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EVALUATION OF THE CONTENT OF INDUSTRIAL ULTRAFINE AEROSOL AT THE WORKPLACE OF A SMELTER AND ALLOYS IN MACHINE-BUILDING PRODUCTION

Sharavara L. P.

Zaporizhzhia State Medical University

Introduction. The working conditions of workers engaged in the process of melting metals are assessed as harmful, and, according to some factors, as dangerous. Dust studies confirm the presence of particles of coarse fraction in the air of the working area.

The aim of the study was to evaluate the content of industrial ultrafine aerosol in the workplace of metal and alloy melters in the machine-building production.

Materials and methods of research. The NanoScan SMPS Scanning Nanoparticle Classifier, Model 3910, was used to study the physical properties of the industrial ultrafine aerosol. The number, surface area, volume, and mass concentration of particles ranging in size from 10 to 416 nm at melter workplaces with open and vacuum melting were determined. Employees of the administrative corps were taken as a control group.

Results. It was found that at the workplace of melters engaged in the open melting method, the total concentration of particles in the nanoscale range is 8.2 times higher than in the melting of metal by vacuum (< 0.00001), by surface area it is 7.5 times higher (< 0.005), by mass concentration – 7.2 times (< 0.04). There was also a significant difference in the open melting of metals compared with the control of the concentration of nanoparticles – of 11.7 times (< 0.00001), the surface area – of 11.3 times (< 0,003), the mass concentration of 10.7 times (< 0.03).

Conclusions. The presence of nanoscale particles at the workplaces of workers engaged in the smelting of metals has been confirmed. Their concentration depends on the method of melting and technological operations performed by the melter during melting. Therefore, the determination of the content of ultrafine industrial aerosol in the workplace is an important step in identifying hazards and assessing occupational risks to the health of workers in order to apply effective methods of prevention.

Key words: ultrafine industrial aerosol, melting conditions, nanoparticles, air of the working area, occupational risk

Introduction

The harmful and hazardous factors of the working environment of melting workers include increased dust and gas content in the air of the working area; unfavorable working microclimate and increased infrared radiation; influence of low and medium frequency noise and industrial vibration, because of which working conditions of melting workers are assessed as harmful, and for some factors as hazardous [1–4]. Combined effect of factors of working environment contributes to development of professional and work-related morbidity (silicosis, dust bronchitis, sensorineural hearing loss), leads to increased morbidity with temporary disability, including acute respiratory diseases and influenza, diseases of upper respiratory tract, bronchitis and pneumonia, skin diseases and diseases of musculoskeletal system [5, 6].

Metal melting processes are accompanied by the formation of fine dust and vapor of molten metals, condensing in an aerosol to form suspended particles of ultrafine size (≤ 100 nm). Investigations of the fractional composition and dust concentration in the air of the working area in workplaces of melting workers confirm the presence of suspended particles with a predominant content of particles of coarse

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fraction PM_{10}, and fine fraction $PM_{2,5}$, which contribute to the development of upper and lower respiratory tract diseases [1, 7–10]. It was studied that due to presence of harmful factors of industrial environment at workplace, melting workers in 1–5 years of work experience first manifestations of nasal breathing disorders and catarrhal bronchial lesions, in 10–15 years of work – catarrhal nasopharyngitis and obstructive bronchial diseases [3, 11].

The study of ultradispersed industrial aerosol content in the workplace air of the workers of the above-mentioned occupation is still relevant for assessment of occupational risk and development of effective preventive measures among high-risk group workers.

The aim of the study is to assess the content of industrial ultradispersed aerosol in the workplace of metal and alloy smelter in mechanical engineering production.

Materials and methods of research

The investigation of the ultrafine particles content in the air of working area in the workplace of a smelter of the machine-building plant was carried out with the help of NanoScan SMPS Scanning Nanoparticles Classifier, Model 3910 (USA), which enables to measure suspended particles in the size range from 10 to 416 nm. The following indexes of ultrafine aerosol were estimated: number of particles, surface area, volume and mass concentration of nanoparticles during open melting of metals during operation of EI-96GL and vacuum induction melting during operation of vacuum induction furnace. All in all, 182 researches of the number (number of particles/cm^3), surface area (nm^2/cm^3), volume (nm^3/cm^3) and mass concentration ($\mu g/cm^3$) of ultrafine particles in the working places of melting of metals and alloys while various types of melting were conducted and in employees of the control group (the administration).

Research results and their discussion

The melting of metals at the investigated machine-building enterprise is carried out using the open and vacuum melting methods. For this purpose two kinds of furnaces are used at the enterprise: vacuum induction furnaces (VIF) and induction crucible melting electric furnaces (ICMEF). VIFs allow to obtain high quality refractory metal alloys which significantly decrease the gas content and number of non-metallic inclusions, provide high homogeneity and density of ingots through directional crystallization of liquid metal, improve the physical and mechanical properties of metal. This type of melting is actively used in aircraft, nuclear, missile and other industries. ICMEF is used to melt metal and produce iron and metal castings of the highest quality, as well as for casting alloyed and stainless steel alloys and ferroalloys, and is therefore used in foundries of metallurgical plants, precision casting shops and repair shops of machine-building plants.

The difference between these methods is that with VIF the melting process uses a sealed vacuum chamber and vacuum pumps, and the temperature in the inductor of the vacuum chamber can reach up to 2200 °C. The ICMEF does not use a vacuum chamber and melting takes place in an open mould – in an air atmosphere and can reach temperatures of up to 1800 °C.

The tasks and duties of the melter when melting metal and alloys at the ICMEF are to prepare a vacuum induction electric furnace for melting, to install electrodes and graphite crucibles in the furnace, and to install a mould in the pouring chamber. The melter switches the vacuum pumps on and off, determines vacuum in the furnace, performs melting of alloys according to the established technological mode, pours the forms and cools castings or ingots in a neutral environment, dismantles the furnace, cleans it as well as the pouring chamber and crystallizers.

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Table 1

Analysis of ultra-dispersed industrial aerosol in the smelter's workplace during open-pit melting (ICMEF)

	Number, number of particles/cm^3	Surface weighted, nm^2/cm^3	Volume weighted, nm^3/cm^3	Mass weighted, µg/m^3
Median (nm)	43.1008	197.5537	260.2217	260.2217
Mean (nm)	69.7799	204.6186	253.6221	253.6221
Geo. Mean (nm)	46.3855	175.0580	232.4201	232.4201
Mode (nm)	36.5174	205.3525	365.1741	365.1741
Geo. St. Dev.	2.4531	1.8538	1.5771	1.5771
Total Conc.	$6.97 \cdot 10^4$	$2.11 \cdot 10^9$	$7.18 \cdot 10^{10}$	86.2240

During the melting of metal and alloys in ICMEF melter prepares various solders for soldering, tinning, prepares furnaces for metal melting, weighs the materials, conducts the melting process of materials in compliance with the specified chemical composition, pours solder into bars, pours furnaces with charge, participates in the melting process and in reparation of furnaces, takes samples of liquid metal and determines its readiness for release by express-analysis.

Study of physical properties of ultrafine particles (UF) of industrial aerosol in the air of the working area of the melting furnace during melting of metals at ICMEF is presented in Table 1. According to the results of investigations, it was found that at the melting workplace of the melter during work using ICMEF, the total concentration of UF was 69 surface area – $2.11 \cdot 10^9$ nm^2/cm^3, total surface volume – $7.18 \cdot 10^{10}$ nm^3/cm^3, total mass concentration – 86.22 µg/m^3.

Nanoparticles with diameters of 15.4; 27.4 and 36.5 nm were found to have the highest quantitative concentration, surface area and volume of particles with diameters ranging from 154 to 365.2 nm (Table 2).

Table 2

Specific weight of UF of different diameters according to physical properties in open melting (ICMEF), %

Diameter of nanoparticles, nm	Number of particles, %	Surface area, %	Surface volume, %	Mass concentration, %
11.5	7.02	0.09	0.006	0.006
15.4	***11.004***	0.27	0.02	0.02
20.5	9.13	0.39	0.04	0.04
27.4	***11.23***	0.87	0.12	0.12
36.5	***11.28***	1.56	0.28	0.28
48.7	9.79	2.41	0.58	0.58
64.9	8.69	3.81	1.21	1.21
86.6	8.75	6.82	2.89	2.89
115.5	8.31	11.52	6.50	6.50
154.0	6.67	***16.43***	***12.36***	***12.36***
205.4	4.43	***19.43***	***19.49***	***19.49***
273.8	2.42	***18.83***	***25.19***	***25.19***
365.2	1.27	***17.54***	***31.31***	***31.31***

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The 18 nm UF concentration during melting of metals at ICMEF ranged from 3061.2 to 6390 (Mean 4670.5; Std.Dev. 740.3) and was observed through the melting time in workplace air (Figure 1).

The dynamics of the concentration of UF particles with the size 35 nm during melting by this method was in the range from 5421.8 to $2.0 \cdot 10^4$ (Mean 9660.7; Std.Dev. 2780.9), the maximum number of particles was fixed directly at casting of metal in the forms and at loading of charge and is visually represented in Figure 2.

The similar tendency was observed with the concentration of particles with the size 52 nm, namely the increase in concentration of particles during casting of metal, loading of charge and electrodes into the furnace (Max $4.15 \cdot 10^3$) and its gradual decrease (Min 3239.8) (Mean 9200.6; Std.Dev. 5607.4).

At the smelter's workplace in vacuum smelting method, the total concentration of UF was 8472.6 particles/cm^3, the total surface area was $2.77 \cdot 10^8$ nm^2/cm^3, the total surface volume was $9.98 \cdot 10^9$ nm^3/cm^3 and the total mass concentration was 11.98 μg/m^3 (Table 3).

In the vacuum method of metal melting, suspended particles with diameters between 27 and 86 nm had the highest specific gravity by quantity,

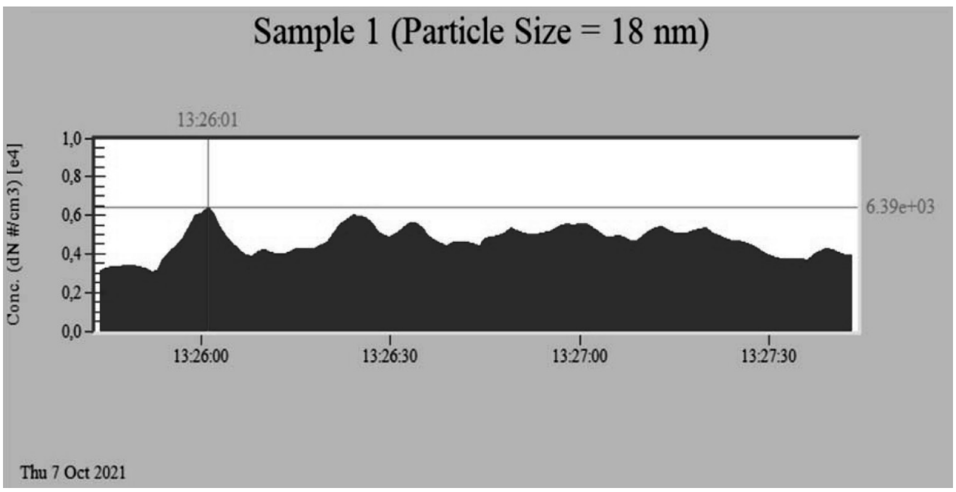

Figure 1. Dynamics of concentration of 18 nm diameter UF particles during open cast iron melting

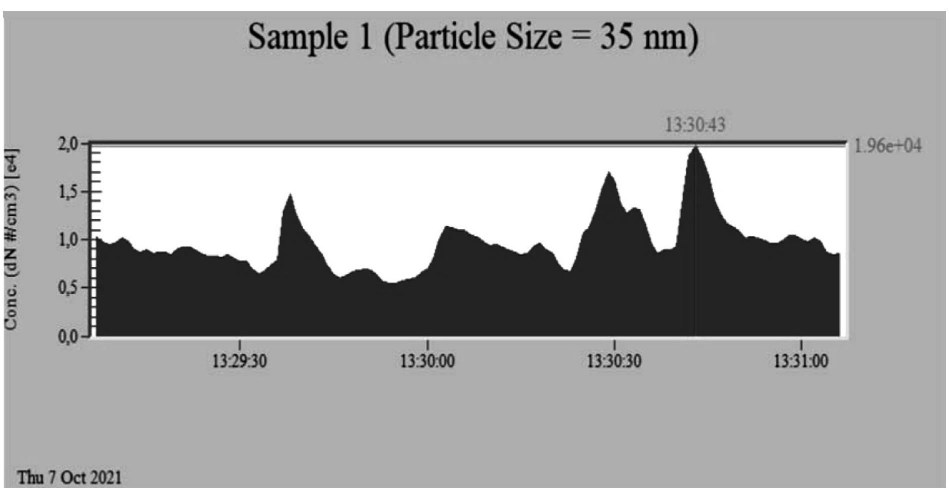

Figure 2. Dynamics of concentration of 35 nm diameter UF particles during open cast iron melting

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Table 3

Analysis of the content of ultrafine industrial aerosol at the melter workplace during vacuum melting (VIF)

	Number, number of particles/cm^3	Surface weighted, nm^2/cm^3	Volume weighted, nm^3/cm^3	Mass weighted, µg/m^3
Median (nm)	53.6603	206.1240	309.7261	309.7261
Mean (nm)	75.0513	215.9894	275.9164	275.9164
Geo. Mean (nm)	54.2240	179.6392	250.8860	250.8860
Mode (nm)	48.6968	365.1741	365.1741	365.1741
Geo. St. Dev.	2.2156	1.9451	1.6275	1.6275
Total Conc.	8472.6249	$2.77 \cdot 10^8$	$9.98 \cdot 10^9$	11.9804

while the highest mass concentration, area and surface volume were those above 154 nm (Table 4).

Examination of the 18 nm diameter nanoparticles during the melting process showed that their quantitative concentration was relatively stable throughout the melting process and was Mean 494.7; Std.Dev. 20.8 (Figure 3).

The 35 nm nanoparticles also had stable amounts during melting, but when the furnace was opened their quantitative concentration increased by almost 8.8 times, which is clearly shown in Figure 4.

The relatively stable concentration at vacuum melting among nanoparticles with size 52 nm

Table 4

Specific gravity of particles of different diameters in the industrial aerosol by physical properties in the vacuum melting method, %

Diameter of nanoparticles, nm	Number of particles, %	Surface area, %	Surface volume, %	Mass concentration, %
11.5	3.19	0.041	0.002	0.002
15.4	5.76	0.13	0.009	0.009
20.5	6.31	0.26	0.02	0.02
27.4	***10.66***	0.77	0.1	0.09
36.5	***13.30***	1.7	0.29	0.29
48.7	***13.85***	3.15	0.71	0.71
64.9	***13.04***	5.28	1.59	1.59
86.6	***11.72***	8.43	3.38	3.38
115.5	9.05	11.58	6.19	6.19
154.0	5.71	***13.00***	9.27	9.27
205.4	3.17	***12.82***	***12.19***	***12.19***
273.8	2.03	***14.61***	***18.52***	***18.52***
365.2	2.21	***28.23***	***47.73***	***47.73***

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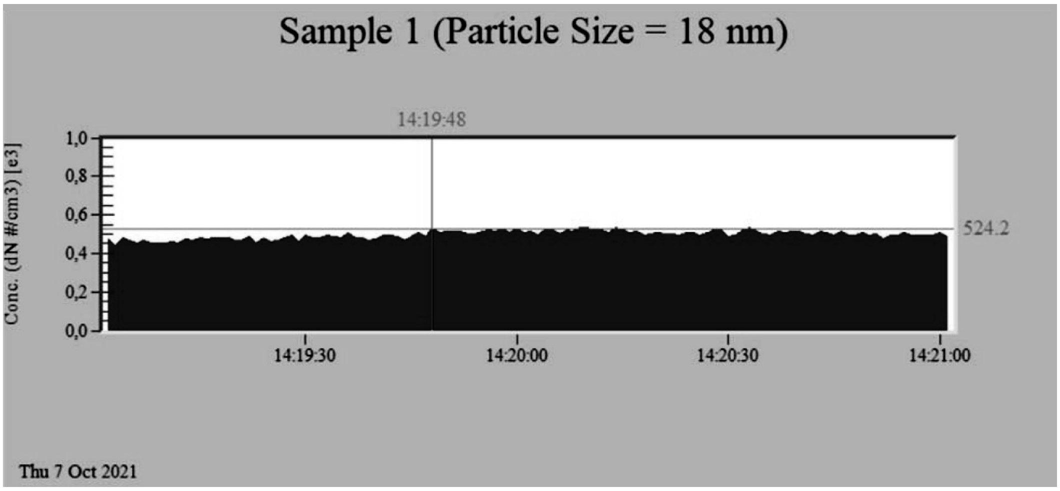

Figure 3. Dynamics of concentration of 18 nm diameter UF particles during vacuum melting

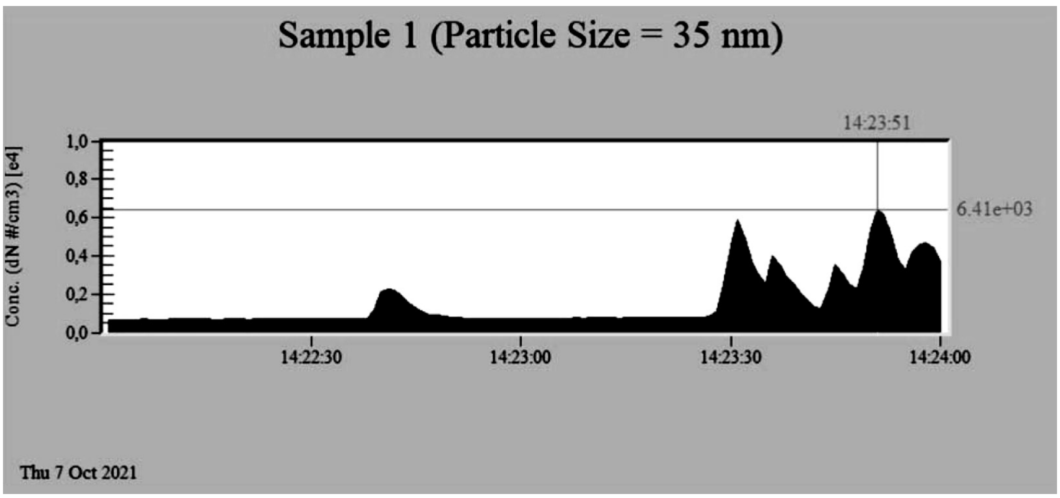

Figure 4. Dynamics of concentration of 35 nm diameter UF particles during vacuum melting

was observed, their concentration was in the range from 452.6 to 825.4 (Mean 547.6; Std. Dev. 59.9).

When examining the concentration of UF in the working area air of the control group workers (the administration), it was found that the total concentration of UF was 5974.4 particles/cm^3, total surface area was 1.88 · 10^8 nm^2/cm^3, total surface volume was 6.68 · 10^9 nm^3/cm^3 and total mass concentration was 8.01 μg/m^3. Suspended particles with diameters from 27 to 86 nm had the highest specific gravity (11.2–13.3 %), while particles above 205 nm had the highest mass concentration (12.96–27.3 %), area (12.4–46.5 %) and surface volume (12.4–46.5 %).

It was found that in open metal melting the total concentration of particles in the nanoscale range was 8.2 times higher compared to metal melting by vacuum method (< 0.00001), by surface area – 7.5 times higher (< 0.005), by mass concentration – 7.2 times higher (< 0.04).

There was also a probable difference of 11.7 times in nanoparticles concentration (< 0.00001), 11.3 times in surface area (< 0.003) and 10.7 times in mass concentration (< 0.03) in open metal melting and in workplace of control group workers.

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Conclusions

1. It has been proved that metal melting process is a source of formation of particles in the nanoscale range entering the atmosphere of the working area and affecting workers throughout the working time. At all kinds of melting of metals at the workplace of a melter nanoparticles sized from 15 to 86 nm prevail.
2. During open melting of metals at ICMEF, the concentration of particles in the nanoscale range is 8.8 times higher as compared with melting of metal by vacuum method at VIF. The probable difference between the indices obtained by open melting and vacuum melting and the control group in terms of total particle concentration, surface area and mass concentration was found.
3. In open smelting of metals smelters are exposed to high concentration of nanoparticles during all the working hours, unlike the smelters using vacuum smelting. In the latter melting method, the concentration of nanoparticles increases significantly (by 8.8 times) only when the furnace is opened, which affects workers for 30 % of the working time.
4. Thus, determination of physical properties of ultradispersed industrial aerosol at a working place of workers is an important step in hazard identification and occupational health risk assessment for the purpose of effective prophylactic methods application.

Prospects for further research. In the future, it is planned to study the chemical composition of ultrafine industrial aerosol in the air of the working area of metal and alloy smelter and assess the risk of negative impact on the health of workers.

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ORCID ID of author:
Sharavara L. P. (ORCID ID 0000-0001-9102-3686) – conducting research, results processing, preparation of material for print.

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Contact person: Sharavara Larysa, PhD, Zaporizzhia State Medical University, pr. Maiakovskogo 26, Zaporizzhia, 69035. Tel.: + 38 0 99 271 7757. E-mail: saravaralarisa@gmail.com