	16 941–334 842	38±5	21–47	117±48	41–401
after work	54 706±55 800	24 056–223 227	35±5	28–50	110±145	43–604
Truck service hall						
background	6 517±76	6 384–6 658	37±0	36–37	13±0	12–13
during work	38 560±32 657	2 595–227 492	31±6	18–55	57±47	6–345
after work	34 937±31 329	11 743–80 930	37±2	34–42	72±67	21–169
Car repair workshop						
background	27 550±1 413	25 026–30 348	41±1	40–41	61±2	56–66
during work	79 842±75 316	16 618–475 143	47±4	29–52	197±167	37–1 081
after work	32 705±3 122	29 418–40 313	50±1	48.6–51	90±6	83–107

* Averaging time was respectively: 16 min for backgrounds, 3.5 h during work and 16 min after works.
LDSA – lung deposited surface area.

was found to increase at each tested stand. The highest mean value of the concentration (8×10^4 p/cm^3) during work involving the emission of nanoparticles from vehicles was noted in the car repair workshop. This high concentration may be associated with a relatively small and closed workplace area with almost constantly closed gates. This value was almost 3 times higher as compared to the value before the work started (3×10^4 p/cm^3). A similar situation was observed for the everyday servicing of buses at the bus depot. The mean number concentration measured before the first bus drove into DSH, i.e., the background value, reached 2×10^4 p/cm^3. While the buses were riding through the hall continuously, the mean number concentration increased over 3-fold, reaching 6×10^4 p/cm^3. Some different conditions were noted in the truck service hall. In the air of that workpost, before the work started, the mean number concentration was 7×10^3 p/cm^3. When the work continued, an average 6-fold increase in that parameter was noted and its value reached 4×10^4 p/cm^3.

It should be particularly emphasized that the type of works carried out in all workplaces under study was highly heterogeneous. Consequently, the emission of particles from engines was also changing very dynamically over time. Figure 1a illustrates the dynamics of changes in the particles number concentration level during measurements with DISCmini.

It can be observed that this average 3- or 6-fold concentration increase relative to the background may be inadequate considering the measurement stages when instantaneous concentrations are much higher. The maximum increase in the instantaneous concentration during work carried out in DSH in the bus depot and in the car repair workshop was 17 times higher than the concentration measured before the work started. In the truck service hall, the maximum number concentration of particles during work was even 35 times higher than before it started.

Particles diameter

The analysis of the value of mean diameters of particles emitted from vehicle engines at the workplaces under study indicates that the mean size of those particles (within the range of 10–700 nm) released in these processes was ≤50 nm. Additionally, at 2 workplaces, a decrease in the particles mean diameter value during work, as compared to the background value, was observed. In the bus depot service hall, the particles mean diameter decreased by 20% (from 47 nm before work to 38 nm during work), while in the truck service hall a decrease of 15% was observed (37 nm – the particles mean diameter before work, 31 nm – the particles diameter during work). In the case of particles measured in the car repair workshop, a 14% increase was observed in the mean diameter of airborne particles at that workplace compared to the background particles, and these values reached 41 nm for the background particles and 47 nm for the particles present during occupational duties. Changes in the particles mean diameter value are shown on Figure 1b.

Lung deposited surface area concentration

The LDSA value is calculated as the surface area by lung deposition probability. This calculation is approximate and valid only for spherical particles.

Before buses inspection in the bus depot, the mean LDSA concentration was 49 μm^2/cm^3. While the buses were riding through DSH, the concentration was increasing almost 2.5 times and reached 117 μm^2/cm^3. In the truck service hall before the work started, the LDSA concentration value reached 13 μm^2/cm^3. During work at this workplace, LDSA increased 4.5 times, reaching on average 57 μm^2/cm^3. The highest LDSA concentration value, i.e., 198 μm^2/cm^3, was observed during the car repair workshop occupational duties; that value was over 3 times higher than the value measured before the work started (61 μm^2/cm^3). Figure 1c shows changes in the LDSA concentration at the workplaces under study.

Determination of the particles number concentration, along with their size distributions, using the particles optical counter GRIMM 1.109 with NanoSizer 1.321

The mean number concentration values of particles emitted from vehicles, along with their size distributions, are presented in Table 2.

This table contains the concentration values for particles ranging 13–265 nm. The concentrations of bigger particles showed a decreasing tendency, and the table presented the results with the size range of the highest concentrations and with the most significant changes in the dynamics. The analysis of the particles number size distributions indicates that the particles emitted by vehicles at all workplaces under study had a wide size range, but most of them had nanometric diameters. A vast majority of the particles emitted in the transport processes are the particles with up to approx. 115–145 nm in diameter, and the highest number concentration was noted for those with the mean size of 60 nm. For particles of

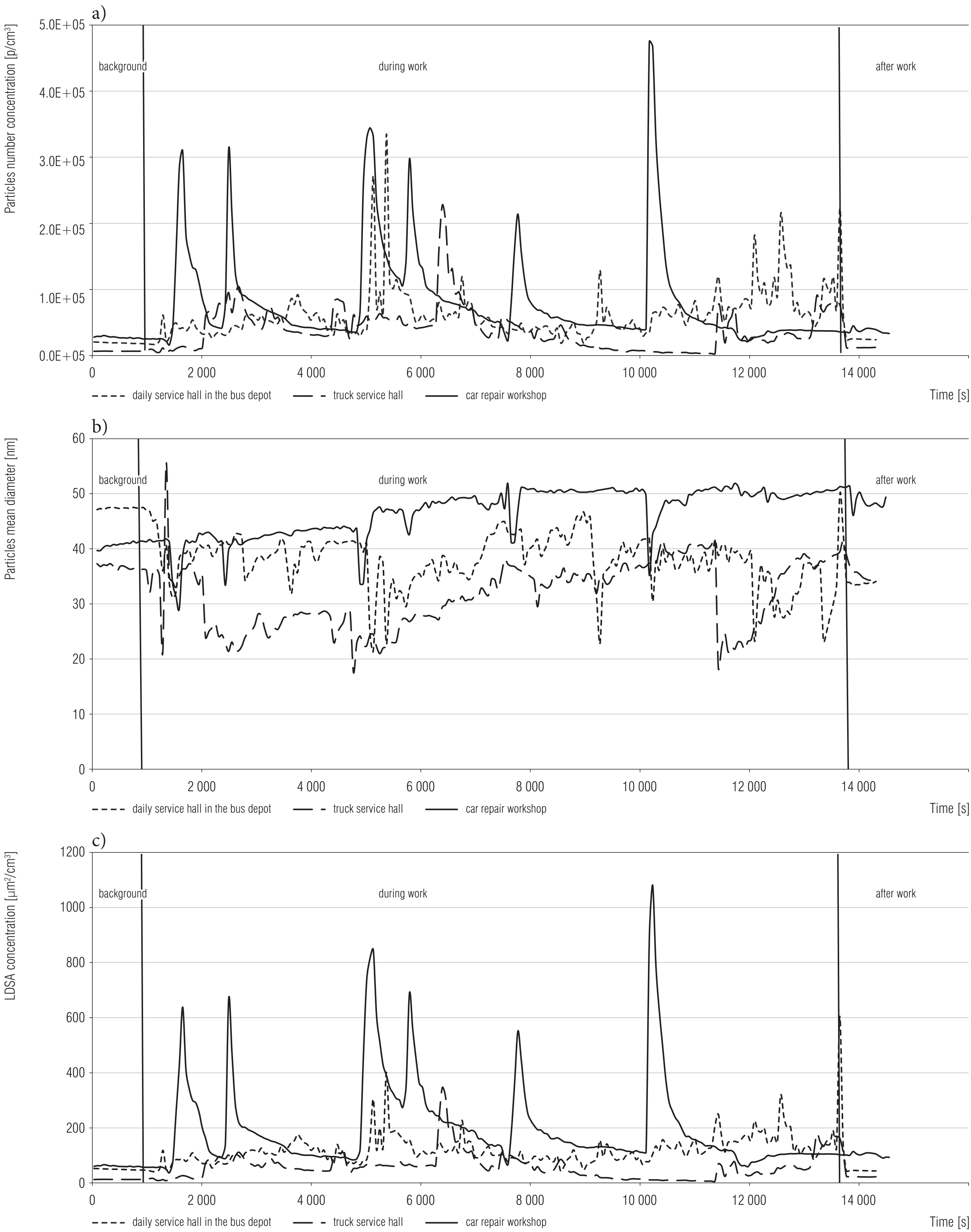

Figure 1. Changes in the particles lung deposited surface area (LDSA) concentration during measurements with DISCmini in: a) the particles number concentration level, b) the particles mean diameter value, c) the particles LDSA concentration at the workplaces under study

Table 2. Particles number concentration with their size distribution during work carried out at the workplaces under study (daily service hall in the bus depot, truck service hall and car repair workshop)

Measurement place and stage*	Particles number concentration [p/cm³] (M)											
	total	13 nm	18 nm	25 nm	35 nm	45 nm	60 nm	85 nm	115 nm	145 nm	180 nm	265 nm
Daily service hall in the bus depot												
background	13 994	688	903	1 188	1 376	1 863	2 947	2 409	1 453	400	243	123
during work	94 568	5 725	6 938	8 632	9 728	12 938	19 905	15 842	8 736	1 908	2 913	510
after work	26 456	1 299	1 700	2 228	2 616	3 580	5 663	4 555	2 699	658	797	225
Truck service hall												
background	5150	292	381	497	570	737	1 101	816	414	84	50	74
during work	16 362	1 289	1 516	1 832	1 995	2 423	3 255	2 123	899	290	282	137
after work	14 916	959	1 234	1 588	1 762	2 259	3 175	2 091	911	327	291	121
Car repair workshop												
background	76 800	3 062	4 068	5 404	6 345	9 097	15 769	14 488	10 998	4 965	484	565
during work	217 339	8 371	10 894	14 258	16 966	24 041	42 710	41 703	34 320	19 311	1 488	983
after work	155 125	5 169	6 878	9 152	11 075	16 313	29 563	29 819	26 550	16 869	785	910

* Averaging time was respectively: 16 min for backgrounds, 3.5 h during work and 16 min after works.

this size, the concentrations ranged from 3.2×10^3 p/cm³ in the truck service hall to 4.2×10^4 p/cm³ in the car repair workshop. In both cases, it was a 3-fold increase, compared to the background value. Instead in DSH of the bus depot, an approx. 7-fold increase was noted in the concentration of particles, and during work it was 2×10^4 p/cm³.

Figure 2 illustrates the concentration particles, along with their size distributions, in individual workplaces.

Determination of the size-segregated proxy mass concentration using the DustTrak monitor

The measured mean values of particles proxy mass concentrations including their fractions: PM_1, $PM_{2.5}$, respirable, PM_{10} and total (particles diameter <15 000 nm) at respective stands are presented in Table 3. The mean concentration of the PM_1 fraction (particles diameter <1000 nm) during work connected with vehicle servicing was the highest in the car repair workshop, where it reached 870 μg/m³. Figure 3 illustartes the changes observed in PM_1 mass concentration during measurements at the workplaces under study. Compared to the concentration measured before the process, that value increased by 60%. At the other 2 workplaces, the concentrations during work were very similar and reached 250 μg/m³ in the bus depot while buses were riding through DSH lines, and 240 μg/m³ in the truck service hall. Despite the evidently lower concentrations at those workplaces, compared to the car repair workshop, a similar percentage increase was observed in comparison with background results (70% and 60%, respectively). At all studied workplaces, the particles mass concentrations decreased after work, approximating the background value measured before work.

DISCUSSION

Exposure to ultrafine particles from transport and road traffic is usually associated with pollution resulting from exhausts, mainly from self-ignition engines and, to a lower extent, from petrol engines. Numerous studies have shown that particles coming from other sources, such as road dust, recurrent airborne suspension of road surface materials, and frictional wear of vehicles elements (tyres, brakes, clutches etc.), also contribute, to the same extent as exhaust gases, to contamination connected with traffic [2,15–18,21]. At present, the measurements of occupational hazards connected with vehicles servicing involve the determination of respirable fractions of diesel engine exhaust particles. The implementation of such research,

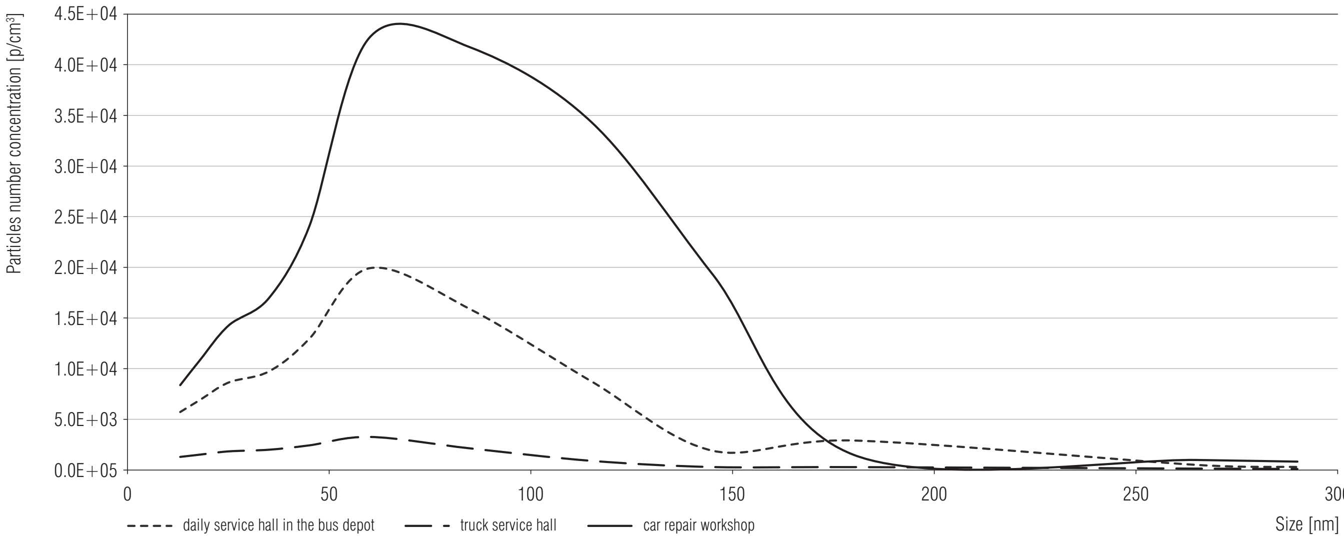

Figure 2. Particles number concentration with size distribution at the workplaces under study (GRIMM 1.109)

Table 3. Size-segregated mass concentration of particles – proxy values during work performed at the workplaces under study (daily service hall in the bus depot, truck service hall and car repair workshop)

Measurement place and stage*	Size-segregated proxy mass concentration of particles [μg/m³]									
	PM_1		$PM_{2.5}$		respirable		PM_{10}		particles <15 000 nm	
	M±SD	min.–max	M±SD	min.–max	M±SD	min.–max	M±SD	min.–max	M±SD	min.–max
Daily service hall in the bus depot										
background	180±0	180–190	180±0	180–190	180±0	180–190	190±0	180–190	190±0	180–190
during work	250±40	160–370	250±40	160–380	250±40	170–380	260±40	170–390	260±40	170–390
after work	210±80	170–350	210±80	170–350	210±80	170–35	220±80	170–360	220±80	170–360
Truck service hall										
background	150±0	140–160	150±0	140–160	150±0	140–160	150±0	150–160	150±0	150–160
during work	240±70	160–430	240±70	160–430	250±70	160–440	260±80	160–490	260±80	160–490
after work	180±30	16–220	19±30	160–220	190±30	160–220	190±30	160–240	190±30	160–240
Car repair workshop										
background	490±10	460–500	490±10	460–500	490±10	460–500	490±20	470–520	490±20	470–520
during work	870±380	420–2300	880±380	420–2300	880±380	420–2300	880±380	430–2310	880±380	430–2310
after work	640±20	630–670	640±20	630–680	640±20	630–680	650±20	630–700	650±20	630–700

* Averaging time was respectively: 16 min for backgrounds, 3.5 h during work and 16 min after works.

and the measurements as well as methods applied in the evaluation of occupational exposure to such pollutants, are described in respective standards and legal regulations [22]. A standard method of determination of the concentration of exhaust gases from diesel engines is the gravimetric method, whereas the value of the maximum allowable concentration of the respirable fraction of particles from diesel engines amounts to 0.5 mg/m³ [4,23].

The presently applied methods do not involve the determination of the concentration of ultrafine particles in diesel exhaust fumes. Unfortunately, reliable evaluation of exposure to nanoparticles emitted from vehicles is not possible only according to weight measurements of the particles concentration at the vehicle servicing workplaces. In the case of nanometric particles, more important information may be provided by the results of measurements of the number and surface area

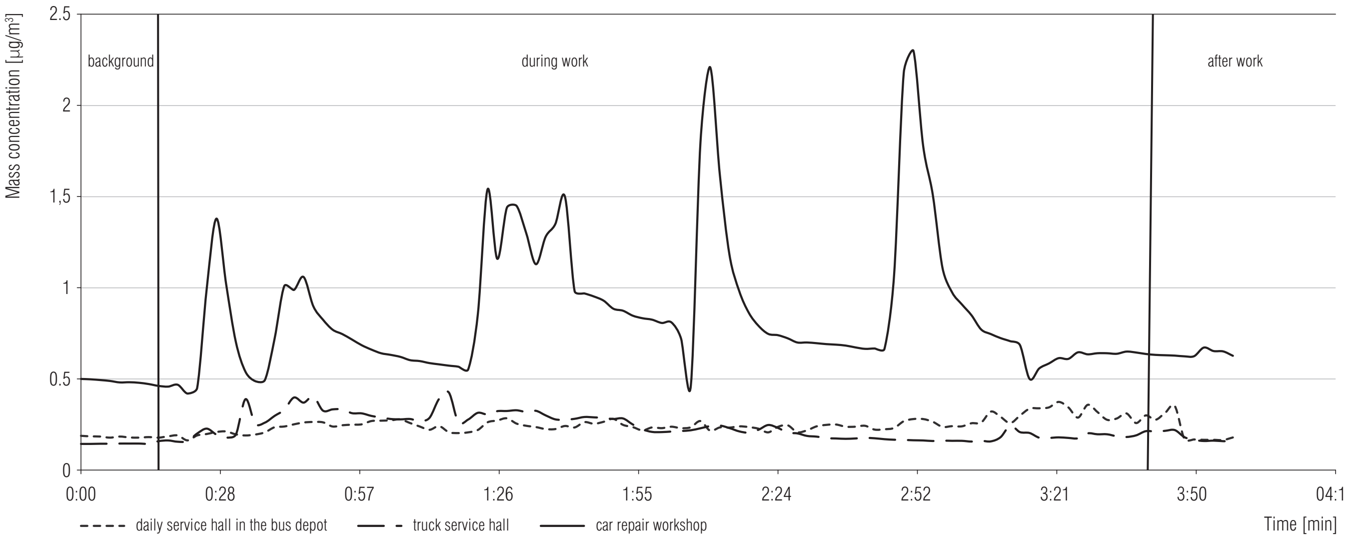

Figure 3. Changes in PM_1 fraction mass concentration during measurements (DustTrak) at the workplaces under study

concentration of aerosol particles and particle size distributions in aerosol because nanoparticles are characterized by a very low weight and a simultaneously high number value of particles.

In this paper, in order to obtain detailed data about exposure to accidentally occurring nanoparticles from transport processes, the parameters of airborne particles were measured, including the number and surface area concentration of particles, the particles mean diameter, and the number concentration including size distributions. Furthermore, the particles weight concentration was determined using the light scattering method. Three different workstations, connected with diesel engine vehicles servicing, were selected for the research: DSH in a bus depot, a truck service hall, and a car repair workshop.

The analysis of DISCmini measurements results (particles ranging 10–700 nm) indicated that the highest number concentrations of the particles mean values occurred in the car repair workshop. The mean value of the particles number concentration at this workplace reached 8×10^4 p/cm^3. However, the highest (6-fold) increase, compared to the background particles concentration, was observed in the truck service hall where the concentration during work reached 4×10^4 p/cm^3. In other studies on particles emitted from diesel engines, a similar correlation was observed where the number concentration was investigated in laboratory (experimental) conditions [24,25]. As revealed by the values obtained in one of these studies [24], focused on particles ranging 10–500 nm, the number concentration was 3.9×10^5 p/cm^3. In real conditions of particles emissions from vehicles: in car repair workshops [26], during the construction of road tunnels [27], at a bus depot [6], and in the road traffic or near busy streets [3], the concentration values were at quite different levels because of the diversity of places and different equipment used by the researchers. Nonetheless, the results of all measurements showed evident differences in the number of airborne particles emitted from vehicle engines.

Highly correlated with the number concentration are values of another parameter characterizing exposure to ultrafine particles emitted from vehicles, i.e., the particles surface area concentration. Nanoparticles emitted from vehicles have very small diameters, which was also indicated by the measurements carried out by DISCmini according to the requirements of this study (the mean diameter value reached up to approx. 50 nm). With such a small particle size and a high number concentration value, the surface area concentration is a parameter which tends to significantly increase. The LDSA value is calculated as the surface area by lung deposition probability. However, although no physical metric can measure particle toxicity, this parameter, from among other physical metrics, is the most important indicator of exposure to nanoparticles. Only those particles that can reach the smallest parts of the respiratory system can induce health effects, which is why they should be measured. The LDSA concentration showed the highest value – as in the case of the number concentration – at the car repair workshop (reaching 198 mm^2/cm^3), whereas the highest increase was observed in the truck service hall where the mean value of this parameter increased by 4.5-fold (the concentration of 57 μm²/cm³).

At present, studies on nanoparticles exposure in real work conditions very rarely include the determination of the surface area concentration. The LDSA concentration value is a parameter occasionally described in literature, compared to the mass or even number concentration. In an earlier study conducted by the same authors, the surface area concentration of the alveolar and tracheo-bronchial fraction of particles emitted by buses in the bus depot was determined. In this research, the concentration of the alveolar fraction particles was at the level of 356 μm²/cm³ and that of the tracheo-bronchial fraction at the level of 96 μm²/cm³, while the buses were riding through DSH in the bus depot. Those values were higher than in the present study but the measurement was done using the apparatus measuring particles in a wider measuring scope (i.e., sizes 10–1000 nm) [6].

In the research carried out under laboratory conditions [24], which monitored a number of parameters characterizing the occurrence of particles within diesel engine combustion fumes, the surface area concentration of those particles reached 2.1×10^{-4} cm²/cm³ (or 21 000 mm²/cm³ when converted, for comparative purposes, to the units applied in this research). In addition, the surface area concentration of the aggregates formed was estimated and its value was equal to 3.5×10^{-4} cm²/cm³ (which corresponds to 35 000 mm²/cm³).

In the urban environment [28], different levels of the particles surface area concentration were found, depending on the place of measurement. The highest surface area concentration of particles, at the level of 94 μm²/cm³, was noted in the city centre. In other measuring points which were also situated near condensed road traffic, the concentrations ranged 53–67 μm²/cm³. As expected, the average surface area concentration was the lowest in the park, reaching 12 μm²/cm³.

The analysis of the number concentrations with the size distributions of particles (determined by GRIMM 1.109 with NanoSizer 1.321) indicates that the sizes of particles released during vehicles work exhibited a wide diameter range but their highest number was up to approx. 145 nm, whereas the highest number concentration was noted for particles with an average size of 60 nm.

Research conducted by other authors but in similar conditions [26] demonstrated that most of the particles were in the dimension range of ≤190 nm, with the highest concentrations for particles with a diameter of 50–60 nm. Despite the differences in the applied measuring devices, these results are consistent with the results obtained by the authors of this publication.

In this research, the size-segregated proxy mass concentration of particles emitted by vehicles was also determined. The concentrations of PM_1 fraction particles, i.e., the smallest particles that may be measured in the DustTrak monitor system, were the highest during work conducted in the car repair workshop. The value of such concentration reached 870 μg/m³ and was almost twice as high as the particles concentration determined before the employees started their work. In the other workplaces, these concentrations were on very similar levels: 250 μg/m³ in DSH and 240 μg/m³ in the truck service hall. An increase in the concentration relative to the background level reached even 60%. Similar studies were also conducted for experimental conditions: in the vehicle cabin [29], a workshop or garage [26], and in tests of traffic particles [2,3].

The results of measurements obtained during this study point to a considerable differentiation within the analyzed parameters, depending on the workplace where the measurements were conducted. This results from the specificity of the workplaces where the measurements were taken: bus depots and truck service halls are characterized by large areas and cubic capacity, whereas the car repair workshop area is much smaller, potentially contributing to the highest accumulation of particles. Furthermore, the dynamics of changes in particle concentrations may be observed in each workplace during a single measurement. This is caused by the specificity of works and engines working in particular places. In DSH of the bus depot, buses were riding continuously through 2 inspection lines, while in the truck service hall and the car repair workshop, engines were started during coming in and out and where necessary due to the repair/inspection specificity. The values of the determined parameters in all workplaces were also under the influence of such factors as air movement caused by the opening of gates, or vehicles or even people's movement, as well as the diversity of vehicles and vehicles work on idle running.

The assumed directives confine transport-induced pollution by the determination standards of exhaust emissions. The currently mandatory standard of emissions from motor cars is the so-called Euro 6 [30] standard which determines the limit values for air pollution, including solid particles contained in engine exhausts. To reduce the solid particles contained in exhausts from self-ignition engines, the 32% urea solution called AdBlue is used. In addition, the currently produced diesel engines offer the combustion efficacy at a high 98% level. Despite these measures aimed at reducing emissions of diesel engine particles, exhausts from such engines include a number of products which are dangerous to human health. Therefore, activities minimizing the risk of exposure should be undertaken, both at the administrative level and at the level of technological solutions. The administrative methods used to reduce exposure to particles from traffic include reducing vehicle speed and decreasing traffic in urban areas, reducing or eliminating idle running, or determining zones inaccessible to vehicles with diesel engines. The technological methods comprise a regular maintenance of engines to reduce emissions, the use of special fuels and fuel additives, the installation of effective ventilation systems, and the capturing and removal of particles directly at the source.

CONCLUSIONS

An increase was observed in the number, mass and surface area concentrations of particles emitted from vehicles during works connected with their servicing. The increase was different, depending on the workplace. The analysis of the number size distributions indicates that the sizes of particles released from vehicles were within a wide dimensional extent, but their highest number concentration was found for particles with a mean diameter of 60 nm. The particles emitted by vehicle in the combustion process are characterized by a very small diameter which, coupled with a large amount and surface area, has a relatively low mass concentration. A complex evaluation of exposure to particles emitted from engine exhausts requires the inclusion of more assessment parameters than mass concentration only.

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