The Built Environment Research Group
advancing energy, environmental, and sustainability research within the built environment at Illinois Institute of Technology

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Emissions Report: Ultrafine particles (UFPs) and volatile organic compounds (VOCs) from desktop 3D printers

Filament: INOVA-1800 Red

Printer: LulzBot Mini

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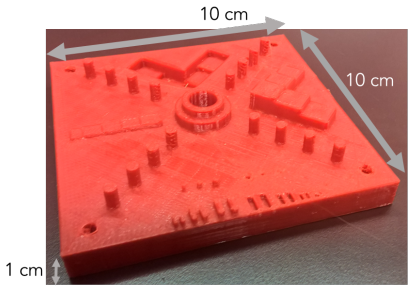

Figure 1. Printed standardized test part from NIST used for emissions testing

Summary:

The goal of this work is to experimentally characterize the emissions of ultrafine particles (UFPs, or particles <100 nm) and speciated volatile organic compounds (VOCs) when printing a standardized test part with a desktop 3D printer and polymer filament following manufacturer recommended settings.

Methods:

We conducted controlled environmental chamber testing following methods described in Azimi et al. (2016) *Environ Sci Technol* 50(3):1260-1268. All measurements were conducted inside a well-mixed 3.6 m^3 stainless steel chamber. The 3D printer bed was prepared for printing before sealing the chamber by wiping the 3D printer bed with 90% propanol following manufacturer recommendations. We printed a 10×10×1 cm standardized sample from the National Institute of Standards and Technology (NIST), as shown in Figure 1.

Results:

UFP emissions

Figure 2a shows time-varying total UFP concentrations resulting from the single print test and Figure 2b shows estimates of time-varying total UFP emission rates. The left guideline in Figure 2a shows the moment that the printer began warming up prior to printing, which we considered part of the printing emissions period. The second guideline shows the moment that the printer stopped printing. The data smoothing method (SM) that was used and the corresponding coefficient of determination (SM-R^2) are shown in Figure 2a. The error bars in Figure 2b show an estimated ~45% uncertainty in the UFP emission rate estimates. The solid line and the upper and lower dashed lines in Figure 2b demonstrate the median and interquartile range of the estimated UFP emission rates. The number of negative estimated emissions (NNEE) is also provided in Figure 2b.

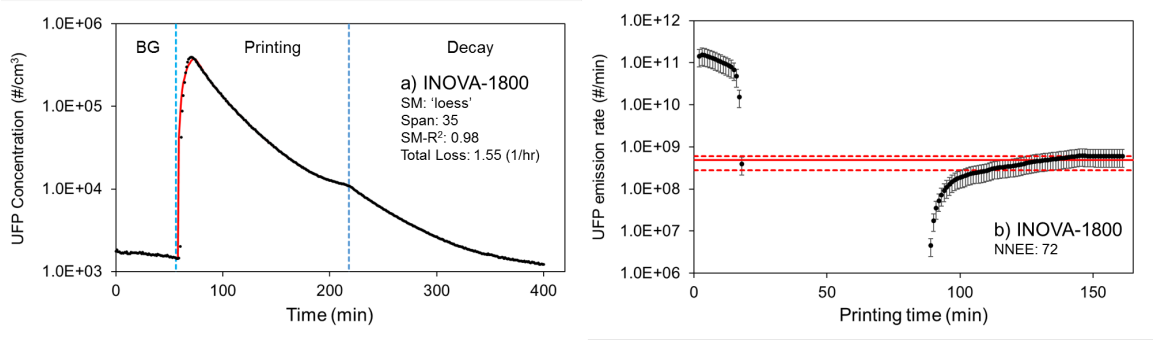

Figure 2. a) Time-varying UFP concentrations inside the chamber during background, printing, and decay time periods, and b) estimates of time-varying UFP emission rates during the printing period

Table 1 summarizes the estimated UFP emission rate results. The UFP concentration in the chamber increased rapidly once the printing period began. Estimates of UFP emission rates were higher at the beginning of the printing period, then decreased rapidly and remained negative for about 70 minutes before becoming steady. The UFP emission rate was low relative to prior tests (e.g., a median UFP emission rate of ~4.9×10^{8} #/min compared to an average of ~2×10^{10} #/min from 15 printer and filament combinations reported in Azimi et al. 2016).

Table 1. Summary of total UFP emission rate results

Average (±SD) (#/min)	Median (#/min)	Max (#/min)	Min (#/min)	Total UFPs emitted (#)	Emission per mass of filament (#/g)	Printing duration (mins)	Printing temperature (°C)	
							Nozzle	Bed
1.9×10^{10} ($\pm8.4\times10^{10}$)	4.9×10^{8}	1.6×10^{11}	4.6×10^{6}	2.0×10^{12}	4.1×10^{10}	163	245	75

Speciated VOC emission rates

Table 2 summarizes estimates of individual speciated VOC and ΣVOC emission rates (i.e., the sum of the emission rates of the top 5 speciated VOCs with the highest individual emission rates) from the tested filament. The results from Table 2 demonstrate that "Arsenous acid, tris (trimethylsilyl) ester", "Caprolactam", and "Nonanal" have the highest individual VOC emission rates from the tested filament, but that ΣVOC emissions from this filament and printer combination (~2.2 µg/min) were very low relative to an average of ~67 µg/min from 15 printer and filament combinations reported in Azimi et al. (2016). The uncertainty in individual VOC emission rates is estimated to be ~36%.

Table 2. Summary of top-five individual speciated VOC emission rates

Compound	Arsenous acid, tris (trimethylsilyl) ester	Caprolactam	Nonanal	Benzene, 1,2-dimethyl-	Butanoic acid, 1-methylethyl ester	ΣVOC
E (µg/min)	0.88	0.54	0.35	0.24	0.22	2.24