Modeling the Process of the Distribution of Suspended Particles of Nano- and Microparticles of Industrial Aerosols in Electroplating Workshop

K Yu Kirichenko¹, I A Vakhniuk¹, A S Kholodov¹, K S Golokhvast¹

¹Far Eastern Federal University, 8 Sukhanova Street, Vladivostok 690950, Russian Federation

E-mail address: Kirichenko2012@gmail.com

Abstract. The paper presents the results of a study of quantitative composition of airborne particles in electroplating workshop working with aluminum and non-ferrous metals using the most common electrochemical processes in industry. Based on the results of the quantitative content of particles in samples located at different spatial points, a 3D model of industrial aerosol cloud was created, demonstrating the propagation of nano- and microparticles inside the workshop.

1. Introduction
Enterprises using electrochemical processes in production are known to be the source of environmental pollution [1]. Despite significant technological progress, electroplating in modern industrial production remains the uncontested and most cost-effective coating method. When electroplated coatings are applied to metal parts, highly toxic compounds are formed which, even with short-term exposure, cause severe damage [2]. This necessitates dealing with the issue of reducing the negative impact of emissions and discharges from electrochemical processes on the environment. A significant amount of research is devoted to the development of effective wastewater treatment systems in electroplating production [3, 4]. Less attention is paid to capture and removal of particulates formed during electrochemical processes. The main technical solution here is the use of local exhaust for hazardous substances [5], installed in immediate vicinity of the electrolyte surface and often integrated into the design of electroplating baths.

This paper describes the nature of propagation of PM₁₀ particles in the working zone of electroplating workshop. A visual simulation of the distribution of industrial aerosol cloud based on the quantitative content of airborne nanoparticles and microparticles at different distances from electroplating baths was performed.

2. Experimental
Samples were taken as follows: the quantity of airborne particles was measured during the operation of the workshop above the electrolyte surface and at a distance of 1 and 3 m from the source (Fig. 1).

AeroTrak Handheld Particle Counter 9306 (TSI Incorporated, USA) was used as a sampler. This model meets all the requirements set out in ISO 21501-4.
The sampling time at each point was 1 minute. The volume of air blown was 2.83 liters per minute. The sampling height was 1.5 m, corresponding to the height of average human breathing level (Fig. 1). Samples were taken near operating baths of the aluminum preparation line, non-ferrous metals preparation line, and protective coatings line. The basic 15 technological processes were considered for sampling, and 3 samples were taken at each process. In total, 45 measurements were obtained for electroplating baths with various purposes during a series of experiments.

![Sampling of industrial aerosol particles in the electroplating workshop.](image1)

**Figure 1.** Sampling of industrial aerosol particles in the electroplating workshop.

![The scheme of the experiment, with dimensioning of sampling points.](image2)

**Figure 2.** The scheme of the experiment, with dimensioning of sampling points.
For the first time, the quantitative composition of airborne particles was measured for the most common electrochemical processes in electroplating production for processing and applying of protective coatings on metal parts (Table 1).

**Table 1.** Electrochemical processes considered in the experiment.

| No. | Sample point                      |
|-----|-----------------------------------|
| 1   | Aluminum cleaning                 |
| 2   | Aluminum etching                  |
| 3   | Sulfuric acid anodizing           |
| 4   | Aluminum degreasing               |
| 5   | Chemical degreasing               |
| 6   | Cathodic degreasing 3             |
| 7   | Desmutting                        |
| 8   | Nonferrous metals etching         |
| 9   | Chromium plating                  |
| 10  | Nickel plating                    |
| 11  | Silvering                         |
| 12  | Zinc plating                      |
| 13  | Tin-bismuth                       |
| 14  | Chromating                        |
| 15  | Chemical nickel plating           |

The 3D model of the cloud was built using the particle size data from samples taken according to the author’s method described above and using specialized AutoCAD software (version J.51.0.0, Autodesk Education Master Suite 2015, Product serial number: 545-89603482).

The following algorithm was used when building 3D models of industrial aerosol cloud in electroplating workshop:

1) A straight line is laid out from the center of each bath, equal to the percentage of 1-300 nm particles in the sample. For bath installed at the breathing level, the straight line is laid along the Z axis.

2) The endpoints of straight lines laid from the sampling points (3 of these were built – with R=0÷3 m from the center of the coordinate axis – electroplating bath with electrolyte) are connected by a curve that connects the upper marks of the laid-off straight lines (point 1).

3) Next, from the curve, a rotation figure was constructed with respect to the Z axis in the center of coordinate axes – electroplating bath – the source of airborne particles.

**3. Results and discussion**

The results obtained indicate the absolute predominance of minute particles (Table 2). The smallest particles of heavy metals in industrial aerosols are able to penetrate deep into the human respiratory system and spread throughout the body [8], causing chronic diseases and a general decrease in staff performance. The number of particles with the diameter of less than 0.3 μm is more than 10,000 times the number of PM10 particles. The maximum number of 0.3 μm and 0.5 μm particles was recorded near the bath for chemical degreasing of non-ferrous metal parts. This is a stationary bath with a temperature of 70-90 °C for electrochemical processing of metal parts from non-ferrous metals with ventilation and heating systems from a constant current source.
### Table 2. Quantitative composition of industrial aerosol particles in electroplating workshop.

| No. | Electroplating process   | L | Proc. No. | PM$_{0.3}$ | PM$_{0.5}$ | PM$_1$ | PM$_3$ | PM$_4$ | PM$_{10}$ |
|-----|--------------------------|---|-----------|------------|------------|--------|--------|--------|----------|
| 1   | Al cleaning              | 0 |          | 241147321  | 27334464   | 3728571| 494107 | 204643 | 26429    |
| 2   | Al cleaning              | 1 |          | 227396786  | 22243393   | 2748929| 373721 | 155893 | 17321    |
| 3   | Al cleaning              | 3 |          | 221426429  | 21623393   | 2678929| 365536 | 145536 | 19643    |
| 4   | Al etching               | 0 |          | 216969464  | 22688393   | 2915000| 407143 | 168214 | 21071    |
| 5   | Al etching               | 1 |          | 240084821  | 23589107   | 2850179| 421607 | 164464 | 20536    |
| 6   | Al etching               | 3 |          | 218697857  | 21319107   | 2671071| 393214 | 158929 | 18393    |
| 7   | Sulfur. acid anod.       | 0 |          | 246164286  | 21822143   | 2510357| 387143 | 157679 | 20357    |
| 8   | Sulfur. acid anod.       | 1 |          | 235722679  | 20709821   | 2598214| 412143 | 176964 | 22143    |
| 9   | Sulfur. acid anod.       | 3 |          | 270116071  | 22805179   | 2523929| 380000 | 152857 | 15357    |
| 10  | Al degreasing            | 0 |          | 243330179  | 29942679   | 4779821| 1108393| 412143 | 35536    |
| 11  | Al degreasing            | 1 |          | 203705179  | 21568214   | 2430536| 379107 | 158750 | 21786    |
| 12  | Al degreasing            | 3 |          | 209848571  | 22188214   | 2429643| 374107 | 155714 | 20179    |
| 13  | Chem. degreasing         | 0 |          | 370734464  | 131011964  | 63129286| 32486786| 19671071| 3648929  |
| 14  | Chem. degreasing         | 1 |          | 249430357  | 26145714   | 3519821| 492857 | 191964 | 22500    |
| 15  | Chem. degreasing         | 3 |          | 251813750  | 26753036   | 3613393| 526964 | 216786 | 28393    |
| 16  | Cathod. degres. 3        | 0 |          | 251251786  | 25302857   | 3471964| 498929 | 202321 | 28393    |
| 17  | Cathod. degres. 3        | 1 |          | 222533393  | 21927857   | 2992500| 445000 | 183393 | 21607    |
| 18  | Cathod. degres. 3        | 3 |          | 247669286  | 23407500   | 3202857| 513571 | 211607 | 32679    |
| 19  | Desmutting               | 0 |          | 287559286  | 27565893   | 3394107| 562679 | 233036 | 35536    |
| 20  | Desmutting               | 1 |          | 262072679  | 22862500   | 2841964| 446071 | 183929 | 26071    |
| 21  | Desmutting               | 3 |          | 281093393  | 24144821   | 2878241| 426071 | 177500 | 26071    |
| 22  | Nonferrous metals etching| 0 |          | 273429821  | 27023214   | 3129286| 488393 | 212321 | 27143    |
| 23  | Nonferrous metals etching| 1 |          | 259968036  | 25299107   | 2944643| 438036 | 182143 | 23393    |
| 24  | Nonferrous metals etching| 3 |          | 257132986  | 24441964   | 2907679| 432143 | 184286 | 27857    |
| 25  | Chromium plating         | 0 |          | 228815179  | 24073929   | 3160536| 579821 | 283214 | 56071    |
| 26  | Chromium plating         | 1 |          | 221768036  | 20414286   | 2562500| 402679 | 171071 | 24286    |
| 27  | Chromium plating         | 3 |          | 218698036  | 20713750   | 2634214| 413571 | 169286 | 22679    |
| 28  | Nickel plating           | 0 |          | 166470714  | 17251964   | 2295536| 428036 | 192500 | 28393    |
| 29  | Nickel plating           | 1 |          | 176129643  | 16159107   | 2035179| 335000 | 139464 | 23214    |
| 30  | Nickel plating           | 3 |          | 170483929  | 16325536   | 2106250| 356071 | 156250 | 22857    |
| 31  | Silvering                | 0 |          | 153599286  | 16458929   | 2560536| 449821 | 196250 | 28571    |
| 32  | Silvering                | 1 |          | 163013929  | 18321607   | 3073393| 478750 | 195179 | 26071    |
| 33  | Silvering                | 3 |          | 150490893  | 16171071   | 2598750| 433214 | 175000 | 23571    |
| 34  | Zinc plating             | 0 |          | 212316071  | 19833750   | 2525000| 445536 | 196071 | 32143    |
| 35  | Zinc plating             | 1 |          | 231096964  | 19339286   | 2502500| 403929 | 159107 | 20000    |
| 36  | Zinc plating             | 3 |          | 216548036  | 18373571   | 2462143| 406786 | 175000 | 25714    |
| 37  | Tin-bismuth              | 0 |          | 204570000  | 17429286   | 2388214| 399464 | 170714 | 24821    |
| 38  | Tin-bismuth              | 1 |          | 207878036  | 17325179   | 2418214| 386250 | 163929 | 21964    |
In order to build a 3D model and visualize the distribution of the particles cloud, the process of chemical degreasing of metal parts was chosen, since this process demonstrates the maximum content of particles of each fraction (Fig. 3). The quantitative content of airborne particles for this process is tens of times higher than similar indicators for the other 14 electrochemical processes.

|    |     |     |     |     |     |     |
|----|-----|-----|-----|-----|-----|-----|
| 39 | Tin-bismuth 3 | 198990000 | 17259821 | 2375893 | 365536 | 152321 | 17679 |
| 40 | Chromating 0 | 194596071 | 16603214 | 2195714 | 344821 | 139643 | 20714 |
| 41 | Chromating 1 14 | 209583929 | 17577679 | 2360179 | 381964 | 155893 | 21429 |
| 42 | Chromating 3 | 194693214 | 16802143 | 2299821 | 375357 | 158036 | 19286 |
| 43 | Chem. nickel plat. 0 | 184300000 | 22040714 | 5597143 | 2051071 | 1070357 | 14629 |
| 44 | Chem. nickel plat. 1 15 | 180073571 | 19436429 | 3437143 | 792500 | 358571 | 55714 |
| 45 | Chem. nickel plat. 3 | 170112500 | 19012500 | 3270000 | 673929 | 309286 | 41786 |

Figure 3. The propagation cloud of 0.3 μm particles from the process of chemical degreasing of metal parts.

The results obtained indicate that primary particles of industrial aerosols formed at the time of electrochemical processes have minute dimensions. Primary particles are generally less than 0.3 microns in size. The number of particles of this fraction is predominant for all studied electrochemical processes. The heterogeneity of the fractional composition of solid particles is due to physicochemical transformations of primary particles during their propagation in the air [7].

4. Conclusions
It is known that harmful particles of industrial aerosols enter the organisms of electroplaters or related workers in electroplating shop not only through the respiratory tract, but also through the skin, ears, eyes and other unprotected parts of the body [8]. Therefore, the use of respirators is necessary, but not
enough to protect workers [9]. Reducing the content of harmful substances is achievable by removing contaminated air from industrial premises and replacing it with the help of mechanical ventilation. Workers in electroplating production need constant medical examination and compensation measures.

The absolute predominance of PM_{0.3} particles was revealed (data obtained using a handheld particle counter). These particles pose the greatest threat to human health. 3D modeling of the propagation of airborne particles in the working zone air was carried out for the electrochemical process of chemical degreasing that generates the maximum number of airborne particles. The data obtained on the propagation pattern of the aerosol cloud formed during various electrochemical processes demonstrate the propagation of nano- and microparticles inside the electroplating shop and inefficiency of existing local exhaust.

References
[1] Mavletov M N, Berezin N B, Yarullin A Z, Farrakhov G R, Nurullin A B 2017 The use of a circulation station for cleaning wash water in electroplating Technological University Bulletin vol 20 2 pp 51-53
[2] Bezborodova O E 2005 Neutralization of chromium-containing wastewater from electroplating shops with antibiotic production wastes. Abstract of candidate of technical sciences dissertation Penza State Academy of Architecture and Civil Engineering (Penza)
[3] Sumarchenkova I A 2018 Modernization of the wastewater treatment scheme of an electroplating shop in an oil and gas equipment plant Bulatov readings vol 5 pp 286-288
[4] Voropanova L A, Gagieva F A, Gagieva Z A 2015 Wastewater treatment of leather, etching and electroplating industries from chromium ions Vladikavkaz Scientific Center Bulletin vol 15 3 pp 55-60
[5] Gritsenko O V 1999 Forecast and increase of the efficiency of local suction exhaust in dust and gas collection to reduce air pollution of working areas Abstract of candidate of technical sciences dissertation / (Rostov state. build. un-t. Rostov-on-Don)
[6] Zheng W, Antonini J M, Lin Y C, Roberts J R, Kashon M L, Castranova V, Kan 2015 Cardiovascular effects in rats after intratracheal instillation of metal welding particles Inhal Toxicol 27(1) 45-53
[7] Baracchini E, Bianco C, Crosera M, Filon F L, Belluso E, Capella S, Maina G, Adami G Nano- and Submicron Particles Emission during Gas Tungsten Arc Welding (GTAW) of Steel: Differences between Automatic and Manual Process Aerosol and Air Quality Research vol 18 Issue 3 pp 579-589
[8] Song Guo, Min Hu, Misti L Zamora, Jianfei Peng, Dongjie Shang, Jing Zheng, Zhuofei Du, Zhijun Wu, Min Shao, Limin Zeng, Mario J Molina, and Renyi Zhang 2014 Elucidating severe urban haze formation in China Proceedings of the National Academy of Sciences of the United States of America vol 111 Issue 49 pp 17373-17378
[9] Halliday-Bell J, Palmer K & Crane G 1997 Health and safety behaviour and compliance in electroplating workshops Occup. Med. (Lond) 47(4) 237–240

Acknowledgements
The authors would like to thank the staff of the Center for Collective Usage FEFU for the provided research equipment. This work was supported by the grant of the President of the Russian Federation for young candidates of sciences No. MK-2461.2019.5.