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Assessing Particulate and Chemical Emissions from Additive Manufacturing Processes

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Introduction

- Additive manufacturing (AM), commonly known as 3-D printing, is a rapidly emerging manufacturing technology. Rather than removing materials (in subtractive manufacturing), AM processes develop three-dimensional parts from Computer-Aided Design (CAD) models. This process allows building parts with geometric and material complexities that could not be produced by alternative processes, such as subtractive manufacturing.[2]
- AM technology could potentially cause emissions of harmful pollutants during the printing process. Thermal treatment and additive manufacturing of plastic materials are known to cause decomposition of the material, enabling the emissions of VOCs and fine particles. Exposure to these agents may cause sensitization, irritation, and inflammatory effects on the skin, lungs, mucous membranes, and vital organs.[4]
- There are no current health standards specific to AM technology. However, it is feasible to compare the results obtained from the printing process to the background measurements taken prior to the start of printing.
- There were concerns regarding the emissions coming from the various types of printers utilized throughout the studied facility.

Objective

The objective of this study was to measure the concentrations of airborne fine particles and VOCs emitted from various printing processes in a plastics printing laboratory and teaching laboratory at the University of Cincinnati.

Methods

- Air monitoring was conducted in two separate locations: Teaching Lab and Plastic Printing Lab. Five types of printers were tested as follows:
  - Teaching Lab:
    - 20 desktop extruders were operating simultaneously with and without the control (two HEPA air cleaners at the LOW and HIGH settings).
  - Plastic Printing Lab:
    - Two Stereolithography (SLA) printers operating simultaneously (no control available).
    - Three Fused Deposition Modeling (FDM) printers operating simultaneously (no control available).
    - Two Polyjet printers operating simultaneously with and without the control (local exhaust ventilation).
    - One Projet printer with and without the control (activated carbon filter).
    - All eight printers operating simultaneously with their respective controls.

- Each test took approximately three hours to complete: 30-minute background monitoring, 2-hour monitoring while printing and post-processing, and 30-minute post-monitoring.
- Stationary monitoring was conducted using a P-Trak ultrafine particle counter (TSI Inc., St. Paul, Minnesota) and a PPBRae 3000 (Rae Systems, San Jose, California) side-by-side. A mobile P-Trak, relocated every 5 minutes, was used to obtain the spatial distribution of airborne particles.
- The ventilation rate in the rooms that housed the printers within the Plastic Printing Lab (SLA, FDM, Polyjet, and Projet) varied between 7-10 air changes per hour.
- The data were analyzed using Microsoft Excel and the statistical computing software, R. A t-test was used for the following comparisons: background vs. during printing and printing without the control vs. with the control.

Results

- The preliminary results show that VOC concentrations in the Teaching Lab, including background, printing, and post-printing, ranged from 266 to 496 ppb when the HEPA air cleaners were on the LOW setting (50 CFM) and from 252 to 416 ppb when the HEPA air cleaners were on the HIGH setting (700 CFM). The VOC concentrations were 2.3 times higher during printing compared to the background when the HEPA air cleaners were OFF ($p<0.001$). During printing, VOC concentrations decreased to almost half with the implementation of the HEPA air cleaners on the LOW setting compared to the experiment without the HEPA air cleaners (Table 1) ($p<0.001$). At the HIGH setting, these concentrations decreased close to the background levels. The maximum VOC concentration was 2649 ppb when the HEPA air cleaners were OFF.
- The fine particle concentrations in the Teaching Lab ranged between 300 and 5700 particles/cc. They progressively decreased with the implementation of the two HEPA air cleaners (from 50-700 CFM). The highest concentration (5680 particles/cc) was noted during printing when the HEPA air cleaners were OFF (Table 1).
- In the Plastic Printing Lab, the overall range of VOC concentrations was 400-4500 ppb. VOC concentrations were higher during printing compared to the background, with the exception of the two SLA printers (Table 2).
- When the Polyjet was operating, the VOC concentrations were not significantly different between the experiments with and without the control (Table 2) ($p = 0.659$). With the Projet, the VOC concentrations were higher with the control than without the control ($p = 0.008$). Furthermore, the VOC concentrations were quite high when all the printers were running simultaneously in comparison to the other tests. The second-highest peak was noted after printing ended (Figure 1A).
- In the Plastic Printing Lab, the overall range of fine particle concentrations was approximately 800-6900 particles/cc, excluding three significant peaks caused when all printers were running simultaneously (Figure 1B). Fine particle concentrations were generally higher during the background than during printing (Table 2). For the Polyjet printers, the concentration was not significantly different with and without the local exhaust ventilation ($p = 0.161$). The concentration decreased significantly with the implementation of the control (activated carbon filter) for the Projet printer ($p<0.001$). The SLA printers had one of the highest fine particle concentrations at approximately 5700 particles/cc after printing (Table 2). The most notable peak was seen with the mobile P-Trak, approximately 27 minutes after all four types of printers had started running (Figure 1B).

Table 1. Pollutant concentrations in the Teaching Lab before, during, and after the use of the desktop extruders.

Concentration: Average ± Standard Deviation			
	HEPA air cleaners OFF	HEPA air cleaners ON – 50 CFM (minimum setting)	HEPA air cleaners ON – 700 CFM (maximum setting)
VOC concentration measured with PPBRae (ppb)			
Background	382 ± 190	320 ± 16	294 ± 24
During printing	885 ± 404	421 ± 56	337 ± 42
After printing	887 ± 15	422 ± 8	268 ± 14
Ultrafine particle concentration measured with stationary P-Trak (#/cm^3)			
Background	1538 ± 31	626 ± 153	766 ± 197
During printing	2204 ± 318	808 ± 139	495 ± 142
After printing	1857 ± 50	834 ± 41	325 ± 35
Ultrafine particle concentration measured with mobile P-Trak (#/cm^3)			
Background	1498 ± 30	574 ± 30	735 ± 208
During printing	2133 ± 319	743 ± 213	493 ± 169
After printing	1813 ± 66	893 ± 83	378 ± 28

Table 2. Pollutant concentrations in the Plastic Printing Lab before, during, and after the use of each printer.

Concentration: Average ± Standard Deviation							
	SLA	FDM	Polyjet (without control)	Polyjet (with control)	Projet (without control)	Projet (with control)	ALL PRINTERS RUNNING (with controls)
VOC concentration measured with PPBRae (ppb)							
Background	7845 ± 429	491 ± 255	552 ± 172	495 ± 19	641 ± 276	817 ± 441	868 ± 372
During printing	1278 ± 612	1014 ± 501	807 ± 478	782 ± 535	892 ± 494	1235 ± 842	1180 ± 589
After printing	1197 ± 388	941 ± 184	862 ± 69	573 ± 31	1025 ± 964	1522 ± 848	1345 ± 1013
Ultrafine particle concentration measured with stationary P-Trak (#/cm^3)							
Background	2190 ± 229	1021 ± 101	2638 ± 185	1999 ± 69	4316 ± 286	1711 ± 277	3511 ± 317
During printing	2549 ± 1200	1699 ± 622	2613 ± 300	1380 ± 164	3518 ± 548	1274 ± 283	3222 ± 802
After printing	5735 ± 491	1083 ± 75	3422 ± 95	1193 ± 67	3333 ± 196	697 ± 66	2202 ± 159
Ultrafine particle concentration measured with mobile P-Trak (#/cm^3)							
Background	2541 ± 139	1026 ± 404	2521 ± 82	1886 ± 50	4431 ± 193	1823 ± 98	3566 ± 398
During printing	2651 ± 1118	1692 ± 518	2429 ± 265	1380 ± 164	3408 ± 465	1151 ± 282	3412 ± 2502
After printing	5740 ± 258	1111 ± 58	3090 ± 115	1236 ± 47	3166 ± 150	525 ± 34	2101 ± 74

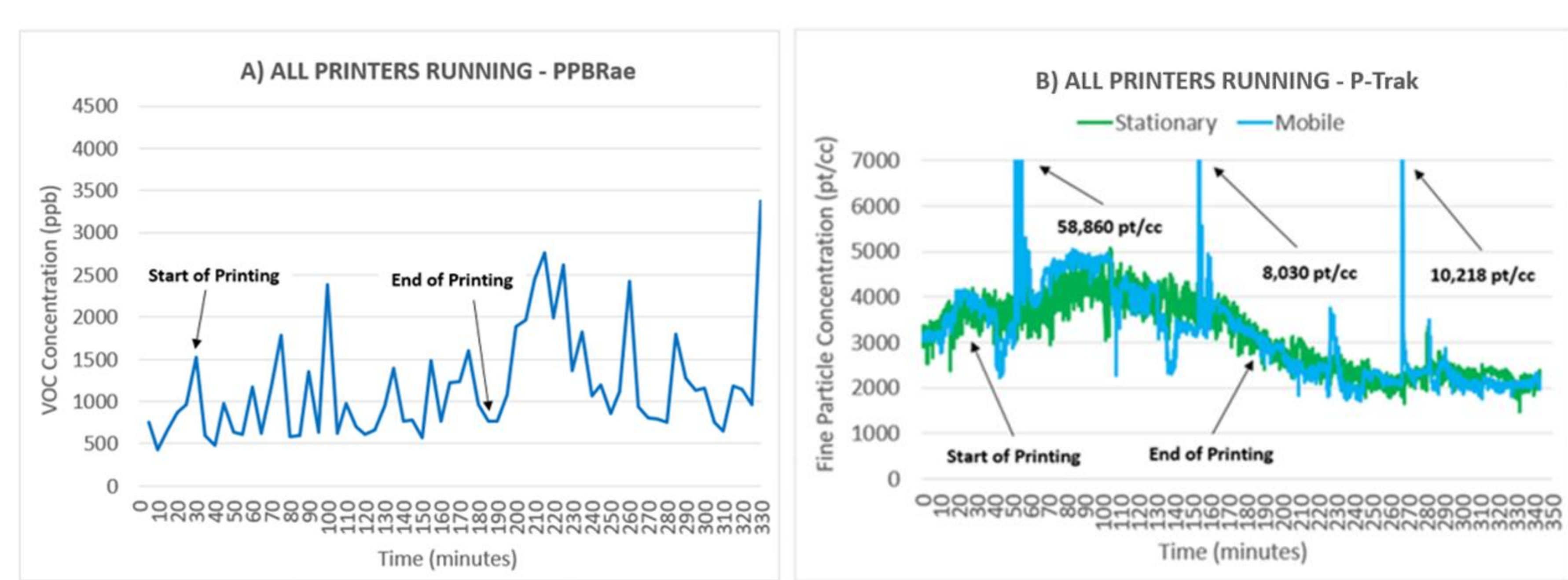

Figure 1. Pollutant concentrations in the Plastic Printing Lab while running all printers at the same time with their respective controls implemented into the process (if applicable). A) VOC concentration measured using the PPBRae. B) Fine particle concentrations measured using the stationary and mobile P-Traks.

Conclusion

- Overall, fine particle concentration peak values for printers in the Teaching Lab and Plastic Printing Lab were much lower than those reported by Zhang et al., 2019[5], who measured concentrations up to 10^6 particles/cc. However, our mean concentrations were similar to what was reported by Steinle, 2016[3]. Furthermore, our VOC concentrations were considerably higher than those obtained by Afshar-Mohajer et al., 2015[1], who reported a maximum value of 750 ppb.
- In conclusion, the HEPA air cleaners in the Teaching Lab proved to be effective in reducing the overall concentrations of fine particles and VOCs. The experiments in the Plastic Printing Lab showed varying results on the efficiency of the control against VOCs. However, the fine particle concentrations were significantly lowered by implementing the control. Based on these results, the local exhaust ventilation is only effective in reducing fine particle concentrations, as opposed to VOCs. Therefore, the local exhaust ventilation in the Plastic Printing Lab requires further evaluation before improvements can be recommended to improve its overall efficiency.

References

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