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ScienceDirect

Procedia Engineering 121 (2015) 506 – 512

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Investigation of Ultrafine Particle Emissions of Desktop 3D Printers in the Clean Room

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Abstract

It is getting more popular to use desktop 3D printers either at homes or offices, which may emit a large amount of particles when in use. This work aims to obtain accurate size-resolved particle emission rates from both single and two desktop 3D printers in a ten–thousand-level clean room, with acrylonitrile butadiene styrene (ABS) for the feedstock. Particle concentrations were measured at three different spots in the clean room. We found that the major size of particles produced by the 3D printers is less than 10μm (PM_{10}). The further it is from the printer, the higher the particle concentrations are. Moreover, the smaller the size of particles, the higher the concentration of particles, with the size ranged from 0.25μm to 0.28μm corresponding to the highest concentration. The maximum value of particle concentration is around 2.5×10^4/L for single printer and 4×10^4/L for two printers.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: 3D printers; clean room; ultrafine particles; ventilation

1. Introduction

People spend 80% of their time indoors, which makes it important to have good indoor air quality to ensure healthy living and working environment, and to avoid discomfort (e.g., headache) or the high absence rate of personnel and poor efficiency at work.

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Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.08.1099

There are many sources of indoor pollutant, such as the decoration materials and furniture, which emit a large amount of Volatile Organic Compounds (VOCs) and particles. Living and office supplies also emit particles and ultrafine particles, such as copiers and printers. This can cause respiratory and cardiovascular disruptions, even lead to severe diseases, like lung cancer. Printers have become important indoor pollutant sources. Ozone is generated when the laser printers work [1], which is associated with increased asthma rates. There are several studies about the influence of traditional printers. Naoki Kagi etc. studied the influence of contaminants (eg., VOCs, ozone, particles, etc.) from printers and copiers. Their findings further confirmed the fact that the concentrations of ozone and ultrafine particles are increased during the printing processes [2]. Another study (Lee and Hsu) investigated the levels of particulate matter smaller than 2.5 μm (PM2.5) and some selected volatile organic compounds (VOCs) at 12 photocopy centers [3], which indicated that toluene had the highest concentration in all photocopy centers. The concentrations of particles smaller than 0.5mm were found to be increased during the first hour of photocopying. Also those particles were increased as the particles sizes were decreased.

Desktop 3D printers are becoming more popular to be used at work or homes, especially some low-cost desktop 3D printer. However, people may underestimate the effects or influences of pollutants generated by these 3D printers. Nowadays most 3D printers utilize acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) as feedstock. 3D models are printed by melting the plastic feedstock. 3D printers may also emit health-influenced particles or VOCs during the printing process. Low-cost desktop 3D printers may emit even more ultrafine particles and VOCs. There are many studies about particles emissions from traditional printers, but few about 3D printers. Brent etc. studied the ultrafine particle emissions from desktop 3D printers [4]. This study mainly investigates the emission rates of ultrafine particles generated from the thermoplastic feedstock of desktop 3D printers (ABS and PLA) in offices. In our work, the measurements were conducted in a clean room using low-cost desktop 3D printers to avoid background pollutant noise.

2. Methods

Measurements were conducted in a ten-thousand-level clean room with a volume of $60m^3$ (5m× 4m×3m). Two desktop 3D printers were placed on a table in the clean room (shown in Fig.1). Particles concentrations were measured in the clean room using a Grimm 1109 logging at a time interval of 6 s. The sampled air is led directly into the measuring cell via the aerosol inlet or other custom-designed air inlets, e.g. for high wind speeds or overpressure. The particles in the sample air are being detected by light scattering inside the measuring cell. The scattering light pulse of every single particle is being counted and the intensity of its scattering light signal is classified to a certain particle size. The basic parameters of Grimm 1109 are tabulated in Table 1.

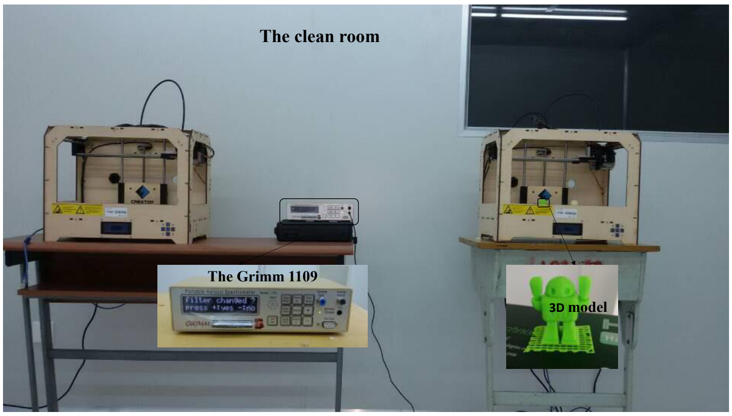

Fig. 1. 3D printers' distribution in the clean room.

Table 1. The basic parameters of Grimm 1109.

Name	Intervals	Particle size range	Channel	C-factor
Grimm 1109	6s	0.25μm-32μm	32	1

The measurements of particle emissions from both one and two printers were carried out at three different spots in the clean room to get full distributions of fine particles. The desktop 3D printer was in a fixed position. We measured particle concentrations in different spots with different distances from the printer by changing the locations of the Grimm. The layout of the printers and the Grimm in the clean room is illustrated in Fig.2.

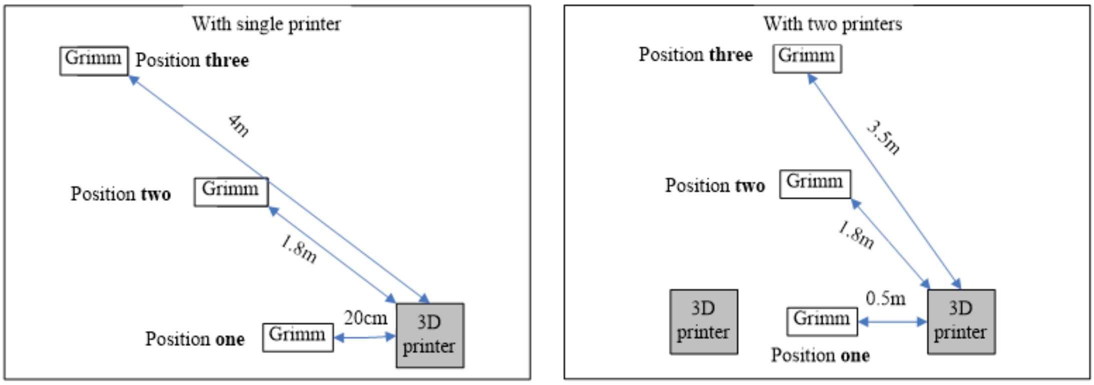

Fig. 2. The distribution of printers and measuring instrument [(a): with single printer; (b): with two printers].

Each experiment has a similar procedure, containing three parts as described below:

1) *Obtaining a standard-level clean environment*
   Firstly, the ventilation system was operated for removing the background contaminants of the clean room to obtain a clean environment, which is required to meet the standards of the clean level of ten thousand. Afterwards, the ventilation system was switch off, and the Grimm 1109 was started to measure the particle concentrations for around 10 min.
2) *Measuring with the printers printing*
   It takes 10 minutes preheating before printing to attain the required temperature of 220℃. The 3D printer was operated to print a plastic Robot shown in Fig.3. It took about 40 minutes for the whole printing process to complete.
3) *Removing particles from the printers*
   After the printing process completed, the ventilation system was opened again to remove the pollutant of particles from the printers, with a ventilation rate of $5400m^3/h$, corresponding to a ACH (Air Change per Hour) of 90 h^{-1}. Hence the pollutants concentrations will be decreased fast and efficiently.

Table 2. The whole printing process.

	With single printer			With two printers		
	Position one	Position two	Position three	Position one	Position two	Position three
3D model	Robot					
The feedstock	ABS (Green)	ABS (Green)	ABS (Green)	ABS (white and green)	ABS (white and green)	ABS (white and green)
Printing time	68 minutes	60 minutes	75 minutes	83 minutes	117 minutes	89 minutes
Process	Time includes three processes: obtaining a standard-level clean environment; measuring with the printers printing; removing particles from the printers					

3. Results

This experiment is conducted under the conditions either with one printer or two printers working. Hereby we have to point out that the trend of particle concentration distribution is comparable for single printer and two printers. Hence, size-resolved particle concentrations are shown only with single printer. The result will be described in two aspects: (1) The particles emission measurement from one printer; (2) The comparison of particle emissions with single printer and two printers. All the tests include three stages: background environmental particle levels measurement, the growth of particle concentrations, and the decay of particle concentrations. Table 3 shows a description of the particle sizes range mentioned in the current manuscript.

Table 3. Description of the particle sizes range.

Resolved sizes	Sizes range
0.265μm	0.25μm to 0.28μm
0.290μm	0.28μm to 0.30μm
0.325μm	0.30μm to 0.35μm
0.375μm	0.35μm to 0.40μm

Fig.3 shows the trend of particle concentrations with single printer in the clean room at position three. Particle concentrations in four different sizes range are compared. It can be seen that the smaller the size of particles, the higher the concentration. The particle size ranged from 0.25μm to 0.28μm corresponds to the highest concentration levels. The maximum value of particle concentration is around 5×10^4/L. During the experiment, size-resolved number concentrations of particles in the size range of 0.25-32μm were fully recorded. However, concentrations of the particles with sizes larger than 0.375μm are very low. It also shows that the similar particle concentrations trend occur in four different size ranges. In the first period (the first ten minutes, ref. Fig. 3), the particle concentrations stayed at a relatively lower level. In the second period, when desktop 3D printer worked, the particle concentrations were obviously increased. When the printing process was completed, the particle concentrations reached the maximum levels. After the printing finished, the ventilation system was turned on, the particle concentrations started declining sharply.

We can clearly see that indoor ventilation has significant effects on the removal of particle contaminants. The distribution of particle concentration at position one is also shown at Fig. 4, and it has similar change trend as at position three.

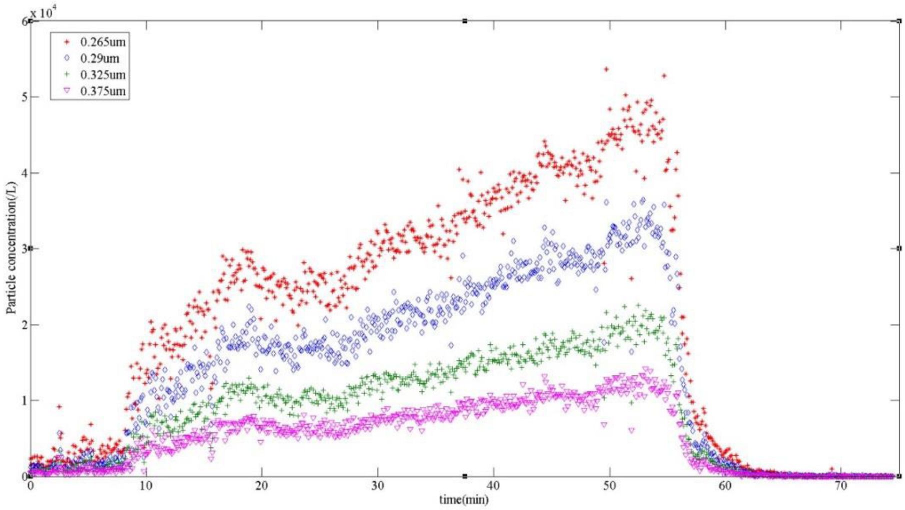

Fig. 3. Particle concentrations with single printer in the clean room at position three.

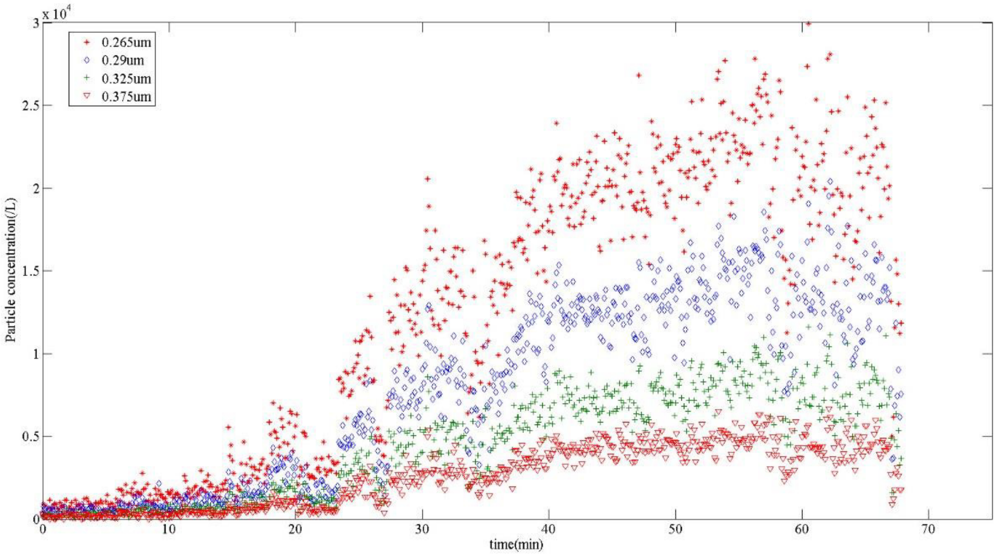

Fig. 4. Particle concentrations with single printer measured in the clean room at position one.

Fig.5 shows a comparison of particle concentrations at three different positions in the size range of 0.25-0.28μm. We can see from the figure that the particle concentrations in position 3 and 2 are both higher than those in position one. The findings suggest that the further it is from the desktop printer, the higher particle concentration is. The mechanism underneath the findings may be growth of ultrafine particles emitted from the printers. Prior studies have reported that in the operating process, printers can emit a larger amount of ultrafine particles [5], which may coagulate together with each when they transport from the printers to positions away from them. In the present study, we did not measure the ultrafine particle emission so it is challenging to quantify the coagulation rates. Further studies will go to understand the ultrafine particle emission rates and the relevant growth phenomenon associated with 3D printer operation.

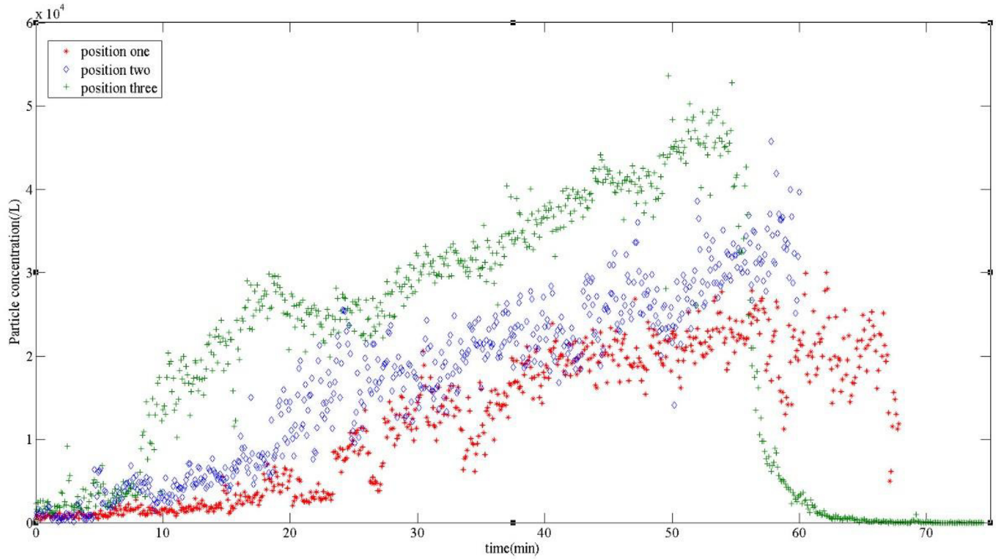

Fig. 5. Comparison of particle concentrations at three different positions with single printer.

Fig.6 shows that the particle concentration emitted from two printers is about two times of that from single printer, with the particle size of 0.265μm (ranged from 0.25μm to 0.28μm). The maximum particle concentration is about 7×104/L for two printers and 4×104/L for single printer respectively.

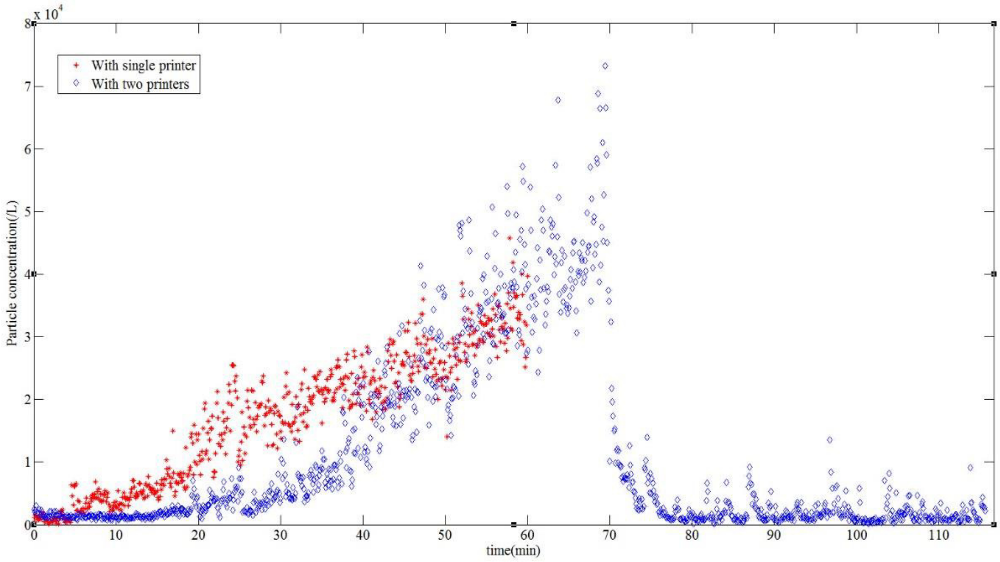

Fig. 6. Comparison of particle concentrations with single printer and two printers at the position two with particle size of 0.265μm.

Fig.7 shows the trend of particle concentrations with two printers in the clean room at position one. Particle concentrations in four different sizes range are compared. The result shows that the trend of particle concentrations with two printers is similar with single printer.

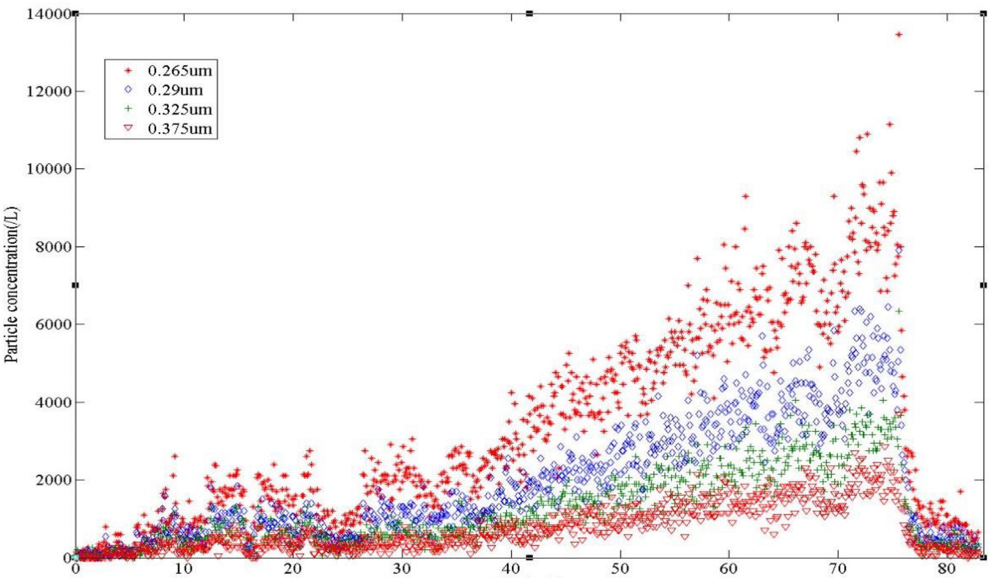

Fig. 7. Particle concentrations with two printers measured in the clean room at position one.

4. Conclusions and discussion

In this study, we investigated size-resolved ultrafine particle emission rates from low-cost desktop 3D printers in a ten–thousand-level clean room. Particle concentrations were measured at three different spots in the clean room from both single and two desktop 3D printers with ABS for the feedstock. We found that the major size of particles produced by the 3D printers is less than 10μm (PM10). The further it is from the printer, the higher the particle concentrations are. Moreover, the smaller the size of particles, the higher the concentration of particles, with the size ranged from 0.25μm to 0.28μm corresponding to the highest concentration. The maximum value of particle concentration is around 2.5×10^4/L for single printer and 4×10^4/L for two printers, respectively. We have two highlights. One is that the measurement was conducted in the clean room to avoid the background noise, with less interference to the measurement of particle emissions. Another one is that we measured three different positions and we can get the rough distribution of particles.

The pollution problem caused by PM2.5 has become a serious concern, eg., the phenomenon of fog and haze. People are more concerned with air pollution especially PM2.5, which can cause respiratory and cardiovascular diseases. Our work will remind people to design a well-performed ventilation system when using 3D printers to remove indoor particle contaminants.

To understand the ultrafine particle emission rates and the relevant growth phenomenon associated with 3D printer operation, further study will be studied in the future.

Acknowledgements

Further, the authors would like to acknowledgement the financial support from the National Natural Science Foundation of China (Grant No. 51406127 and 51406128).

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