MEASUREMENT OF NANOPARTICLES IN 3D PRINTING USING FFF / FDM TECHNOLOGY

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Abstract

For additive production, where the material is prepared by applying thin layers, a simplified designation 3D printing has been used. During this production volatile organic compounds and ultrafine particles are emitted into the air. A number of measurements for a given type of printer with a specific type of thermoplastic are published on this topic. The procedure of our measurement of the concentration of nanoparticles (10-700 nm) and their mean diameters can be called "field", because it took place in a real environment with mass deployment of 3D printing on the principle of FFF / FDM, with the measuring device moving between printers in various premises and activities:

- in the production of parts intended for the assembly of printers,
- in the manufacture of components for shields during the lockdown period associated with Covid-19,
- in the creative workshops and laboratories of Prusa Research a.s.

The aim of these measurements in real situations was to find measures to reduce the concentration of nanoparticles. Evaluation of the results was proceeded according to the ISO / TR 27 628 standard and determined a proposal of measures of a technological and organizational nature to reduce concentrations. Based on the results of our measurements these measures include (a) using central extract ventilation of the entire workplace, (b) separating the printer area from the workplace and using extract ventilation, and (c) filtering the air in the entire workplace using an air purifier. When adopting these measures, the financial requirements and technical feasibility must always be considered.

Keywords: Nanoparticles, 3D printing, FFF/FDM technology, concentrations of nanoparticles, safety measures

1. INTRODUCTION

Over the past two decades, 3D printing from thermoplastics using Fused Filament Fabrication (FFF), or Fused Deposition Modeling (FDM) has become a very popular manufacturing method. The international RepRap project launched in 2005 [1] has contributed significantly to its popularity. However, subsequent studies on the emission of substances and materials during 3D printing have shown that volatile organic substances (VOS) and ultrafine particles (UFP) are released into the environment during the manufacturing process [2-4].

Previous studies have usually compared the measured concentrations of UFPs, their averages or their emission rates into the environment depending on the different types of filaments used in the printing process [5-16]. These measurements have shown that the composition of emissions from 3D printing is influenced by a number of factors, such as the chemical composition of the filament, its colour, the operating temperature of the print, the effect of the nozzle used, and the functionality of the printer [5-16]. The observed results are also influenced by the measurement scenario [11] or the type of instrumentation used [12].

Recent research has also compared the composition of emissions for a larger range of filaments, e.g. between ABS, PLA, PVA, HIPS, NYLON and PET [6], the number of particles in the emissions when printing between a pair of filaments, e.g. between ABS and PC, where PC generates more particles than ABS [13], or between ABS and PLA, where a strong concentration of styrene was found in the emissions [14].

Importantly, previous experiments were performed under reproducible conditions, where external influences were eliminated, for example, by placing the 3D printer in a sealed chamber of defined volume (e.g. 2.5 m3), supplying air to the chamber through a HEPA filter, and positioning a particle counter and spectrometer inside the chamber to measure the concentration of particles in the environment near the printer [15]. These exact measurements were performed for filaments made from materials most commonly used for 3D printing, such as ABS, PLA and HIPS. The average total concentration of UFP was 217,000 #.cm-3 for the HIPS material under the given conditions, 20,000 #.cm-3 for ABS and 14,000 #.cm-3 for PVA. [15].

In our research, the chosen method to measure nanoparticle concentrations and their mean diameter can be described as "field" because it was carried out in the real environment of selected workplaces. This fact is one of the reasons why our results differ from past experiments in which external influences were excluded.

2. MEASUREMENTS WHEN RUNNING MULTIPLE 3D PRINTERS USING FFF/FDM TECHNOLOGY

The Testo Disc mini 133 device was used for all measurements - measuring range 10-700 nm.

2.1. Large-scale production of 3D printers based on thermoplastic deposition

The measurements in the large-scale production of 3D printers took place at the workplace of one of the largest manufacturers of this type of printers, Prusa Research a.s. The measurements were carried out at three different workplaces of the company, namely at a workplace called "The Farm", in the area intended for the work of designers, and in the development laboratories.

2.2. The Farm

The Farm is a room in which rows of printers are placed on racks three levels above each other. The room in which the printers are located is partially separated from the surroundings by a plastic film (**Figure 1A**).

A B C

Figure 1 A) Production of parts for assembling 3D printers using 3D printing at Prusa Research, a.s.; B) Design workplace at Prusa Research, a.s.; C) Small laboratory

At the time of the measurements, the Farm had 480 printers printing parts for the assembly of 3D printers made of filaments of the chemical composition polyethylene terephthalate-glycol (PET-G; trade name Prusament PETG Prusa Orange). The actual measurements were performed while walking between the stands with the measuring equipment placed at a height of 1 m above the floor surface. The results obtained are presented as the change in the number of particles per unit volume of atmosphere over time (**Figure 2**) and the change in particle size over time. During the measurements, the concentration of nanoparticles varied in the range of 50,000-70,000 #-cm^3, with a mean particle diameter of 29-30.5 nm.

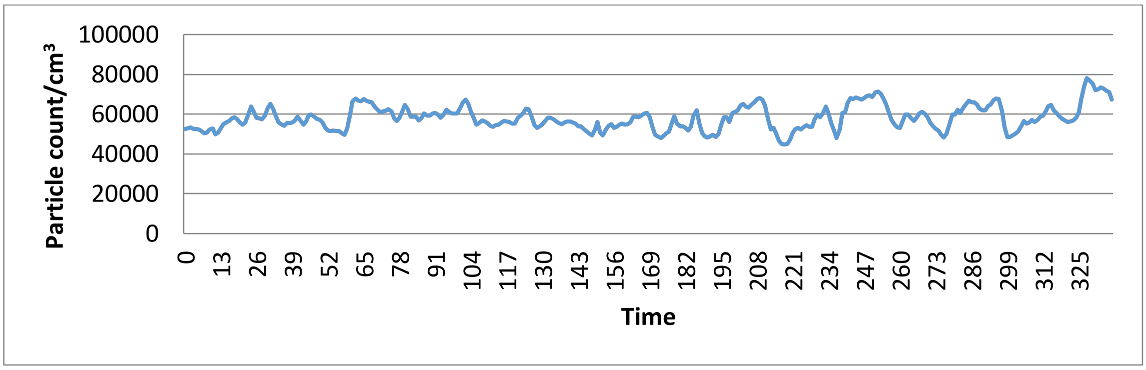

Figure 2 Concentration of nanoparticles measured at the Farma workplace during thermoplastic 3D printing with 480 printers running simultaneously

2.3. The Designers' Workplace

The designers' workplace contains the designers' workbenches (**Figure 1B**) and the 3D printers are freely placed on tables. The designers' workplace is not equipped with central extract ventilation, and air exchange is only provided through windows. During the measurements, the windows were closed, 9 designers were present at the workplace, and seven 3D printers were running simultaneously (chemical composition of PETG and PLA filaments). The measurements took place while walking between the tables, with the measuring equipment placed at a height of 1m above the floor surface. The results obtained are presented as the change in the number of particles per unit volume of the atmosphere over time (**Figure 3**). The concentration of nanoparticles in the engineers' room had a pulsed character and reached a value of up to 200,000 #-cm^{-3} (**Figure 3**). In the rooms with the maximum concentrations, the mean diameter of nanoparticles decreased from 30 nm to about 20 nm.

During simultaneous thermoplastic 3D printing on multiple printers, the concentration of nanoparticles in the working environment exceeded the values identified in the methodology of the Ministry of Labour and Social Affairs of the Czech Republic [17] as hazardous and thus requiring the application of protective equipment.

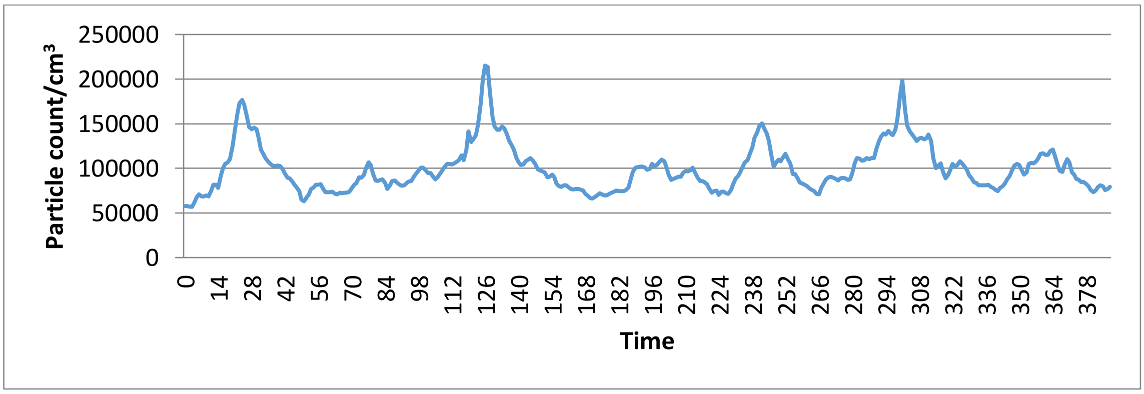

Figure 3 Concentration of nanoparticles in the designers' workplace

2.4. The Development Laboratories

At Prusa Research a.s., several measurements were also carried out in the laboratories. Their activities are focused on further development, but at the same time they search for optimal solutions for the protection of employees and the possibility of reducing the concentration of nanoparticles in the environment of the existing production facilities. For example, they test the effect of the use of different air purifiers (performance in the range of 100-400 m^3/h) in short- and long-term cleaning of the laboratory air. **Figures 4** and **5** show the changes in the concentration and mean diameter of nanoparticles measured during the normal operation of six 3D printers in a small laboratory environment (**Figure 1C**). The effect of air purification can be compared with the values recorded in **Figures 5** and **6** which were measured after the ETA Nubela 2569 air purifier was activated and filtered the laboratory air for 15 minutes. Filtration of the air resulted in a significant decrease in the concentration of nanoparticles even with the printers running.

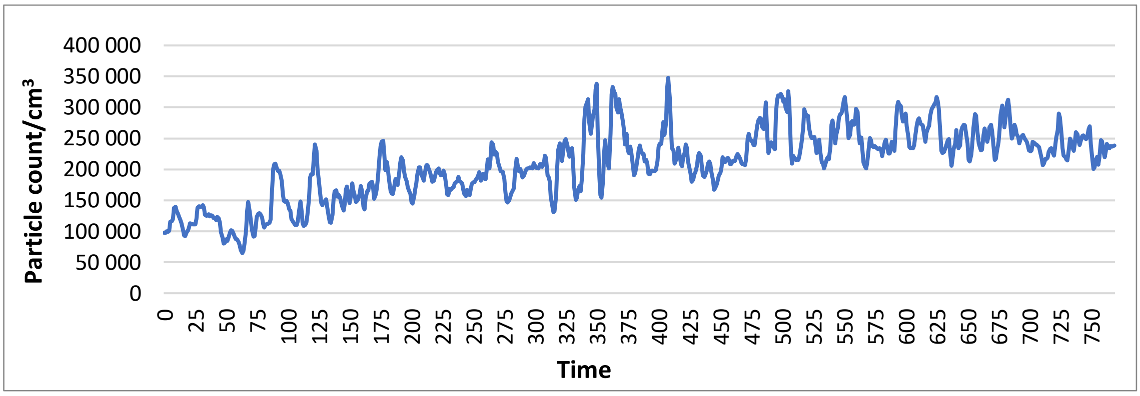

Figure 4 Nanoparticle concentration in a small laboratory with 6 3D printers running

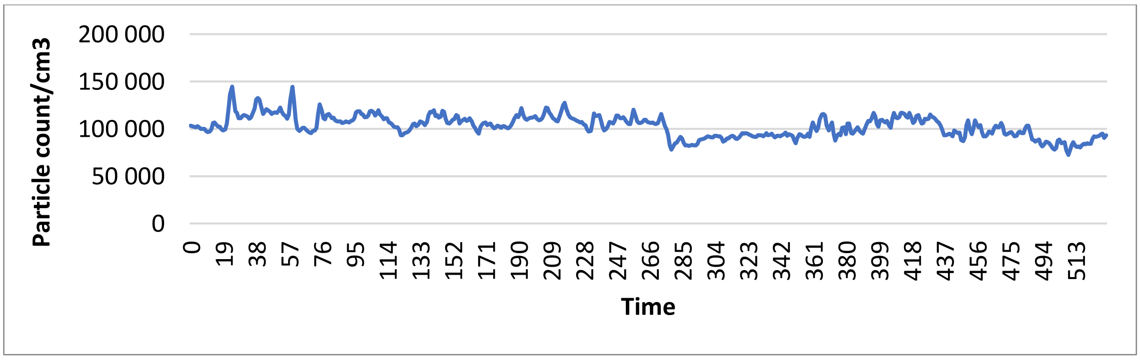

Figure 5 Concentration of nanoparticles in a small laboratory after 15 min of air filtration

2.5. Production of components for protective shields

The COVID-19 disease pandemic has activated efforts to use 3D printing to produce protective devices in both the private (Prusa Research a.s.) and academic spheres. At the Technical University of Ostrava (VŠB-TUO), the production of components for protective shields took place at the Protolab workplace (the business incubator of VŠB-TUO) where, in cooperation with the Ostrava City Council, all the available 3D printers based on FFF/FDM technology were concentrated. The temporary production facility was set up in a meeting room with about 60 3D printers placed on tables (**Figure 6**). The meeting room is equipped with ceiling ventilation, which was switched on during 3D printing. The measurements followed the same scenario as in Prusa Research Inc.

Figure 6 Production of components for protective shields at VŠB-TUO

The pulsed nature of the values on the graph in **Figure 7** is a consequence of the chosen measurement method, since the measuring instrument was placed at different distances from the particle sources when passing between the tables. During the measurements, the concentration of nanoparticles ranged from 22,000-55,000 #-cm^{-3}, with a mean particle diameter of 21-27 nm. Also in this measurement, a response (not a direct proportion) of the change in mean particle diameter to the particle concentration in space was observed (**Figure 7**).

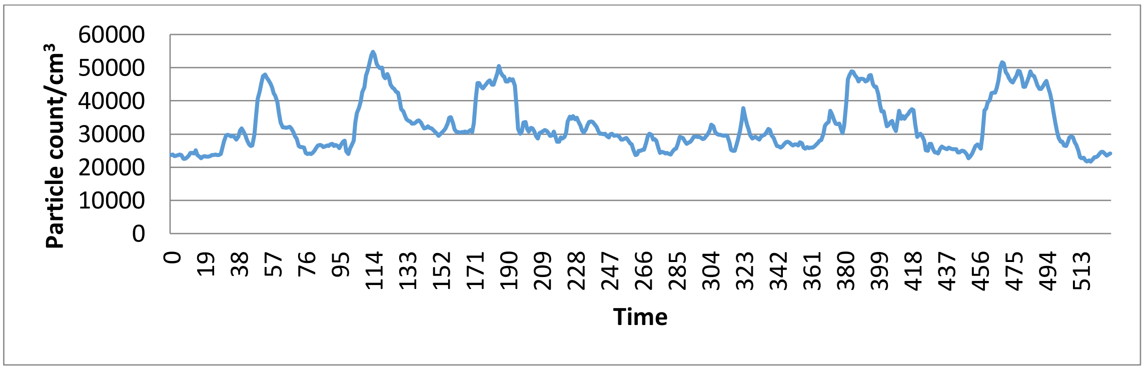

Figure 7 Concentrations of nanoparticles produced in the manufacturing of shielding components

3. CONCLUSION

During 3D printing with FFF/FDM technology, nanoparticles are emitted into the environment around the printers. On the basis of the measurements carried out, it was found that the fastest and most affordable solution is to filter the workplace air with air cleaners of various capacities with HEPA and C-filters. Their use does not require structural modifications, but additional operating costs, in particular the replacement and disposal of filters.

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